Resources

Improving productivity of the private native forest resource in southern Queensland and northern New South Wales

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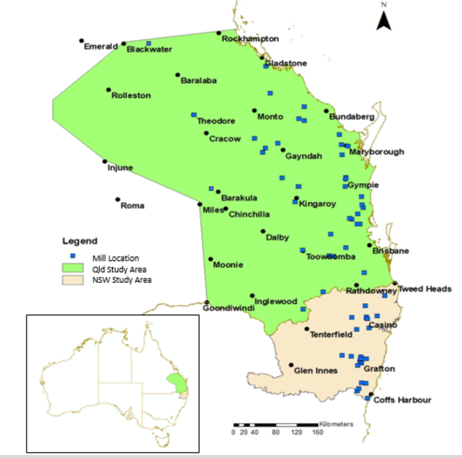

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Forest & Wood Products Australia

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Prepared for

Forest & Wood Products Australia

by

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Executive Summary

Private native forests across Queensland and New South Wales (NSW) are an important source of domestic timber supply upon which the Australian hardwood timber industry depends. This project aimed to generate new information for the timber industry and landholders on the timber producing potential of private native forests in southern Queensland and northern NSW. Specifically, the project aimed to determine: (i) the spatial extent and condition of the private native forest resource and establish a framework for ongoing inventory; (ii) the influence of forest management (i.e. thinning regimes) on tree growth rates, carbon stocks and ecological attributes; and (iii) the potential return on investment associated with silvicultural management.

Mapping carried out during this project suggests there are approximately 1.9 million ha of commercially harvestable private native forest in southern Queensland and 525,600 ha in the Upper North East NSW region. In Queensland, private native forests account for at least 58% of the processed hardwood logs, hardwood timber industry employment and sawmill-gate sales value in the study area. These forests are also important in northern NSW, providing approximately 56% of hardwood sawmill throughput. The need for privately grown hardwood timber is likely to increase over the next decade. However, data analysed through this research suggests that the productive condition of private native forest resource is highly variable and many private forests are in a poor growing condition, with a high proportion of unmerchantable trees. Inventory data (from the Private Forestry Service Queensland and collected through establishment of plots in this study) suggests that on average, around 78% of trees had a diameter at breast height (DBH) of <30 cm and that 54% of trees were considered unmerchantable. In terms of ecological condition, the majority of private native forest sites surveyed in the project were considered to be in good condition, suggesting that these forests have a positive contribution to make to regional biodiversity conservation. Encouraging forest management in regrowth forests, as an alternative to re-clearing for grazing production alone, represents an opportunity to improve ecological condition across the landscape, whilst providing additional benefits to the forest industry.

Data from 203 permanent monitoring plots were analysed to determine the impacts of forest management. On average, silviculturally treated plots had DBH growth increments that were approximately four times higher than those on trees in plots that had not been treated. As this growth is concentrated on merchantable trees in treated stands, merchantable volume growth increments on individual trees were also significantly greater in these stands (five times that of untreated stands). At a plot-level, merchantable volume growth (which included currently merchantable trees and trees likely to be merchantable in the future) was 0.76 m^3/ha/year in untreated forest and 1.45 m^3/ha/year in treated forest and approximately 2.2 tonnes of biomass is accumulated per hectare per year. Individual property case studies showed that silvicultural treatment is a financially viable option for landholders. The net present value (NPV) of ongoing native forest management with and without silvicultural thinning treatments was estimated for each of the six commercially important forest types in Queensland. At a discount rate of 5%, silvicultural thinning treatments generated a positive financial return on investment (NPV > $0) and exceed returns from harvesting without silvicultural treatment for all but one forest type.

To gain benefit from this research, there is a need for the outcomes to be communicated with private forest owners. Extension groups, such as the Private Forest Service Queensland (PFSQ), are well placed to provide extension activities (e.g. field days and workshops) that

encourage individual landholders to undertake forest management activities. Outputs developed through this project, include fact sheets, property case studies and a decision support tool. These outputs help demonstrate the importance and effectiveness of forest management. However, to achieve widespread adoption of silvicultural treatments, there is a need for incentives, such as annuity payments to landholders. Incentives of this type would enable landholders to engage trained forestry professionals to carry out appropriate silvicultural treatments. As an example, annuity payments of $30/ha/yr are predicted to be financially viable at a 5% real discount rate, based on treatment of 100,000 ha of private native forest (and silvicultural treatment costs determined through this study). Such an investment program could increase the annual sustained yield by 91,480 m^3, and would likely lead to many flow-on benefits, including regional employment.

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Glossary of abbreviations:

ANOVA: Analysis of variance
ATO: Australian taxation office
BA: Basal area
BVG: Broad vegetation group
C: Carbon
CWD: Coarse woody debris
DAF: Department of Agriculture and Fisheries (Queensland Government)
DBH: Diameter at breast height (130 cm)
DES: Department of Environment and Science (Queensland Government)
DNRME: Department of Natural Resources, Mines and Energy (Queensland Government)
EDL: Ecologically dominant layer
FPC: Foliage projective cover
FTE: Full time equivalent
GPS: Global positioning system
GRASP: Grass production model
MAI: Mean annual increment
NPV: Net present value
NSW: New South Wales
PAI: Periodic annual increment
PFSQ: Private Forestry Service Queensland
PMAV: Property map of assessable vegetation
PNF: Private native forest
PV: Present value
RE: Regional ecosystem
REDD: Regional ecosystem description database
SMSF: self-managed superannuation fund
SOC: Soil organic carbon
SPH: Stems per hectare

Chapter 1: Introduction

Tom Lewis

Private native forest is natural forest or woodland that grows on privately owned land. In sub-tropical eastern Australia these forests commonly exceed 25 m in height and contain tree species with commercial value for timber. These forests are dominated by eucalypt species which are an important source of timber for the Australian hardwood industry and in particular the hardwood processors located in southern Queensland and northern New South Wales (NSW). Previous studies have shown that in Queensland, the private native forest resource contributes approximately 60% of the annual hardwood log volume (ABARES 2017). These forests cover large areas; around 1.4 million ha in the south east region of Queensland alone (MBAC Consulting Pty Ltd 2003a). The demand for privately grown hardwood timber is likely to increase in the next decade as constraints on State-owned native forest are likely to increase and hardwood plantations are not expected to deliver the volume shortfall. The private native forest resource also represents an important alternative source of income for landholders to supplement traditional livestock grazing enterprises.

Private native forests can offer benefits in timber production, particularly when the forest has been managed to promote the growth of merchantable trees. A range of timber products may be harvested, including sawlogs, poles, piles, girders, fencing and landscaping materials. Private native forests in sub-tropical eastern Australia are usually uneven-aged and contain a mix of tree species and sizes. However, a range of stand structures are possible, and many regrowth forests are dominated by a small number of size cohorts. Harvesting commercial-size trees usually involves selective tree removal. This creates minimal disturbance and the additional space promotes growth of the remaining trees. Well planned harvesting represents an opportunity to improve the future productivity of the forest by strategic removal of mature trees and trees of lower vigour and retention of good quality growing stock. Time between harvests is usually in the order of 20–40 years, depending on the forest type, harvest intensity, and forest condition (e.g. silvicultural management history). Harvest intervals can be as little as 10 years in a well-managed forest, or highly productive forest types where selection has optimised tree spacing and quality of retained growing stock.

Actively managing the native forests on a property has the potential to return multiple benefits to the landholder, particularly in the form of a dual income stream and improved environmental outcomes. Most privately owned native forest in the region is grazed by cattle. Grazing under native forests is usually less productive than on open pastures because trees compete to a certain degree with pasture growth. In addition, private native forests often occur on steeper slopes and ridges, on less fertile soils with low water holding capacity. This means that grazing under forests generally occurs at lower stocking rates (i.e. number of cattle per hectare). However, because private native forests cover an extensive area and often constitute a high proportion of a property’s land-use, they remain an important grazing resource. Further, the area available for grazing production on a given property could potentially for improved where thinning is used to enhance pasture growth. Prescribed fire is often used by landholders to encourage pasture growth and grazing production in these forests through the control woody understorey plant species. Prescribed burning is also an important management tool that encourages or controls regeneration, maintains forest health and protects valuable timber resources (Debuse and Lewis 2007). Where fire is less frequent the understorey may become shrubby with acacias, *Lophostemon confertus* (brush box or supple jack), *Alphitonia excelsa* (red ash) and lignotuberous regeneration being common components. Grazing production is reduced in these circumstances as the woody plant species competitively exclude grasses. A mesic understorey can develop in the absence of fire in wet sclerophyll forests (Lewis et al. 2012).

The current project focusses on an area of approximately 24.4 M ha that extends from Rockhampton in the north to Injune and Goondiwindi in the west and south to Coffs Harbour to include the Upper North East Regional Forest Agreement area in NSW. Anecdotal evidence, and a study by Jay (2017) in northern NSW, suggest that many private native forests in the study region are not in the optimum state for timber production because they have a history of poor timber harvest management. In many cases, most trees with potential value are removed at a single harvest or over multiple harvests, leaving a high proportion of non-commercial (unmerchantable) trees in the stand and reducing the forests' productive value. This practice is referred to as 'high-grading'; it results in an increase in the proportion of unmerchantable trees over time. In addition, many private native forests include stands of regrowth that have developed from regeneration on previously cleared land. Regrowth stands are often characterised by young densely stocked trees (e.g. more than 500 stems per hectare) which are competing for limited resources (i.e. moisture, nutrients and light). Growth rates in these stands are often very low. In such cases, silvicultural treatment, or thinning the forest, provides an opportunity to reduce the competition between the trees, encouraging merchantable volume growth on the retained higher value stems. However, currently, silvicultural thinning is rarely practiced in the region.

Improving the productivity of the private native forest resource is important for both landholders and the timber industry. Generally, well managed timber production forests contain a lower density of trees and a high proportion of merchantable stems. Thus, they are likely to be more productive from both a timber production e and grazing production perspective. A key aim of this project was to better understand and communicate the options for improving forest productivity, by quantifying the influence of stand management, in particular silvicultural thinning treatments. The project established a framework of new and existing inventory plots to identify the spatial extent, resource condition and productive capacity of the private native forest resource in southern Queensland and northern NSW. At a sub-set of these plots the ecological condition (as measured by the BioCondition assessment framework, Eyre et al. 2015b) and carbon stocks were assessed to provide additional information on private forests managed for timber and grazing. Few studies have thoroughly investigated the influence of silvicultural treatments on ecological attributes, or on on-site carbon stocks, including debris and soil carbon pools, in native forest managed for timber production in the region.

There is little published data available for the private native forests of south-eastern Queensland and northern NSW to determine forest growth rates. Existing inventory studies (e.g. MBAC Consulting Pty Ltd 2003a) have provided a useful snapshot of the likely size of the private native forest resource. However, there is a need to monitor growth rates within permanent plots, to help determine the growth potential of the resource into the future. Previous work by the Private Forestry Service Queensland (PFSQ) in conjunction with an early study by Lewis et al. (2010) established a series of permanent plots for monitoring growth, where growth increments on individual trees can be measured over time. A key objective of the current project was to utilise this existing data and extend the network of plots to provide a baseline for continued resource assessments. While the existing growth data were limited in terms of forest type coverage, and period of monitoring, data were sufficient to develop a forest growth model that could be used to inform mangers about the potential of the resource. Forest growth models and decision support systems can help guide forest management and future manage decisions (i.e. whether silvicultural treatments are cost-effective).

To determine whether silviculture is cost-effective in private native forest, detailed financial analysis is required on a case by case basis. Where forestry extension groups have strong financial case studies and decision support tools they are well placed to communicate the potential benefits of forest management to landholders. A lack of rigorous analyses on the cost-effectiveness of silvicultural treatments is believed to be an impediment to their uptake by landholders. This project aimed to provide such information to aid in private native forest extension activities.

Report aims and structure

There were three broad aims of this project:

1. To undertake a resource analysis to identify the spatial extent, resource condition and productive capacity of the private native forest resource and establish a framework for ongoing inventory.
2. To determine the influence of forest management (i.e. thinning regimes) on tree growth rates, carbon stocks and ecological attributes across a number of private native forest sites.
3. To undertake economic analyses of the potential return on investment associated with silvicultural management, including case studies for thinning of overstocked stands.

The report is presented as a series of chapters based on key project milestones. Detailed aims, methodology and results are reported in each of these chapters.

Chapter 2 provides an overview of the methodology followed, and specifically focusses on the field measurement methods. These methods provide a framework for ongoing inventory in the private native forest resource.

Chapter 3 describes the extent and condition of the private native forest resource in the study region. The specific aims of this chapter were to: (1) determine the area of potentially harvestable private native forest; (2) determine the productive condition of this resource; and (3) determine the ecological condition of these forests.

Chapter 4 provides an overview of the private native forest resource, with a focus on its economic contribution and potential. The specific aims of this chapter were to: (1) quantify the volume of hardwood logs processed annually from private native forests; (2) determine the contribution that private native hardwood processing makes to regional economies, including income and employment generation; (3) highlight opportunities and challenges for private native forest management and hardwood sawmilling in the region; and (4) review existing information on the importance of livestock grazing as part of silvo-pastoral systems.

Chapter 5 reports on the effect of silviculture on forest growth rates and describes the development of a decision support tool for prediction of future forest value. Specifically, this chapter utilised existing permanent trial plots with temporal measures to determine the effects of silviculture on stand growth and growth of individual trees; and builds a prediction tool (decision support tool) to demonstrate the effects of silviculture on future wood products and livestock grazing value.

Chapter 6 reports on the effect of silviculture treatments and forest age (regrowth or remnant forest) on forest ecological condition attributes and in-situ forest carbon stocks. Detailed carbon stocks (including carbon stored in trees, soil, ground-layer vegetation and debris) were assessed at four sites with varying ages of forest maturity.

Chapter 7 provides an assessment of the cost-effectiveness of thinning in private native forest. Specifically, this chapter investigated different thinning options, including tordon axe treatment, brush-cutting and chopper rolling treatments and investigated optimal treatments across stands with differing tree densities.

Chapter 8 provides detailed economic case studies for four specific properties in the study region. These case studies demonstrate the costs and benefits associated with management of regrowth forests for timber and grazing production.

Chapter 9 utilises figures reported in earlier chapters to determine the economic potential of forest management. This includes the benefits of silvo-pastoral systems and the potential for an annuity scheme to allow broad-scale silvicultural management.

Chapter 10 provides a literature review on the environmental opportunities and impacts associated with native forest management in the study region.

Chapter 11 provides a summary of key findings and provides recommendations for future work and industry development.

Chapter 2: Methodology and a framework for ongoing monitoring

Tom Lewis

Introduction

Inventory is essential for understanding the current state and growth potential of a forest. Data obtained through inventory can be used to help justify timber extractions and management prescriptions as part of sustainable forest management (Florence 1996). For example, inventory is useful in determining current stocking (tree density) of native forest and hence provides information on the number of trees that may be removed to obtain a desired stocking level. Forest inventory can also include valuable information on recruitment, mortality and the condition of the forest, which is useful when determining if forestry operations are sustainable (e.g. for determining if there are declines in tree growth and regeneration). In fact, to ensure that forest management is sustainable from an ecological perspective, it is increasingly important to consider the ecological condition of the forest in inventory assessments. Further, inventory data is increasingly used to provide a better understanding of carbon stocks and fluxes in native forest (e.g. Moroni et al. 2010).

Information on forest growth is needed by forest managers and policy makers to allow prediction of the future forest resource under alternative management strategies. There is currently little long-term inventory data available for the private native forests of south-eastern Queensland and northern NSW. There is a need to monitor growth rates within permanent plots, to help determine the growth potential of the resource into the future (Beetson et al. 1992). Previous work by the Private Forestry Service Queensland (PFSQ) in conjunction with an early study by Lewis et al. (2010) established a series of permanent plots for monitoring growth, where growth increments on individual trees can be measured over time. Enough time has passed since the establishment of these plots to provide a reliable indication of growth trends. A number of different datasets have been utilised through this project to investigate not only forest growth, but also the current productive and ecological condition of private native forests. Measurement of ecological condition is based on the BioCondition assessment framework (Eyre et al. 2015b). These datasets and the methodology used to collect them are described in this chapter.

This chapter covers the methods followed for field assessments, laboratory analysis and mapping of the forest resource and provides a monitoring framework for future assessments of the private forest resource. Further methodology details (e.g. statistical analysis) are provided within the relevant chapters and methodology for the financial analyses conducted are also included in the relevant chapters (Chapters 7 and 8).

Key terms utilised

In assessing the productive condition and areal extent of private native forest a number important terms are used throughout this report. Additional terms are defined in a glossary at the end of this report.

Basal area is a forestry term used to compare the density of trees in a forest. It is calculated as the sum of the cross sectional area of each tree at 1.3 m height (based on diameter at breast height, DBH) and is expressed on a per hectare basis in this report (m^2/ha). Stand basal area incorporates all trees irrespective of size (although normally down to a specified minimum size) and is often used as a guide to determine whether the stand density is appropriate for the desired use of the forest (i.e. whether the stand requires thinning or not).

Tree stocking is another measure of stand density. This is expressed on a per hectare basis (stems per hectare, SPH) and trees are usually divided into diameter classes (e.g. trees with a DBH 10-20 cm) to provide information on the size distributions for a stand. One of the main advantages of stocking is that it is easy to measure and stands are often thinned or harvested to provide a specified residual stocking (e.g. there are often code of practice requirements regarding stocking rates to be retained after a harvest). In a forest, trees are usually regarded as being a permanent part of the stand (i.e. not susceptible to mortality through factors like fire) when they are greater than 10 cm DBH. Below this size, trees are usually regarded as being 'regeneration' and are counted separately or ignored during inventory.

Silvicultural thinning also referred to as **silvicultural treatment** for the purposes of this report, is the process of thinning the forest, to reduce the level of competition for resources (sunlight, moisture and nutrients) between the trees, thereby encouraging greater growth rates on the retained trees. Thinning often kills the unwanted or non-productive component of a timber stand. For the purposes of this report silvicultural thinning includes thinning that is carried out with no immediate return to the landholder (i.e. thinning to waste).

Wood volume provides a measure of the volume of timber product that is stored in a tree (usually the bole of the tree) and is expressed on a per hectare basis (m^3/ha). Volume is usually calculated by incorporating measures of DBH and height (either total tree height, or the length of the bole). Various formulas exist for calculating volumes (e.g. volume of a cone) and specific formula have been derived from key hardwood eucalypts in Queensland (Henry 1991). In this report **merchantable volume** was calculated based on measures of DBH and the height measured to a likely merchantable product. Some trees have no merchantable volume and in many cases a merchantable product cannot be accurately determined until a tree reaches a DBH of approximately 20 cm.

Regional Ecosystem (RE) classification has been used in the report to assist with forest type mapping in Queensland. Regional ecosystems are vegetation communities in a bioregion that are consistently associated with a particular combination of geology, landform and soil (Sattler and Williams 1999; https://www.qld.gov.au/environment/plants-animals/plants/ecosystems/about). The Regional Ecosystem Description Database (REDD) supersedes the regional ecosystem descriptions in Sattler and Williams (1999) and mapping of REs was developed by the Queensland herbarium (Queensland Herbarium 2018).

Study region

The project study area was based on that of an earlier private native forest project (Lewis et al. 2010), and is roughly the extent of 'commercially productive' hardwood forest in southern Queensland and northern NSW. It extends from Rockhampton in central Queensland, south to include the Upper North East Regional Forest Agreement area in NSW, and covers approximately 24.4 M ha (Figure 2.1). To investigate variation across this region, the study area was divided into four sub-regions: (1) south-east Queensland; (2) Wide Bay-Burnett; (3) western Queensland (Fitzroy and Darling Downs regions); and (4) north-eastern NSW (Figure 2.1). In Queensland these sub-regions were based on catchment area boundaries. In NSW, the Upper North East Regional Forest Agreement area was used.

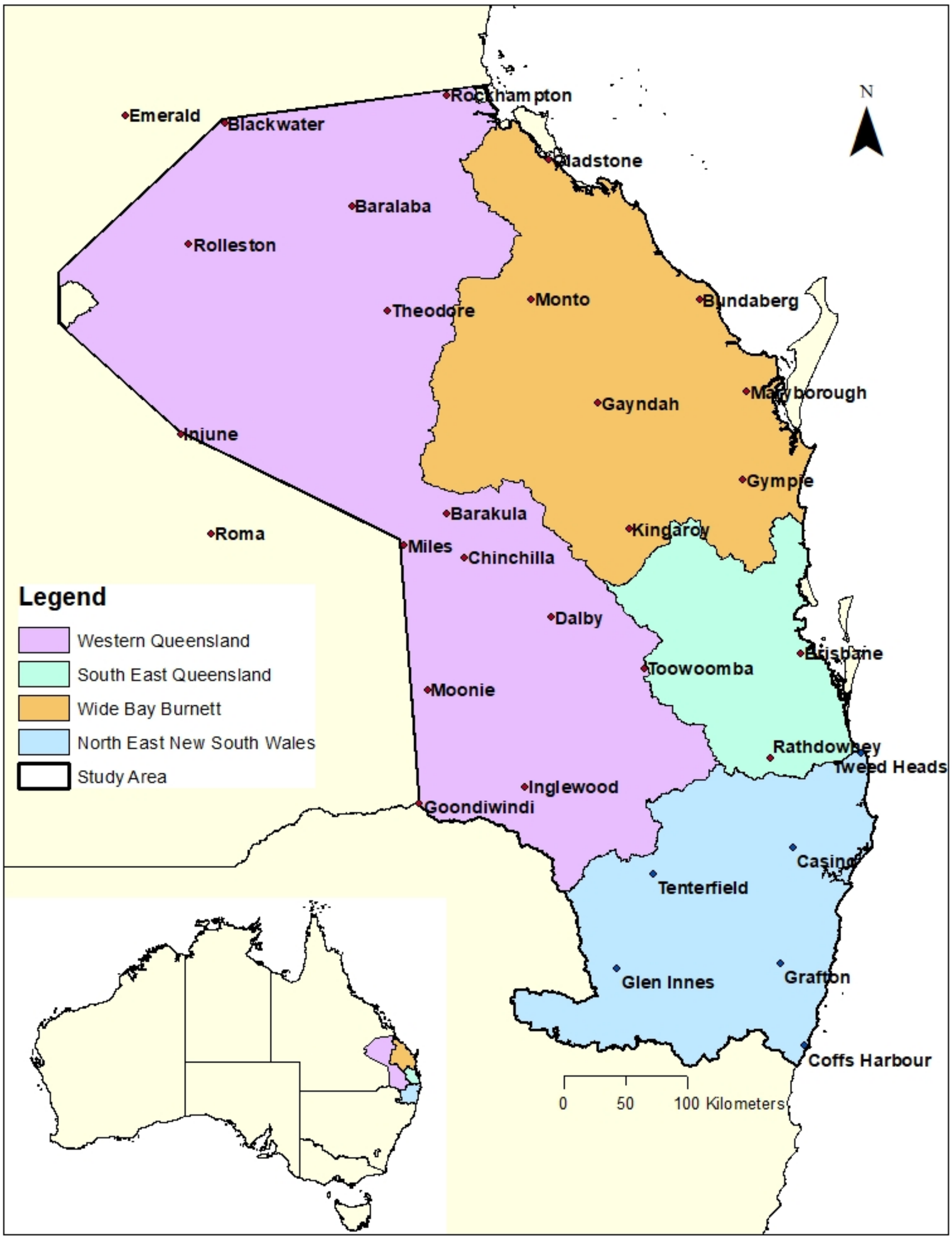


Figure 2.1. The project study area, showing the boundaries of the four sub-regions.

Existing permanent monitoring plots

Trial plots

Previous studies of the private native forest resource (e.g. Lewis et al. 2010) and work by PFSQ, have established a number of permanent plots for monitoring tree growth. A previous FWPA funded study (Lewis et al. 2010) established trial or monitoring plots at twelve properties to investigate the influence of forest management (e.g. thinning). These plots vary in size and shape. They were mostly located in dry eucalypt forest, usually with spotted gum (*Corymbia citriodora* subsp. *variegata* or subsp. *citriodora*) as one of the dominant species and cover both remnant and regrowth forest. The focus on spotted gum dominant stands reflected the large extent of these forests (e.g. Chapter 3) and their commercial importance to the timber industry (Chapter 4). Where possible, these sites were re-measured as part of the current study. Only in one instance, where property ownership has changed, were we unable to re-visit an existing site.

This study utilised permanent monitoring plots that were established by PFSQ at six new sites, established between 2010 and 2014. Existing data from these plots was added to the DAF Forestry Science database. The current project provides commencement reports for these sites (Appendix 1), and these plots were re-measured during the current project to provide additional time-series data. At these sites three to eight plots were established to cover a range of different management scenarios, with some plots logged and or thinned and other plots with no logging or thinning. Locations of existing and new permanent trial plot sites are shown in Figure 2.2.

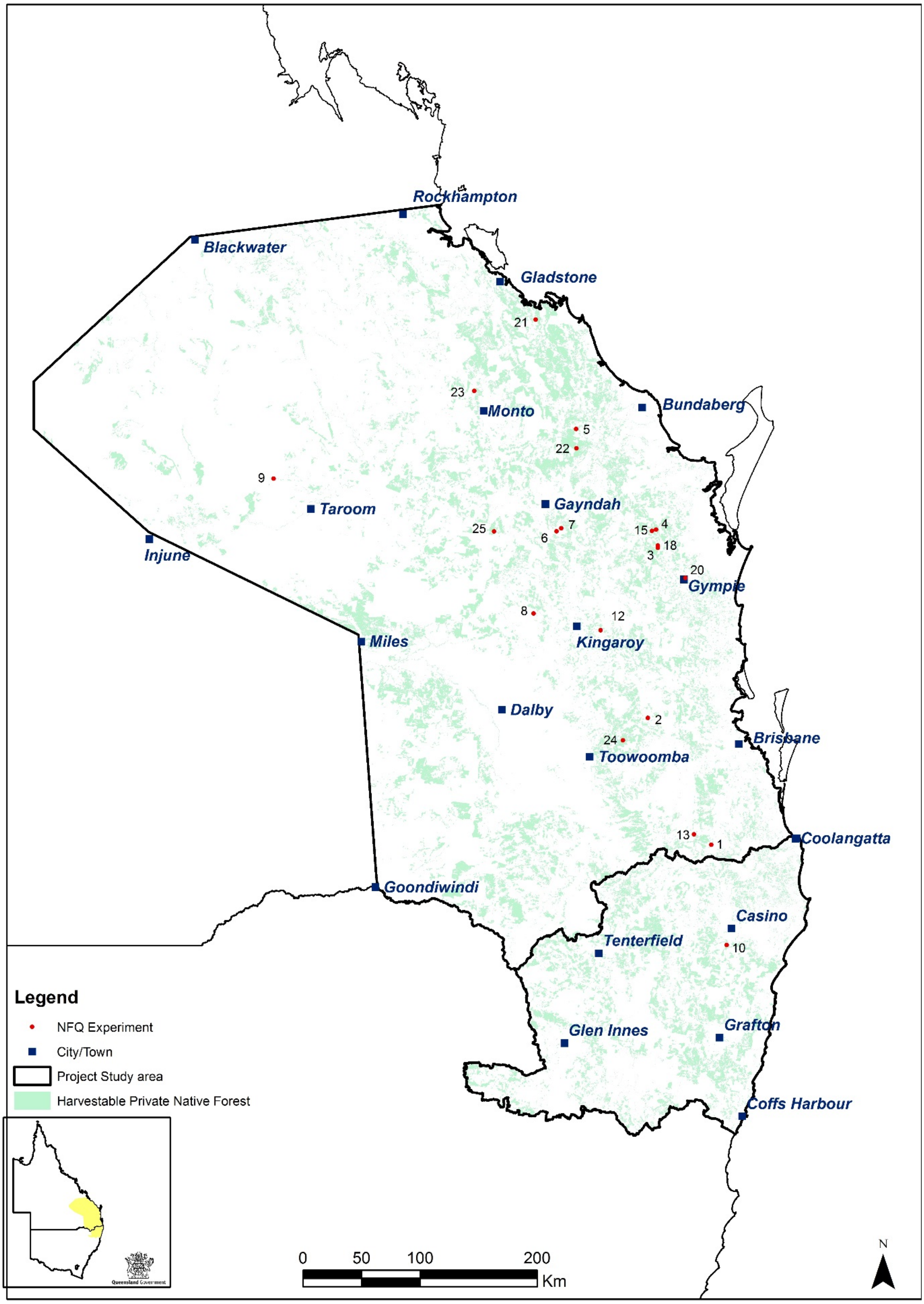


Figure 2.2. Locations of the trial sites (NFQ experiments) where permanent monitoring plots have been established in private native forest to monitor tree growth over time. Some sites were established during an earlier FWPA funded project (NFQ1–13) and the remaining sites were established by PFSQ or through the current project. The harvestable private native forest layer was based mapping conducted during this study (see text for details).

State Forest yield plots

This study also utilised forty-five permanent plots located in Queensland State Forest (Figure 2.3). These plots were used specifically to provide information on remnant forests without recent silvicultural treatment. Only plots where no recent harvesting or thinning (in the last 20 years) had taken place were selected for the current study and plots were selected from State Forests that occurred within the area where most of the private native forest plots were located (i.e. with a focus on the Wide Bay-Burnett region). Further justification for inclusion of these plots is provided in Chapter 5. State Forest plots were selected from existing experimental plots (in the DAF forestry science database) and the native forest permanent sample plots. The ‘detailed yield plots’ and native forest permanent sample plots form part of a comprehensive permanent sample plot system in Queensland State Forest (Beetson et al. 1992) and have been recently utilised in analyses of the Crown forest resource (e.g. Ngugi et al. 2015).

New permanent monitoring plots established

Trial plot establishment

Two new thinning trials were established in the Wide Bay-Burnett region. Detailed commencement reports for these trials is provided in Appendix 1. Establishment of new experimental plots followed standard protocols for experiment establishment (e.g. Burridge 2010, Research Manual). Both sites included two replicates of three silvicultural treatments, including control plots that received no silvicultural thinning treatment. In each replicate, the different treatments were established within relatively homogenous sections of forest. Pre-treatment measurements were conducted just prior to implementation of treatments. In both trials square measure plots were established that were 0.16 ha in size (i.e. 40 × 40 m). The corners of these plots were marked with hardwood pegs and locations recorded with a GPS (Global Position System) unit. An area of isolation (gross plots were 70 ×70 m) ensured treatment effects did not influence adjacent measure plots (nett plot). Detail on the assessments made at these plots are provided in Appendix 1 and in the sections that follow.

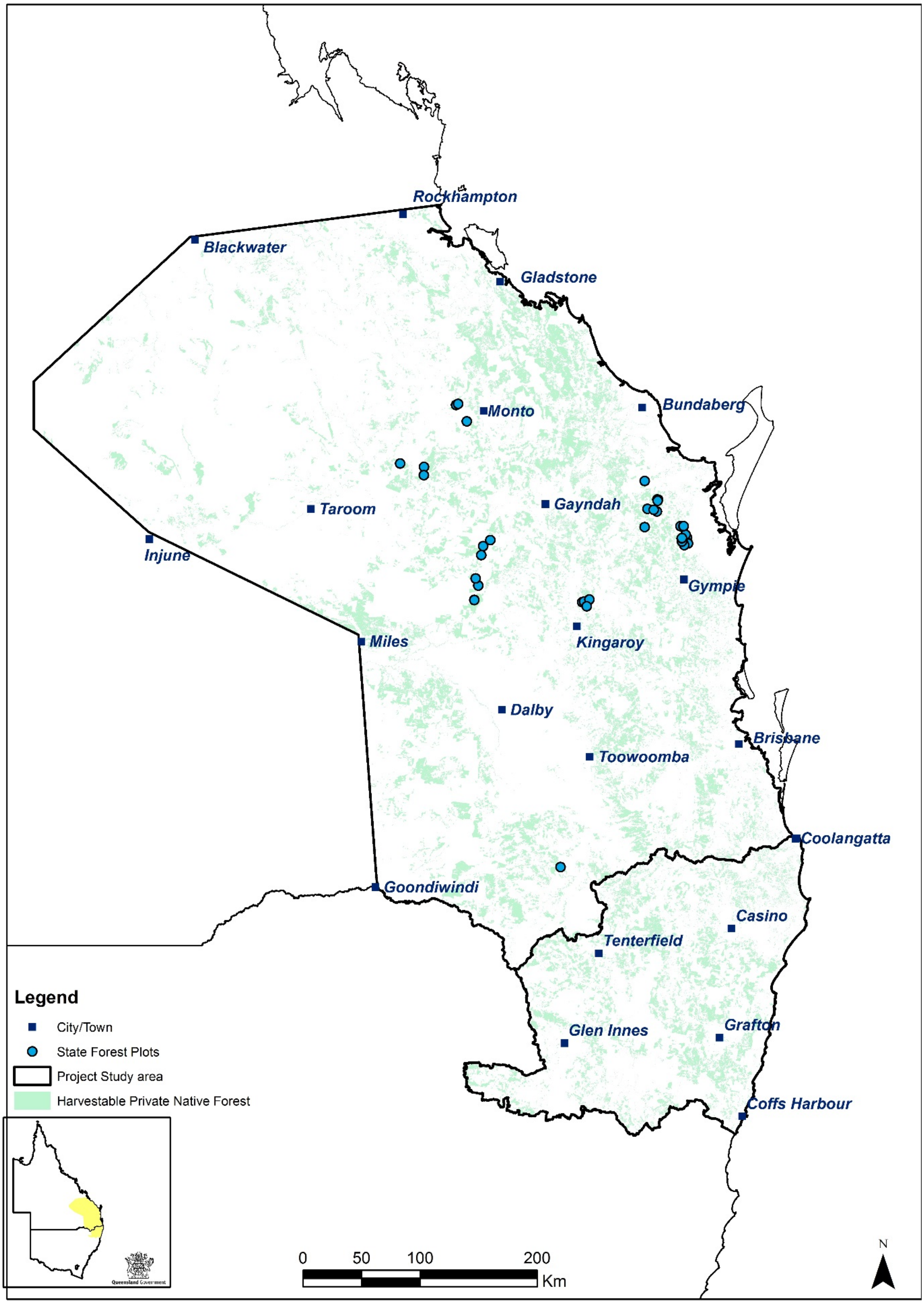


Figure 2.3. Locations of the permanent monitoring plots in Queensland State Forest (a mixture of native forest permanent sample plots and experimental plots from the Forestry Science database) that were utilised in the current study.

Stand-alone yield and BioCondition plots

Twenty-nine plots stand-alone plots (separate to trial plots) were established across the study region during the current study. The locations of most of these plots were determined using a stratified random approach, to ensure plots were distributed across the study region. This involved sampling in each of the four sub-regions (Figure 2.1). The following methodology was used to determine the location of these plots in Queensland:

1. Potentially productive private native forest was mapped in the study area using existing data layers. Potentially productive private native forest was based on Regional Ecosystem (RE) mapping, and knowledge of which REs were harvestable under the native forest practice code.
2. A 5 × 5 km grid was placed over each of the sub-regions.
3. Grid cells that contained an adequate area private native forest were randomly selected in each sub-region. If suitable, the centre point of the grid cell was chosen for the plot location.
4. Landowners were identified using databases and contact details obtained, where possible. Landholders were contacted to determine if access to property and sampling would be permitted. It was not possible to obtain landholder contact details in some cases.
5. The property was visited, and the plot location decided upon using a GPS. If the site was suitable, the plot was established and sampling commenced. Sites were considered suitable if: (a) slopes were <25° and the plot did not cross major gullies, creeks, roads or power line clearings; (b) no other regulatory restrictions would prevent a future harvest operation at the site; and (c) the site was accessible (e.g. utilising existing tracks etc on the property). Recent logging or thinning operations at the site were acceptable, but evidence of such activity was rarely encountered. Where possible, the plot location was representative of the surrounding forest in an area that was homogenous in terms of topography, stand structure and floristics. The plot was located at least 30 m from the forest edge to avoid possible edge effects.
6. If the site was unsuitable (e.g. non-commercial forest type after site inspection) or if the landholders could not be contacted, the process was repeated after randomly selecting another grid cell in the sub-region.

Six plots were located in the south-east Queensland sub-region, eleven plots were located in the Wide Bay-Burnett sub-region and eight plots were located in the western Queensland sub-region (four in the Fitzroy and four in the Darling Downs catchments).

In NSW, mapping of the potentially productive private forest was not available at the time of sampling. Project collaborators (e.g. NSW Department of Primary Industries, Southern Cross University and PFSQ) were used to help locate sites in NSW. Four plots were established in the north-eastern NSW sub-region.

Sampling plots were established to allow a full BioCondition assessment within a 0.5 ha area (i.e. 100 × 50 m plot). However, measurement of forest production attributes (e.g. DBH, height, crown health etc) took place within a 0.2 ha (i.e. 100 × 20 m) subplot. Trees were assessed 10 m either site of a central transect (Figure 2.4). Trees ≥10 cm DBH within this area were tagged using copper-wire tags for ongoing measurements into the future.

A 0.2 ha area for monitoring tree growth and forest production attributes was selected as a compromise between the time requirements for tagging and measuring all trees ≥10 cm DBH and the variation among plots. Ideally, plot size should be sufficiently small to fit within a homogeneous stand but sufficiently large to provide a representative sample of the ecosystem

(Vanclay 1994). The ideal plot area for monitoring trees depends on the stand structure, in particular, the evenness and distribution of stems in the stand (e.g. Eyre et al. 2017). Given that sampling was restricted to forest and woodland with potential commercial value (i.e. very low stem densities were unlikely), the 0.2 ha area was selected to provide a reasonable sample of the stand.

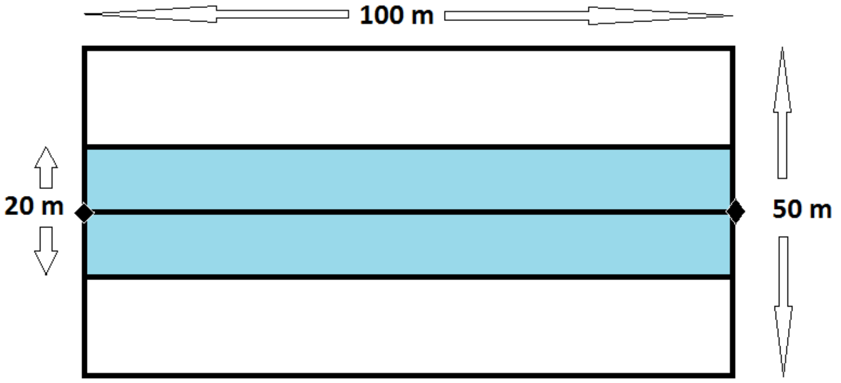


Figure 2.4. Layout of stand-alone measurement plots for assessment of BioCondition (assessed within a 100 × 50 m area) and for ongoing forestry measurements (shaded 100 × 20 m area).

After deciding upon an appropriate location for the plot using a GPS, a 100 m tape was laid out following the contour. A star picket was placed at the start point, the 50 m point and at the end point (100 m) of the central transect. A steel label was attached to transect start and end pegs, with the forward compass bearing attached to the start peg and the back-bearing attached to the end peg. The locations of the start and end point of the central transect were marked with a GPS unit (with accuracy of approximately 5 m). Flagging tape, temporary pegs and marking paint were used to establish the four corners of the plot using an optical square. The 25 m and 75 m points on the central transect were marked using marking paint for establishment of subplots for BioCondition assessment. Detail on assessment of BioCondition subplots is provided below (*Assessment of BioCondition*).

At each plot the following information was recorded:

(1) Unique plot identification number (referenced to the DAF Forestry Science database).
(2) Sampling date.
(3) Transect bearing from the start point of the central transect.
(4) Position in the landscape, recorded as either: (1) crest; (2) upper slope; (3) mid slope; (4) lower slope; or (5) flat.
(5) The slope of the plot (in degrees) measured using a Suunto clinometer.
(6) The dominant aspect of the plot, recorded as a compass bearing to the nearest 10 degrees.
(7) Portrait and landscape photographs. Photographs were taken from the start peg, facing along the central plot transect. Photos are also taken facing N, S, E and W at the 50 m point of the central transect.

Information on management history was recorded based on field observations and through talking to the land managers. For example, evidence of recent fire, time since harvesting, time since thinning treatments, occurrence of livestock grazing was recorded.

These plots were established as a starting point to provided representative data for the region. It is acknowledged that far more plots need to be established across private native forests in the future to ensure the data are statistically defensible. These plots and the methodology used here, along with resource inventory plots established by PFSQ (see below) should provide a framework for future monitoring and assessment of the private native forest resource.

PFSQ inventory for resource assessment

PFSQ have conducted inventory at a number of properties since 2005, referred to here as resource assessments. This inventory data collected by PFSQ covers a large part of south-eastern Queensland and northern NSW (Figure 2.5). Generally the resource assessments involve gathering forest resource data across approximately 1% of the productive forest area on a property. In advance of the field work, desk top evaluation of the vegetation cover on the property is completed utilising the latest available imagery, slope gradient and Regional Ecosystem overlays. Strip lines are located to cover the forecast forest types. In the field all trees 5 m either side of the strip line are measured by experienced operators who have knowledge on different forest products. Measurements include:

1. Tree number, DBH, species;
2. Whether each stem should be retained for future products, logged, retained as habitat, or treated;
3. Product type (pole, sawlog, salvage log, fencing); and
4. Product length.

The data collected is transferred into a mapping program and the property is broken into units of similar vegetation cover and condition. The collected field data is then allocated to the relevant units. This allows calculation of:

1. Total stocking (stems per hectare, SPH), and basal area and stocking of stems to be retained, logged or treated;
2. Species distribution, diameter distribution;
3. Volume that could be logged;
4. Retained volume; and
5. The number habitat trees (per ha) and trees that need to be retained for native forest practice code compliance.

PFSQ’s forest assessment has evolved since 2005 with the use of hand held computers with a GPS function that now allows the location of each tree to be recorded (with GPS accuracy of 0-5 m).

These assessment areas have been used in the current project in assessments of resource condition (Chapter 3). A total of 392 plots (across approximately 40 properties) have been assessed in the project study area, covering a total area of 195 ha. In adding this dataset to the DAF Forestry Science database we assigned each strip to a plot, based on the total length of the strip (which was variable) and the width of the strip (10 m). Plot sizes varied from 0.037 ha to 5.24 ha, and the average plot size was 0.50 ha.

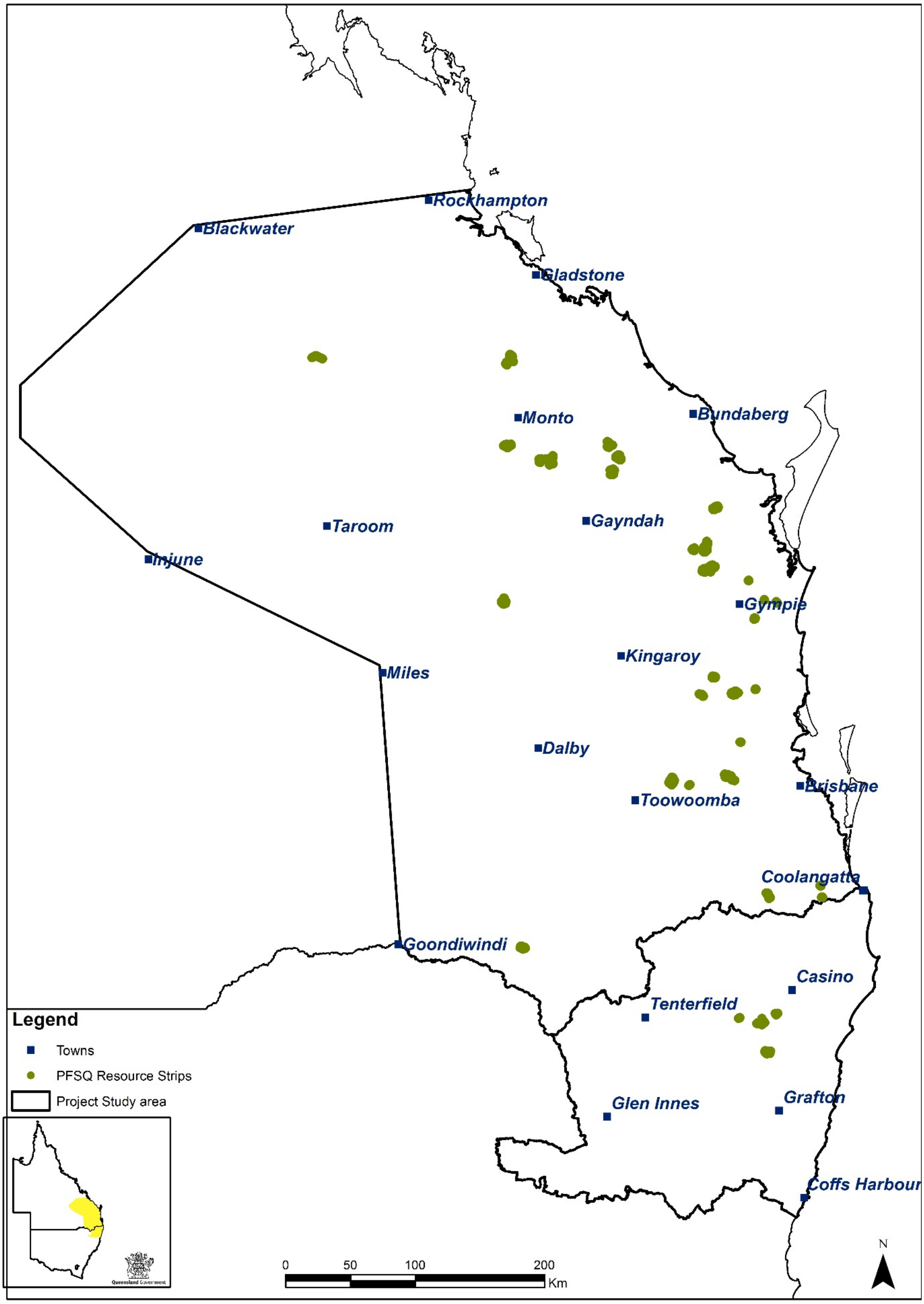


Figure 2.5. Location of the resource assessments plots (strip transects) established by PFSQ within the project study area. Multiple plots were located on a given property.

Summary of plots utilised

The existing plot network used in this study is summarised in Table 2.1. These plots provide a useful baseline for ongoing monitoring.

Table 2.1. Inventory plots in the project study area utilised for better understanding the private native forest resource. All plots, except the State Forest yield plots are located in private native forest.

Plot description	Number utilised	Use
Trial plots	158 plots (19 sites) plus twelve new plots (two sites)	To determine rates of growth over time in stands with varying densities and treatment regimes. A sub-set of plots (94) also used to determine ecological condition.
State Forest yield plots	45	Permanent sample plots used to determine rates of growth over time. Focus in the current study on plots that had not received recent silviculture. Additional permanent sample plots also exist in Queensland State Forest (e.g. Ngugi et al. 2015).
Stand-alone yield and BioCondition plots	29	For BioCondition assessment to provide a snap-shot of ecological condition. Also provide information on the productive condition and have been established to allow future measurements (to determine growth rates).
PFSQ inventory for resource assessment	392 (287 used in Chapter 3)	Individual property assessments. Used in the current study to provide information on the productive condition of the resource.

Assessment of tree growth and health

This protocol applied to permanent monitoring plots measured and established as part of this project.

All living trees (commercial and non-commercial) with DBH ≥10 cm within plots were tagged. This involved stabbing a copper-wire into the tree (at approximately 1.5 m from the ground, using a copper-wire approximately 20 cm in length) and attaching a steel label with a unique tree number. In cases where copper-wire could not be inserted, a slip knot was used around the bole of the tree, using galvanised tie-wire. All tags were secure so to ensure they are not removed by animals or bark-shedding. In some experiment plots, selected trees <10 cm DBH were also tagged, depending on the aims of the trial. For example, if there were not enough trees with a DBH ≥10 cm within the plot to meet the stocking requirements for the designated treatment some smaller trees may have been tagged. Trees were considered to be in the plot if at least 50% of the base of the tree was within the plot boundary.

For each living tree measured the following information was recorded:

1. Numerical identifier (tree number). Using sequential numbers (e.g. 1 to 50) for each plot.
2. The species, recorded using DAF database species codes (Appendix 2) and species state (either dead, alive or recruit since previous measure).

3. Diameter at 1.3 m (DBH).
4. Total height (for trees ≥20 cm DBH).
5. Merchantable height (for trees ≥20 cm DBH).
6. Grimes crown score (trees ≥10 cm DBH).
7. Stem straightness code (trees ≥10 cm DBH).
8. Degree of defect code (trees ≥10 cm DBH).
9. Potential product code (trees ≥10 cm DBH).
10. Reason for death code.

Diameter and heights

Diameter was recorded to the nearest mm and height was recorded to the nearest decimetre. Measurement of DBH was at 1.3 m on the high side of each tree. Diameters are measured with either a fibre glass tape, or retractable steel tape graduated in centimetres and tenths of a centimetre diameter. All living stems ≥10 cm DBH were measured. For determination of standing dead tree biomass (for carbon stock assessments) the DBH of dead trees was also recorded in some plots. For trees with multiple stems (where a tree had stems which are clearly separated at 1.3 m above ground level) both stems were measured and it was noted that the tree had multiple stems. In certain plots (e.g. thinning experiments) trees <10 cm DBH that had been selected for retention (and tagged in previous measures) were also measured.

When measuring DBH, the tape was held firm (not tight) and at right angles to the axis of the tree and loose or flaky bark was removed prior to measurement. Where a bump, scar, fork or other abnormality occurred at the 1.3 m point, DBH was measured either just above or below 1.3 m mark and the height at which DBH was taken was recorded. Future measurements could then take place at this height.

The total height of all live stems ≥20 cm DBH was recorded. Total tree height was defined as the distance from the ground to the highest living point of the tree. Tree heights were measured using a Vertex hypsometer or Laser (e.g. Truepulse). The Vertex hypsometer calculates tree height using (a) horizontal distance to tree and (b) angle to top of tree. It consists of two units, the hypsometer unit and the transponder. The transponder was placed at a predefined height (usually 1.3m above ground) on the tree to be heighted. When measuring trees with a lean, or where the top of the tree was not directly above the bole, the transponder was held under the highest part of the tree. The Vertex was calibrated prior to use (using instructions provided with the instrument) and was used in preference to the Laser, particularly in forests where it was difficult to see a clear line of sight to the bole of the tree that was being heighted.

Merchantable height was recorded for all live stems ≥20 cm DBH. Merchantable height was recorded as zero for trees with no potential commercial value. Merchantable height was defined as the height from the ground to the highest merchantable point on the bole (e.g. height to crown break or a heavy branch). This was based on species, straightness and defect, not the size of the bole. Thus merchantable volumes calculated included small trees (i.e. <30 cm DBH) that were not currently merchantable, but were likely to be merchantable in the future. We use the term ‘potentially merchantable volume’ in this report as a measure of current and future merchantable volume. Small defects were included within this height and the degree of defect was recorded as a separate variable (see below).

Canopy health assessment

Canopy health was assessed on trees ≥10 cm DBH using the attributes of the Grimes crown score (Grimes 1987), which was developed for native forest in Queensland. This was considered an important variable given its relationship with tree growth (Grimes 1987). This involved a scoring system for the following attributes (Figure 2.6):

- Crown Position (score of 1–5);
- Crown Size (score of 1–5);
- Crown Density (score of 1–9);
- Dead Branches (score of 1–5); and
- Crown Epicormics (score of 1–3)

Scores for each attribute did not have to follow the discrete scores in the following tables. For example, for crown density, scores of 2, 4 and 8 can be assigned for trees that have densities that fit between the descriptions below. A total Grimes crown score out of 27 was calculated for each individual.

Crown position is the position of the tree crown relative to adjacent crowns.

Description	Score
The entire crown is open with no competition from above or the side. The tree is in a dominant position with unrestricted light.	5
The upper surface is exposed and all or part of the sides may be in competition with adjacent crowns. There is no restriction to vertical growth. The tree is in a co-dominate position.	4
Only part of the upper crown is exposed, and the stem has mostly side light. The crown has competition in part from above and side.	3
None of the upper surface is exposed and only part of the side of the crown is free. The tree is growing completely under the crown of a dominating tree in a partly suppressed position.	2
The crown has no direct access to light either from above or the side and is in a completely suppressed position.	1

Crown size considers the depth, width and shape and varies with diameter and species.

Description	Score
The crown is wide, deep and roughly circular in plan, without any obvious faults.	5
The crown has easily observed but slight faults, such as lopsidedness or is partly underdeveloped.	4
Obvious deficiencies in size and/or shape are present. The crown is considered satisfactory.	3
Small poorly shaped crown that is considered unsatisfactory.	2
Useless crown, very small and ungainly.	1

Crown density is a measure of the tree’s photosynthetic area.

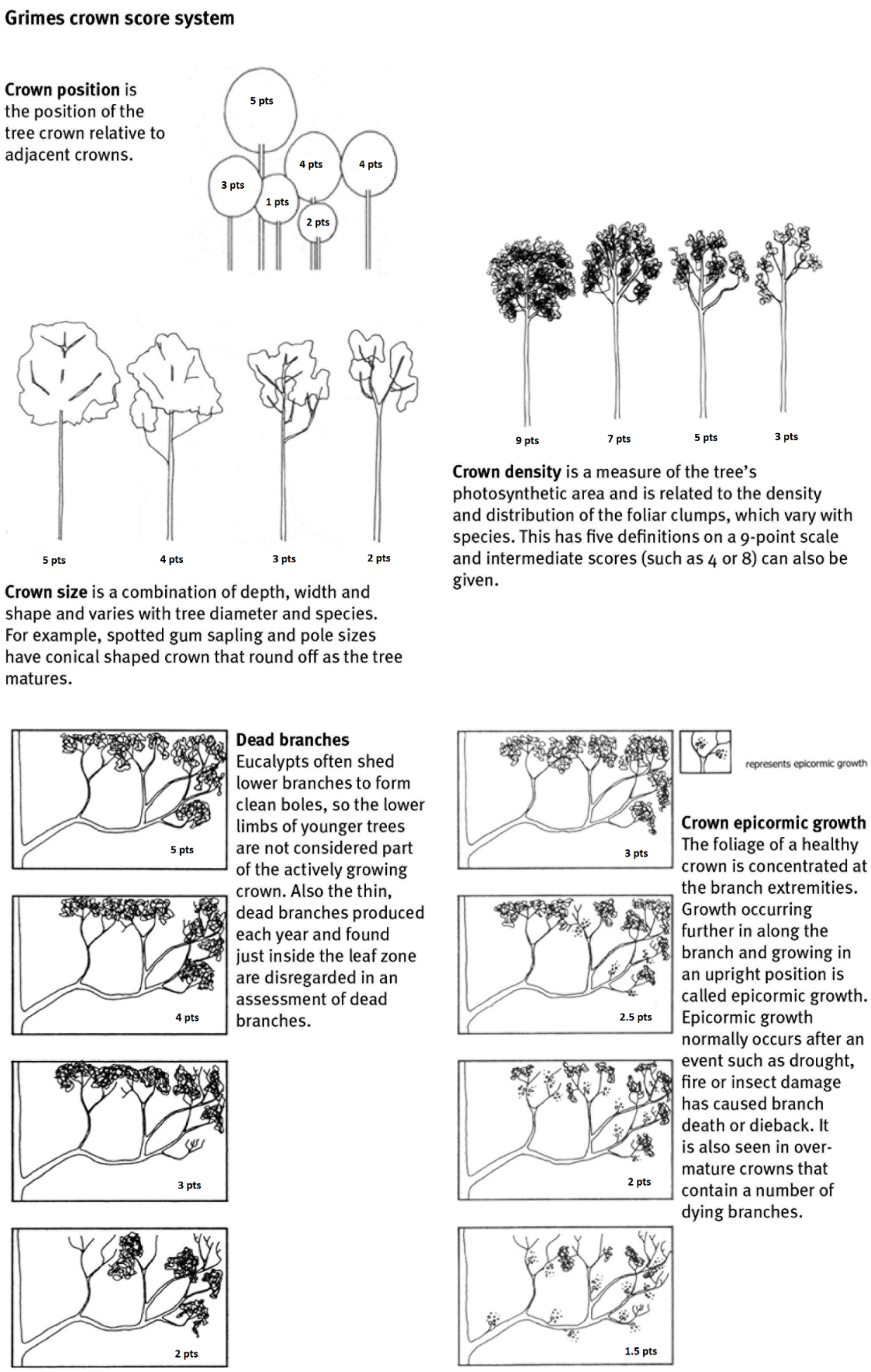
Description	Score
Very dense leaf clumps with even distribution of clumps over crown.	9
Dense leaf clumps distributed unevenly over crown.	7
Clumps of average density with reasonable distribution or dense clumps very unevenly spread.	5
Clumps are sparse and poorly spread.	3
Very few leaves anywhere on crown.	1

Dead branches provide some indication of the growth stage of the tree. Unhealthy or very old trees often have more dead branches.

Description	Score
No visible branchlets or branches in the crown apart from the thin twigs immediately inside the new leaf development and the lowest branches in the process of being shed.	5
On close inspection dead branchlets are present but not all over crown.	4
Small branches are dead but not all over crown. These are easily observed but do not give the impression of seriously affecting the crown.	3
Large and/or small branches dead over part of the crown with the obvious impression of serious branch death.	2
Large and small branches dead over most of the crown, which is obviously dying.	1

A perfectly healthy crown has the foliage concentrated at the branch extremities. Growth occurring further in along the branch and growing in an upright position is termed epicormic growth. Epicormic growth normally occurs after some disturbance (e.g. fire or insect attack) has caused branch death or dieback, with consequent slowing of growth.

Description	Score
No epicormic growth is present.	3
Slight epicormic growth is seen in part of the crown.	2.5
Moderate epicormic growth is present over most of the crown.	2
Epicormic growth is evident over most of the crown.	1.5
Epicormic growth is present over most of the crown and stem.	1



Grimes crown score system

Crown position is the position of the tree crown relative to adjacent crowns.

Crown density is a measure of the tree's photosynthetic area and is related to the density and distribution of the foliar clumps, which vary with species. This has five definitions on a 9-point scale and intermediate scores (such as 4 or 8) can also be given.

Crown size is a combination of depth, width and shape and varies with tree diameter and species. For example, spotted gum sapling and pole sizes have conical shaped crown that round off as the tree matures.

Dead branches Eucalypts often shed lower branches to form clean boles, so the lower limbs of younger trees are not considered part of the actively growing crown. Also the thin, dead branches produced each year and found just inside the leaf zone are disregarded in an assessment of dead branches.

Crown epicormic growth The foliage of a healthy crown is concentrated at the branch extremities. Growth occurring further in along the branch and growing in an upright position is called epicormic growth. Epicormic growth normally occurs after an event such as drought, fire or insect damage has caused branch death or dieback. It is also seen in over-mature crowns that contain a number of dying branches.

Figure 2.6. Grimes crown score assessment and the five attributes assessed (position, density, size, dead branches and epicormic growth). Modified from Ryan and Taylor (2006) and Grimes (1987).

Stem straightness, defect, product code and reason for tree death

For stem straightness the following rating system, based on QDPI Forest Service (1995) was used for the merchantable log.

Description	Code
Straight. Less than a 2.5 degree bend.	S
Okay. A 2.5 to 5 degree bend.	O
Bent. A 5 to 10 degree bend.	B
Kinky. A greater than 10 degree bend.	K

Degree of defect on the bole, also based on QDPI Forest Service (1995) was recorded using the following rating system for the merchantable log.

Description	Code
Good. No observable external defect. For example, no swellings, hollows, fungus, borer holes, fire scars, spiral grain or dead main growing branches.	G
Moderate amounts of any of the above defects but not enough to cause classification as defective.	M
Defective. High quantities of apparent defect. Unsuitable for sawlog, however may have potential for fencing material.	D
Useless. Not able to be utilised for commercial purposes.	U
Defect unknown (not recorded)	X

Product codes, based on merchantable height, species, straightness and degree of defect were recorded as:

Description	Code
Potential pole, girder or pile	P
Potential sawlog	S
Useless by either form or species	U
Other product / fencing, sleepers	R
Intermediate (between useless and sawlog). Usually small trees retained for future stocking	I
Tree was removed/died at a previous measure	#

Reason for tree death was recorded as:

Description	Code
Logged	L
Treated	T
Unknown natural causes	O
Smashed during logging	S
Crushed - by falling stag (not during logging)	C
Other human causes	H
Fire	F
Wind	W
Drought	D
Lightning	E
Retained / alive (for trees recorded as dead in the previous measure)	R

Assessment of carbon stocks

Carbon stock assessments were made at sites where most plots were at least 0.16 ha in area or greater. Due to time and budget constraints, soil, litter and herbaceous vegetation sampling only took place at a small sub-set of sites across the study region. Carbon stocks for trees and coarse woody debris (CWD) were calculated for a larger number of sites (details provided in Chapter 6).

Soil, litter and ground-layer vegetation sampling

For soil and leaf litter sampling, the plot was divided into 10 × 10 m subplots (e.g. 16 subplots for a 40 × 40 m plot). Five subplots were randomly selected for sampling. Subplots were established using tape measures, optical squares and sighting posts to ensure right-angles. A 1 × 1 m square was randomly selected for sampling within the subplot. Each selected subplot and square was marked with line-marking paint to delineate the sampling positions. The positions of subplots and sampling squares are referenced from the plot corner positions (GPS points) to allow future sampling at the same locations.

A steel square quadrat, 0.5 × 0.5 m, was placed in the centre of each selected 1 × 1 m sample square, and all dead and detached vegetation (litter) was collected down to the soil surface, being careful to exclude mineral soil. All litter material ≤25 mm diameter was defined as fine litter and litter material >25 mm and <100 mm diameter was defined as coarse litter. All litter was collected in paper bags for each sample square and oven dried at 70°C to a constant weight to allow determination of biomass. Litter carbon stocks were estimated by multiplying biomass by carbon concentration (based on published literature). Ground-layer vegetation, which was generally herbaceous vegetation, was collected in a similar way. All living vegetation (with a stem ≤25 mm diameter) was collected from within the steel sampling frame. This material was placed in a separate paper bag for oven drying and biomass determination.

Following litter and ground-layer vegetation collection, at each randomly selected sampling location soil samples were collected to a depth of 30 cm using 70 cm long hardened steel cores, usually with a 42 mm cutting head and an internal tube diameter of 45 mm (cutting head size varied depending on the soil type). The cores were driven into the ground using a Bosch GSH16 jack-hammer powered by a portable generator (Honda EU20i 240V). A specially designed soil-core lifter was used to remove the core from the ground.

The soil samples were then pushed out of the core onto hemi-cylindrical tubes, divided into two sampling depths: 0–10 cm and 10–30 cm and transferred into labelled, sealable plastic bags. Soil samples collected within each of the five 10 × 10 m subplots were kept separate for each depth. Once collected, soils were kept in a cool dark location until the samples were air dried, processed and sent to the laboratory.

In addition to the above samples collected for analysis, samples for ‘soil core mass’ (oven-dried mass per unit core volume for bulk density) determinations were collected from two randomly selected, previously sampled squares in each plot. Each of these samples was collected using the same core sampler as that used for soil carbon samples. Soil core mass samples were collected for the same sampling depths as for the standard soil samples, and were placed in individually labelled plastic bags for each depth. These samples were later dried in an oven at 40°C to constant weight, to determine air-dry weights, and then dried at 110°C to constant weight, to determine the oven-dry weight for calculation of core mass and the moisture correction factor between air-dry and oven-dry soil for a plot.

All soil samples, except the core mass samples, were weighed after air drying and carefully processed by hand through a 2 mm sieve. The dry weight of material removed during sieving (organic material, charcoal and rocks) was recorded. Total carbon and nitrogen concentrations were determined by dry-combustion with a LECO CNS-2000 analyser (LECO Corporation, MI, USA).

Soil organic carbon (SOC) stocks for each depth interval should be calculated using:

$$\text{SOC (t/ha)} = \%\text{C} \times \rho \times V \times (1\text{-}f)$$

where %C is the C concentration (g/100 g); ρ the soil bulk density (g/m^3); and V the volume (m^3) of soil per hectare (depth in m × 10^4 m^2) in the samples depth interval, after the volume fraction (f) of the organic material, charcoal and rocks have been subtracted.

Coarse woody debris carbon stocks

Material ≥100 mm in diameter and ≥50 cm in length was defined as coarse woody debris (CWD). CWD for carbon estimates included stumps and fallen debris. At BioCondition assessment plots CWD was measured within a 50 × 20 m subplot. For monitoring plots that formed part of the silvicultural trials, each piece of CWD was measured within a subplot of known area (generally 40 × 20 m, for a 40 × 40 m plot). For smaller plots (25 × 25 m), CWD was assess over the entire plot area. Volume of CWD was determined by measuring the length and end diameters of each piece (to 100 mm) within the assessment area. A percentage decay was also attributed to each piece to account for potential volume loss through decay.

The total volume of woody debris per unit area was calculated (m^3/m^2). To convert CWD volumes to a mass per unit area, the volumes of CWD were multiplied by their respective wood densities (e.g. 650 kg m^{-3}, Ilic et al. 2000). Carbon concentration of CWD was not measured in the current project, but carbon stocks of CWD were estimated by multiplying CWD mass by a default carbon concentration value of 50%.

Tree carbon stocks

The DBH of measured trees was used to provide an estimation of the above-ground biomass and tree carbon stocks for all tree species. The above-ground biomass was estimated using general allometric relationships for eucalypt vegetation (Paul et al. 2016). These allometrics were developed based on existing biomass datasets in Australia and were based on 6004 eucalypt individuals (*Eucalyptus* and closely-related genus of *Corymbia* and *Angophora*). The following equation was used for eucalypts, which made up most of the dataset:

$$\text{Above-ground biomass (kg)} = \exp\,[-2.016 + 2.375\ \ln(\text{DBH})] \times 1.067$$

For non-eucalypts (e.g. Cypress pine) separate equations were used based on Paul et al. 2016. An estimate of below-ground biomass was made assuming that 35% of the above ground biomass is roots (based on unpublished data and Paul et al. 2019).

Tree biomass was converted to carbon using a carbon concentration of 49% (Gifford 2000).

At soil sampling sites (selected experimental sites), the carbon stored in understorey vegetation was also be estimated. In the five subplots selected for soil and litter sampling the diameter of all woody plants with a DBH 2.5–9.9 cm was measured to allow estimation of carbon stored in these understorey plants, using the above allometrics.

Assessment of BioCondition

This methodology for assessing BioCondition has been summarised from the BioCondition assessment manual (Eyre et al. 2015b) and the reader is referred to the full manual for more detailed methodology. The BioCondition manual (Eyre et al. 2015b) provides a robust framework for monitoring as it provides a quick and relatively easy assessment of ecological condition and key habitat structures, and has been widely tested (e.g. Kelly et al. 2011; Neldner and Ngugi 2014).

The locations of the BioCondition plots sampled are shown in Figure 2.7. For each plot sampled, the likely regional ecosystem was designated based on available mapping layers (i.e. remnant and regrowth forest mapping and the likely ecosystem prior to clearing) and plot species composition data. Benchmarks for each relevant ecosystem were sourced through collaboration with the Department of Environment and Science (DES). Expert advice was sought from project collaborators in DES where no benchmarks were available for a given ecosystem, or where benchmarks are based on a limited number of sites, so that a reasonable benchmark could be attributed to each site. As no benchmark information was available for the NSW sites, we used the plot data (tree species composition), along with available geology GIS layers to determine the Queensland equivalent regional ecosystem and corresponding benchmark values.

BioCondition was assessed within a 100 × 50 m plot. In summary, this included measurement of 10 site based attributes within five assessment areas in the 100 × 50 m plot (Figure 2.8):

(1) 100 × 50 m area: assessed for number of large trees, recruitment of canopy species, tree canopy height and native tree species richness.
(2) Central 100 m transect: tree canopy cover and native shrub canopy cover assessments.
(3) 50 × 10 m subplot, centred from the 25 m point to the 75 m point along the central transect, and encompassing 5 m either side of the transect: assessed for non-native plant cover and native plant species richness of shrubs, grass and non-grass species.
(4) 50 × 20 m subplot, centred from the 25 m point to the 75 m point along the central transect, and encompassing 10 m either side of the transect: assessed for coarse woody debris.
(5) Five 1 × 1 m quadrats, starting at the 35 m point and located on alternate sides of the centre-line, starting on the right hand side in the direction of the transect, 10 m apart along the 100 m transect: assessed for native grass cover and organic litter (an average value is derived over the five quadrats).

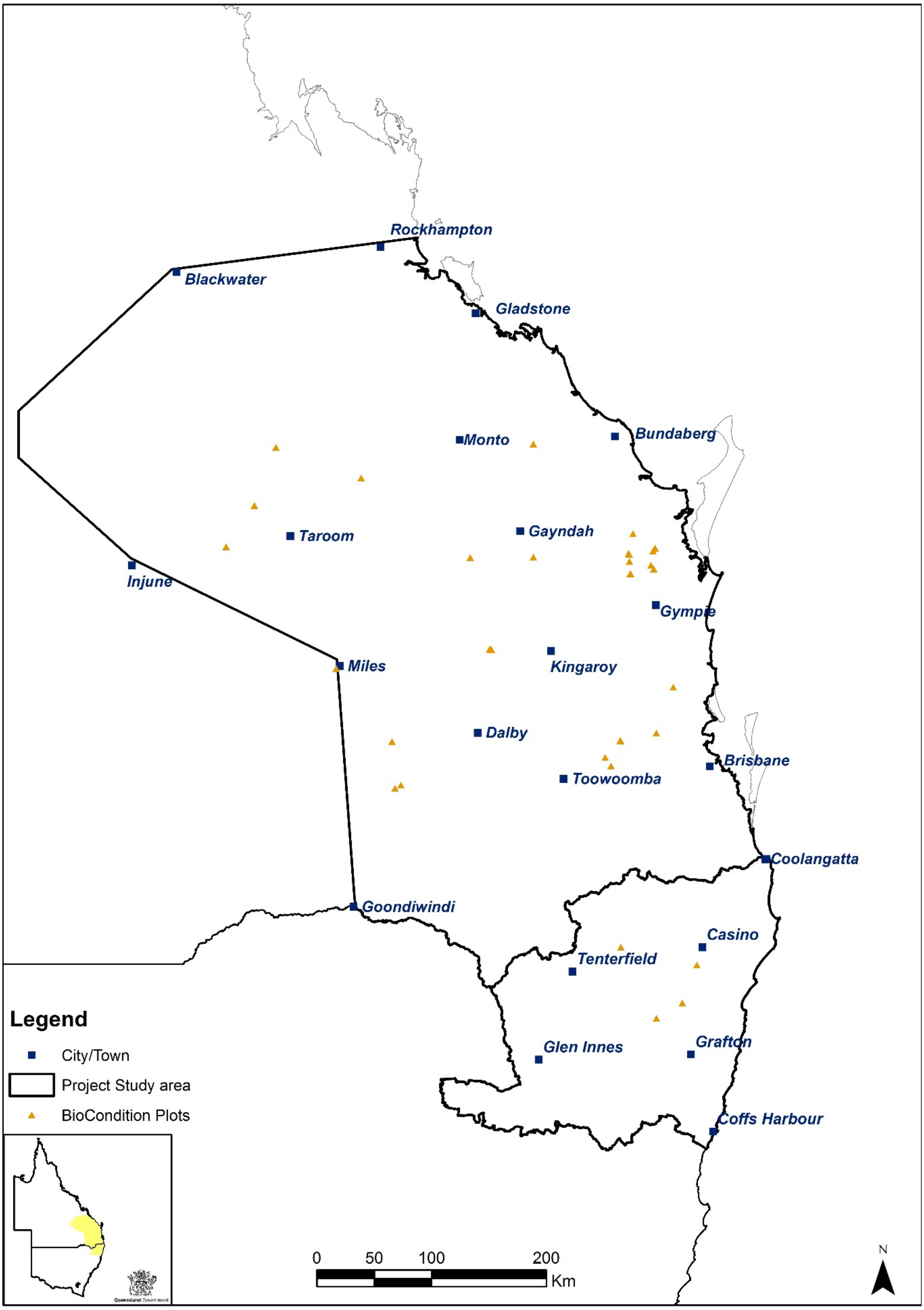


Figure 2.7. Locations of the 29 BioCondition plots established across the study area in the current study.

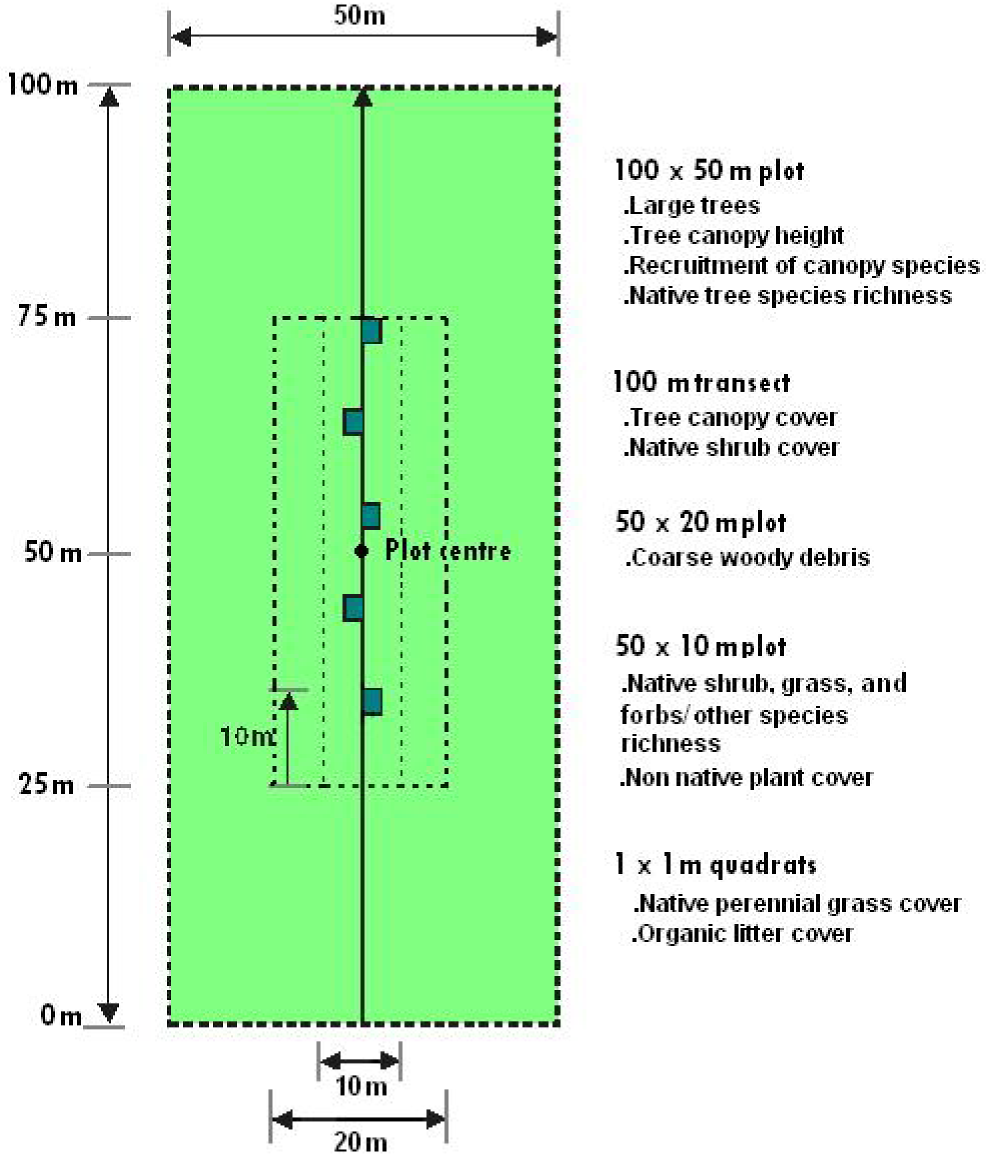


Figure 2.8. Standard BioCondition plot and attributes recorded within the plot (Source: Eyre et al. 2015b).

In addition to the 10 site based attributes, three landscape attributes were also assessed. Landscape attributes include: (1) A measure of the size of the patch of vegetation (remnant and regrowth) in which the assessment unit is located. (2) The connectivity of the patch or the degree to which the assessment unit is connected with adjacent native vegetation (remnant and regrowth). (3) Context, which refers to the amount of native vegetation that is retained in the landscape proximal to the site being assessed, where scoring relates to the proportion of native remnant vegetation and/or regrowth vegetation that is retained within a 1 km radius landscape. Landscape attributes were calculated in the office using mapping layers in ArcGIS® software by ESRI (Environmental Systems Research Institute). The Department of Environment and Science (DES) have developed a landscape metrics tool to allow easy and consistent calculation of the landscape scores.

BioCondition uses the following scoring system for these site and landscape attributes:

1. Large trees.

Description	Score
No large trees present	0
0 to 50% of benchmark number of large trees	5
≥50% to 100% of benchmark number of large trees	10
≥ benchmark number of large trees	15

2. Tree canopy height.

Description	Score
<25% of benchmark height	0
≥25% to 70% of benchmark height	3
≥70% of benchmark height	5

3. Recruitment of canopy species.

Description	Score
<20% of dominant canopy species present as regeneration	0
≥20 – 75% of dominant canopy species present as regeneration	3
≥75% of dominant canopy species present as regeneration	5

4. Tree canopy cover.

Description	Score
<10% of tree canopy cover relative to the benchmark	0
≥10% and <50% of tree canopy cover relative to the benchmark	2
≥50% or ≤200% of tree canopy cover relative to the benchmark	5
>200% of tree canopy cover relative to the benchmark	3

5. Shrub canopy cover.

Description	Score
<10% of benchmark shrub cover	0
≥10 to <50% or >200% of benchmark shrub cover	3
≥50% or ≤200% of benchmark shrub cover	5

6. Coarse woody debris.

Description	Score
<10% of benchmark number or total length of CWD	0
≥ 10 to <50% or >200% of benchmark number or total length of CWD	2
≥50% or ≤200% of benchmark number or total length of CWD	5

7. Native plant species richness. Species richness is assessed for four life-forms: trees, shrubs, grasses and forbs/other.

Description	Score
<25% of benchmark number of species within each life-form	0
≥25% to 90% of benchmark number of species within each life-form	2.5
≥90% of benchmark number of species within each life-form	5

8. Non-native plant cover.

Description	Score
>50% of vegetation cover are non-native plants	0
≥25 – 50% of vegetation cover are non-native plants	3
≥5 – 25% of vegetation cover are non-native plants	5
<5% of vegetation cover are non-native plants	10

9. Native perennial grass cover.

Description	Score
<10% of benchmark native perennial grass cover	0
≥10 to 50% of benchmark native perennial grass cover	1
≥50 to 90% of benchmark native perennial grass cover	3
≥90% of benchmark native perennial grass cover	5

10. Cover of organic litter.

Description	Score
<10% of benchmark organic litter	0
≥ 10 to <50% or >200% of benchmark organic litter	3
≥50% or ≤200% of benchmark organic litter	5

11. Size of patch of remnant or regrowth vegetation.

Description	Score
<5 ha remnant AND/OR regrowth	0
≥5 – 25 ha remnant AND/OR regrowth	2
≥25 – 100 ha remnant OR ≥25 – 200 ha remnant and regrowth OR ≥25 – 200 ha regrowth	5
≥100 – 200 ha remnant OR >200 ha remnant and regrowth OR >200 ha regrowth	7
≥200 ha remnant	10

12. Connectivity to adjacent native vegetation.

Description	Score
Low connectivity. The assessment unit is not connected using any of the below descriptions.	0
Medium connectivity. The assessment unit: is connected with adjacent remnant vegetation along >10% to <50% of its perimeter OR is connected with adjacent remnant vegetation along <10% of its perimeter AND is connected with adjacent regrowth native vegetation > 25% of its perimeter.	2
High connectivity. The assessment unit is connected with adjacent remnant vegetation along 50% to 75% of its perimeter.	4
Very high connectivity. The assessment unit: is connected with adjacent remnant vegetation along >75% of its perimeter OR includes > 500 ha remnant vegetation.	5

13. Context, which refers to the amount of native vegetation that is retained in the landscape proximal to the site being assessed.

Description	Score
<10% remnant vegetation AND <30% native non-remnant vegetation (regrowth)	0
≥10% to 30% remnant vegetation AND <30% regrowth OR <10% remnant vegetation AND ≥30% regrowth	2
≥30% to 75% remnant vegetation OR ≥10% to 30% remnant vegetation AND ≥30% regrowth	4
>75% remnant vegetation	5

Scores were derived for each attribute and a total BioCondition score, between 0 and 1 (where 1 represents the maximum score, e.g. 100/100) was derived for each site, based on available benchmark data for the relevant ecosystems. A weighting was applied to the site-based attributes and the landscape attributes based on Table 2.2. Scores are reported as a proportion to allow comparison between sites where not all attributes are assessed.

Sites that scored between 0.8 and 1 were considered to be in ‘very good condition’, and are likely to be functioning in a similar manner to the relevant benchmarks. Sites that scored between 0.60 and 0.8 were considered to be in ‘good condition’ and show a strong potential to be recovered to a benchmark condition. Sites that scored between 0.4 and 0.6 (moderate condition) or less than 0.4 (poor condition) were likely to be highly degraded through management, or in earlier stages of regrowth.

Table 2.2. Weights for the different attributes assessed using BioCondition, to give a total score for each plot out of 100 (converted to a score of between 0 and 1).

Site based attributes:	Maximum score
Large trees	15
Tree canopy height	5
Recruitment of canopy species	5
Tree canopy cover (%)	5
Shrub layer cover (%)	5
Coarse woody debris	5
Native plant species richness for four life-forms	20
Non-native plant cover	10
Native perennial grass cover (%)	5
Litter cover	5
Landscape attributes:	
Size of patch	10
Patch context	5
Patch connectivity	5
Total Score	**100**

In addition to the BioCondition scoring, some additional assessments were made at the stand-alone BioCondition plots. These included estimation of CWD volumes (in addition to total length of CWD) and an assessment of soil erosion. These attributes were not included in the calculation of the total BioCondition score.

BioCondition assessments involve measuring the length (m) of pieces of coarse woody debris (CWD) within a 50 × 20 m subplot. In addition, volume of CWD was determined by measuring the length and end diameters of each piece. Where volume was calculated using Smalian's formula (Woldendorp et al. 2002):

$$V = L\,(Ab + As)/2$$

Where V = volume, L = length of piece, Ab = cross-sectional area at large end piece, As = cross-sectional area at small end piece.

A percentage decay was attributed to each piece to account for potential volume loss through decay. Volume data is more informative and allows an estimation of carbon storage in CWD, when combined with estimates of wood density.

Due to the potential influence of forest management and livestock grazing on soil erosion (e.g. through machines traversing the forest etc), soil erosion was assessed on the 100 m central transect and the two perpendicular 50 m ends of the BioCondition plot, giving a total transect length of 200 m. Erosion was rapidly assessed at 1 m intervals along each transect, recording percentage bare-ground cover (i.e. areas where no organic litter of vegetation is present). These observations were made within a 30 cm diameter circle centred around the 1 m intervals on a tape measure. Each observation point was also assessed for erosion severity by recording:

(1) No evidence of erosion;
(2) Minor erosion that may be due to natural processes;
(3) Moderate erosion (active sheet or rill erosion); or
(4) Severe erosion (active gully, tunnel or mass movement erosion)

Type of erosion (where present) was recorded, based on the following definitions:

1. Sheet erosion: relatively uniform removal of soil without development of channels;
2. Rill erosion: small channels less than 30 cm deep;
3. Gully erosion: channels 30 cm or more deep;
4. Tunnel erosion: removal of subsoil by water while the surface soil remains relatively intact; or
5. Mass movement: large down-slope movement of soil and/or rock.

For each plot, the proportion of points (200 in total) that showed signs of no erosion, minor erosion or moderate-severe erosion was calculated.

BioCondition scoring for trial plots

Due to the limited areas of different treatments at the trial plots, full BioCondition transects could not be established at these plots. BioCondition assessments were made within the existing plots for sites with plots ≥0.16 ha in area (although sometimes a smaller area assessed for 'untreated' plots). These assessments were relatively rapid because they could draw on data already collected within the plot area. Plots with a smaller areas than 0.16 ha (e.g. some of the sites with circular plots) could not be reasonably assessed for BioCondition. This is because some of the attributes assessed in BioCondition (e.g. number of large trees / ha, CWD) are unlikely to be accurately reflected in smaller plots (Annie Kelly pers comm.). Details on the BioCondition scoring are provided in the methods section of Chapter 6.

Mapping of the resource

The methodology for mapping the resource differed between NSW and Queensland. This was necessary as many of the data layers available in Queensland (e.g. Regional Ecosystem mapping) were not available for NSW.

Mapping of the NSW private native forest extent was made available by the NSW Department of Primary Industries (see https://www.dpi.nsw.gov.au/forestry/private-native-forestry), who contracted ForeSense Pty Ltd (2017) to carry out a forest productivity assessment using three-dimension aerial photograph interpretation. The extent of potentially harvestable private native forest in Queensland was determined through mapping carried out by the Department of Environment and Science, Remote Sensing Centre (using ArcGIS Version 10.4.1). The key aim of this mapping in Queensland was to determine potentially harvestable areas, with the total area of private native forest also determined. The following methods were followed in Queensland.

The mapping covered MGA Zones 55 and 56 and used the ALBERS94 projection (gda94 datum and grs80 spheroid). Mapping was based on the 2014 foliage projective cover (FPC) dataset (FPC14, Statewide Landcover and Trees Study, SLATS), remnant mapping (remnant cover 2015) and high value regrowth mapping (2016). Forests were considered potentially harvestable if they had a suitable mix of species, based on Regional Ecosystem (RE) classification (see https://www.qld.gov.au/environment/plants-animals/plants/ecosystems/about), that are utilised by the hardwood milling industry. Only REs where timber harvesting is allowed under the native forest practice code (*Managing a native forest practice – accepted development vegetation clearing code*, see: https://www.qld.gov.au/environment/land/vegetation/codes) were included. Note that at the time of writing the native forest practice code is currently undergoing revision and current conservation status of each of the listed REs is being reviewed. Native forests in Queensland are mapped at a scale of 1:100,000 using the regional ecosystem mapping framework

(Neldner et al. 2017a). Each RE is a discrete vegetation community in a bioregion that is consistently associated with a particular combination of geology, landform and soil. This RE mapping framework is the principal vegetation information resource used for planning, development and legislation in Queensland (e.g. QLD Vegetation Management Act 1999).

Areas were determined separately for (1) remnant forest; (2) high-value regrowth forest; and (3) other woody vegetation with a cover of at least 30%, that were not considered remnant or high-value regrowth. The pre-clear RE mapping was used to assign REs to the 'high-value regrowth' and the 'other woody areas' and again, only those in the REs listed in the native forest practice code as 'harvestable' were mapped. These different classifications are defined below.

Remnant: Areas may be mapped as 'remnant' if the vegetation covers more than 50% of the undisturbed predominant canopy; averages more that 70% of the vegetation's undisturbed height; and if the vegetation contains species characteristic of the undisturbed predominant canopy (Accad et al. 2019).

Regrowth: The areas of regrowth mapped here are 'high-value regrowth' (https://www.cabinet.qld.gov.au/documents/2009/sep/vegetation%20mgt%20amendment%20bill%202009/Attachments/regrowth%20vegetation%20code.pdf). This includes (a) regional ecosystems that are either 'endangered', 'of concern' or 'least concern'; (b) areas that have not been cleared since 31 December 1989; and (c) areas shown on a Queensland Government regrowth vegetation map.

Woody non-remnant: Areas that have woody vegetation cover (with at least 30% foliage projective cover) but are not mapped as either of the above. These areas are effectively regrowth forest; they can be managed without following the native forest practice code (referred to as Category X vegetation; Department of Environment and Resource Management 2010).

A native forests feature class was created by removing plantation areas from woody vegetation coverage. A private native forest feature class was created by selecting freehold land parcels from the digital cadastral database (DCDB, current July 2016). Only areas where slopes that were less than 25 degrees were mapped as potentially harvestable, as this is the slope threshold set by the native forest practice code to reduce risk of soil erosion. Further, only polygons with a land area of potentially harvestable forest that was greater than 20 ha were included. In some cases this was split across properties (LotPlans, lot and plan number) or tenures. No attempt was made to exclude buffer areas (e.g. waterways) where logging may not be permissible under the native forest practice code. While exclusion of buffer zones would result in reduction of harvestable areas, the majority of watercourses in these mainly dry sclerophyll forests are mapped as stream type of order 1 to 4, and have a buffer zone requirement of between 0–5 metres stipulated by the native forest practice code (Department of Natural Resources and Mines 2014).

In summary, the following sequence of steps was followed to create the maps and determine the area extent:

1. The study area (or sub-region) was selected.
2. Slope was classified as either greater than or less than 25 degrees. A raster dataset for slope was generated from one second SRTM (Shuttle Radar Topography Mission, NASA) derived hydrological Digital Elevation Model (DEM-H, Version 1.0, 2011).
3. Foliage projective cover (FPC) dataset (FPC14, Statewide Landcover and Trees Study, SLATS), remnant mapping (remnant cover 2015) and high value regrowth (HVR) mapping (2016) was added. The union of the FPC, HVR and remnant cover resulted in a total forest cover layer.

(4) Regional Ecosystems where timber harvesting is allowed under the native forest practice code were mapped, based on RE mapping and pre-clear mapping and these were intersected with the woody vegetation layer created in the step above.
(5) Freehold land was selected using the Queensland Cadastral DCDB layer.
(6) Forest areas less than 20 ha were excluded at three stages:
    1. At the FPC level, any polygon considered as woody on the landscape but was <20 ha in extent was excluded at landscape level upfront.
    2. After union of the FPC with HVR and remnant cover, we examined the area of harvestable REs within all mapped polygons. Where the REs were mixed (some are harvestable others are not), we used RE percent to determine the area proportion of harvestable REs within the polygon. If that area was < 20 ha, then that polygon was excluded.
    3. We then overlayed the tenure boundaries and free hold and any Lot On Plan < 20 ha was excluded.
(7) Relevant layers were intersected to create maps and allow analysis of private native forest extent for each sub-region and the entire study region.

This mapping has not been tested for accuracy with on ground surveys. As many private native forests are in poor productive condition, this mapping provides an over-estimate of the forest area that might actually be available for timber harvesting at a given point in time. Observations made whilst travelling to field sites suggest that further work is need to improve the accuracy of the mapping. Some areas that were mapped as potentially harvestable forest clearly did not contain forest that was productive enough to be harvested for timber products (e.g. while the RE mapping may have been accurate, the level of site productivity was too low). Further, there are potentially other regrowth areas that have <30% woody vegetation cover, in which trees have been or could be harvested.

Future monitoring and inventory

Future assessments of the private native forest resource should complement existing data (and methodology) and include a combination of permanent plots, where trees are tagged to follow growth over time, and where more detailed measurements are made (e.g. trial plots), and once-off inventory assessments (e.g. PFSQ resource inventory) over a broad area and range of forest types.

Future plots established should be representative of the resource and it is important that a consistent monitoring framework is followed at these plots over time. In addition to carrying out measurements, plot maintenance should also be carried out at existing plots (Table 2.1). This should involve replacing any missing or degraded plot pegs, re-tagging trees that have lost their tags and determining whether further treatment is necessary (e.g. if there has been recruitment of stems since the previous measure). It is recommended that the permanent plots be assessed on a five-yearly cycle. Measurements made more frequently than this are not really necessary given the relatively small annual growth increments and inaccuracies associated with measuring DBH (e.g. associated with bark-shedding etc).

For once-off assessments of the forest resource the PFSQ inventory system (resource assessment) should be used. This allows detailed information to be provided to the landholders (i.e. value of the current standing timber) and will allow data transfer to the decision support system developed here to predict the future value of the timber resource (Chapter 5). Further, through recording the location of each individual tree (through GPS systems integrating with data recording systems), this inventory data allows potential for re-assessment over time.

Data collected at the 158 trial plots in private native forest, that were sampled during this project was used to investigate variability in different measured parameter (in particular basal area, stocking and DBH growth rate) at these sites. An estimate of the number of plots required to sample the population (n) was calculated using the formula provided in Shiver and Borders (1996):

$$n = 4 \times (\text{coefficient of variation})^2 / (\text{allowable error})^2$$

Where the desired allowable error was set at 10%, and coefficient of variation is expressed as a percentage (the ratio of the standard deviation to the mean).

Based on this, sample size estimates ranged from 160 plots (to account for variability in basal area) to 263 plots (to account for the variation in merchantable volume) (Table 2.3). It should be pointed out that most of these trial plots (150 of 158) were in forest with spotted gum as one of the locally dominant species. Assuming similar levels of variability in the measured parameters, ideally a similar number of plots would be established across the resource in different commercial forest types (key commercial forest types are identified in Chapter 3).

Table 2.3. Number of plots that should be sampled to adequately represent stand basal area, stocking and volume growth in private native forest, based on variability in the existing 158 trial plots in private native forest.

Measured parameter	CV (%)	Number of plots required
Stand basal area (m^2/ha)	63.2	160
Stand stocking (SPH)	75.5	228
Merchantable volume (m^3/ha)	81.1	263
Volume PAI (m^3/ha/year)	76.8	184

Most of the trial plot data utilised above is from spotted gum dominated forest. Further work is required to determine is similar levels of variation (CV) exist for other forest types.

Data collected at the PFSQ resource inventory plots was also investigated. As these plots cover a broader range of forest types, variation (and the required sample size) was expected to be higher and this dataset is more likely to be representative of the resource. Based on this dataset the number of inventory plots required ranged from 199, to cover variation in stocking, to 373, to cover variation in merchantable volume (Table 2.4). To accurately sample current merchantable volume on trees with a DBH of ≥ 30 cm, a much higher sample size would be required (Table 2.4). As these inventory plots tended to be more commonly located in the eastern half of the study region (Figure 2.5), further inventory in the western half of the region could result in greater required sample sizes. Nevertheless, the current resource inventory data (392 plots) is a great starting point to better understand this resource.

Table 2.4. Number of plots that should be sampled to adequately represent stand basal area, stocking and volume growth in private native forest, based on variability in 392 resource inventory strip plots in private native forest.

Measured parameter	CV (%)	Number of plots required
Stand basal area (m^2/ha)	72.8	212
Stand stocking (SPH)	70.5	199
Merchantable volume (m^3/ha)	96.6	373
Merchantable volume ≥ 30 cm DBH (m^3/ha)	112.1	503

While the datasets introduced in this chapter provide a reasonable sample, in terms of covering the variation in basal area and stocking, further inventory data is needed to provide more accurate estimates of merchantable volume in large trees (≥ 30 cm DBH), which varies greatly between sites.

Chapter 3: Extent and condition of the private native forest resource.

Tom Lewis, Tyron Venn, Ben Francis, Tracey Menzies, Sean Ryan, Nick Cameron and Annie Kelly

Introduction

Private native forests provide an important source of timber to the timber processing industry (Chapter 4), and are also important in terms of the habitat they provide for the conservation of fauna and flora. If managed appropriately, they will likely provide both ongoing resources to the timber industry and aid in the retention of local wildlife. A need was therefore identified to provide an up-to-date analysis of the extent and condition of privately owned native forests that are considered to be potentially able to produce timber products. Earlier work by The Queensland Comprehensive Regional Assessment – Regional Forest Agreement (CRA/RFA) Steering Committee (1998a), MBAC Consulting Pty Ltd (2003a) and PFSQ (c2015) have provided area estimates in Queensland, and recent work has estimated the potential resource in north-eastern NSW (Foresense Pty Ltd 2017). These studies cover different regions (and total areas) depending on their objectives. Nevertheless, it is clear from these previous studies that the private forest resource covers a large area in southern Queensland and northern NSW. In this chapter we report an estimate of private native forest extent, based on latest available mapping layers for a study region which covers a total area of 24.4 M ha.

Forest condition is dependent on a range of factors including its biology (i.e. ecosystem processes), climate and its current and historic management. The term ‘forest condition’ is subjective, as condition can be defined in different ways depending on the objective of the study. In this report we refer to two aspects of forest condition. Firstly, ‘productive condition’, which is defined from a commercial forestry perspective (i.e. availability of merchantable timber volumes). Factors that influence the potential of a site, in particular, stand growth, tree health, composition and structure can influence productive condition. Environmental factors (e.g. rainfall), biotic factors (e.g. competition for resources) and management history (e.g. silvicultural management) can all influence productive condition. The second aspect of condition is ‘BioCondition’, which measures the ecological condition (Eyre et al. 2015b) and provides a measure of the capacity of a terrestrial ecosystem to maintain biodiversity values. In BioCondition, ‘condition’ refers to the degree to which the attributes of a patch of vegetation, known to be important for biodiversity functioning, differ from the attributes of the same vegetation in a reference (‘best on offer’) state. It is important to consider both aspects of condition in long-term sustainable forest management as there is a growing demand for timber sourced from forests that strike the right balance between social, environmental and economic benefits (Howell et al. 2008). Indeed, both aspects of condition are known to vary over time (e.g. depending on the time since last timber harvest, natural disturbances, such as wildfire, and the growth stage of the forest). While our assessments in the current project will provide a snap-shot of the condition, it is important that condition is monitored over time to reflect the changes that occur over a forest cycle (e.g. from regrowth through to mature forest).

Previous inventory studies of the private forest resource (Queensland CRA/RFA Steering Committee (1998a), MBAC Consulting Pty Ltd (2003a) and Bureau of Rural Sciences (2004) have provided estimates of available timber volumes. However, previous studies in the region have provided little information on the productive condition of private native forest stands, in terms of stand diameter class distributions and growth. Further, few studies have measured ecological condition of private native forests managed for timber production in the study region. One study however, took place in northern NSW (Jay 2009) used condition metrics to assess habitat value, stand structural features and timber productivity at 21 sites in Clarence Lowland Spotted Gum forests. Jay (2009) reported that all sites received high condition scores, irrespective of their forest structure and management history.

The aims of this chapter were to: (1) determine the geographic extent of private native forest that may be potentially productive for timber harvesting; (2) determine the productive condition of these forests; and (3) provide a snap-shot of the BioCondition of these forests. Given the paucity of inventory data available for private native forest in the region, it was considered important to determine how forest condition varied throughout the study region. As such, the extent and condition of these forests were determined across the entire study region, and also for each of four sub-regions (Wide Bay-Burnett, south-east Queensland, western Queensland and north-east NSW). Fact sheets based on the information presented in this chapter were created and are available online (https://publications.qld.gov.au/dataset/private-native-forest-resource-extent-and-condition/resource/56cf2996-f5e5-4553-a607-3ca799601bf0).

Methods

In this analysis, the study region was divided into four sub-regions: (1) Wide Bay-Burnett (total area of 6.3 M ha), (2) south-east Queensland (total area of 2.2 M ha), (3) western Queensland, which included the Fitzroy, Darling Downs regions (total area of 12.0 M ha), and (4) north-east NSW (total area of 3.9 M ha). In Queensland these sub-regions were based on catchment boundaries. In NSW the Upper North East Regional Forest Agreement area was used.

Assessment of standing timber volumes and BioCondition were made in the ‘stand-alone yield and BioCondition plots’ (Chapter 2). Standing timber volumes were calculated using measures of DBH and merchantable height, and species specific volume equations for Queensland native forest (Henry 1991). Volumes were calculated for all trees that recorded a merchantable height, irrespective of whether they were currently merchantable, or merchantable in the future (merchantable height was recorded on trees with a DBH ≥20 cm). A total of 29 plots were established and assessed, based on methodology in Chapter 2. These plots were located across all of the four sub-regions: 11 in the Wide Bay-Burnett, six in south-east Queensland, eight in western Queensland and four plots north-east NSW. In addition, four sites were available for calculation of BioCondition from an earlier study by Jay (2009) in northern NSW. The Jay (2009) study used alternative condition metrics, but based on data supplied by Alex Jay, we were able to determine an equivalent BioCondition score for each site. In this case at least five plots were established on each property, but an average score was used for the property. Of the 33 sites utilised in our analysis, all were mapped as remnant vegetation (in Queensland), or were likely to be considered remnant vegetation (NSW sites, based on the Queensland definitions). This was necessary for BioCondition scoring.

This chapter also utilised the PFSQ resource assessment inventory data (described in Chapter 2). This data set was used to determine the density of merchantable and unmerchantable stems that are typical in private native forest. A total of 392 plots were assessed over a total area of 195 ha (Figure 2.5). However, some plots only included assessments of commercial timber volumes and did not record all stems. Using the combined PFSQ resource inventory and BioCondition datasets, our analysis focussed on 316 plots (over 147 ha) that had assessments of all stems, where trees were classified as either: (1) should be removed at a near-term harvest; (2) should be retained for future harvest; (3) should be retained as habitat or for other native forest practice code requirements; or (4) should be silviculturally treated. These plots were mostly located in the Wide Bay-Burnett (147 plots), and south-east Queensland (123 plots), but 32 plots were located in north-east NSW and 14 plots were located in the western Queensland region. Of the Queensland plots, 70 (25% of plots) were mapped as non-remnant (regrowth forest) vegetation.

Mapping of the private native forest resource was initially carried out by the Department of Environment and Science (Queensland Government), following the methodology in Chapter 2. In Queensland, the mapped private native forest areas are based on regional ecosystems that are potentially harvestable under the current (as of 2018) native forest practice code. It is important to point out that the areas reported do not include the more open woodlands with less than 30% foliage projected cover. The mapped areas do not reflect the areas currently managed for timber production. This mapping has been refined somewhat in Chapter 4 to allow estimates of commercially important forest types (eucalypt dominated forests and woodlands).

A key determinant of the productive condition of private native forests is the proportion of merchantable stems, relative to those that are unmerchantable. These proportions were calculated for each sub-region based on the combined data from the new BioCondition plots established and the PFSQ resource inventory data. We focus on trees with a DBH of at least 10 cm here, as trees smaller than this were not consistently recorded. In addition, smaller DBH trees are more likely to fluctuate greatly in density in response to factors such as fire, drought and grazing (Lewis and Debuse 2012). While regeneration of stems <10 cm DBH is important to ensure a future stand, achieving adequate regeneration is rarely an issue in most native forests in the region. Summary statistics on stocking, basal area and volume are provided as means (± standard errors).

Results

Summary for the region

Across the study region, there is a total of approximately 2,597,700 ha of potentially harvestable private native forest. The Wide Bay-Burnett region contained a large proportion of this (1,005,300 ha) and there were approximately 525,600 ha of private native forest in the north-eastern NSW region.

Across the Queensland component of the study region, the five most common forest types, based on broad vegetation groups (BVGs; Neldner et al. 2017a) are reported in Table 3.1. Spotted gum forests and woodlands were the most common vegetation types. A total of 196 potentially harvestable regional ecosystems were present in the Queensland component of the study region. The five most common regional ecosystems in the study region were: (1) *Corymbia citriodora* subsp. *variegata*, *Eucalyptus crebra* woodland on metamorphics +/- interbedded volcanics (12.11.6, 138,164 ha); (2) *Corymbia citriodora* subsp. *variegata*, *Eucalyptus crebra* woodland on Mesozoic to Proterozoic igneous rocks (12.12.5, 138,002 ha); (3) *Corymbia citriodora* or *Eucalyptus crebra* woodland on Cainozoic lateritic duricrust (11.7.6, 110,922 ha); (4) *Corymbia citriodora* woodland on coarse-grained sedimentary rocks (11.10.1, 110,707 ha); and (5) *Eucalyptus crebra* and/or *E. populnea*, *Callitris glaucophylla*, *Angophora leiocarpa*, *Allocasuarina luehmannii* woodland on Cainozoic sand plains and/or remnant surfaces (11.5.1, 103,262 ha).

Table 3.1. Forest types most common in potentially harvestable ecosystems in the Queensland component of the study region (based on BVG, broad vegetation grouping, mapping of Neldner et al. 2017a).

Potentially harvestable forest type	Area	% of area
Corymbia citriodora (spotted gum) dominated open forests to woodlands on undulating to hilly terrain (BVG 10)	715,900	34.5
Dry to moist eucalypt woodlands and open forests, mainly on undulating to hilly terrain (BVG 13)	637,300	30.8
Moist to dry eucalypt open forests to woodlands usually on coastal lowlands and ranges (BVG 9)	235,500	11.4
Dry eucalypt woodlands to open woodlands, mostly on shallow soils in hilly terrain (BVG 12)	219,500	10.6
Eucalyptus spp. dominated open forest and woodlands drainage lines and alluvial plains (BVG 16)	123,700	6.0
Other forest types (BVGs 8, 11, 15, 17, 18 and 22)	140,100	6.8

Across all plots (PFSQ resource inventory and BioCondition plots) average stocking was 268.6 (± 7.36) stems per hectare and average basal area was 14.4 (± 0.45) m^2/ha. Total potentially merchantable volume was 28.5 (± 1.32) m^3/ha with 23.1 (± 1.28) m^3/ha on trees with a DBH ≥ 30 cm. A large proportion of trees were considered unmerchantable, particularly in the 10–20 cm DBH class (Figure 3.1). These are trees that could potentially be thinned through silvicultural treatments. Regrowth forests had a particularly high stocking in the 10–20 cm DBH class, where approximately 76% of stems where assessed as unmerchantable (Figure 3.2). Unsurprisingly, regrowth forests had a lower density of trees in the larger size classes (30 cm plus DBH, Figure 3.2), reflecting their previous clearing history.

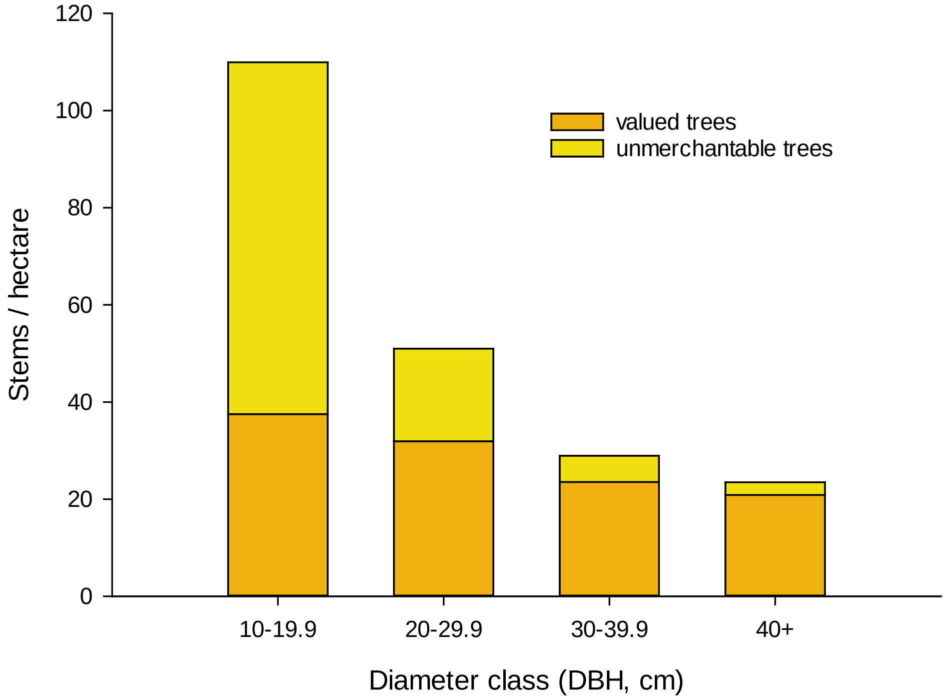


Figure 3.1. Stocking across all private native forests (stems / ha) in different size classes. Different coloured bars represent the stems that are valued (for current or future timber resource, or required for environmental purposes) or were considered unmerchantable, and would ideally be thinned to improve productivity of the retained stand.

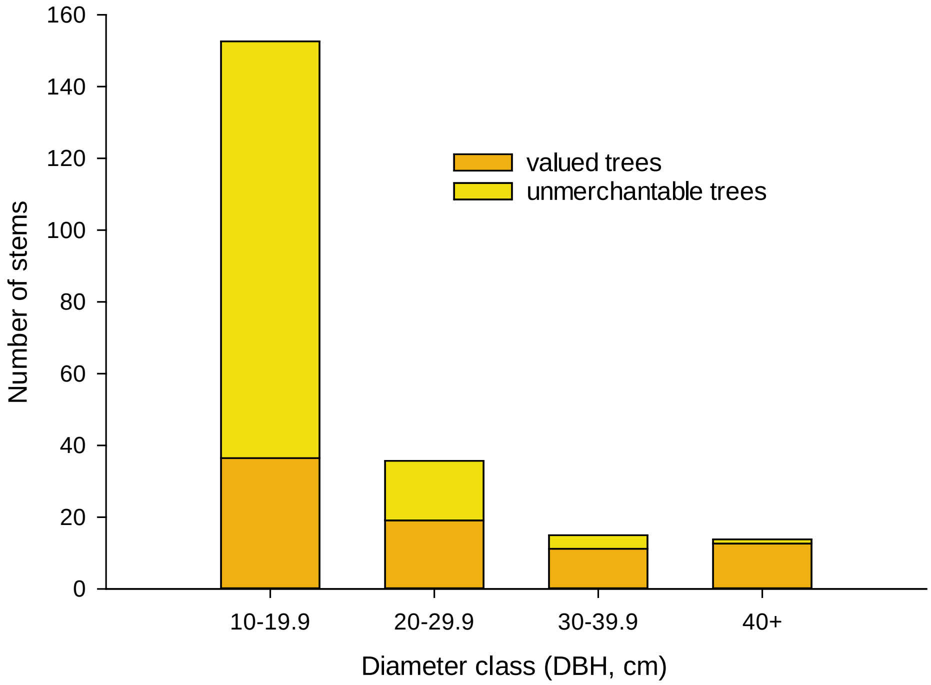


Figure 3.2. Stocking in regrowth (non-remnant) private native forests (stems / ha) in different size classes. Different coloured bars represent the stems that are valued (for current or future timber resource, or required for environmental purposes) or were considered unmerchantable, and would ideally be thinned to improve productivity of the retained stand.

Based on the 33 BioCondition surveys, the average overall BioCondition score was 0.75 (± 0.018). One-third of sites (11) scored 0.8 or more, and thus were considered to be in very good ecological condition. No sites score less than 0.6. A separate review of the scoring of individual BioCondition attributes revealed that attributes such as tree height, recruitment of canopy species, litter cover consistently scored very well (with scores of greater than 90% relative to the benchmark). Only one attribute (shrub canopy cover) had an average score of less than 60%, despite having an average percentage cover that was similar between private native forest and the benchmarks. Attributes that on average scored between 60 and 70% included the number of large trees, species richness of forb/other plant functional groups, native perennial grass cover and degree of connectivity in the landscape.

A summary of the site-based attributes, along with their corresponding average benchmark values is provided in Table 3.2. For many attributes, including median canopy height, tree cover, shrub canopy cover, perennial grass cover, litter cover, tree species richness, shrub species richness and perennial grass species richness, average values in private native forest were similar or greater than benchmark values. For attributes such as CWD length and introduced species cover, values were higher in private forest sites than in the corresponding benchmarks, resulting in a lower condition score. Other attributes had lower values at the private native forest sites than in the corresponding benchmarks (i.e. large tree density, regeneration of canopy species and forb species richness). However, in the case of regeneration of canopy species, values were still high (i.e. 94.2%) in private native forest, resulting in high scores for this attribute in most cases.

Table 3.2. Mean (and standard error) values for BioCondition site-based attributes assessed across 29 sites in the study region. Corresponding benchmark averages (based on relevant Regional Ecosystem benchmarks) are also provided.

	Private native forest		Benchmark	
Site-based attribute	mean	se	mean	se
Large tree density (stems / ha)	19.2	3.11	28.4	2.72
Median canopy height (m)	25.8	0.87	22	0.61
Regeneration of canopy species (%)	94.2	2.41	100	0
Woody debris (m length / ha)	645.3	90.6	364.1	24.39
Tree cover (%)	54	2.87	47.8	2.97
Shrub canopy cover (%)	11.8	2.55	10.4	1.09
Perennial grass cover (%)	19	2.07	21.8	1.4
Litter cover (%)	62.6	3.23	47	2.02
Introduced species cover (%)	4.1	0.91	0	0
Tree species richness (per 0.5 ha plot)	5.1	0.37	5.4	0.45
Shrub species richness (per 0.05 ha plot)	7.4	0.56	6.9	0.33
Perennial grass species richness (per 0.05 ha plot)	8.7	0.56	7.9	0.36
Forb species richness (per 0.05 ha plot)	12.7	1.06	15.0	0.95

Evidence of moderate or severe soil erosion (i.e. rill or gully erosion) was rare across the surveyed plots (less than 1% of the area surveyed, Table 3.3). This was likely due to a high level of ground cover (perennial grasses and litter cover, Table 3.2), resulting in a relatively low percentage cover of bare earth (7.6%). It should be pointed out that most of the sites surveyed had not been recently harvested or silviculturally treated. Where evidence of erosion was present, it was usually sheet erosion. This type of erosion which results in relatively uniform removal of soil (without development of channels) can arise naturally (after heavy rainfall events) but may also be related to fire and grazing regimes.

Table 3.3. Mean (and standard error) values for attributes assessed to determine levels of soil erosion. Values were calculated across 29 sites in the study region.

Attribute	mean	se
Average bare ground cover (%)	7.55	1.38
Proportion of points with no erosion	0.76	0.04
Proportion of points with minor erosion	0.23	0.04
Proportion of points with moderate or severe erosion	0.008	0.005

South-east Queensland sub-region

Mapping suggests there are approximately 286,300 hectares of potentially harvestable private native forest in the south-eastern region. This was mostly located in areas mapped as ‘remnant’ in the regional ecosystem database (Table 3.4, Figure 3.3). Regrowth forests (both mapped and those in Category X areas) together contributed 94,400 ha.

Table 3.4. Areas mapped as remnant forest, regrowth forest and woody non-remnant forest in the south-east Queensland region.

Vegetation category	Area (ha)
Remnant forest	191,900
Mapped regrowth forest	43,500
Woody, non-remnant forest	50,900

Spotted gum forests were most common in this region, but forests and woodlands dominated by ironbarks and stringybarks were also common (Table 3.5).

Table 3.5. Forest types most common in potentially harvestable ecosystems in the south-east Queensland region (BVG, broad vegetation grouping, based on Neldner et al. 2017a, is provided in parentheses).

Potentially harvestable forest type	Area	% of area
Moist open spotted gum forests (BVG 10b)	90,400	31.6
Woodlands of narrow-leaved ironbark (BVG 13c)	54,100	18.9
Moist, open eucalypt forests (often dominated by grey ironbark) (BVG 9a)	52,700	18.4
Open forests with stringybarks (BVG 9g)	22,500	7.9
Eucalypt woodlands (often dominated by stringybarks) (BVG 9h)	14,000	4.9
Mixed other forest types (7 in total)	52,500	18.3

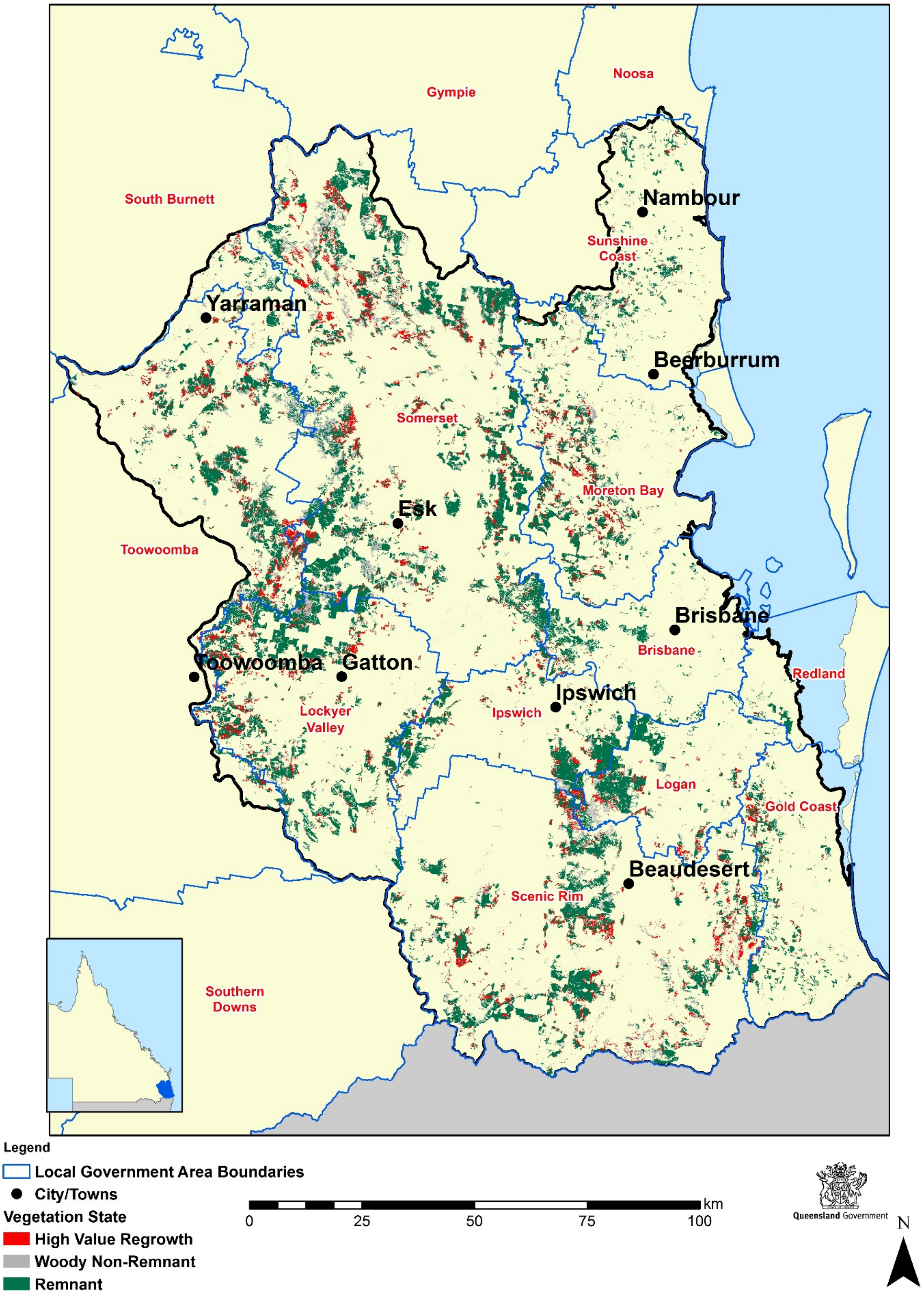


Figure 3.3. Potentially productive private native forest extent in the south-east Queensland region. Forests are categorised as remnant vegetation, high value regrowth vegetation or woody non-remnant vegetation (regrowth that unregulated) based on Queensland mapping layers.

Across all plots in the south-east Queensland region average stocking was 326.7 (± 13.15) stems per hectare and average basal area was 16.6 (± 0.92) m^2/ha. Potentially merchantable volume was 30.9 (± 2.61) m^3/ha with 24.6 (± 2.58) m^3/ha on trees with a DBH $\geq$ 30 cm. There were a high proportion of unmerchantable stems in these forests, particularly in the 10–19.9 cm DBH class and to a lesser extent in the 20–29.9 cm DBH class (Figure 3.4).

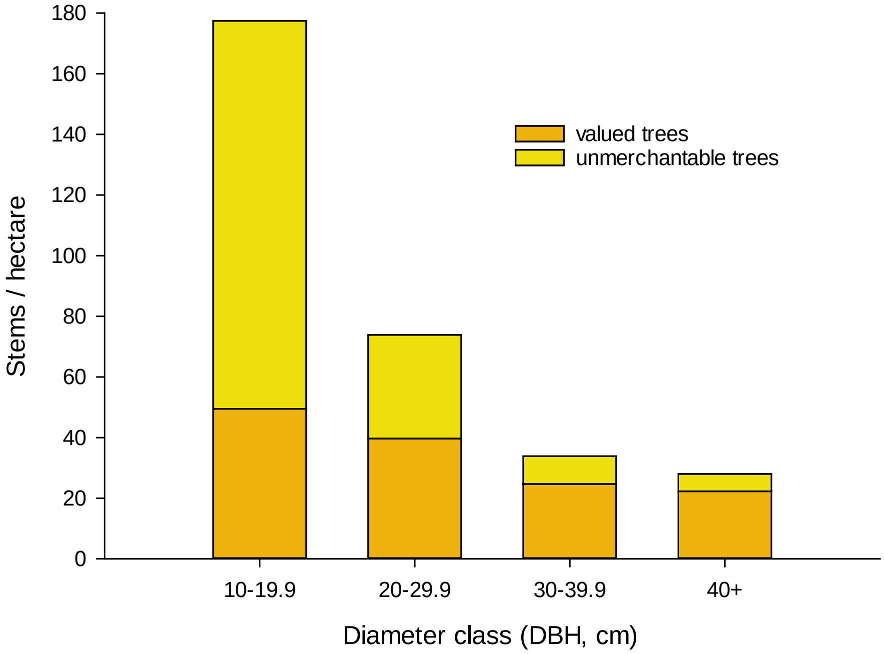


Figure 3.4. Stocking in private native forests (stems / ha) in different size classes in the south-east Queensland region. Different coloured bars represent the stems that are valued (for current or future timber resource, or required for environmental purposes) or were considered unmerchantable, and would ideally be thinned to improve productivity of the retained stand.

Based on the six BioCondition surveys in this region, the average overall BioCondition score was 0.68 (± 0.031). Only one of the six sites scored more than 0.8. Sites in south-east Queensland generally scored poorly in terms of the presence of large trees (average score of 6.7 (± 2.1) out of 15) and site connectivity (average score of 2.2 (± 0.8) out of 5). Cover of non-native species was also relatively high (average cover of 8.7% and an average score of 6.3 (± 1.2) out of 10). All other attributes scored 60% or higher.

Wide Bay-Burnett sub-region

Mapping suggests there are approximately 1,005,300 hectares of potentially harvestable private native forest in the Wide-Bay Burnett region. This was mostly located in areas mapped as ‘remnant’ in the regional ecosystem database (Table 3.6, Figure 3.5). Regrowth forests (both mapped and those in Category X areas) together contributed 278,900 ha. Spotted gum forests and woodlands were most common in this region, but woodlands dominated by ironbarks, forest red gum and stringybarks were also common (Table 3.7).

Table 3.6. Areas mapped as remnant forest, regrowth forest and woody non-remnant forest in the Wide Bay-Burnett region in Queensland.

Vegetation category	Area (ha)
Remnant forest	726,400
Mapped regrowth forest	76,900
Woody, non-remnant forest	202,000

Table 3.7. Forest types most common in potentially harvestable ecosystems in the Wide Bay-Burnett region in Queensland (BVG, broad vegetation grouping, based on Neldner et al. 2017a).

Potentially harvestable forest type	Area	% of area
Moist open spotted gum forests (BVG 10b)	327,000	32.5
Woodlands of narrow-leaved ironbark (BVG 13c and 18b)	175,500	17.5
Spotted gum forests and woodlands (BVG 10a)	167,700	16.7
Woodlands on floodplains (often dominated by forest red gum) (BVG 16c)	72,100	7.2
Eucalypt woodlands (often dominated by stringybark) (BVG 9h)	60,000	6.0
Mixed other forest types (11 in total)	203,000	20.2

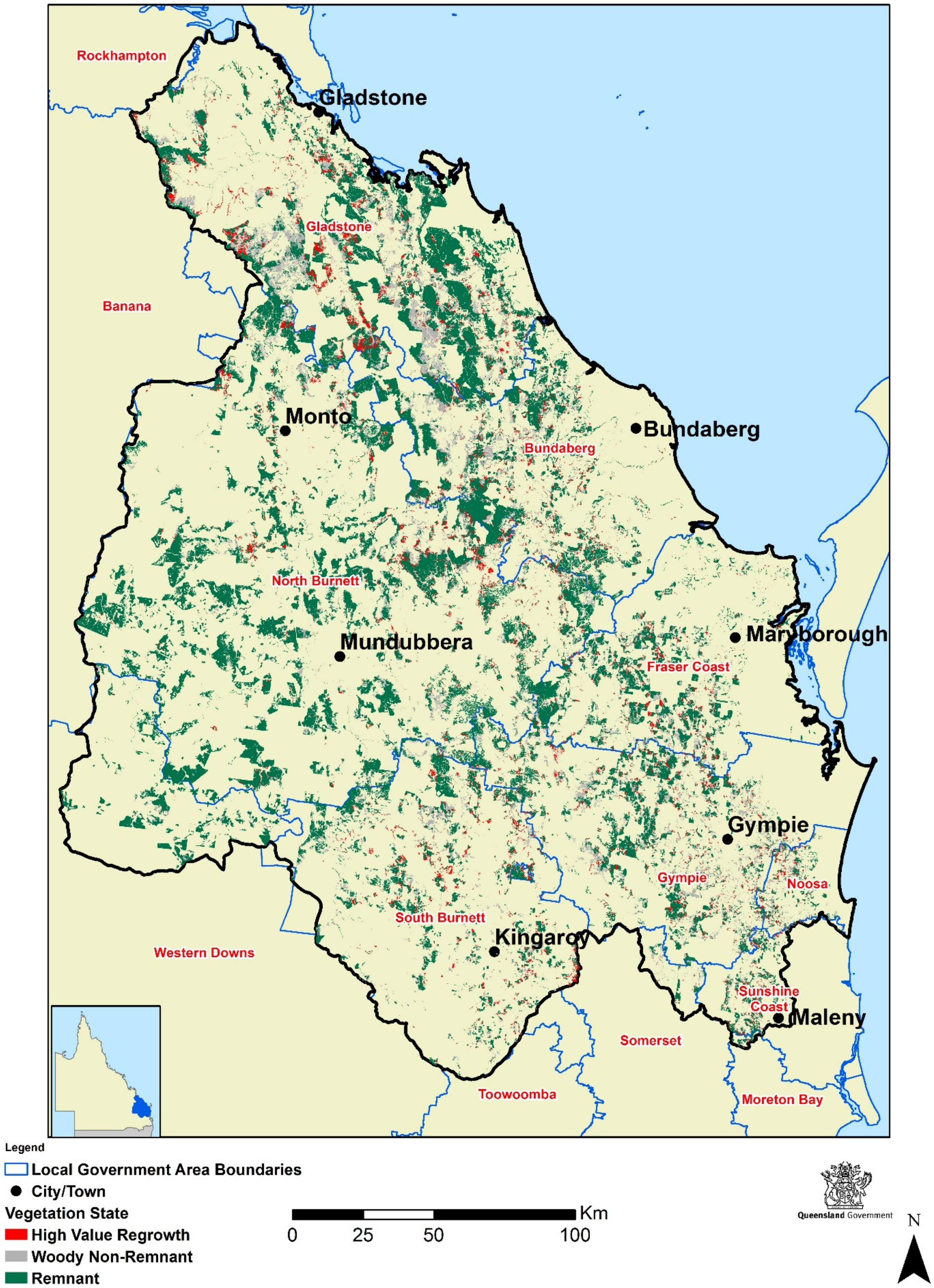


Figure 3.5. Potentially productive private native forest extent in the Wide Bay-Burnett region of Queensland. Forests are categorised as remnant vegetation, high value regrowth vegetation or woody non-remnant vegetation (regrowth that unregulated) based on Queensland mapping layers.

Across all plots in the Wide-Bay Burnett region average stocking was 210.4 (± 7.68) stems per hectare and average basal area was 11.5 (± 0.43) m^2/ha. Potentially merchantable volume was 25.1 (± 1.43) m^3/ha with 20.3 (± 1.34) m^3/ha on trees with a DBH $\geq$30 cm. There were a high proportion of unmerchantable stems in these forests, particularly in the 10–19.9 cm DBH class and to a lesser extent in the 20–29.9 cm DBH class (Figure 3.6).

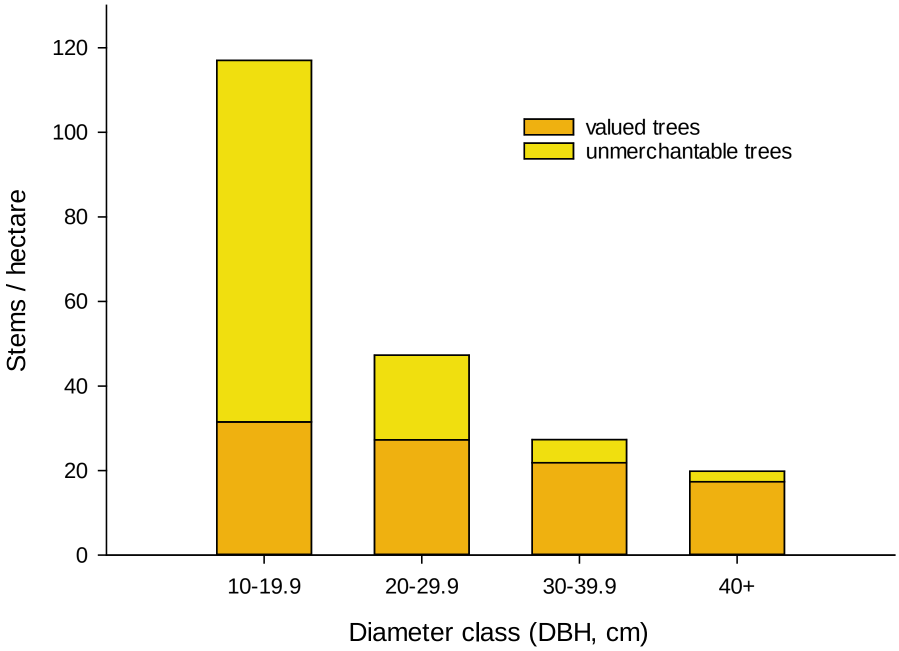


Figure 3.6. Stocking in private native forests (stems / ha) in different size classes in the Wide Bay-Burnett region. Different coloured bars represent the stems that are valued (for current or future timber resource, or required for environmental purposes) or were considered unmerchantable, and would ideally be thinned to improve productivity of the retained stand.

Based on the 11 BioCondition surveys in this region, the average overall BioCondition score was 0.77 (± 0.025). Four of the 11 sites scored more than 0.8. Sites in the Wide Bay-Burnett region in Queensland generally scored well (60% or higher) for most of the attributes. They scored poorly in terms of the richness of ‘forb/other plant functional groups’ (score of 2.7 (± 0.4) out of five) and site connectivity (average score of 2.9 (± 0.5) out of 5).

Western Queensland sub-region

Mapping suggests there are approximately 780,600 hectares of potentially harvestable private native forest in the western Queensland region. This was mostly located in areas mapped as ‘remnant’ in the regional ecosystem database (Table 3.8, Figure 3.7). Regrowth forests (both mapped and those in Category X areas) together contributed 124,500 ha. Woodlands dominated by ironbarks were most common in this region, but spotted gum dominated forests and woodlands and mixed species open forests and woodlands were also common (Table 3.9).

Table 3.8. Areas mapped as remnant forest, regrowth forest and woody non-remnant forest in the western Queensland region.

Vegetation category	Area (ha)
Remnant forest	656,100
Mapped regrowth forest	37,600
Woody, non-remnant forest	86,900

Table 3.9. Forest types most common in potentially harvestable ecosystems in the western region in Queensland (BVG, broad vegetation grouping, based on Neldner et al. 2017a).

Potentially harvestable forest type	Area	% of area
Woodlands of narrow-leaved ironbark (BVG 13c and 18b)	320,000	41
Woodlands mainly dominated by ironbarks (BVG 12a)	175,700	22.5
Spotted gum forests and woodlands (BVG 10a)	130,100	16.7
Eucalypt woodlands and open forests with a mix of species (BVG 15a)	34,700	4.4
Woodlands mainly dominated by bloodwoods and ironbarks (BVG 18a)	34,300	4.4
Mixed other forest types (13 in total)	85,800	11

Figure 3.7. Potentially productive private native forest extent in the western region of Queensland (Fitzroy and Darling Downs). Forests are categorised as remnant vegetation, high value regrowth vegetation or woody non-remnant vegetation (regrowth that unregulated) based on Queensland mapping layers.

Across all plots in the western Queensland region average stocking was 351.4 (± 37.35) stems per hectare and average basal area was 14.0 (± 1.38) m^2/ha. Potentially merchantable volume was 10.8 (± 3.13) m^3/ha with 5.8 (± 2.85) m^3/ha on trees with a DBH ≥30 cm. There were a high proportion of unmerchantable stems in these forests, particularly in the 10–19.9 cm DBH class and to a lesser extent in the 20–29.9 cm DBH class (Figure 3.8). The density of larger stems (>40 cm) was generally lower in this region than the in other sub-regions.

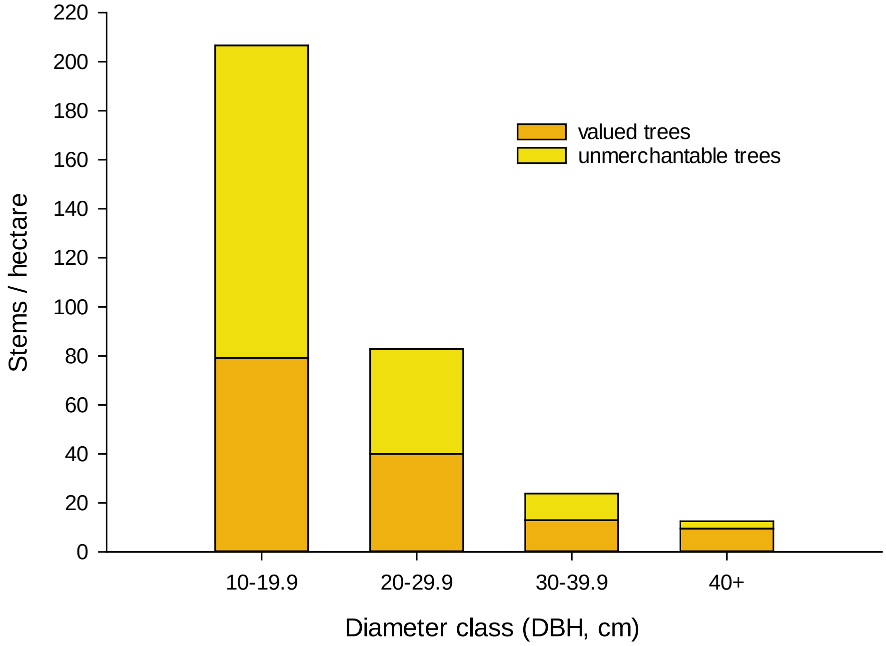


Figure 3.8. Stocking in private native forests (stems / ha) in different size classes in the western Queensland region. Different coloured bars represent the stems that are valued (for current or future timber resource, or required for environmental purposes) or were considered unmerchantable, and would ideally be thinned to improve productivity of the retained stand.

Based on the eight BioCondition surveys in this region, the average overall BioCondition score was 0.77 (± 0.25). Three of the eight sites scored more than 0.8. Sites in the western Queensland region generally scored well (60% or higher) for most of the attributes. They scored poorly in terms of the number of large trees (average score of 7.5 (± 2.1) out of 15) and shrub canopy cover (score of 2.9 (± 0.5) out of five).

North-eastern NSW sub-region

There are approximately 525,600 ha of potentially harvestable private native forest in the north-eastern NSW region (Figure 3.9). This excludes rainforest vegetation and areas considered to be non-commercial or low productivity. While detailed regional ecosystem classification is not available for NSW, common forest types were similar to those in southern Queensland. However, there was a higher proportion of semi-moist and tall eucalypt forests in the northern NSW region (Table 3.10). Dry eucalypt forests and woodlands, including those dominated by spotted gum, were common, making up more than 49% of the potentially productive private native forests in the region (Table 3.10).

Table 3.10. Common forest types in potentially harvestable private native forest in northern NSW.

Potentially harvestable forest type	Area	% of area
Semi-moist and tall dry eucalypt forest	109,800	20.9
Dry eucalypt forest and woodland	104,500	19.9
Dry eucalypt forest and woodland occurring on the tablelands	90,300	17.2
Dry eucalypt dominated by spotted gum	64,800	12.3
Semi-moist eucalypt forest occurring on the tablelands	46,900	8.9
Other, mixed forest types (6)	109,300	20.8

Across all plots in the north-eastern NSW region average stocking was 286.3 (± 17.92) stems per hectare and average basal area was 20.1 (± 0.73) m^2/ha. Potentially merchantable volume was 43.4 (± 3.91) m^3/ha with 37.9 (± 3.72) m^3/ha on trees with a DBH ≥30 cm. As reported for the Queensland regions, there were a high proportion of unmerchantable stems in these forests, particularly in the 10–19.9 cm DBH class and to a lesser extent in the 20–29.9 cm DBH class (Figure 3.10). The density of larger stems (>40 cm) was generally higher in this region than the in other sub-regions, which contributed to the higher basal area and merchantable volumes.

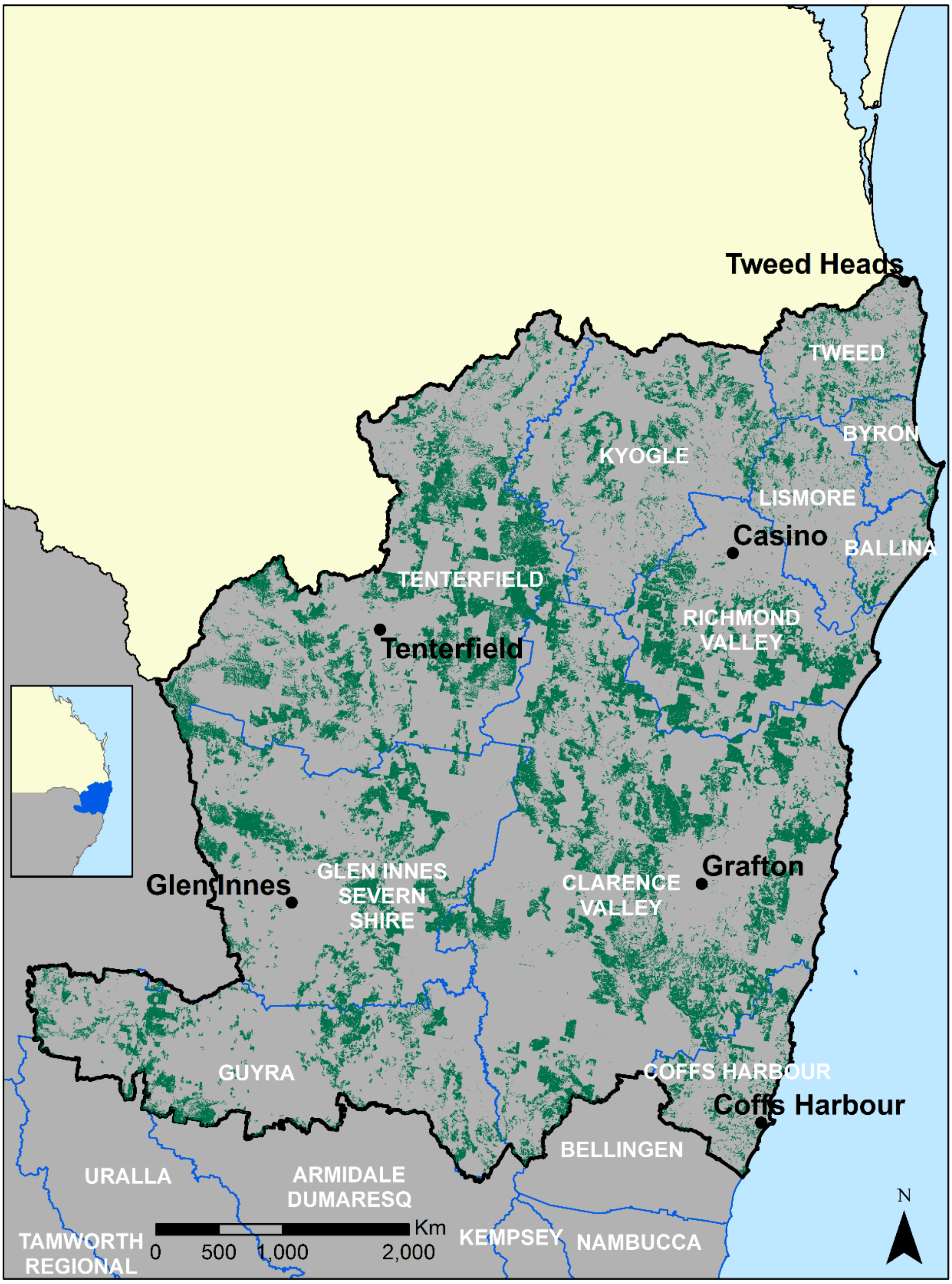


Figure 3.9. Potentially productive private native forest extent in the northern NSW region (Upper North East Regional Forest Agreement area).

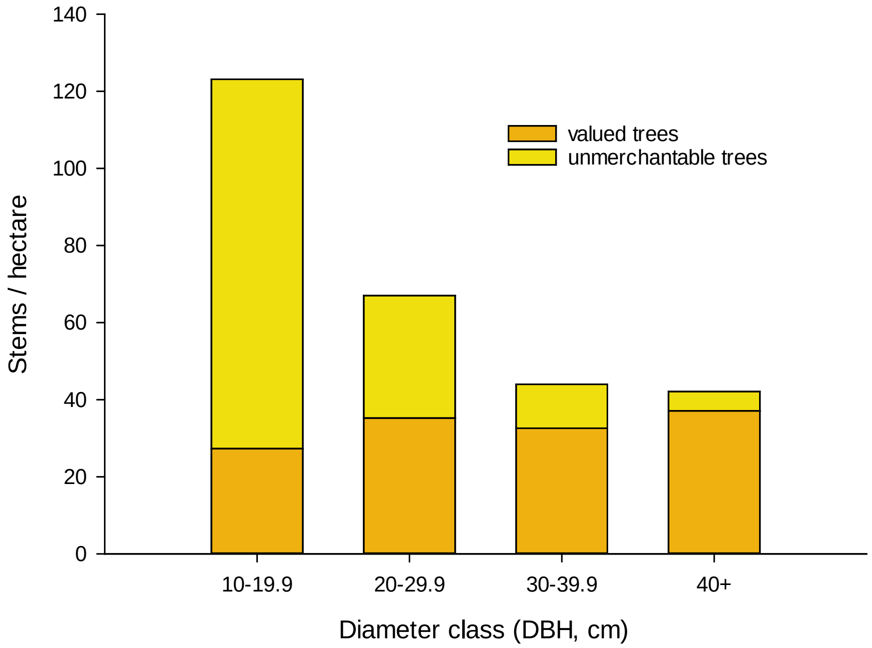


Figure 3.10. Stocking in private native forests (stems / ha) in different size classes in the north-eastern NSW region. Different coloured bars represent the stems that are valued (for current or future timber resource, or required for environmental purposes) or were considered unmerchantable, and would ideally be thinned to improve productivity of the retained stand.

Based on the eight BioCondition surveys in this region (four in this study and four through the earlier study by Jay 2009), the average BioCondition score was 0.74 (± 0.054). Three of the eight sites scored more than 0.8. Sites in the northern NSW region generally scored well (60% or higher) for most of the attributes. They only scored poorly in terms of native shrub canopy cover (average score of 1.8 (± 0.7) out of five).

Discussion

Extent

Across the 24.4 M ha project study region, there is a total of approximately 2,597,700 ha of potentially harvestable private native forest. There have been four private native forest inventory projects over the past 20 years that have all reported different areas of private native forest extent and have focused on different study regions. Figure 3.11 demonstrates how the previous study regions intersect with the present study area. The Queensland CRA/RFA Steering Committee (1998a) and MBAC Consulting Pty Ltd (2003a) each conducted inventories of private native forests in the South East Queensland Forests Agreement region. This 6.17 M ha region is almost entirely within the present study area, ranging from the border with New South Wales, north to Gladstone and west to Toowoomba. Queensland CRA/RFA Steering Committee (1998a) reported the area of potentially harvestable private native forest at 1.2 M ha, while MBAC Consulting Pty Ltd (2003a) reported the potentially harvestable area at 0.75 M ha. The large difference can be attributed to different methods for forest mapping, stream zone exclusions, minimum private landholding size (10 ha vs 5 ha, respectively) and forest patch sizes (10 ha vs 20 ha, respectively).

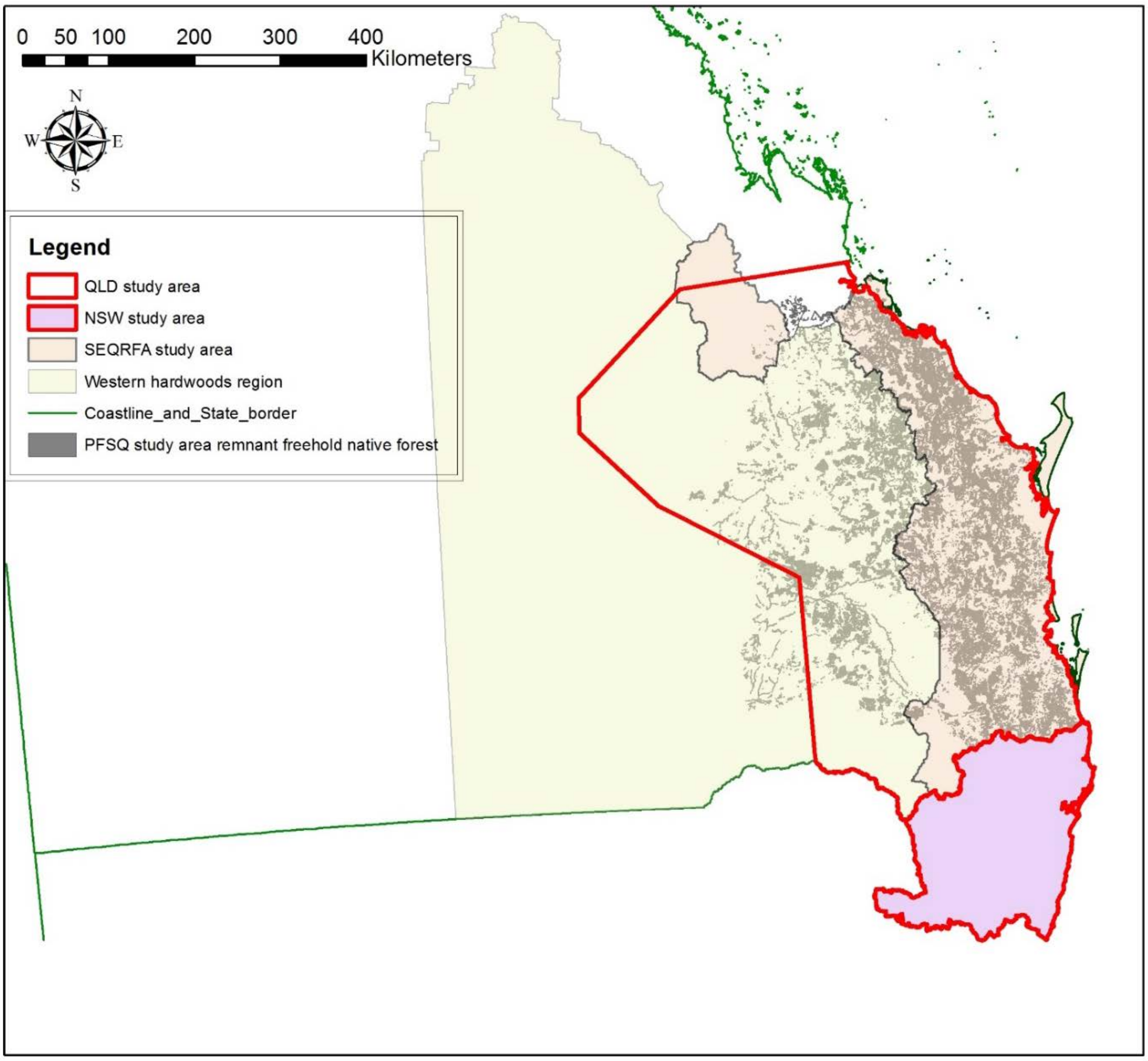


Figure 3.11. Study areas of past private native forest inventories relative to the present study area.

The Western Hardwoods Region of Queensland extends from the border with New South Wales to near Charters Tower in the north, Charleville in the west and Toowoomba and Gladstone in the east. The total area is 31.5 million ha, of which potentially harvestable private native forests cover 1.39 M ha (4.4 %) (MBAC Consulting Pty Ltd, 2003b), most of which is within the present study area. The Private Forestry Service Queensland (PFSQ, c2015) study area totals 16.8 M ha, with commercially important native forests covering 4.12 M ha, of which 1.77 M ha is on freehold lots at least 20 ha in area.

In common with the present study, all four inventories did exclude areas of greater than 25 degrees slope. However, apart from the obvious differences in study area size, there were some important methodological differences with the present study, which makes comparing forest area estimates from these inventories with the present study challenging. Key methodology differences include whether or not certain areas where excluded (i.e. stream zone exclusions were not excluded in this study), differences in the minimum private landholding size and forest patch sizes, and most importantly the definition used to define ‘forest’ in the mapping process. Both MBAC consultancies used much lower FPCs than the 30% adopted in the present study: 10% in Western Hardwoods and 12% in South East Queensland. The rationale for 12% in South East Queensland was that a 12% FPC generally equates to a canopy cover of approximately 20%, which is a commonly considered the minimum tree cover for forest environments (Montreal Process Implementation Group for Australia and National Forest Inventory Steering Committee 2018). Forest areas in PFSQ (c2015) were based entirely on mapped regional ecosystems with no separate accounting for FPC. Queensland CRA/RFA Steering Committee (1998a) used modelled vegetation types (a precursor to regional ecosystems), as they were the only comprehensive coverage of the region available at the time. There appears to have been no separate accounting for FPC in that study. It is recommended that further work is done to determine an up-to-date estimate of private native forest extent in Queensland woodlands with FPC less than 30%.

A key finding of this study and the previous estimates of private native forest extent, is that potentially productive forest covers a large area. Thus, there is huge potential for these forests to be managed appropriately to help meet the future demands for sustainably managed wood products, while maintaining or improving biodiversity values. The following chapter refines this (through defining commercial forest types) and chapter 9 applies the figures of area extent to determine the potential of the private native forest resource to meet future timber demands.

Condition

The private native forest inventory plots used in this analysis show that this resource is in poor productive condition, with a high proportion of unmerchantable trees. In all sub-regions there were high densities of unmerchantable trees, particularly in the 10–19.9 cm DBH class category. The high tree densities, with high proportions of unmerchantable stems back up the anecdotal information (e.g. Sean Ryan pers comm.) regarding the poor productive state of private native forest in the region. This is further supported by recent work in northern NSW, where stands are characterised by trees in small size classes with weak crowns (Jay 2017). A lack of silvicultural treatment and management that involves high-grading the stand during a harvest has undoubtedly contributed to the high proportion of small and unmerchantable trees at many sites. Despite this poor productive condition, many stands still have the capacity to produce timber (where desirable timber species occur) and could be transformed into more productive forests through management. Chapter 5 demonstrates the potential for future timber production through silvicultural management and chapters 7, 8 and 9 evaluate the financial performance of silvicultural treatments.

The high densities of stems in the 10–19.9 cm DBH class across all regions, suggests that there may be adequate regeneration in these stands. Most of the forests assessed here have a high proportion of stems that regenerate through a pool of lignotubers (Henry 1961; Henry and Florence 1966; Florence 1996). The lignotuber regeneration pool remains relatively stable over time. An estimated 20–30 % of non-lignotuberous seedlings (i.e. seedling that are yet to develop a lignotuber) may survive to join the lignotuber pool (Henry and Florence 1966) and make this regeneration more resistant to high temperatures, drought, fire regimes and browsing (Florence 1996). Lignotuberous regeneration may persist for decades (DAF unpubl. data) but their growth can be limited, usually by competition from the overstorey (Henry and Florence 1966, Florence 1996). While assessment of stems <10 cm DBH was not included in our current analysis, the high densities of stems in the 10–19.9 cm DBH class suggest that regeneration of stems <10 cm DBH is occurring, at least in the dry sclerophyll forest types, where lignotuberous regeneration occurs. Densities of eucalypt regeneration <1 m in height are often very high in dry eucalypt forests (e.g. spotted gum) in Queensland, often exceeding 1000 stems per hectare (Lewis and Debuse 2012) due to the pool of lignotubers that persist in the understorey. However, Henry and Florence (1966) showed that with a high basal area of mature trees and some advanced regrowth, small lignotuberous regeneration remained static for over 15 years until competition was reduced by complete canopy removal. Further, in some cases this regeneration does not always immediately develop after overstorey reduction (Henry and Florence 1966).

There were differences in the densities of trees in the different size classes between the four sub-regions. The density of merchantable trees with a DBH ≥40 cm was much higher in northern NSW (i.e. 31 SPH) than in western Queensland (i.e. 4 SPH) and merchantable volumes were lower in the western region. This is likely to be related to lower site productive potential in drier climatic zones. The work by Alex Jay in south-east Queensland, shows how productivity varies across the landscape, and this has important implications in terms of merchantable volume production (Appendix 3). Further work is recommended to extend this site productivity mapping further west. Lewis et al. (2010) also showed the important influence of site productivity, in particular rainfall, on stand volume growth rates in native spotted gum dominant forests.

Volume estimates in the current study are generally higher than those reported in previous inventory assessments. This is likely due to volume estimates including all trees considered potentially merchantable either now or in the future. That is, estimates made in the current study do not reflect the material that would be immediately available to a sawmill. MBAC Consulting Pty Ltd (2003a) estimated the average total standing volume of all commercial log types in the SEQ region to be 20.4 m^3/ha; however, 63% of this volume is small rounds and fence posts, with only 7.5 m^3/ha being conventional log volume (compulsory and optional sawlogs, poles and girders). This seems consistent with our estimated volume for the south-east Queensland sub-region of 24.6 (± 2.58) m^3 for trees with a DBH of ≥ 30 cm.

Average total density of trees with a DBH of at least 10 cm was higher in the western Queensland sub-region than expected (351 SPH); with a particularly high density of stems in the 10–19.9 cm DBH class (Figure 3.8). Tree density was lowest in the Wide Bay-Burnett sub-region (210 SPH). The high stem density in the western Queensland sub-region probably reflects the relatively low number of plots sampled (14 plots) with an unintentional bias towards sites with an understorey of cypress and wattle species. The more open woodlands with grassy understories were not represented in the available dataset. Despite the relatively low standing merchantable volumes in the western Queensland plots, further inventory work is recommended, given the large areal extent of forest (780,600 ha) and woodlands (not mapped here) in this sub-region.

In terms of BioCondition, the private native forest sites surveyed were in most cases considered to be in good (sites scoring between 0.6 and 0.8) or very good (one-third of sites scored 0.8 or more) condition. The high levels of tree, shrub, perennial grass and litter cover (relative to benchmark values) suggest these sites are functioning well, for some attributes of biodiversity condition, despite a history of selective harvesting and high-grading in most cases. Key features that encourage faunal diversity (Eyre et al. 2011) were present at most sites. The density of large trees was an attribute that tended to be lower in private native forest, relative to benchmark values. Large trees are limited in the landscape and provide important habitat for a range of fauna species, some of which rely on them exclusively through the provision of greater floral and nutritional resources and hollows for nesting and sheltering sites (Eyre et al. 2009; Goldingay 2009; Smith et al. 2007; Eyre and Goldingay 2005; Lindenmayer 2016). Large trees are one of the key attributes in BioCondition as they take a long time to replace, are in serious decline across our landscapes and have a disproportionally greater role in the support of biodiversity. A proportion of large trees are likely to be removed during high-grading harvest operations, but for regulated forest (e.g.

remnant forest) there is a requirement to maintain habitat trees under the relevant Codes (i.e. native forest practice code in Queensland).

The chapter did not attempt to determine the impact of forest management on BioCondition, as more detail on the impacts of silvicultural treatments on specific BioCondition attributes is provided in Chapter 6. However, it provides a snap-shot of ecological condition, where sampled sites are assumed to be broadly representative of current management practices. Ideally, future studies will build on this dataset to provide a better understanding of the ecological condition of privately owned forest that is managed (at least in part) for timber production. Long-term monitoring is needed to track changes in ecological condition over time through the forest harvesting cycle. A study by Jay (2009) in northern NSW did investigate the impacts of selective timber harvesting on ecological condition (different metrics). This study reported that logging, and other forest management activities like livestock grazing and fire, had little impact on condition scores and that habitat values were generally high across a wide range of stand structures in the Clarence Lowlands Spotted Gum forest type. Further, the abundance and richness of fauna species was not shown to be discernibly influenced by forest management practices (Jay 2009). However, this study does caution that the fauna survey had essentially no power to detect differences between sites with different forest management (Jay 2009). The impacts of forest management practices on biodiversity are discussed further in Chapter 10.

While no BioCondition assessments were made in cleared pasture areas in this project, such areas tend to have very low BioCondition scores (Eyre et al. 2011). As such, private native forests have significant ecological benefits not found in the adjacent, cleared areas. Development of regrowth forest in the region can therefore provide dual benefits for both future timber production and through encouraging native biodiversity. As regrowth forests mature, they contain more structural habitat values like ‘large trees’, woody debris, shrub cover and greater plant diversity which will improve the BioCondition score, and therefore biodiversity benefits at some sites (Eyre et al. 2015b; Peeters and Butler 2014). Further, managing forests for timber production, with silvicultural treatment for example, may improve the growth of larger trees. It may also encourage perennial grass cover, which should improve biodiversity benefits over time.

The impact of forest management activities (harvesting and silvicultural treatment) on soil exposure and erosion has received very little attention in selectively harvested forests (i.e. single tree selection harvesting) in the study region. Surveys conducted here suggest that moderate or severe erosion, such as rill or gully erosion, is not common. While soil remediation (e.g. drainage) is required under the current relevant Codes (i.e. native forest practice code) to prevent soil erosion, few studies have specifically addressed whether the current management practices are effective in minimising soil loss. Hence, further work is needed to determine likely impacts immediately following harvesting activities, particularly given the tendency for soil erosion (erodibility) in many of the common soil types and slopes where native forests occur.

Conclusion

The private native forest resource is clearly important to the timber industry due to large area (~2.6 M ha) it covers in the study region. Field inventory data show large variability in merchantable volume estimates, between sites and sub-regions. The productive condition of this resource is often poor, with a high proportion of unmerchantable trees. Nevertheless, the capacity to restore productivity seems reasonable assuming management interventions (e.g.

silvicultural treatment) are economically justified. The effectiveness of silvicultural treatments will be discussed in following chapters.

In terms of BioCondition, the private native forest sites surveyed were generally in good or very good condition, suggesting these forests play an important role in maintaining local biodiversity values. Encouraging forest management in regrowth forests, as an alternative to re-clearing for grazing production alone, represents an opportunity to improve BioCondition across the landscape.

Chapter 4: A review of the private native forest resource, with a focus on economic contributions.

Ben Francis, Tyron Venn and Tom Lewis

Introduction

Native forests in sub-tropical eastern Australia contain a diverse suite of hardwood timber species, many with excellent, unique structural and aesthetic qualities. The management and processing of harvested logs from this resource has sustained employment and income generation opportunities for generations in many regional communities (Jay and Dillon 2016; State of Queensland 2016). However, in recent decades, there has been increased scrutiny of public forest management, which has resulted in substantial declines in timber supplied from Crown native forests (Aenishaenslin et al. 2007). The hardwood timber industry has become increasingly dependent on private native forests to maintain log supply. In northern New South Wales, private forests now account for 50% of log supply (Jay and Dillon 2016), while it has varied between 50% and 70% in Queensland over the last 20 years (Queensland Department of Agriculture and Fisheries 2015; Leggate et al. 2017; ABARES 2017). The reliance on private forests in Queensland is likely to increase in the next decade as long-term wood supply agreements from Crown land conclude.

Research performed for this study identified 2.6 M ha of potentially harvestable (after accounting for regulatory restrictions) private native forest in the study region (Chapter 3). Although large in area, the forests are generally in poor productive condition due to decades of 'high-grading'[1] without follow-up silvicultural treatment. The poor management appears to have two root causes. First, and most importantly, landholders heavily discount potential future returns from timber because of:

(i) high sovereign risk – the risk that government rules regarding management of forests for timber will change;
(ii) long pay-back periods in forestry versus the need for an annual income, which is more readily provided by cattle or crops; and
(iii) other risk factors, such as severe bushfire, which may reduce the value of their timber crop.

Second, most landholders are not well-informed about how to manage their forests for timber production, are not familiar with timber markets, and do not appreciate the higher timber value of well managed forests.

The social, environmental and economic values of private native forests, and the industry they supply, is increasing in importance as forests and woodlands continue to be fragmented and cleared, mostly for beef cattle grazing, but also urban development and mining (Preece and Oosterzee 2017). Dependence on private native forest will increase as future supply from crown forest becomes uncertain. Importantly, timber production from private native forests:

- supports sustainable regional jobs and communities;
- improves environmental outcomes through well-managed native forests on private land that provide watershed protection, biodiversity conservation (e.g. habitat for wildlife), and aesthetically pleasing landscapes; and

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[1] High-grading involves the harvesting of commercially valuable trees, while leaving unmerchantable and damaged trees standing.

- provides market incentives to invest in well-managed native forests on private land.

There are strong socio-economic arguments to maintain or expand the private native forest hardwood industry. A significant impediment to investment by landholders, industry and third party investors is a lack of detailed economic analysis on the potential returns on investment in forest management.

The overall aim of this chapter is to assess the importance of private native forests for the timber industry and regional economies in the study region, and to assess the potential for this resource to contribute to employment and income generation goals in the future. This has been achieved by completing the following research objectives:

i. Determine the extent of potentially harvestable and commercially important private native forests in sub-tropical eastern Australia;
ii. Quantify the volume of hardwood logs processed annually in the study region, the proportion that comes from private native forests, and the reliance of primary processors on private native forests;
iii. Determine the contribution that private native hardwood processing makes to regional economies, including income and employment generation; and
iv. Highlight opportunities and challenges for private native forest management and hardwood sawmilling in sub-tropical eastern Australia.

Legislation regulating private native forest management in Queensland

From early settlement up until the mid-1980s, Queensland government legislation with respect to private native forest management was largely laissez faire (Stephens and Stunzner 2008). Legislation directed at forest management, such as the *Forestry Act 1959*, was mostly focused on the management of Crown forests. An early example of Queensland legislation that regulated private native forest management is the *Nature Conservation Act 1992*, which regulates the harvesting of restricted plant species (those species classified as endangered, vulnerable, near threatened and special least concern) (Australian Government and Queensland Government 2015).

The most important legislation for private native forest managers in Queensland is the *Vegetation Management Act 1999*, the purpose of which is to regulate the clearing of vegetation on freehold land, including Indigenous land. The *Vegetation Management Act 1999*, defines native forest in Queensland as being ‘remnant regional ecosystems’ (Category B vegetation), ‘regrowth regional ecosystems’ (Category C or R vegetation) or ‘non remnant’ (Category X vegetation) (Department of Environment and Resource Management 2010). Landholders can request a free property map of assessable vegetation (PMAV) to determine the status of vegetation on their property. Additionally, in 2014, amendments to the *Nature Conservation Act 1992* commenced and the Department of Environment and Heritage Protection developed a state-wide data set of Protected Plant Trigger Maps (Blue Trigger Maps). These Trigger Maps identify areas in which high risk (endangered, vulnerable or near threatened) flora could be found. In these areas forest thinning and clearing cannot occur unless a plant survey is conducted by a suitably qualified person to confirm the absence of high risk species.

Remnant regional ecosystems in Queensland refer to vegetation that has never been cleared or, if it has been cleared in the past, has regrown to meet particular criteria[2]. Regrowth regional ecosystems have been cleared in the past and are less mature than remnant vegetation, but often contain many of the biodiversity and habitat values of remnant vegetation. Regrowth regional ecosystems in Category C are high value regrowth vegetation and in Category R are within 50 m of a watercourse in the Burdekin, Mackay, Whitsunday and Wet Tropics Great Barrier Reef catchments. Category X areas had been cleared of native vegetation in the past, and when a PMAV applying to the area was made, did not contain remnant or regrowth vegetation (Department of Environment and Resource Management 2010). In the years since being categorised as Category X, native vegetation may or may not have re-established on the area.

Due to the importance of private native forests on freehold and Indigenous land for hardwood timber supply, the *Planning Act 2016* (formerly the *Sustainable Planning Act 2009*) provides exemptions, known as exempt clearing work, under Schedule 21 of the *Planning Regulation 2017*, for removing or harvesting vegetation in Category B, C and R areas, provided the activities comply with the requirements of the *Vegetation Management Act 1999*, and the conduct of activities is in accordance with the native forest practice code (Department of Natural Resources and Mines 2014). These codes were known as 'Self-assessable Vegetation Clearing Codes' and, at the time of writing, this phrase is still in their titles. However, under the *Planning Act 2016*, these codes are now known as 'Accepted Development Vegetation Clearing Codes'. There are codes applicable to Category B (Department of Natural Resources and Mines 2014), Category C (Department of Natural Resources and Mines 2013a) and Category R vegetation (Department of Natural Resources and Mines 2013b). Forestry activities on Category X land is exempt from requiring management in accordance with a code.

The Department of Natural Resources, Mines and Energy (DNRME) is currently responsible for the regulation of private native forest management for timber production in Queensland. The majority of private native forest within the study area is in remnant regional ecosystems (Category B vegetation), and a brief description of key elements of the relevant *accepted development vegetation clearing code, Managing a Native Forest Practice: A Self-Assessable Vegetation Clearing Guide* (Department of Natural Resources and Mines 2014), hereafter referred to as the 'native forest practice code', is provided online (see https://publications.qld.gov.au/dataset/self-assessable-vegetation-clearing-codes/resource/a73f5b44-008c-4f92-8644-f92e6caf6592).

The native forest practice code defines a native forest practice as the 'sustainable management of a forest area for timber harvesting within a framework that conserves the natural values of the forest' (p. 6). The native forest practice code defines required outcomes, specifies mandatory practices and provides key definitions with regards to managing native forests for timber production. The private native forest owner must notify the DNRME before commencement of harvesting. The forest practice must produce value-added products (other than woodchips for export) as part of an ongoing forestry business, and landholders must maintain documentary evidence of the sale of products.

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[2] Vegetation mapped as 'remnant' has a canopy cover that is at least 50% of the undisturbed predominant canopy cover; averages more than 70% of the vegetation's undisturbed height; and contains species characteristic of the undisturbed predominant canopy (Accad et al. 2015).

The native forest practice code lists the regional ecosystems (REs) in which a native forest practice is permitted. These include three coastal wet sclerophyll native hardwood forest REs, 241 other native hardwood forest REs, four cypress forest REs, and 37 rainforest REs. Three permissible silvicultural regimes are described: a rainforest selective harvesting regime; a coastal wet sclerophyll forest group selection regime; and a selective harvesting regime for all other hardwood and cypress pine forests. Clearfelling is not permitted.

The native forest practice code specifies several other restrictions to a native forest practice, including:

- forestry is not permitted where the majority slope is greater than 25 degrees;
- minimum number of retained trees per hectare;
- minimum number of habitat and recruitment habitat trees per hectare;
- which silvicultural treatment methods, including thinning, planting, fire and weed control, are permissible;
- restrictions on harvesting within buffer zones and filter zones around wetlands and watercourses;
- the placement and management of snig tracks and landings; and
- protection measures to minimise soil degradation.

Standards for health, safety and welfare in forest harvesting are set out in the Forest Harvesting Code of Practice 2007 (Workplace Health and Safety Queensland 2007). This Code complies with the *Work Health and Safety Act 2011*. Logs sourced from native forest and plantations on freehold land may also be subject to local government requirements implemented through local planning schemes.

Constitutionally, legislation regarding the management of most of Australia’s natural resources, including forests, is the responsibility of state and territory governments. Consequently, there are few pieces of federal legislation likely to have a direct impact on the potential for forestry operations in the study area. However, the federal government can assert the national interest by invoking its powers in areas such as trade, investment, and compliance with international treaties, obligations and conventions, under legislation such as the *Export Control Act 1982*, the *World Heritage Properties Conservation Act 1983* and the *Environmental Protection and Biodiversity Conservation Act 1999*. An infamous example of these powers is the 1988 Hawke Labor Federal Government listing of 894,000 ha of rainforest between Townsville and Cooktown for World Heritage (The Wet Tropics World Heritage Area) against the protests of the Bjeilke-Peterson National Party Queensland Government. This empowered the federal government to prohibit all logging within the World Heritage Area, which effectively shut-down the north Queensland timber industry (Dargavel 1995).

Sawmills and other log processors in Queensland are obliged under the federal government legislation, *Illegal Logging Prohibition Regulation 2012* (which supports the *Illegal Logging Prohibition Act 2012*) to carry out due diligence to ensure they are not processing illegally harvested logs. Documentation that may assist processors to meet their due diligence requirements will be required from private native forest owners, including confirmation of lodgement received from DNRME, confirming that the vegetation management notification form for self-assessable vegetation clearing codes has been provided to DNRME for managing a native forest practice.

Commercial forest types

In New South Wales commercial forest types are classified according to yield association group. The main yield association groups in northern New South Wales were provided by the New South Wales Department of Primary Industries – Forest Science, and area estimates are reported in Table 4.1. The area estimates include areas that are not harvestable private native forest (e.g. non-commercial, plantation, rainforest, swamp sclerophyll, viney scrub). The total area of potentially harvestable private native forest was 525,600 ha (Chapter 3).

Table 4.1. Forest area by yield association groups in the New South Wales part of the study area.

Yield Association Group	Area (ha)
Blackbutt - Moist	2,400
Blackbutt - Semi-moist	3,200
Dry Sclerophyll	104,500
Moist Coastal Eucalypts	35,600
Non-commercial & negligible productive	124,100
Plantation	600
Rainforest	24,000
Semi-moist and Taller Dry Eucalypts	109,800
Spotted Gum - Dry	64,800
Spotted Gum - Semi-moist	39,600
Swamp Sclerophyll	12,200
Tableland Eucalypts - Dry	90,300
Tableland Eucalypts - Moist	16,400
Tableland Eucalypts - Semi-moist	46,900
Unclassifed	8,800
Viney invasive scrub / degraded	15,800
Total	1,020,800

In Queensland both regional ecosystems (REs) and broad vegetation groups (BVGs) are commonly used to classify vegetation, where BVGs are a higher level grouping than REs. All vegetation in Queensland is classified into one of 1461 REs (in 2017) and one of 98 broad vegetation groups (BVGs) (Neldner et al. 2017a; Neldner et al. 2017b). The REs and BVGs were not designed specifically for the forestry industry. Regional ecosystems often map forest types at too fine a scale to be useful for forestry. Conversely, a single BVG typically encompasses several distinct forest types that the timber industry recognises to vary substantially in productivity.

The commercial forest type classification system developed by Private Forestry Service Queensland (PFSQ) has been adopted in this report for Queensland native forests. It contains19 commercial native forest types for southern inland and south east Queensland (PFSQ c2015), which are meaningful to the timber industry and landholders. They comprise only REs where at least one of the dominant species was a recognised commercial *Eucalyptus* or *Corymbia* species, or brush box or turpentine. Appendix 4 lists the classification of 19 forest types according to PFSQ, along with the REs used to define them and the BVGs in which each forest type belongs.

A key objective of the present study was to estimate the potential productivity of the private native forest resource. There is insufficient information to confidently assign productivity estimates to the 19 PFSQ forest types, so these were grouped into the six forest types described in Table 4.2. The grouping is based on potential productivity, appropriate silviculture and commercial timber values. Dominant commercial species for each forest type are listed in Table 4.2. Appendix 4 reports the relationship between PFSQ forest types and the six forest types adopted in this study. Mapping within ArcGIS has been utilised to determine the extent and distribution of these six commercial forest types and is presented in Figure 4.1. The Department of Environment and Science (DES) provided a spatial layer of potentially harvestable REs according to the native forest practice code, on private land where slope is less than 25 degrees and clipped to the study area (discussed in chapter 2). The REs listed in the attribute table of the DES mapping have been grouped into their relevant commercial forest type (Table 4.2) and displayed spatially, allowing area calculations for each forest type.

Table 4.2. Area of private native forest in the Queensland study area by forest type.

Forest type	Dominant commercial species	Harvestable area (ha)[b, c]	Percent of total
Moist tall	*Eucalyptus pilularis* (blackbutt), *E. grandis* (flooded gum), *E. saligna* (Sydney blue gum), *E. acmenoides* (white mahogany), *E. cloeziana* (Gympie messmate), *Syncarpia glomulifera* (turpentine)	33,400	1.6
Mixed hardwood[a]	*E. propinqua* (grey gum), *E. siderophloia* (grey ironbark), *E. acmenoides* (white mahogany)	159,600	7.6
Spotted gum	*Corymbia citriodora* subsp. *variegata* and *citriodora* (spotted gum), *E. crebra* (narrow-leaved ironbark)	693,000	33.1
Queensland blue gum	*E. tereticornis* (Queensland blue gum / forest red gum), *E. crebra* (narrow-leaved ironbark), *E. siderophloia* (grey ironbark)	253,300	12.1
Gum-topped box	*E. moluccana* (gum-topped box)	105,600	5.1
Ironbark	*E. fibrosa* (broad-leaved red ironbark), *E. crebra* (narrow-leaved ironbark), *E. decorticans* (gum-topped ironbark), *E. siderophloia* (grey ironbark)	641,500	30.7
Non-commercial (but harvestable under *Managing a Native Forest Practice*, an accepted development vegetation clearing Code)		204,700	9.8
Total		2,091,000	100.0

Notes:

a. the mixed hardwood forest type is so named because relative to the other forest types: (i) the number of commercially important canopy species on any hectare is higher; (ii) the most common commercial species on any hectare varies considerably throughout the study area; and (iii) the relative frequency of the most common commercially important canopy species on any given hectare is lower than in the other listed forest types. The dominant species listed are the three most common in this forest type; however, there are at least 14 additional commonly associated commercial species in this forest type, as listed in Appendix 4.

b. Total forest area of each forest type has been reduced by 5% to account for stream buffers and a further 1.2 % to account for forest area where slope exceeds 25 degrees.

c. Hectares refer to potentially harvestable areas available according to the Code. These area estimates do not indicate area that has been harvested historically, nor do they reflect future management intentions of landholders.

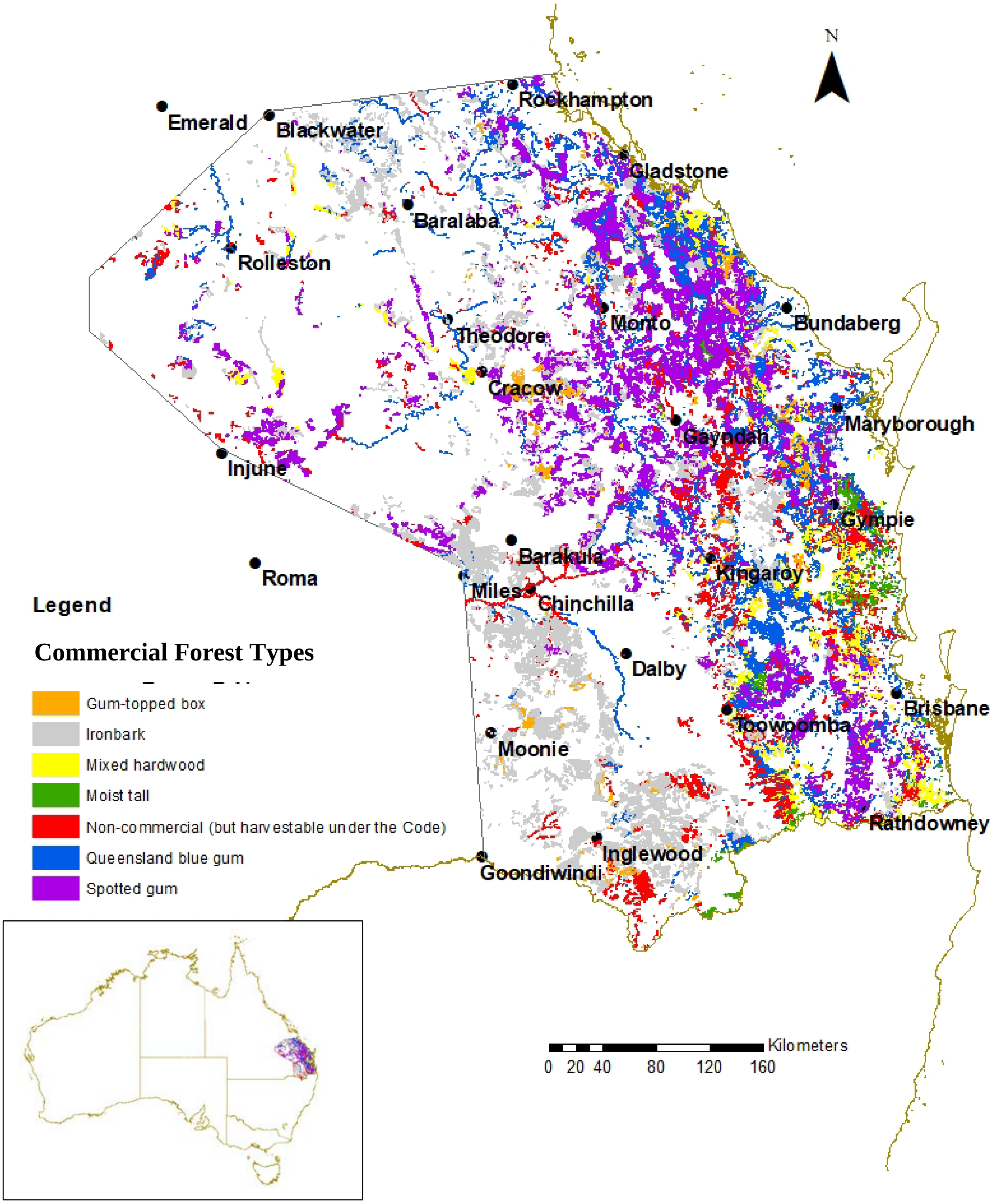

Figure 4.1. The spatial distribution of commercial private native forest in the Queensland part of the study area.

The moist tall forests cover a small area, but when well-managed are the most productive private native forests in the Queensland study area, capable of 1 to 5 m^3/ha/yr (Florence 1996; PFSQ c2015). They are generally associated with more fertile sites receiving high rainfall (>1300 mm/yr). However, these forests can have a dense mesic understorey, lantana infestation is common, and most of the dominant commercial species require relatively large canopy openings and site disturbance for successful regeneration to develop into merchantable trees. Therefore, intensive silviculture is typically required for adequate seedling establishment. The dominant commercial *Eucalyptus* species of this forest type are relatively intolerant of competition (Florence 1996). Regeneration will sort into crown dominance classes from a relatively young age, and weaker trees will be naturally thinned. Timely silvicultural treatment can speed along this process. Sawmillers reported that well-stocked moist tall forest on private land can have return periods as low as five years, but more commonly between eight and 20 years (Bureau of Rural Sciences 2004).

As rainfall (or soil water holding capacity) and soil fertility decline, the moist tall forests transition into mixed hardwood forest (Florence 1996). Rainfall for this forest type exceeds 900 mm/yr and in wetter or more sheltered locations a mesic understorey and lantana thickets may be present. However, the understorey can also be shrubby to grassy depending on soil moisture and the fire regime. Timber species from the moist tall forests may be present in small patches with a suitable microclimate. The dominant commercial species in the mixed hardwood forest type are more tolerant of competition for site resources than dominant commercial species in the moist tall forest. Most, including *E. siderophloia* and *E. acmenoides*, are lignotuberous. These characteristics facilitate some regeneration and accumulation of advanced regrowth under a canopy of mature trees where the understorey is more open or after a disturbance such as fire. However, the species of this forest type generally cannot match the fast rate of height growth of the moist tall forest species or spotted gum (on favourable sites), so competition for growing space with native shrubs and lantana can be intense. Furthermore, advanced growth of most species in the mixed hardwood forest type lose their capacity for apical growth relatively quickly if the competing overstorey is not removed (Florence 1996). Also, unlike the self-thinning tree species of the moist tall forests, trees of the mixed hardwood forest can persist as stunted lignotuberous advanced growth and small trees for decades, never to make a commercial product, but suppressing new regeneration (Florence 1996).

Mixed hardwood forests require timely silviculture to promote optimal growth. They are often on steep to undulating topography that may pose some logistical challenges for silvicultural management relative to drier spotted gum and ironbark forest types common on flatter country. Well-managed stands are moderately productive, capable of 1 m^3/ha/yr, but they are a challenging forest type to manage and growth rates of between 0.1 and 0.5 m^3/ha/yr are typical when the forests are not intensively managed (Florence 1996; Queensland CRA/RFA Steering Committee 1998a). In well-managed stands, return periods can be as frequent as about every 15 years, but every 30 years is more common in unmanaged private forest (Bureau of Rural Sciences 2004).

Spotted gum forests dominate private native forest holdings in southern Queensland. For the purposes of this report, the spotted gum forest type refers to forest with *C. citriodora* subsp. *variegata*, *C. citriodora* subsp. *citriodora* or *C. henryi*. *Corymbia maculata* was not included in the study area of the current project. These forests can be found on more exposed or lower water holding capacity soils in higher rainfall areas (>1000 mm/yr), often adjacent to mixed hardwood forests, but are most common in drier (600 to 1000 mm/yr), areas in northern and western parts of the Queensland study area. Spotted gum is lignotuberous, and can remain as a shrub to small tree while retaining the capacity for vigorous apical growth (upon release from overstorey competition) for longer than most species of the mixed hardwood forest. Nevertheless, without active management of regrowth by fire, poison or mechanical means, spotted gum forests can become overstocked with suppressed trees.

Private Forestry Service Queensland (PFSQ) has identified the spotted gum forests on private land as having the greatest potential to substantially contribute to long-term sustainable hardwood log supply. There is strong market demand for spotted gum, and even in low rainfall environments, this species has the capacity to grow merchantable sawlogs and poles at growth rates of between about 0.3 and 1.3 m^3/ha/yr. Throughout much of the range of this forest type, favourable terrain makes access by machinery for silviculture (e.g. thinning by chopper rolling) feasible and, relative to the moist tall forests and the mixed hardwood forests, spotted gum forests are structurally less diverse. Together, these characteristics of spotted gum make management of these forests by landholders a relatively low-risk investment.

Ironbark forests are the second most common commercial forest type in southern Queensland, representing 30% of the total harvestable forest. The productivity of ironbark forests are variable and declines considerably with rainfall. It is estimated that ironbark stands will grow at a rates between about 0.15 and 0.6 m^3/ha/yr depending on management and rainfall. Therefore, some ironbark forests are likely to require longer intervals between harvests than other forest types to maximise product value potential. The ironbark forest type does not include the coastal ironbarks (such as *Eucalyptus siderophloia* and *E. fibrosa* subsp. *fibrosa*) which often grow within the spotted gum or mixed hardwood forest types. These ironbark trees often exhibit reasonable growth rates (0.45–0.49 cm DBH per year on acceptable trees), but represent only a component of the stand (Grimes and Pegg 1979).

Distribution of private native forest among landholders in southern Queensland

Spatial analysis carried out by DES for this project revealed there are 37,287 private landholdings with unique LotPlans that are at least 20 ha in area and have some forest harvestable under the Code. The total number of actual landholders is less, since some landholders own more than one LotPlan. Of these, 19,622 have less than 20 ha of harvestable forest, meaning they are unlikely to have sufficient timber resource for harvesting operations to be commercially viable, and have been excluded from further analysis[3]. That leaves 17,665 LotPlans with a total harvestable (under the Code) forest area of 2,091,000 ha, and total commercial forest area of 1,886,400 ha (as reported in Table 4.2).

Figure 4.2 illustrates the distribution of harvestable and commercial private native forest among landholders in the Queensland. The 2,950 (17 % of total) LotPlans with at least 150 ha of commercial and harvestable forest account for 66% of the commercial forest in the study area. The 653 (4% of total) LotPlans with at least 500 ha of harvestable and commercial forest account for 36% (680,000 ha) of commercial forest in the study area, including 283,000 ha of spotted gum.

Table 4.3 reports area by commercial forest type for LotPlans with at least 150 ha of commercial forest. For most forest types, it is the properties with at least 150 ha of commercial forest that account for at least 50% of the area of that forest type. For example, 69% of spotted gum forest is on properties with at least 150 ha of commercial forest. However, the majority of the moist tall and Queensland blue gum forest is on properties with less than 150 ha of commercial forest. In the case of moist tall forests, this is because property sizes tend to smaller closer to the coast where these forests occur. In the case of Queensland blue gum, while this forest type is distributed over properties ranging from small

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[3] It is conceivable that neighbouring properties could together provide a large enough forest area to be attractive for timber harvesting, but all LotPlans with less than 20 ha of harvestable forest has been excluded in this assessment.

to large in total area, this forest type tends to be found in lower elevation areas, which are commonly cleared for grazing on larger properties, such that total area of Queensland blue gum forest on the property is low.

Figure 4.2. Cumulative area of harvestable and commercial forest by LotPlans categorised by area of commercial forest on individual LotPlans.

Notes: 100% of LotPlans represents the 17,665 LotPlans with at least 20 ha of harvestable forest under the Code. 2,113 LotPlans (12%) have at least 20 ha of harvestable forest, but less than 20 ha of commercial forest. 100% of commercial forest area is 1,886,400 ha.

Table 4.3. Area by commercial forest type for LotPlans with at least 150 ha of commercial forest.

Forest type	Area (ha)	% of total of forest type
Moist tall	10,400	31.0
Mixed hardwood	83,900	52.6
Spotted gum	477,100	68.8
Queensland blue gum	110,800	43.8
Gum-topped box	68,600	64.9
Ironbark	484,400	75.5
Total	1,235,200	65.6

Contribution of private native forests to the hardwood timber industry

Historic hardwood log supply

Total production of native forest hardwood sawlogs from State and private land in Queensland peaked in the early 1950s at about 1.4 M m^3/yr, and gradually fell to approximately 800,000 m^3/yr by the early 1980s (Queensland CRA/RFA Steering Committee 1998b; Timber Queensland 2012). Carron (1985) asserted that private native forests contributed about 50% of that volume, which was double the national average throughout that period. Harvested sawlog volume continued to decline to an annual cut of about 500,000 m^3/yr by the mid-1990s (Queensland CRA/RFA Steering Committee 1998b; Timber Queensland 2012), and total hardwood log harvest (not only sawlog) of 280,000 m^3 by the mid-2010s. Figure 4.3 illustrates harvested volumes from Crown and private forests in Queensland since 2004–05, revealing that the private hardwood cut is somewhat counter-cyclical to Crown supply. There is general consensus in the literature that, over the period 1990 to 2016, private native forests supplied between around 40% and 70% of the hardwood resource to industry in Queensland (Bureau of Rural Sciences 2004; DPI Forestry 1998), (State of Queensland 2016; Timber Queensland 2012), with the mean over the period 2004–05 to 2016–17 being 55%.

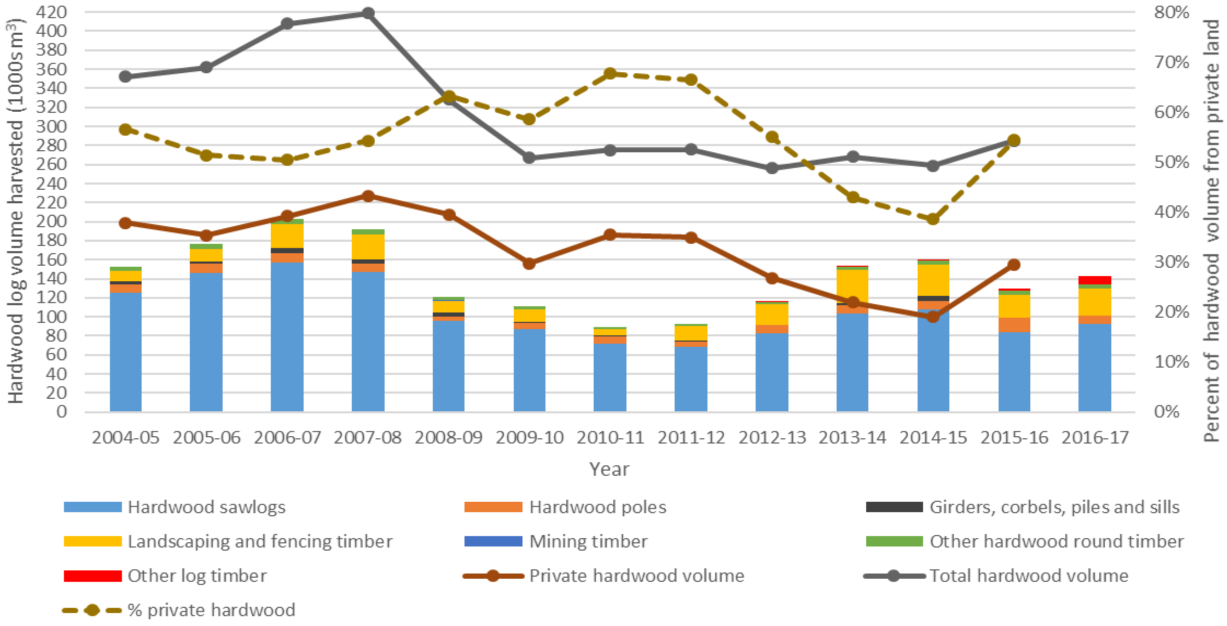


Figure 4.3. Harvest of hardwood logs from Crown and private forests in Queensland between 2004–05 and 2016–17.

Note: Crown hardwood log volumes are reported in stacked columns by log type. Private hardwood log volumes have been estimated by subtracting Crown log volumes reported in Queensland Department of Agriculture and Fisheries (2015) and Leggate et al. (2017) from total hardwood log volumes reported in (ABARES 2017).

Historically in northern New South Wales, about one-third of hardwood log supply to industry came from private land (Northern NSW Forestry Services 2002). However, demand for logs from private land has been increasing due to Regional Forest Agreements, and Jay and Dillon (2016) estimated that now about 50% of hardwood logs processed in northern New South Wales are harvested from private land.

Current reliance of the hardwood timber industry on private native forests

The primary processing segment of the industry, otherwise known as the sawmilling sector, converts the raw log from harvesting into a saleable final or intermediate product. Historically, the largest sector based on native forests in Queensland has been sawmilling (Ryan and Taylor 2006). Significant volumes of electricity distribution poles, girders, fencing, and landscaping supplies are also sourced from native forest (Ryan and Taylor 2006).

Currently in Queensland, there are 61 operational hardwood sawmills (State of Queensland 2016), with 40 of those being located within the study area, as indicated by a sawmill register provided by DAF (Figure 4.4). The NSW Department of Primary Industries provided information for 23 hardwood sawmills are located within the NSW component of the study area (Figure 4.4). This was based on a survey of primary processors in northern NSW (NSW Department of Primary Industries 2018) and included data on log throughput and employment generated. Of the 23 hardwood sawmills in the NSW component of the study area, 15 responded to the separate survey carried out in that region.

The Queensland Department of Agriculture and Fisheries (DAF) and the authors of this report designed a questionnaire to be completed by Queensland sawmill managers to assist with this research. This survey aimed to provide insights into the current reliance of the timber industry on private native forests. Questions addressed sawmill-specific topics, such as cost and revenue information, employment, reliance on private hardwoods, and general opinions about the state of the industry. The questionnaire is provided in Appendix 5. The survey of sawmills in Queensland commenced in February 2017, and 22 of the 40 sawmills located within the study area were surveyed. These 22 sawmills process 77% of the sawn timber products in the Queensland study area.

The 40 sawmills within the Queensland component of the study area source logs from both Crown and private native forest, and collectively process approximately 298,100 m^3 of sawlogs annually, of which, approximately 177,800 m^3 (60%) comes from private native forests (Table 4.4). An additional 27,372 m^3 of pole products are processed by sawmills within the study area annually, with 22,663 m^3 (83%) coming from private native forests (Table 4.5). However, some caution is needed in interpreting this figure because only three of the 22 hardwood sawmills surveyed reported pole volumes. Although this number is considered reflective of the industry, with poles being a specialty product that only a small number of sawmills produce, it is possible that the numbers reported in this report are an underestimate of total pole volumes. This is consistent with the finding of the survey of northern NSW primary processors (NSW Department of Primary Industries 2018), where only two of the 15 sawmills surveyed in the study area process poles. It is also possible that some large companies, such as energy providers, source poles independently. Pole volumes sourced and produced independently of hardwood sawmills have not been estimated.

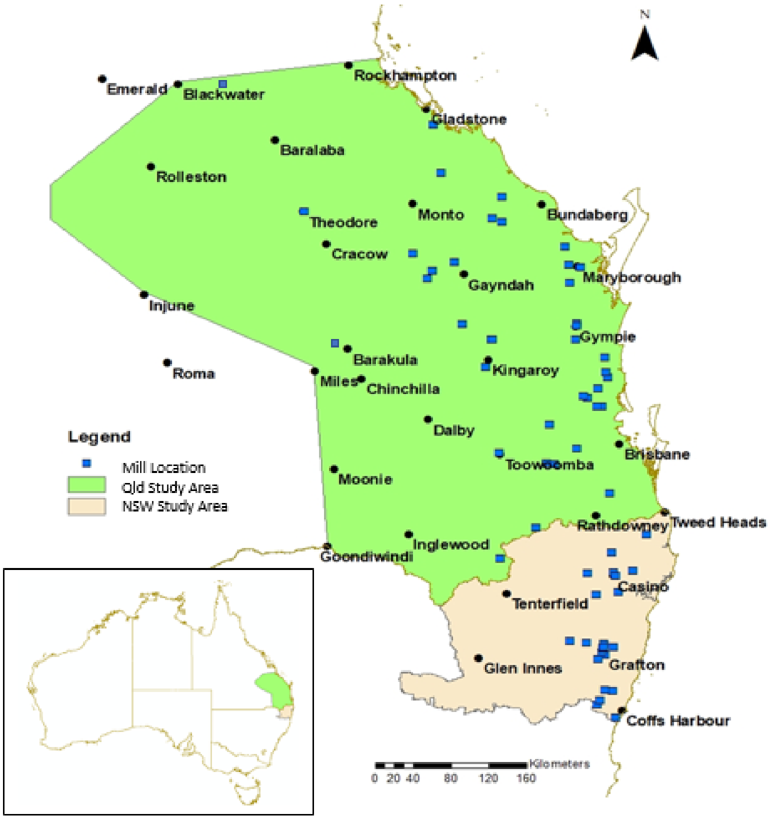


Figure 4.4. Locations of all hardwood sawmills within the study area.

Table 4.4. Number of sawmills by throughput category and estimated total and private native forest (PNF) sawlog throughput for sawmills within Queensland study area.

Throughput category (m^3/yr)	Number of sawmills surveyed	Mean throughput of surveyed sawmills (m^3)	Mean % PNF of surveyed sawmills[a]	Total number of sawmills[b]	Estimated total sawlog throughput of all sawmills (m^3)[c]	Estimated total PNF throughput (m^3) [d]
<3,000	4	1,077	89	15	16,200	14,900
3,000–10,000	9	6,356	62	15	95,300	65,600
10,000–50,000	9	18,656	53	10	186,600	92,600
Total	22		64	40	298,100	177,800

Notes:

a. Average percentage of PNF logs were calculated for each throughput category, based on individual sawmill responses to source of their logs (Crown or private).

b. Total number of sawmills were provided by DAF Forestry.

c. DAF Forestry provided estimated throughput categories for non-surveyed sawmills in the study area. Mean throughput of surveyed sawmills was allocated to the non-surveyed sawmills in the relevant throughput category. These were added to actual throughputs collected from surveyed sawmills to estimate total throughput volume within the study area.

d. DAF Forestry indicated which of the non-surveyed sawmills have a state log allocation. Sawmills with no state allocation were assumed to be 100% reliant on PNF. Non-surveyed sawmills with a state log allocation were allocated the average % reliance on PNF of surveyed mills from the relevant throughput category. Surveyed sawmills indicated the proportion of their total throughput that came from PNF. PNF volumes for surveyed sawmills was calculated by multiplying individual sawmills total throughput by the proportion of throughput originating from PNF. PNF volumes for surveyed sawmills were added to the estimated PNF volumes for non-surveyed sawmills to give the estimated total PNF throughput.

Table 4.5. Number of sawmills by throughput category and estimated total and private native forest (PNF) pole throughput for sawmills within study area.

Throughput category (m^3/yr)	Number of surveyed sawmills with a pole volume	Mean pole throughput of surveyed sawmills (m^3)[a]	Mean % PNF of surveyed sawmills	Total number of sawmills	Estimated total pole throughput of all sawmills (m^3)[b]	Estimated total PNF throughput (m^3)
<3,000	0	0	NA	15	0	0
3,000–10,000	1	14.3	100	15	231	197
10,000–50,000	2	3,016	93	10	27,142	22,466
Total	3		95	40	27,372	22,663

Notes:
a. Mean pole throughput is the total reported pole throughput in the throughput category divided by the total number of surveyed sawmills in the throughput category (Table 4.4).
b. With only three out of 22 surveyed sawmills indicating that they process poles, mean pole throughput to be allocated to non-surveyed sawmills was calculated as follows. The number of non-surveyed sawmills was multiplied by the proportion of surveyed sawmills reporting a pole throughput volume, and then multiplied by the mean pole throughput for surveyed sawmills in the relevant throughput category. Mean pole throughput from surveyed sawmills have been added to estimated pole volumes of non-surveyed mills.
c. PNF pole throughput for individual sawmills was estimated by multiplying estimated total pole throughput by each sawmill's reported reliance on PNF for sawlog (Table 4.4).

Throughput volume data by the source of logs (Crown and private native forests) were available for 15 of the 23 sawmills in the Upper North East NSW region. However, the throughput category of the eight sawmills that were not surveyed could not be estimated confidently. The average throughput of the 15 surveyed sawmills by source of logs was applied as a throughput estimate for the non-surveyed sawmills to predict total throughput for the region (Figure 4.5). This assumes that the data obtained for the surveyed sawmills is representative of all the sawmills in this region.

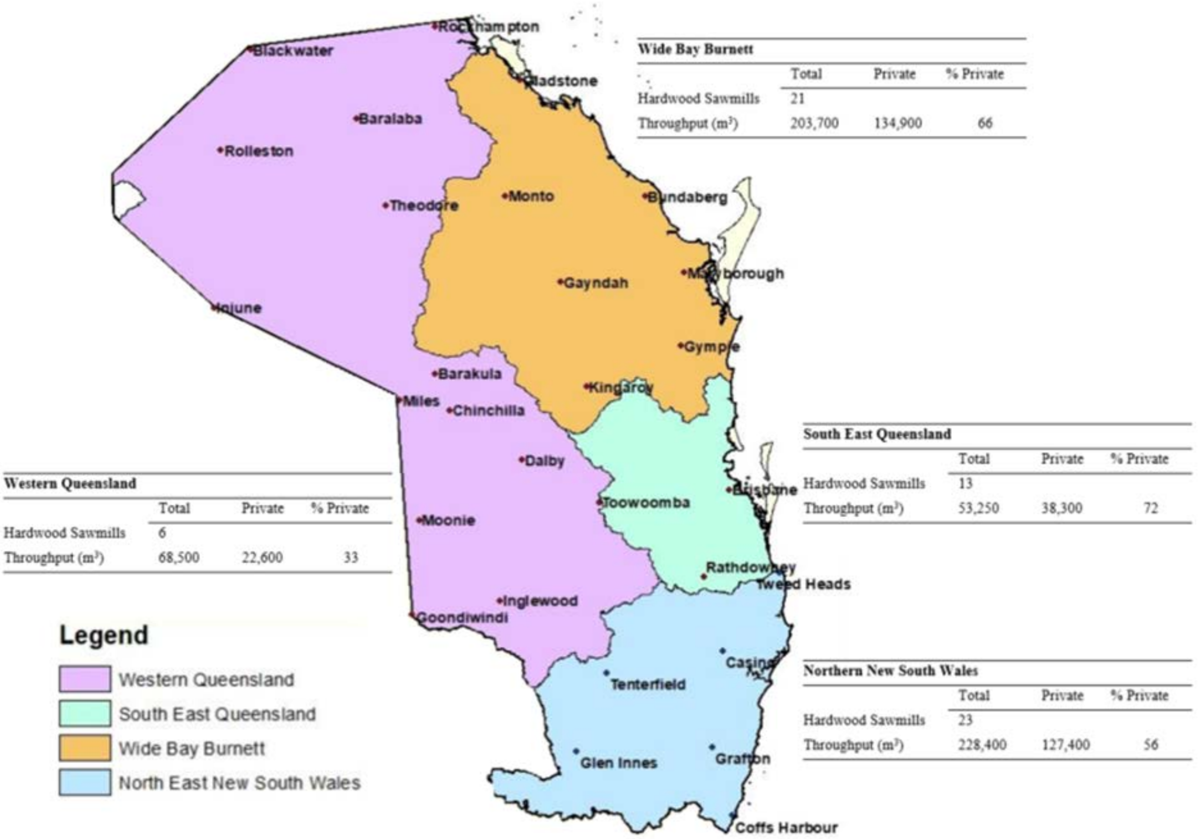
The total estimated volume (sawlogs and poles) processed by the 40 sawmills in the Queensland part of the study area exceeds the ABARES (2017) reported total hardwood volume processed in Queensland, which was 285,000 m^3 in 2015–16. Nevertheless, the authors are confident with these estimates. The 2017 sawmill survey suggests 125,009 m^3 of logs supplied from Crown forests to industry was processed in the study area. This is consistent with DAF records from 2016, which suggested the harvest of hardwood logs (sawlogs, poles, landscape and other) from Crown forests in Queensland was between about 130,000 m^3 and 140,000 m^3 (Department of Agriculture and Fisheries 2017). ABARES have access to DAF records. Therefore, the difference between the ABARES log volume estimates and this report appears to be due to differences in private native forest log estimates.

The Wide Bay-Burnett region is very important for the Queensland hardwood industry, containing the largest number of sawmills and also the highest throughput in the Queensland part of the study area (Table 4.6). The region is also highly reliant on log supply from private native forest, obtaining 66%, of their sawmill throughput from this resource.

Table 4.6. Total log throughput volume by region from private and Crown forest.

Supply Region	Log throughput in the year leading up to the survey (m^3)		
	Sawlogs	Poles	Total
Wide Bay-Burnett	177,900	25,800	203,700
South-east	53,200	50	53,250
Western	67,000	1,500	68,500
Total	298,100	27,350	325,450

Note: for accounting purposes, sawlogs include all logs that were processed into green sawn, dry sawn and landscaping products (sawn or not).



Wide Bay Burnett

	Total	Private	% Private
Hardwood Sawmills	21		
Throughput (m^3)	203,700	134,900	66

South East Queensland

	Total	Private	% Private
Hardwood Sawmills	13		
Throughput (m^3)	53,250	38,300	72

Western Queensland

	Total	Private	% Private
Hardwood Sawmills	6		
Throughput (m^3)	68,500	22,600	33

Northern New South Wales

	Total	Private	% Private
Hardwood Sawmills	23		
Throughput (m^3)	228,400	127,400	56

Figure 4.5. Number of sawmills, total throughput and percent private native forest timber by sub-region.

Data collected from the 2017 Queensland sawmill survey suggests that the main products milled within the study area are:

- green-off-saw products, such as house framing;
- dry flooring and decking;
- structural products, such as beams;
- landscaping products;
- electricity distribution poles and cross arms; and
- made to order and specialty products.

Sawmills within the 10,000–50,000 m^3 throughput category produce proportionately larger amounts of dry and pole products than the sawmills in the lower throughput categories (Table

4.7). The sawmills in the <3000 m^3 category, produce proportionally larger amounts of other products, suggesting that smaller sawmills are more likely to maximise product revenue potential from each log. Green-off-saw products represent the most common product type from sawmills within the Queensland study area, contributing to 41% of the total sawlog and pole products across the study region (Table 4.7). The Wide Bay-Burnett region produced a high proportion of poles relative to other regions, while the south-east region produced a high proportion of 'other' products, relative to other regions (Table 4.8). Green-off-saw products were relatively high in the western region.

Table 4.7. Sawmill products by throughput category at Queensland sawmills.

Sawmill Throughput Category (m^3)	Product volume (m^3/yr)[a]					
	Green sawn	Landscape	Dry sawn	Poles	Other[b]	Total
<3,000	5,700	1,000	150	0	17,000	23,850
3,000–10,000	25,400	4,100	13,900	250	18,200	61,850
10,000–50,000	54,900	4,000	22,200	27,100	15,300	123,500
Total	86,000	9,100	36,250	27,350	50,500	209,200

Notes: a. Product volumes of surveyed sawmills have been applied as reported. Product volumes for all products from non-surveyed sawmills were calculated as follows. For each sawmill throughput category, the weighted (by throughput volume) average proportion of throughput log volume for surveyed sawmills that was processed into a particular product was estimated. Non-surveyed mills were assumed to have the mean throughput volume in Table 4.4. These proportions were multiplied by the mean throughput volume per sawmill reported in Table 4.4 to estimate the product volumes for non-surveyed sawmills. Estimated product volumes for non-surveyed sawmills were added to the volumes reported by surveyed sawmills to give a total product volume.

b. Other products predominantly include chip and sawdust product.

Table 4.8. Sawmill products by the different sub-regions of the Queensland study area.

Region	Products volume (m^3/yr)					
	Green sawn	Landscape	Dry sawn	Poles	Other	Total
Wide Bay-Burnett	49,500	5,900	29,800	25,800	22,000	133,000
South-east	14,400	2,700	4,450	50	22,700	44,300
Western	22,100	500	2,000	1,500	5,800	31,900
Total	86,000	9,100	36,250	27,350	50,500	209,200

Employment generated by private native forests

Jobs in primary processing

The 2016 census (ABS 2017) reported that the Queensland forest and timber industry directly employed an estimated 8,027 people across three main sectors - forestry and logging, wood product manufacturing, and pulp and paper manufacturing. Schirmer et al. (2018), in an assessment of the socio-economic impacts of the forest industry found that 3,661 direct jobs up to the point of primary processing in 2017, with 991 being generated by native hardwood forests. This assessment however did not consider the proportion of jobs generated by private native forests.

ABS reporting of forestry employment does not consider resource types, grouping softwood and hardwood employment in the same category. Therefore, it was not possible to accurately allocate employment to a specific resource with census data alone. To overcome this problem, employment estimates in primary processing, and contractor harvest, snig and haul were derived from the DAF 2017 sawmill survey and other databases provided by DAF Forestry that include sawmill location and estimated sawmill throughput categories. Data collected from the 22 sawmills that responded to the survey has been utilised to estimate employment numbers for non-surveyed sawmills. There was a total of 503 full time equivalent (FTE) employees across the 22 surveyed sawmills, with varying rates of FTE per 1000 m^3 processed depending on sawmill throughput volumes (Table 4.9). Approximately sixty-three percent of all FTE employment within Queensland primary processors in the study area can be attributed to private native forest.

Table 4.9. Full-time equivalent (FTE) employment at sawmills in the study area (PNF, private native forest).

Throughput category m^3	Number of sawmills surveyed	Total FTEs of surveyed sawmills[a]	FTE / $1000m^3$ [b]	Total number of mills	Estimated total FTEs[c]	PNF FTEs[d]	% PNF FTEs
<3,000	4	20	4.5	15	73	70	95
3,000–10,000	9	182	3.2	15	302	203	67
10,000–50,000	9	269	1.8	10	336	174	52
Total	22	470	2.2	40	711	447	63

Notes:

a. Total FTE was calculated by combining reported full time employees with reported part time employees for each sawmill in each throughput category. Each part time employee was allocated 0.5 FTE.

b. The total reported FTEs of all surveyed sawmills within a throughput category, was divided by the total throughput sawlog volume (in units of thousands of cubic metres).

c. Non-surveyed sawmills in each throughput category were assumed to process the mean sawlog throughput for each category from Table 4.4. Employment at the sawmill was then estimated by multiplying the estimated throughput by the estimated FTE/1000 m^3 for that throughput category. These estimated FTEs for non-surveyed sawmills were added to FTEs reported by surveyed sawmills to estimate total FTEs in the study area.

d. FTEs reliant on PNF were calculated by multiplying the total estimated FTEs at individual sawmills by the proportion of sawlog throughput coming from PNF (Table 4.4).

Sawmill employment estimates were also determined for each of the sub-regions in the Queensland study area (Table 4.10). From this, it is evident that the Wide Bay-Burnett is an important region, with high levels of employment in the hardwood sector, and 64% of that employment is associated with private native forest. The finding is consistent with Schirmer et al. (2018), where it was found the Wide Bay-Burnett generates the most jobs in primary processing across the State, with 1,100 direct jobs including softwood and 527 jobs coming from native hardwood forests, with a cluster of large processors in the region. However, this assessment also included people involved in wholesaling of products produced by these processors, which this current assessment has not.

Table 4.10. Full time equivalent employment in private native forest (PNF) at hardwood sawmills by sub-region in the Queensland study area.

Sub-region	Total	PNF	% PNF
Wide Bay-Burnett	448	286	64
South-east	145	113	78
Western	118	48	40
Total	711	447	63

Employment by primary processors was also estimated for the 23 sawmills within the NSW study area. Average FTE employment for the 15 surveyed sawmills was applied to the eight non-surveyed sawmills. It was estimated that there are 574 FTEs employed by primary processors in the NSW study area, with 321 attributed to timber sourced from private native forests. These estimates were provided by the NSW DPI.

Jobs in harvest, snig and haul

Where Queensland sawmills reported contractor information, those contractors were involved in cut, snig or haul activities. As indicated in Table 4.11, the survey revealed that mills in the three sawmill throughput categories engaged varying numbers of contractors. Three sawmills in the <3000 m^3 throughput category reported that they carry out their own cut, snig and haul operations, and a fourth sawmill in the same category reported that they carry out their own cutting. Thus, smaller sawmills often employ sawmill staff to carry out cut, snig and haul. Larger sawmills engage contractors. Contractor employment for each of the regions has also been estimated (Table 4.12), with the Wide Bay-Burnett being important for contactor employment, which is related to the high level of sawmilling activities in this sub-region.

Table 4.11. Contractor employment within the Queensland part of the study area.

Throughput Category (m^3)	Number of sawmills providing contractor information	Reported contractor FTEs [a]	Mean contractor FTEs/1000 m^3 of log[b]	Total contractor FTEs [c]	PNF contractor FTEs [d]	PNF % contractor FTEs
<3,000	1	3	0.70	11.3	9.9	88
3,000 to 10,000	7	19	0.40	32.2	22.8	71
10,000 to 50,000	2	9	0.36	68.9	35.1	51
Total	10	31	0.4	112.4	67.8	60

Notes:

a. Total number of reported contractor FTEs associated with all surveyed sawmills.

b. Within each throughput category, the weighted (by sawlog throughput volume) average contractor FTEs per 1000 m^3 of sawlog was calculated from surveyed sawmills.

c. Non-surveyed sawmills in each throughput category were assumed to process the mean sawlog throughput for each category from Table 4.4. Contractor employment at the sawmill was then estimated by multiplying the estimated throughput by the mean estimated contractor FTEs for that throughput category. These estimated contractor FTEs for non-surveyed sawmills were added to FTEs reported by surveyed sawmills to estimate total FTEs in the study area.

d. Contractor FTEs reliant on PNF were calculated by multiplying the total estimated FTEs at individual mills by the proportion of sawlogs coming from PNF (Table 4.4).

Table 4.12. Full time equivalent employment in private native forest (PNF) in cut, snig and haul by sub-region.

Sub-region	Total	PNF	% PNF
Wide Bay-Burnett	63.4	40.0	66
South-east	24.3	17.4	72
Western	24.6	8.4	34
Total	112.3	67.8	60

Total employment generated by private native forests

From the 2017 DAF sawmill survey, it was found that there are approximately 112 FTEs in contractor harvest, snig and haul in native forests in the Queensland study area, and 711 FTEs at native hardwood primary processors in the Queensland study area. As indicated in Table 4.13, 515 of these FTEs, that is 62% of employment generated by native hardwood harvest, snig, haul and milling in the study area, can be attributed to the private native forest resource. Total sawmill and contractor employment by sub-region is provided in Table 4.13. These employment numbers are potentially conservative, as they not all sawmills could provide all contractor information. As such, it is likely that there are greater numbers of contractors than are reported.

Table 4.13. Private native forest (PNF) primary processing and contractor employment by sub-region.

Sub-region	Total	PNF	% PNF
Wide Bay-Burnett	511.5	328.0	72
South-east	169.1	130.3	73
Western	142.9	56.2	39
Total	823.5	514.5	62

Economic value of production from private native forests

Of the 22 hardwood sawmills surveyed as part of the 2017 DAF sawmill survey, only 14 provided sales data. Due to the limited availability of sales data from surveyed sawmills, weighted average (by product volume) mill-gate prices per cubic meter for each product were calculated across all sawmill throughput categories, and these are presented in Table 4.14. No sales data were available for the sawmills surveyed in the NSW study area.

Table 4.14. Average reported mill-gate price ($/m^3) of products at surveyed sawmills.

Green sawn	Dry sawn	Poles	Other
1066	1778	377	15

Note: Green sawn and landscape products (Table 4.14) have been combined into green sawn for sales and values, because mills did not report landscape product value separately.

In non-surveyed sawmills, and surveyed sawmills not providing sales information, the weighted average product values (Table 4.14) were multiplied by estimated product volumes (Table 4.7) to provide product values. These product values were added to the product sale values provided by surveyed sawmills to give total product values (Table 4.15). Across the 40 hardwood sawmills within the study area, approximately $181 million worth of sawn timber, poles and other products, such as chip and mulch, are sold annually (Table 4.15). That equates to an average sale value of $865 per cubic metre of product sold. Of the products listed in Table 4.15, green sawn products generate the highest sale value in each of the throughput categories, with dry sawn products attracting the highest sale value per cubic meter of product sold. Green sawn products also represent the highest sale value for each of the sub-regions (Table 4.16).

Table 4.15. Total estimated annual sales by throughput category.

Sawmill throughput category (m^3/yr)	Total annual sales sawmill by product type ($1000s)				
	Green sawn	Dry sawn	Poles	Other	Total
<3,000	7,610	257	0	262	13,200
3,000–10,000	30,413	24,882	80	291	44,000
10,000–50,000	62,698	43,864	10,329	190	132,000
Sum of all categories	100,721	69,004	10,320	743	180,789
Average sawmill-gate price ($/$m^3$ final product)[a]	1,060	1,902	377	15	865

Note a Average sawmill-gate sale value ($/$m^3$) was calculated by dividing the total sale value of each throughput category in each product type by the total estimated volume for that product type from Table 4.7.

Table 4.16. Total estimated annual sales ($) by region.

Supply Region	Value of products sold by sawmills ($1000)					% PNF
	Green sawn	Dry sawn	Poles	Other	Total	
Wide Bay-Burnett	57,630	57,719	9,733	360	125,444	59
South-east	18,810	7,706	18	308	26,848	76
Western	24,274	3,579	569	75	28,497	35
Total	100,721	69,004	10,320	743	180,789	58

The Wide Bay-Burnett region is extremely important for the Queensland timber industry, representing 69% of all sales from hardwood sawmills within the study region (Table 4.16). In summary, private native forests account for 60% of the processed hardwood logs, 62% of hardwood timber industry employment, and 58% of sawmill-gate sales value in the Queensland study area. They account for 56% of the total log throughput and employment at primary processors in the NSW study area.

Sawmiller and landholder attitudes and perceptions

Sawmiller perceptions

As part of the Queensland sawmill survey, sawmillers were asked their opinions and outlooks on the industry as a whole and the future of the private native forest resource. Questions are in bold italicised text and sawmiller responses follow.

Do you think there will be adequate supply of private native forest resource to meet future timber industry needs?

Figure 4.6 represents the opinions of surveyed sawmills regarding the future availability of private native forest log supplies. Forty percent responded that there would not be adequate timber from private native forests. Forty-five percent suggested that the availability of future log supplies is dependent on government regulation and /or sound silvicultural management. Only 15% of those sawmills surveyed indicated there would be adequate supply of private native forest to meet future timber needs.

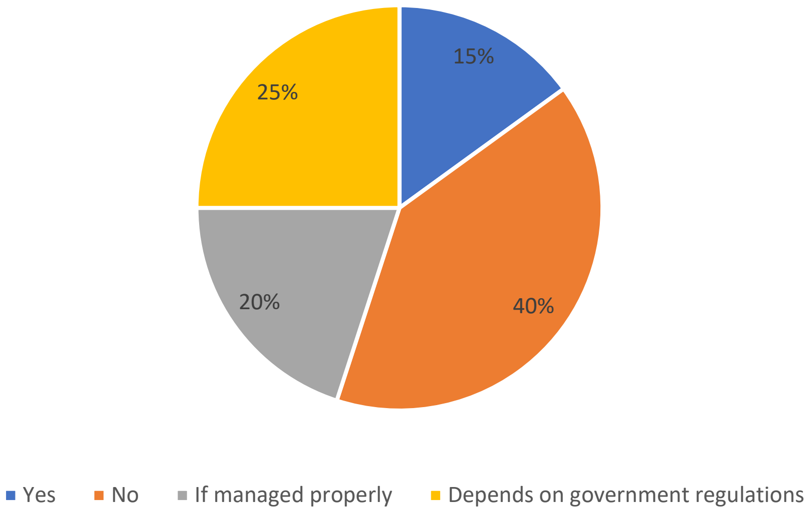


Figure 4.6. Sawmiller attitudes to future timber supplies (n = 20).

Has the availability of logs from private native forests changed over the past 10 years?
Figure 4.7 highlights sawmiller opinions on the availability of private native forest log supplies over the past 10 years. Respondents who have seen a decrease in log supply from private native forest suggest that the decrease is due to overcutting, increased competition for logs (with larger sawmills sourcing logs from further away than historically), and government restrictions. Sawmillers who suggest there has been no change generally highlighted that it varies from year to year and it can be dependent on cattle prices. It was also acknowledged among those who indicated no change in log supply from private native forest, that haul distances are increasing. This is also a sign of resource scarcity.

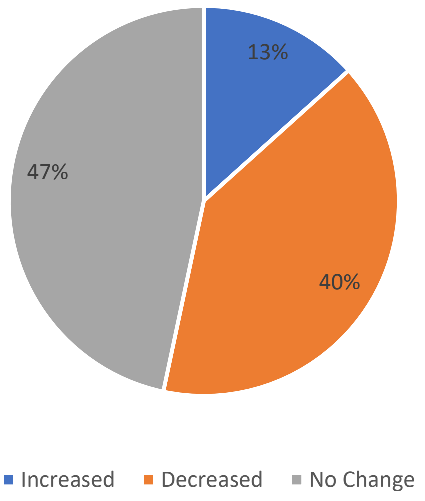


Figure 4.7. Sawmiller opinions on private native forest log supply over the past 10 years (n = 15).

Has the quality of logs and the products obtained from private native forests changed over the past 10 years?

The majority of sawmillers suggested that the quality of private native forest logs has decreased over the past 10 years (Figure 4.8). It was suggested that the primary reasons for this are poor management and that a higher proportion of the cut is in smaller tree diameter classes. It was also suggested that higher quality logs are becoming more difficult to obtain.

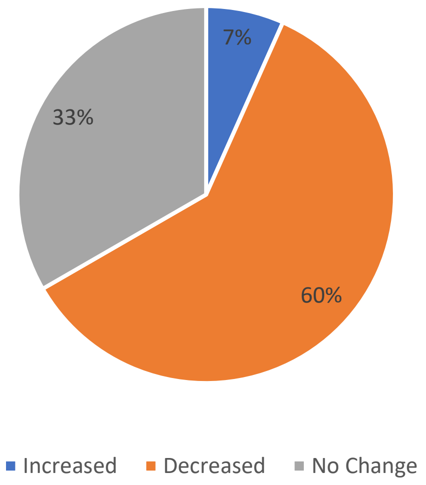


Figure 4.8. Quality of private native forest logs over the past 10 years (n = 15).

Do you perceive there to be a difference in the distribution of log size, desired species and wood quality of private native forest compared with the State-owned native forest resource?

The most common response (40%) to this question was that the quality of logs is higher from private native forests (Figure 4.9). However, it was widely acknowledged by respondents that the greater quality is because sawmills have greater control over log selection in privately owned forests, relative to the State-owned resource. Thus, many respondents were answering in terms of the quality of the logs arriving at their sawmill and not the quality of standing logs in the forest. Private native forests were of comparable quality or lower quality than State-owned forests for 40% of respondents, and 20% of respondents indicated private native forests are extremely variable in quality, making it difficult to compare them with the State-owned resource.

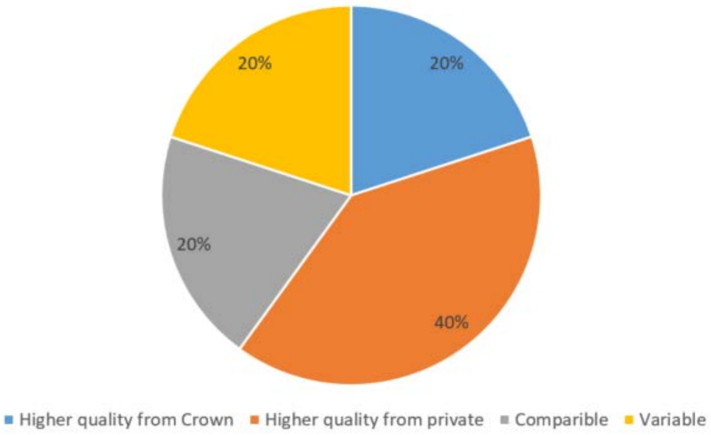


Figure 4.9. Difference in log quality between State-owned and private native forests (n = 15).

Do you think the productivity of the private native forest resource can be increased? How?
Responses to many of the earlier questions were quite negative about private native forests; however, 88% of sawmillers surveyed agreed that the productivity of private native forest can be increased with silvicultural treatments (Figure 4.10). Many sawmillers acknowledged that this depends on landholder attitudes and knowledge, and government policy.

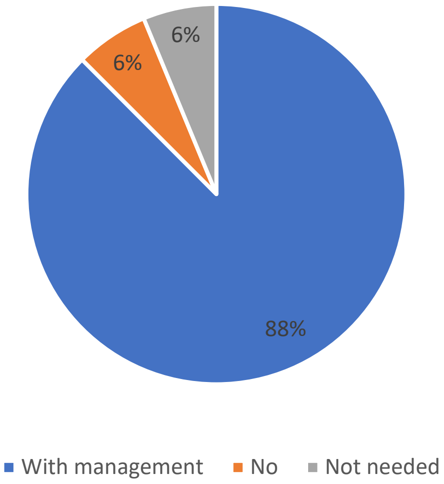


Figure 4.10. Potential for private native forest resource to be increased (n = 16).

What factors would influence your future investment decisions?
The main factor influencing future investment for 82% of respondent sawmillers was resource security (Figure 4.11). Many of these sawmillers referred to the need for clarity and certainty about government legislation regarding access to the private native forest resource, and State-owned forest allocations into the future.

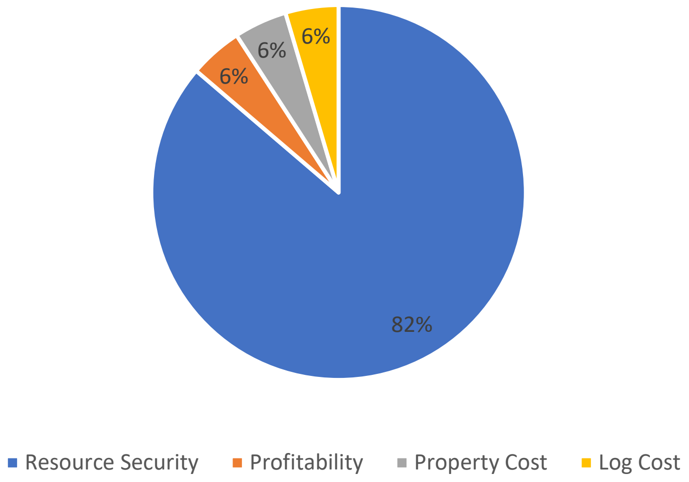


Figure 4.11. Factors influencing future investments (n = 22).
Note: Resource security, government legislation, species availability and log supply responses have been grouped as resource security.

What is the maximum distance you would travel to source private native forest logs?
A large range of maximum distances to source private native forest logs was provided by surveyed sawmills (Figure 4.12), with 21% indicating a willingness to source logs from 300 km to 400 km. Several sawmills indicated they work off a price to get the product to the sawmill rather than a maximum distance. One sawmill highlighted that they would be willing to haul up to 2000 km for a specific or higher quality product. The positive to be taken from responses to this question is that haul distances to sawmills should not be a major constraint to private native forest management in the study area. Average haul distance does not appear to be correlated to sawmill size.

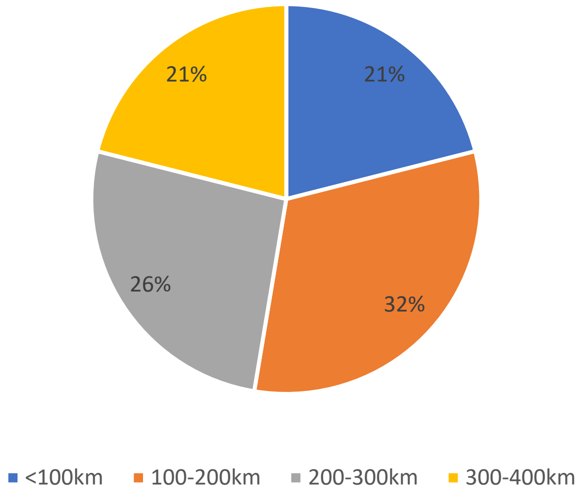


Figure 4.12. Maximum distance travelled to source private native forest logs (n = 19).

Landholder perceptions

The limited and mostly dated literature suggest that sovereign risk; landholder motivations and attitudes; State government forestry policy; vegetation management regulations; and timber industry practices explain why private native forests have been mostly unmanaged over many decades.

Dare et al. (2017) conducted a landholder attitude survey for the NSW Department of Primary Industries. They found that, of the seven most common barriers restricting private landholders from harvesting timber, the only barrier that was not related to government and regulatory requirements was ‘concern about environmental impacts’, which was reported by 55% of landholders. Nearly 30% of respondents in this assessment were not sure of the potential financial benefits of timber harvesting and 35% of respondents had no knowledge of timber management options.

Historically, sovereign risk has been a major reason landholders are reluctant to manage their private native forests for timber production (Queensland CRA/RFA Steering Committee 1998a). Bureau of Rural Sciences (2004) asserted sovereign risk has motivated landholders in south east Queensland to harvest and then convert their forest to pasture or other land uses that hold fewer uncertainties for them. Indeed, results of a survey of sawmills conducted by Queensland CRA/RFA Steering Committee (1998a) indicated that about 30% of the landholders sawmills dealt with at that time were clearing and thinning for grazing, rather than managing forest for long-term timber yields, and the majority of sawmillers felt that the area of private native forest contributing to timber supplies in the South East Queensland Forests Agreement region was decreasing. The 2017 DAF sawmill survey reported in this chapter has revealed that lack of resource security due to sovereign risk is the greatest impediment to hardwood sawmiller investment in Queensland today.

Bureau of Rural Sciences (2004) found a common reason as to why landowners do not manage trees for timber production was that they get better returns from other parts of their agribusiness and timber was only a limited portion of total farm income. Although timber provided adhoc financial returns it was cattle and crops that provided secure annual income to landholders.

Queensland CRA/RFA Steering Committee (1998a) reported that attitudes of private native forest landholders in the South East Queensland Forests Agreement region included that native forest:

- is a hindrance to other potential land uses;
- is a resource that can be capitalised on while clearing their land for other agricultural purposes;
- should be retained for conservation and wildlife habitat; and
- can be used to supply on-site timber needs.

Although that study did not quantify the prevalence of these attitudes, it is clear that landowners with these attitudes are unlikely to be interested in investing resources into improving the timber production of their forest. These findings are consistent with a nation-wide survey of landholders with native vegetation conducted by the Australian Bureau of Statistics (2007), which found that 27% and 40% of Queensland landowners indicated they had native vegetation (including native forest) on their land because it was difficult to clear, or because of restrictions on vegetation clearing. Many landowners indicated positive reasons for retaining native vegetation, including that it provides wildlife habitat (53%) and provides shelter and shade for stock and crops (61%).

Some landholders have reported poor experiences with logging contractors and timber mills during previous harvesting activities on their land, sometimes expressing a perception that they were exploited by sawmills (Bureau of Rural Sciences 2004; Queensland CRA/RFA Steering Committee 1998a). Some landholders who had expressed dissatisfaction with the value of timber cut from their land may have had unrealistic expectations given the condition of their resource (Queensland CRA/RFA Steering Committee 1998a).

In State-owned native forest, the need for silvicultural treatment became apparent in the early 1900s, and silvicultural treatment began as early as 1919 (Ryan and Taylor 2006). However, there seems to have been little or no extension effort to inform private landowners about the benefits of native forest silviculture (Ryan and Taylor 2006), and landholders have a poor understanding of the subject (Queensland CRA/RFA Steering Committee 1998a; Ryan and Taylor 2006). Even among landholders with an interest in timber production, there is limited knowledge about how to manage their forest and high uncertainty about the costs and benefits. Generally, landholders are not familiar with timber markets, and do not appreciate the higher timber value of well managed forests.

Opportunities for silvo-pastoral systems

Much of the private native forest in the study area, particularly in Queensland, is on properties where the main economic activity is beef cattle grazing. Silvo-pastoral systems refers to the dual management of land for timber and livestock. For most beef producers, there is a trade-off between trees and grass. Although there are many reported benefits of trees within pasture for livestock welfare, as well as pasture quality, the net effect of trees is one of pasture growth suppression and reduced returns per hectare from cattle (Schulke 2017). At the time when most grazing properties were first selected, high quality native forest timber was relatively abundant, while cattle were relatively scarce. Markets reflected these relative scarcities. The majority of landholders cleared their more easily accessible forestland in valleys, flats and undulating country to take advantage of the three to four-fold increase in pasture production that can generally be achieved when trees are removed from the landscape (Scanlan and Turner 1995). Steeper hilly areas have mostly only been selectively cleared.

Over the last 30 years, the relative abundances of cattle (both within Australian and globally) and Queensland's unique native forest hardwood timbers have reversed. This is evidenced by the trend in real (net of inflation) prices since 1980, which has been negative for cattle and positive for timber in Queensland (Schulke 2017). Accumulating anecdotal and empirical evidence about the potential returns to silvo-pastoral systems in eastern Australia suggests they may generate greater returns than grazing alone in the medium and long-term, particularly on undulating to steeper country. However, the financial performance of silvo-pastoral systems in the sub-tropics and tropics of Australia is poorly understood (Donaghy et al. 2010).

This section proceeds with a review of returns to grazing on cleared land in southern Queensland, which provides a benchmark against which returns to silvo-pastoral systems can be compared. This is followed by a review of the effects of trees on the productivity of grazing properties. Then, literature on the financial performance of silvo-pastoral systems in sub-tropical Australia is reviewed.

Financial benefit of grazing on cleared land

There is limited recent published information about the financial performance of grazing on cleared land in the sub-tropics of Australia, and that which is available tends to be more relevant for the drier western and northern parts of the study area. The studies summarised below estimated net present values (NPVs) of gross margins[4] in 2005 to 2007 dollars assuming 20 years of operation at a real (net of inflation) 5% discount rate, and active management that periodically removes regrowth woody vegetation to maximise pasture production. Star and Donaghy (2010) estimated the NPV of gross margins of cattle operations in various land types of the Fitzroy Basin (which includes the north western part of the study area) at between $12/ha and $190/ha. Estimates of the NPV of gross margins for cleared brigalow country have ranged from $320/ha to $550/ha (Department of Primary Industries and Fisheries 2007; Stephens et al. 2008; Donaghy et al. 2010). The NPV of grazing on cleared spotted gum–ironbark country around Gayndah (north-west of Gympie) has been estimated at $540/ha (Schulke 2012).

Maraseni and Cockfield (2011) reported the NPV of gross margins from grazing on cleared land around Kingaroy at $3079/ha for 34 years of operation and a discount rate of 6%. However, this site appears to be unusually productive with red ferrosol soils, moderate mean annual rainfall of 781 mm, and an average carrying capacity of 1.8 ha/hd[5].

Declining productivity is a common phenomenon in dryland cropping and grazing systems (Radford et al. 2007). For example, the higher brigalow NPV estimate above is based on actual costs and returns from a research site given the weather and market conditions experienced over the period 1983–84 to 2004–05. Average annual gross margins for the first eight years post-clearing between 1984–85 and 1991–92 were 275% higher than the average for the final 13-years from 1992–93 to 2004–05 (Stephens et al. 2008). The initial high production was attributed to the release of accumulated nutrients when the brigalow forest was cleared at the start of the research, and higher than average rainfall. It has been demonstrated that nitrogen fertiliser treatments can avert long-term decline in cattle production on brigalow country, but that the costs may not outweigh the benefits (Jones et al. 1995).

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[4] Gross margins are revenues less variable costs.

[5] hd is an acronym for head. One head of cattle is one animal.

Effects of trees on the productivity of grazing properties

It is generally accepted there is a linear to curvilinear negative relationship between tree density and pasture production in the study area. Competition for site resources means there is a trade-off between trees, and pasture and cattle production. However, numerous studies in Queensland have reported benefits of trees on grazing properties (Cameron et al. 1989; Wilson et al. 1990; Bird et al. 1993; Gutteridge and Shelton 1994; Lamb and Borschmann 1998; Jackson and Ash 2001; Radford et al. 2007; McKeon et al. 2008; Stephens and Stunzner 2008; Stephens 2009; Donaghy et al. 2010; Maraseni and Cockfield 2011; Schulke 2017). These include:

- increased nutrient cycling;
- improved soil condition and structure;
- reduced runoff, erosion and transport of nutrients and agricultural chemicals;
- lowering water tables where salinity is a problem;
- reducing temperature and wind speed;
- higher pasture quality;
- biodiversity conservation; and
- carbon sequestration.

Trees provide microclimate benefits for grazing properties, particularly in relation to reduced temperatures created by shade from the trees. Gutteridge and Shelton (1994) reported that the effect of heat stress on growth and reproductive performance of cows has been well documented, with recordings in Australia of a reduction of 0.9% in calving rate for every 0.1 degrees Celcius increase above 39°C in the rectal temperature of cows. The average depression in calving rate due to heat stress was reported to be 15% to 25% for British breeds and 10% in Brahman-cross herds. Stressed cows also gave birth to lighter calves. In a study by Davison et al. (1988, cited in (Gutteridge and Shelton 1994), animals without shade had a mean rectal temperature of 40°C while those with shade had a mean rectal temperature of 39.4°C. Given that the ‘best estimate’ of climate change across the rangelands of Australia is for a decline in rainfall and an increase in temperature (McKeon et al. 2009), the microclimate benefits of trees on grazing properties are likely to increase in the future.

Four trials examining the effect of tree stocking on pasture production were established in southeast Queensland in the late 1980s and early 1990s, two at Samford (Cameron et al. 1989; Wilson et al. 1990), and one each at Mount Mee (Lamb and Borschmann 1998) and Warril View (Dunn et al. 1994). Each of these studies involved planting trees within pasture on sites that had been completely cleared of trees. In contrast to the generally accepted wisdom that pasture production is inversely proportional to tree stocking, the Samford and Mount Mee sites found pasture production was maximised at low tree stockings of between about 100 to 300 SPH (basal area of 0.5 to 3.2 m^2/ha, tree heights 8 to 14 m for trees at 4 to 6 years after planting), relative to open pasture[6]. Unfortunately, the research sites appear to have been abandoned when project funding ran out, such that findings from only the first three to six years since establishment are published. A search of online aerial imagery revealed that the Mount Mee and Warril View sites are still standing. Development in the Samford Valley has been rapid in the last two decades, and it is possible that these sites have been lost.

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[6] At the much drier Warril View site, there was no statistically significant difference in pasture production due to tree stocking (80 to 1200 SPH) or position on the hillslope between planted areas and open pasture up until the last measure at three years since planting.

Writing from their experience at Samford, Cameron et al. (1989) suggested high pasture growth might be maintained throughout long sawlog rotations by progressive thinning to a final stocking of 20 to 50 SPH. Further research is required to determine whether tree competition impacts on pasture can be limited, or indeed whether pasture production benefits can be maintained throughout the rotation, at low tree densities. There is likely to be a trade-off with timber quality at low tree densities, as many tree species do not shed their branches as readily and have greater taper in their bole when open grown.

The traditional approach to pasture development in Queensland has been the total clearing of forest, sometimes excluding vegetation near watercourses and small areas near cattle camps. Cook and Gnuvtnst (1977) investigated improved pasture establishment and the first 14 months of improved pasture growth on a 77 ha site under a spotted gum native forest canopy near Gympie in south east Queensland, where mean annual rainfall is about 1200 mm. Timber was harvested from the site and the residual stand was silviculturally treated to retain trees of desirable species with acceptable crowns, spaced a minimum of 8 m, and with at least 6 m of log or potential log. Following treatment, the stand had a mean basal area between 3.4 m^2/ha and 5.3 m^2/ha, mean stocking of between 48 and 96 SPH, and mean projected crown cover between 17% and 28%. The site was burned and aerially sown with a mix of grass and legume seed at a total pasture establishment cost about 40% lower than the traditional approach. Pasture dry matter yields were measured 14 months after sowing (stock had been excluded).

The authors concluded that improved pasture yields compared favourably with yields on conventionally cleared land. Cook and Gnuvtnst (1977) wrote that this was not surprising given the minimum light penetration throughout their study area was 72%[7], and this light level minimum is close to the light saturation point for grass and exceeded the light saturation level for legumes. An update was provided by Ryan et al. (1986) where it was reported that pasture remained in good condition, including a strong legume component eight years after establishment. Pasture yields under spotted gum were still comparable with pasture yields on conventionally cleared land. Trees had provided climatic amelioration at the site. Quality green standover feed was available throughout winter, compared to severe frost damage on adjacent cleared pasture, and there was reduced moisture stress in pasture under trees during dry periods. In both papers, the authors acknowledged longer term measurements are necessary to accurately assess the stability, resilience, productivity and profitability of silvo-pastoral systems, and asserted this would be reported on in subsequent papers.

McKeon et al. (2008) studied the effect of tree strips on pasture growth in southern Queensland. They examined sites on three grazing properties near Theodore, Mungallala and St George, respectively, where tree strips ranged in width from 15 to 75 m and were separated by between 120 and 500 m of pasture. On average, beneficial effects of the tree strips on pasture production were observed between one and six times tree height away from the tree strips. In one example near Theodore, 90% to 95% compensation[8] in pasture growth occurred where the tree strip to pasture ratio was 1:4. However, substantial variation in effects on pasture were observed between locations and between tree strips at the same location. Consequently, the authors recommended against extrapolating their findings to general guidelines for Queensland and that further studies be performed on different sites, and tree strip orientations.

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[7] The maximum projected crown cover on the study area was 55% with approximately 50% light interception by the canopy.

[8] Meaning 90% to 95% of the pasture productivity of cleared paddocks without tree strips was achieved.

Review of literature on the financial performance of silvo-pastoral systems

Literature on the financial performance of silvo-pastoral systems in sub-tropical Australia is scarce. Indeed only one published study was found that specifically assessed the type of silvo-pastoral system of interest to this review; cattle and timber production within native forest (Schulke 2012; 2017). Two studies have estimated grazing values in native forest and woodland, but did not consider potential timber values within a silvo-pastoral system (Queensland CRA/RFA Steering Committee 1999; Star and Donaghy 2010), and two papers have estimated the financial performance of silvo-pastoral systems, but not within commercial native forest (Maraseni et al. 2009; Donaghy et al. 2010). These studies are briefly reviewed. Schulke (2012; 2017) estimated annual gross margins generated from cattle and timber for spotted gum–ironbark country around Gayndah in three scenarios:

(i) grazing on cleared land;
(ii) periodically high-grade harvested and grazed; and
(iii) silviculturally treated and managed for timber and cattle.

There is no timber production under the first scenario, a MAI of 0.1 m^3/ha/yr in the second scenario, and timber growth under the third scenario was estimated with the Spotted Gum Assessment Tool (SPAT) (Lewis et al. 2010) at 0.7 m^3/ha. A timber value of \$80/m^3 was assumed for scenario ii and \$100/m^3 for scenario iii, reflecting a higher proportion of higher quality boles. Schulke (2012) estimated annual grazing gross margins in scenarios i, ii and iii at \$43/ha, \$10/ha/yr and \$18/ha/yr, respectively. Present values of grazing gross margins and timber revenues for each scenario have been estimated for 20 years of operation and a real discount rate of 5%. The present value of the silvicultural treatment scenario was \$750/ha. The costs of silvicultural treatment would need to be deducted from this to derive a NPV. Grazing on cleared land returned a NPV \$540/ha. Land clearing and pasture establishment costs would have to be deducted from this to derive a NPV of grazing on cleared land. The periodically high-grade harvested and grazed scenario had the worst performance, with a present value of \$200/ha. There are no additional management costs to deduct in this scenario, the NPV is also \$200/ha.

Forest grazing in native forests within Queensland's State Forests and Timber Reserves was encouraged early after their establishment to maximise benefits from these areas for the State. The Queensland CRA/RFA Steering Committee (1999) estimated that 412,000 ha of State Forests and Timber Reserves in the SEQ RFA area in the late 1990s had grazing leases. Most of the leases were north and west of Gympie, where carrying capacities were generally in the range of 11 to 30 ha/hd, and north and west of Mount Perry, where carrying capacities were generally greater than 30 ha/hd. These grazing leases generated operating profits (which do account for fixed costs) of \$2.3 M/yr (inflated by the CPI to 2017 dollars) or \$5.64/ha/yr (Queensland CRA/RFA Steering Committee 1999)[9]. This is equivalent to a grazing NPV of \$113/ha at a 5% discount rate. Timber values need to be added to these forest grazing returns to estimate the potential financial performance of a silvo-pastoral system in these forests. Since the 1970s, State Forests and Timber Reserves generally have not received any silvicultural treatment other than a harvest approximately every 20 to 40 years. Silvicultural treatments would likely increase grazing and timber values in these forests.

Star and Donaghy (2010) developed a bioeconomic model to estimate the financial performance of grazing properties on major land types in the Fitzroy Basin, with tree basal area scenarios considered to be representative for these land types. The opportunity cost of retaining trees, that is the foregone present value of grazing gross margins relative to land

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[9] In 1996-97, the annual profit from grazing in Crown native forests was estimated at \$1.4 M.

cleared of trees, was estimated at between $60/ha and $150/ha depending on land type. Comparing the reported NPVs for cleared land against the reported NPVs for the same land types with trees, it can be determined that a timber harvest of between $500/ha and $750/ha every 20 years would be sufficient for a silvo-pastoral system to earn equivalent returns to grazing on cleared land when the real discount rate is 5%. This value can be achieved with a MAI of 0.5 m^3/ha/yr over 20 years and an average stumpage price of $80/$m^3$.

Donaghy et. al. (2010) developed a bioeconomic model to examine several regrowth strip and plantation spotted gum strip silvo-pastoral systems in poplar box and brigalow woodland country of the Fitzroy Basin. In all scenarios, the silvo-pastoral systems were 20 m wide strips of trees separated by 60 m of pasture. Positive and negative effects of the strips of trees on pasture productivity were modelled over time as a function of expected basal area and tree height, with relationships coming from several sources, but particularly from McKeon et al. (2008). Several conclusions can be drawn from the Donaghy et al. (2010) study. First, there was no financial incentive for landholders to retain natural regrowth strips in the absence of carbon payments, even after the positive impacts of trees on pasture growth were accounted for. Second, the recognition of carbon benefits at a price of $10/t CO_2 e was sufficient to make the retention of regrowth strips financially viable for landholders, even if methane emissions for associated livestock were accounted for. Third, the net benefits of carbon sequestration in regrowth strips were higher on the lower cattle productivity country. Fourth, there appeared to be large potential benefits from spotted gum plantation strips, with the NPV of this silvo-pastoral system being $210/ha greater than cleared grazing land.

Maraseni et al. (2009) estimated the returns to a silvo-pastoral system with plantation spotted gum on a property near Kingaroy in south east Queensland over 31 years at a real discount rate of 6%. Nearby open pasture had a carrying capacity of 1.8 ha/hd. Cattle would be introduced to the plantation when the trees were aged 4 years and the stocking 400 SPH. Carrying capacity declined as trees aged, beginning at 3.4 ha/hd at age 4, falling to 4.2 ha/hd by age 12 when the stand would be thinned to 250 SPH, and then to 7.1 ha/hd at age 26, when canopy closure would be achieved and carrying capacity was expected to be constant thereafter until clearfall at age 31. Assuming the mean DBH was 40 cm at 31 years, with 250 SPH this would be equivalent to a basal area of 31 m^2/ha. A carrying capacity of 7.1 ha/hd may be optimistic in a stand with this basal area. The grazing component of the silvo-pastoral system had a NPV of $779/ha and the timber $2099/ha, for a total of $2879/ha (Maraseni et al. 2009). On the basis of market values alone, the land was more profitable when cleared for grazing, but with a carbon price of at least $2.50/t CO_2 e, the silvo-pastoral system became the more profitable alternative (Maraseni and Cockfield 2011).

This review highlighted how little is known about the financial performance of silvo-pastoral systems in the sub-tropics of Australia. Findings from Star and Donaghy (2010) and Donaghy et. al. (2010) are applicable to only a small part of the study area and do not consider timber harvesting in commercial native forests. The Queensland CRA/RFA Steering Committee (1999) study is applicable to a large part of the study area, but did not consider timber values. Maraseni et al. (2009) considered returns to a plantation spotted gum silvo-pastoral system (not native forest), and their study area was unusually productive. The silvo-pastoral study by Schulke (2012; 2017) is the most applicable, but considers only one forest type in the Gayndah region of Queensland. This literature review did highlight the potential for returns to silvo-pastoral systems to exceed those from clearing for grazing, but further research is necessary.

Conclusions

Research performed for this study identified 2.6 M ha of potentially harvestable private native forest that is comprised of species commercial value. In the Queensland study area, these forests have been classified into six forest types totalling 1.9 M ha. In upper north-east NSW, commercial forests classified by yield association groups cover approximately 0.5 M ha.

Since 2004 private native forests have supplied between 40% and 70% of the hardwood resource to primary processors. Based on data collected from a sawmill survey conducted as part of this study, it is estimated that private native forests currently supply around 83% of poles and 60% sawlog hardwood to sawmills, accounting for around 22,663 m^3 of pole and 177,800 m^3 of sawlog throughput in the Queensland study region. It is estimated that the hardwood timber industry, including primary processors and contractors, employs around 888 full time equivalent employees in this region of Queensland, and 62% of those employees can be attributed to the private native forest resource. Across the 40 hardwood sawmills within the Queensland study region, approximately $180 million worth of sawn timber, poles and other products, such as chip and mulch, are sold annually. Around 58% of those mill-gate sales can be attributed to timber sourced from private native forests, which is worth around $104 million. In the NSW study region, it has been estimated that 127,400 m^3 of private native forest timber is processed by sawmills, with private native forest responsible for 321 full time equivalent employees.

The Wide Bay-Burnett region appears to be a particularly important region for the hardwood industry in Queensland, accounting for 63% of the total hardwood throughput and providing 512 jobs, of which 72% can be attributed to private native forests. This region is also particularly reliant on private native forests for timber supplies, with 66% of hardwood sawlog supplies in the region coming from privately owned forests. The Wide Bay-Burnett region accounts for 69% of the total annual sales in the Queensland study region.

It was found that only 15% of sawmillers indicated private native forests could adequately supply their future timber needs, and 60% of sawmillers indicated there has been a decline in the quality of timber sourced from private native forest in the past 10 years. Although sawmillers were negative about the productive condition of the private native forest resource, nearly 90% of respondents thought the productivity of private native forests could be increased with better management. In terms of factors influencing their future investment decisions, 82% of sawmillers cited resource security as a major limiting factor, referring to the need for clarity and certainty about government legislation regarding timber harvesting on State and private land.

Most landholders are not well-informed about how to manage their forests for timber production, are not familiar with timber markets, and do not appreciate the higher timber value of well managed forests. Additionally, it appears that the primary concerns for landholder in regards to forest management is government and regulatory requirements, particularly uncertainty of future legislation.

In forested parts of Queensland, the literature suggests land clearing can increase cattle carrying capacity by three to four fold. Net present values of land in the study area cleared for grazing typically range from about $12/ha to $550/ha, although a study from Kingaroy suggested a much higher NPV. There are many recognised benefits of retaining trees on grazing properties, including microclimate benefits to improve reproductive success and animal health, improved soil condition, improved pasture quality, and reduced runoff, erosion and transport of nutrients. Five silvo-pastoral system field studies conducted in south east

Queensland between the 1970s and early 1990s examining the effect of tree stocking on pasture production all revealed opportunities for equivalent or increased cattle production with trees, relative to cleared land. When this is coupled with the farm income diversification benefits of timber production, there appears to be a strong farm profitability argument for silvo-pastoral production systems in southern Queensland. Existing literature on the financial performance of silvo-pastoral systems is scarce, Literature on the financial performance of integrating timber production and grazing as a silvo-pastural system is scarce. In chapter 8, silvo-pastoral systems are evaluated for case study properties. In Chapter 9, the financial performance of silvo-pastoral systems in different forest types in the study area are estimated.

Chapter 5: The effect of silvicultural treatments on forest growth rates and development of a decision support tool to determine forest value

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Introduction

Despite the broad extent of privately owned native forests, the productive condition of these forests is generally poor (Chapter 3; Ryan and Taylor 2006; Jay 2017). This is often due to a history of poor harvest management (e.g. high-grading) and a lack of silvicultural treatments, and over time can lead to a stand with a high proportion of unmerchantable trees, and often a high density of small, competing stems. Silvicultural treatment, or thinning, can be done to reduce the number of small and unmerchantable trees, which encourages growth of the remaining, higher value stems and merchantable volume. Thinning is also used to remove non-commercial species, stems that are too close together, stems with poor form (i.e. not straight) and stems with defects, such as large fire scars. Thinning has been utilised as a management strategy to improve forest growth for over a century (Florence 1996). There is a large body of literature that shows the positive influence of thinning on the growth of retained trees (e.g. Goodwin 1990; Kariuki 2008; Roberts and Harrington 2008). Previous research in similar forest types, which are managed with selection harvesting systems, has recognised the need for investment in silvicultural thinning to improve growth of merchantable trees (Bauhus et al. 2002; Jay and Dillon 2016; Jay 2017). For example, Bauhus et al. (2002) in their study of spotted gum forest in southern NSW, cautioned that harvest frequency will be reduced without management practices to lower the basal area of unmerchantable trees. Despite this, thinning as part of forestry management is rarely practiced on private land in the study region. There may be a number of reasons for this, as discussed in Chapter 4, but one of the key reasons is that many landholders who own potentially productive forest see themselves primarily as graziers and not as forest managers and the costs associated with forest management are often prohibitive.

Forestry extension groups, such as the Private Forestry Service Queensland (PFSQ) have been working with private landholders to help them realise the potential of their native forest stands. However, useful extension tools to help demonstrate the effects of native forest management are lacking. Previous tools have not been developed to demonstrate the effect of forest thinning (i.e. SPAT, Lewis et al. 2010), have not been developed for uneven aged mixed-species native forests (Farm Forestry Toolbox, Private Forests Tasmania 2008) or for a range of reasons, have not been widely used in extension activities (e.g. EUCAMIX, Jay 2009). Earlier studies in private native forest (e.g. Lewis et al. 2010; PFSQ unpublished data) have established a number of permanent plots for monitoring tree growth. The current project has analysed this permanent plot data from silvicultural trials in southern Queensland. Understanding the impacts of thinning treatments on future total merchantable volumes and products harvested is critical when trying to demonstrate the long-term benefits associated with stand management. Further, there can be additional benefits of silvicultural treatments on grazing production that also need to be considered. Hence, there was a need to develop a decision support tool that can be used to predict the likely consequences of stand management and a lack of management, specific to private native forests in the study region. Such a decision support tool can then be used to analyse different management scenarios and demonstrate where investment in management is most effective (e.g. Chapter 8).

There were two key objectives of this chapter. Initially, we aimed to analyse data collected from plots monitored over time to determine the effect of silvicultural treatments on tree growth rates, and determine the key drivers of tree and stand growth. Following this analysis we aimed to develop a decision support tool to assist with extension activities around the need for improved management of the private native forest resource. As the Private Forest Service Queensland are the main extension group in the study region, we aimed to develop a tool that specifically aligned with inventory data they collect.

Methods

Permanent plots utilised

The datasets utilised are introduced in Chapter 2. In this analysis we used data from a total of 203 plots, located across the four sub-regions outlined in Chapter 3. Most of these were located on private land (158 plots) across 19 sites (Appendix 1). Forty-five plots were located in Queensland State Forest. These State Forest plots were selected to help boost the number of plots in the data that had not been recently treated (or logged), as there were only 33 plots that had not been thinned in the private native forest dataset. State Forest plots were selected from existing experimental plots (in the DAF Forestry Science database) and the native forest permanent sample plot network. Sixteen plots were ‘control’ plots in existing trials where management had been excluded, but where adjacent plots had been thinned or harvested. The remaining plots were permanent sample plots, representative of harvested native forest in the region. Only plots where no recent harvesting or thinning (in the last 20 years) had taken place were selected and only plots that were located in the vicinity of the private native forest plots were used (Figure 2.2). The State Forest sites selected had a similar average basal area (15.5 m^2/ha) to the untreated private native forest plots located in remnant forest (16.4 m^2/ha). While the State Forest monitoring data often extended beyond 10 years, we restricted this data set to a period from the latest measure through to 6 to 12 years prior to that measure, to be consistent with the private native forest data.

The variables assessed in the permanent plots were outlined in Chapter 2. Each living tree measured in the plots utilised had been tagged with a numerical identifier, to allow diameter growth to be determined on an individual tree basis. Stand-level growth was determined based on all trees within the plot and the total plot area, to allow reporting on a per hectare basis. As measurements were made periodically through time, we calculated a periodic annual increment (PAI) in terms of basal area, merchantable volume and above-ground tree biomass. Basal area and above-ground tree biomass assessments were based on DBH measures, while merchantable volume was calculated using existing volume equations that incorporated DBH and merchantable height. At the individual tree-level we were principally interested in DBH PAI as this was needed to model projected growth on individual stems in the decision support tool. In this report forest productivity refers to the stand’s capacity to produce wood products of commercial value.

Environmental variables

Climatic variables were extracted from the Silo database (https://legacy.longpaddock.qld.gov.au/silo/). The following climatic summary is based on the period of growth data for each plot (average of 7.8 years). Average annual rainfall varied from 545 to 1245 mm, with an average of 891 (± 12.3) mm across all 203 plots. Other key climatic variables are provided in Table 5.1. Average maximum and minimum temperatures were calculated using mean daily averages. Wetness index was calculated as annual rainfall divided by annual evaporation. Dry months refers to the annual mean maximum number of consecutive months with rainfall ≤ 30 mm. Drought was defined as the seasons with at or below the 10th percentile in rainfall. Both maximum number of consecutive drought seasons and the total number of drought seasons were calculated over the growth period.

Table 5.1. Climatic summary for plots utilised in the current study.

Variable	Minimum	Maximum	Average	Standard error
Maximum temperature	23.1	29	26.7	0.1
Minimum temperature	9.6	16.9	13.6	0.1
Annual rainfall	545	1245	891.1	12.3
Wetness index	0.28	0.77	0.53	0.01
Number of dry months	1.4	4.5	2.56	0.04

Soil type was determined through a description of the soil profile at most sites. Where soil types were not classified in the field existing data layers in GIS were used to determine the likely soil type, where this information was available. Soil type, based on Isbell (1996) classification, varied between sites. Most plots (134) were located on soils with a texture contrast in the soil profile (i.e. Kurosols, Sodosols and Chromosols). Kurosols were the most common soil type (101 plots). Sodosols (22 plots), Rudosols (21 plots) and Kandosols (17 plots were also common in the dataset. Dermosols (10 plots), Chromosols (8 plots) and Tenosols (7 plots) were less frequently encountered.

Other variables recorded in the field included slope and predominant aspect of the plot.

Management history

Trial commencement reports were updated for most sites, or were written as part of this project (Appendix 1). These reports provide detailed site descriptions. All private native forest sites utilised had a range of different silvicultural treatments, or through historic management had plots with a range in stand stockings. Most thinning treatments were carried out using the axe and stem injection system to poison pre-selected trees via chemical treatment, typically with herbicide like Glyphosate or Tordon®. For sites established by PFSQ, information on the management history was sourced through PFSQ or the property owners. Management history (e.g. logging) of the State Forest sites was determined through examining the data (stored on the DAF Forestry Science database) to determine where trees had been removed through logging.

Statistical analysis

As treatment (either treated or untreated) and the state of the stand (either regrowth or remnant) were consistently important drivers of diameter growth, we have reported the results based on these categories. There were 123 treated plots and 80 untreated plots. Of the treated plots, 64 were categorised as remnant (with a total of 1016 individual trees) and 59 were categorised as regrowth (with a total of 950 individual trees). Of the untreated plots, 63 were categorised as remnant (with a total of 4636 individual trees) and 17 were categorised as regrowth (with a total of 380 individual trees).

To determine the key drivers of plot-level growth and tree-level (e.g. DBH increment) growth we considered a number of variables. The response variables considered included basal area PAI, merchantable volume PAI and live tree biomass PAI at the plot-level. At the tree-level we were principally interested in DBH PAI. As an accurate increment could not been determined for trees that recruited between the first and last measure and for trees that died between these measures, such stems were removed from the analysis of tree-level growth (but were retained for calculation of standing basal area). Initially factorial ANOVA was carried out to determine the effect of treatment and stand state (remnant or regrowth). The effect of soil type on stand growth (basal area and volume) was also investigated, although, it should be pointed out that there was low replication for some soil types. In some cases a logarithmic transformation was required (logarithm base 10 + 1) to help meet the assumptions of ANOVA. Observed means and standard errors are reported in the results.

To determine the relative importance of the large suit of continuous variables we used the 'Rsearch' function in GenStat (16th Edition). This involved using all-possible subset regression for screening of explanatory variables to select the best explanatory variables for subsequent regression. The method allowed determination of the best model for each number of explanatory (or predictor) variables and provides output to compare competing models (to see how similar they are). Correlation matrices were used to determine whether explanatory variables were highly correlated. Explanatory variables considered included: stand basal area at the first measure (as a measure of competition), latitude, longitude, slope, aspect, annual rainfall, number of consecutive dry months annually, number of droughts (maximum and number), wetness index, maximum and minimum temperatures and evapotranspiration (potential evapotranspiration calculated using the FAO Penman-Monteith formula).

Given the known influence of Grimes crown score on tree growth (Grimes 1987) we also investigated how Grimes score (total and individual components) influenced individual DBH PAI and whether treatment influenced crown health. Grimes crown scores were measured in all private native forest plots in this study, but such scores were rarely available for the State Forest plots utilised.

Decision support tool

The decision support tool was developed using R (R Core Team, 2013; http://www.R-project.org/). Detailed R script can be requested from DAF, if required. Users of the tool will need a computer with R (version 3.5.1) and RStudio installed to read the scripts developed by DAF. Both R and R studio are freely available: https://cran.r-project.org/bin/windows/base/. The decision support tool runs in a separate window (from RStudio) using the Shiny application (https://shiny.rstudio.com/).

The key purpose of the decision support tool was to enable conversion of native forest inventory data into information that can be used to guide land owners in making more informed decisions regarding forest management. Extension staff (e.g. PFSQ staff) would run the decision support tool to demonstrate the range of potential outcomes possible for the stand (e.g. with and without forest management). Caution is needed in interpretation of the outputs, and the values obtained may not be accurate for a given site, given the levels of uncertainty associated with inputs to the tool (e.g. high levels of uncertainty in growth rates, product types, product values, grass production etc).

Results

Stand growth (tree basal area, volume and biomass)

At the time of the last measure, plot standing basal area ranged from 1.8 to 34.0 m^2/ha with an average (± standard error) of 10.7 (± 0.43) m^2/ha. Basal areas were higher in untreated stands and in remnant stands (Table 5.2). Predictably, stocking was also higher in the untreated stands. In untreated stands, stocking tended to be higher in regrowth forest, while in treated stands, stocking was on average higher in remnant stands (Table 5.2). Live tree biomass ranged from 10 to 212 t/ha with an average value of 70.8 (± 3.0) t/ha. Tree biomass was significantly higher in the untreated stands and tended to be higher in remnant forest areas (Table 5.2). Potentially merchantable volume (calculated on stems with a DBH of at least 20 cm) ranged from 0 to 123.5 m^3/ha with an average of 36.4 (± 2.0) m^3/ha. Potentially merchantable volume was higher in untreated stands and remnant stands (Table 5.2), reflecting the greater number of stems in these stands.

Table 5.2. Stand attributes (basal area, stocking, live tree biomass and potentially merchantable volume) of treated and untreated plots, in both remnant and regrowth stands.

	Basal area (m^2/ha)		Stocking (stems/ha)		Live tree biomass (t/ha)		Merchantable volume (m^3/ha)	
	mean	se	mean	se	mean	se	mean	se
All not treated	**14.8**	**0.6**	**350.2**	**16.9**	**96.7**	**4.4**	**40.2**	**3.5**
Regrowth, untreated	11.3	1.9	470.7	50.8	63.8	11.6	17.6	4.9
Remnant, untreated	15.7	0.5	317.7	14.2	105.6	3.9	46.2	3.9
All treated	**8.1**	**0.4**	**153.8**	**8.4**	**54.0**	**3.2**	**34.0**	**2.5**
Regrowth, treated	6.8	0.5	135.5	9.3	44.5	4.1	27.5	3.8
Remnant, treated	9.3	0.7	170.7	13.5	62.7	4.6	39.9	3.0
All plots	**10.7**	**0.4**	**231.2**	**10.8**	**70.8**	**3.0**	**36.4**	**2.0**

Periodic annual increments for different stand productivity measures are provided in Table 5.3. Regrowth stands generally showed greater stand growth in terms of basal area, biomass and volume than remnant stands. Similarly, treated stands had greater stand growth rates than untreated stands for these parameters (Table 5.3). The effect of treatment on plot-level basal area PAI was not significant ($F_{1,197} = 2.04$, $P > 0.05$), but the state of the stand did have an important influence on basal area growth ($F_{1,197} = 44.2$, $P < 0.001$). Across all plots, average merchantable volume PAI was 1.2 m^3/ha/year. The effect of treatment was significant for merchantable volume PAI ($F_{1,187} = 28.8$, $P < 0.001$) and the state of the stand was also important ($F_{1,187} = 19.8$, $P < 0.001$; Table 5.3). Plot-level volume growth in treated stands was almost twice that of untreated stands (Table 5.3). Plot biomass PAI tended to be higher in treated stands than untreated stands ($F_{1,197} = 3.9$, $P = 0.049$) and higher in regrowth stands than in remnant stands ($F_{1,197} = 29.3$, $P < 0.001$).

Table 5.3. Periodic annual increments (PAI) in basal area (BA, m^2/ha), merchantable volume (m^3/ha) and live tree biomass (t/ha) for treated and untreated stands in remnant and regrowth forest areas.

	BA PAI		Merchantable volume PAI		Live tree biomass PAI	
	mean	se	mean	se	mean	se
All not treated	**0.30**	**0.02**	**0.76**	**0.09**	**1.99**	**0.14**
Regrowth, untreated	0.56	0.07	1.18	0.25	3.13	0.34
Remnant, untreated	0.24	0.02	0.66[1]	0.09	1.69	0.13
All treated	**0.34**	**0.02**	**1.45**	**0.09**	**2.31**	**0.11**
Regrowth, treated	0.40	0.03	1.67	0.17	2.64	0.18
Remnant, treated	0.29	0.01	1.25	0.08	2.00	0.11
All plots	**0.32**	**0.01**	**1.20**	**0.07**	**2.19**	**0.09**

[1] Note: Average (± SE) merchantable volume PAI in the untreated remnant plots on State Forest tenure was 0.35 (±0.05) m^3/ha/year, perhaps reflecting different management regimes at the State Forest sites.

Several environmental variables also influenced stand growth rates. The most important continuous predictor variables for explaining stand growth in terms of basal area PAI were wetness index (which combines rainfall and evaporation, adjusted $R^2 = 0.18$), evapotranspiration (adjusted $R^2 = 0.18$), maximum daily temperature (adjusted $R^2 = 0.17$), latitude (adjusted $R^2 = 0.15$) and rainfall (adjusted $R^2 = 0.12$). As a number of these variables were correlated, the variation in basal area PAI explained by a model with multiple terms was generally around 31%. The best model with four terms included explained 29.7% of the variation in basal area PAI and included initial stand basal area, maximum daily temperature, number of droughts and wetness index.

Stand merchantable volume PAI was influenced by a similar set of variables. The most important continuous predictor variables for explaining stand growth in terms of merchantable volume PAI were maximum daily temperature (adjusted $R^2 = 0.27$), evapotranspiration (adjusted $R^2 = 0.19$), wetness index (adjusted $R^2 = 0.12$) and latitude (adjusted $R^2 = 0.12$). The best model with three terms explained 32.6% of the variation in volume PAI and included maximum daily temperature, wetness index and longitude. Adding more terms to the model had only a small influence on the explained variation (e.g. the best model with 10 terms only explained 33% of the variation).

Plot-level live tree biomass PAI was also influenced by similar variables. The most important continuous predictor variables for explaining stand growth in terms of tree biomass PAI were evapotranspiration (adjusted $R^2 = 0.25$), maximum daily temperature (adjusted $R^2 = 0.24$), wetness index (adjusted $R^2 = 0.23$), latitude (adjusted $R^2 = 0.21$), annual rainfall (adjusted $R^2 = 0.15$) and the annual number of dry months (adjusted $R^2 = 0.10$). The best combined models explained around 35% of the variation in tree biomass PAI. The best model with three terms fitted explained 33.6% of the variation and included minimum temperature, wetness index and the number of droughts in the period.

Soil type also had a significant influence on plot basal area and merchantable volume PAI ($F_{6,175} = 4.8$, $P < 0.001$ and $F_{6,165} = 5.8$, $P < 0.001$, respectively). Greatest plot basal area and volume growth was achieved on Kandsols and Sodosols, moderate growth rates were recorded on Kurosols, Rudosols and Chromosols and relatively lower growth rates were recorded on Tenosol and Dermosol soil types (Table 5.4). Some caution is needed in interpreting these results due to low replication of certain soil types (i.e. Chromosols, Tenosols and Dermosols).

Table 5.4. Periodic annual increments (PAI) in basal area (BA, m^2/ha) and merchantable volume (m^3/ha) for plots located on different soil types.

	BA PAI			Merchantable volume PAI		
Soil type	mean	se	n	mean	se	n
Chromosol	0.29	0.031	8	1.67	0.319	7
Dermosol	0.20	0.029	9	0.65	0.218	8
Kandosol	0.46	0.070	17	1.89	0.506	16
Kurosol	0.31	0.015	100	1.05	0.067	97
Rudosol	0.37	0.050	20	0.93	0.181	17
Sodosol	0.44	0.049	21	2.00	0.249	20
Tenosol	0.19	0.016	7	1.13	0.168	7

Given that plot-level growth (basal area or volume growth) provides little information on the products of value within the stand, growth rates were determined for individual trees.

Key drivers of individual tree growth

Analysis showed the significant effect of tree basal area on individual tree DBH growth, which differed by thinning treatment (thinned vs unthinned) and the state of the forest (regrowth vs remnant). The effect of treatment alone was highly significant, with greater diameter growth in treated stands ($F_{1,6980}$ = 5301, P <0.001) and the effect of stand state was also highly significant, with greater diameter growth in regrowth stands ($F_{1,6980}$ = 2825, P <0.001). Mean annual DBH increment was 0.18 (± 0.003) cm/yr in the untreated plots and 0.76 (± 0.010) cm/yr in the treated plots (Table 5.5). Mean annual DBH increment was 0.24 (± 0.004) cm/yr in the remnant forest plots and 0.78 (± 0.014) cm/yr in the regrowth forest plots. Individual tree volume growth was also significantly greater in treated stands ($F_{1,2292}$ = 869, P <0.001) and regrowth stands ($F_{1,2292}$ = 503, P <0.001; Table 5.5). Biomass growth on individual trees was also higher in treated stands than in untreated stands and was higher in regrowth stands relative to remnant stands (Table 5.5). Diameter (DBH) growth rates of around 2 cm per year on larger trees (e.g. 40 cm DBH) can result in biomass accumulation of around 100 kg per year for such individuals.

Table 5.5. Individual tree DBH, merchantable volume and biomass periodic annual increments (PAI) in treated and untreated stands classified as regrowth and remnant forest.

	DBH PAI (cm)		Merchantable volume (m^3) PAI		Biomass (kg) PAI	
	mean	se	mean	se	mean	se
All not treated	**0.18**	**0.003**	**0.004**	**0.0007**	**4.9**	**0.11**
Regrowth, untreated	0.37	0.014	0.012	0.0009	6.4	0.30
Remnant, untreated	0.16	0.003	0.004	0.0007	4.8	0.12
All treated	**0.76**	**0.010**	**0.020**	**0.0005**	**16.6**	**0.31**
Regrowth, treated	0.95	0.015	0.024	0.0007	19.2	0.48
Remnant, treated	0.59	0.012	0.017	0.0006	14.2	0.37
All plots	0.34	0.005	0.012	0.0004	8.2	0.13

Interestingly, the plots located in State Forest had a lower DBH increment (0.15 cm/yr) than the remnant private native forest plots that had not been treated (0.26 cm/yr).

Of all the predictor variables analysed, initial plot basal area (as a measure of competition) had the strongest influence on the diameter growth of individual stems. Across all data a polynomial regression was used to fit a cubic relationship to the data that explained 52.8% of the variation in DBH PAI ($F_{2,6966} = 2600$, $P < 0.001$; Figure 5.1). Separate quadratic relationships were fitted based on whether a tree was in a plot that had been treated or not and whether the plot was located in remnant or regrowth forest. Clear relationships were apparent in all cases, except the untreated remnant forest (Figure 5.2), but in all cases the relationships were statistically significant ($P < 0.001$). The lack of low plot basal areas in untreated remnant stands (which is a feature of such stands) made it difficult to detect a strong relationship.

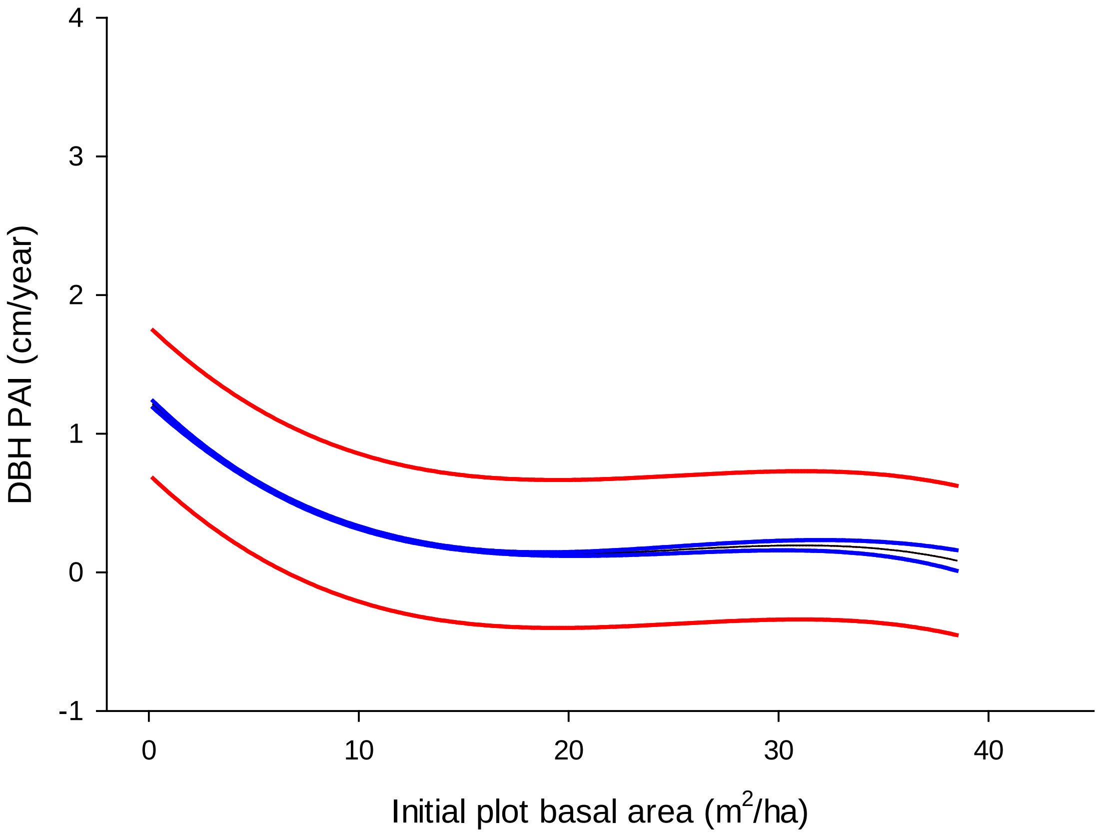

Figure 5.1. The relationship between DBH PAI and initial plot basal area based on data from all individual trees in the dataset. DBH PAI = 1.2406 –0.14407x + 0.006026x^2 –0.00007957x^3 (adjusted R^2 = 0.53). Red lines represent the 95% prediction bands (area in which you expect 95% of all data points to fall) and blue lines represent the 95% confidence bands (area that has a 95% chance of containing the true regression line).

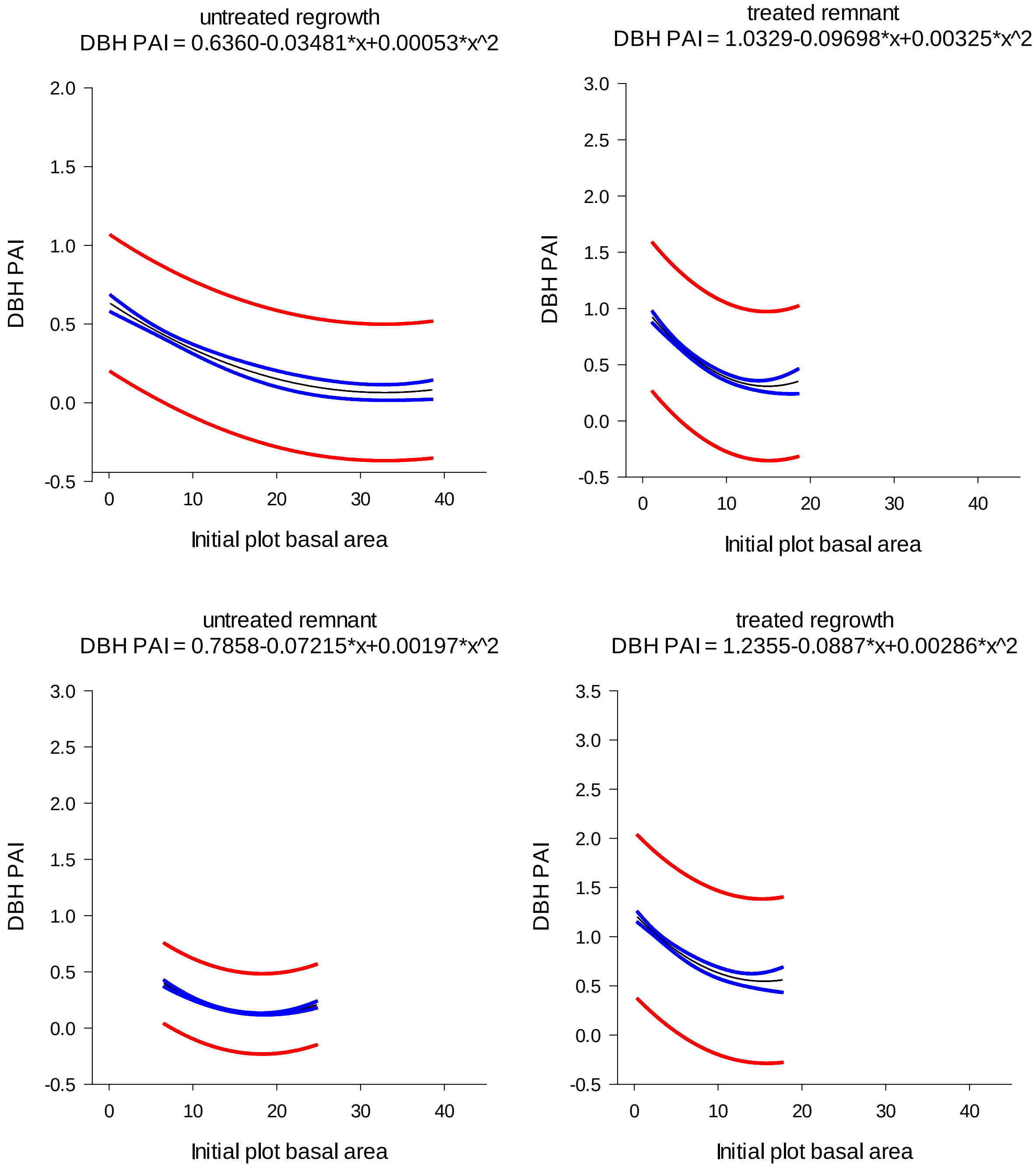

Figure 5.2. Relationships between DBH PAI and initial plot basal area for: (a) untreated regrowth stands; (b) treated remnant stands; (c) untreated remnant stands; and (d) treated growth stands. Red lines represent the 95% prediction bands (area in which you expect 95% of all data points to fall) and blue lines represent the 95% confidence bands (area that has a 95% chance of containing the true regression line).

The next most important predictors of individual tree DBH PAI were wetness index (adjusted $R^2 = 0.11$), annual rainfall (adjusted $R^2 = 0.07$), evapotranspiration (adjusted $R^2 = 0.07$) and maximum daily temperature (adjusted $R^2 = 0.07$). The best models with three terms fitted included initial plot basal area and either maximum daily temperature and wetness index or minimum daily temperature and wetness index. While the above climatic factors had a small but significant influence of DBH growth they were not included in the resultant growth model used in the decision support tool, to minimise complexity and the number of input values required. These variables could be added to a future growth model, where the aim is not to produce a model for use in a decision support tool.

Growth of different product classes (see Chapter 2 for definitions) was assessed for plots on private land that were last measured in 2016 or 2017. There were significant differences in the growth rate, depending on the product classification (Table 5.6). Poles grew at a greater rate than all other products, sawlogs and intermediate product classes show moderate levels of growth, and fencing and the useless product categories had the lowest growth rates (Table 5.6). In terms of biomass accumulation, trees classified as poles were producing twice as much biomass per year than trees classified as sawlogs and nearly seven times as much biomass than trees classified as ‘useless’ (i.e. trees unlikely to produce a merchantable product).

Table 5.6. Growth rates (PAI, periodic increment per stem) of different product classes, across all stands (treated, untreated, remnant and regrowth). Product class definitions are provided in Chapter 2.

	DBH PAI (cm)		Merchantable volume (m^3) PAI		Live tree biomass (kg) PAI	
Product	mean	se	mean	se	mean	se
Intermediate	0.45	0.013	0.01	0.001	5.23	0.158
Pole	0.68	0.022	0.02	0.001	21.20	0.721
Fencing	0.15	0.008	0.01	0.001	4.15	0.330
Sawlog	0.38	0.007	0.01	0.000	10.76	0.213
Useless	0.17	0.006	–0.09	0.029	3.11	0.159
All products	**0.34**	**0.005**	**0.01**	**0.000**	**8.22**	**0.133**

Thinning treatments had a significant influence on crown health. Total Grimes crown score was significantly higher (i.e. healthier tree crowns) in treated stands, and all five aspects of crown health were higher in treated stands than in untreated stands (Table 5.7). That is, trees in treated stands had on average, larger, denser crowns, with better positioning, and a lower number of dead branches and epicormics shoots than trees in untreated stands (Table 5.7). There was a significant quadratic relationship between total crown score (at the last measure) and individual tree DBH growth ($F_{2,2732} = 645$, $P < 0.001$, adjusted $R^2 = 0.32$). Thus it appears silvicultural treatment improves crown health, resulting in greater photosynthetic efficiency and improved diameter growth.

Table 5.7. Grimes crown scores (Total score out of 27) and scores for different crown components (density (maximum score = 9), dead branches (maximum score = 5), position (maximum score = 5), size (maximum score = 5) and epicormic growth (maximum score = 3)), in treated and untreated stands classified as regrowth and remnant vegetation.

	Total score (27)		Density (9)		Dead branches (5)		Position (5)		Size (5)		Epicormics (3)	
	avg	se	avg	se	avg	se	avg	se	avg	se	avg	se
All not treated	**15.7**	**0.094**	**4.8**	**0.041**	**3.1**	**0.025**	**2.8**	**0.026**	**3.1**	**0.025**	**1.90**	**0.012**
Regrowth, untreated	16.7	0.137	4.9	0.058	3.6	0.032	3.0	0.042	3.1	0.043	2.10	0.017
Remnant, untreated	15.3	0.116	4.8	0.053	2.8	0.029	2.8	0.032	3.0	0.030	1.82	0.014
All treated	**18.7**	**0.056**	**5.9**	**0.026**	**3.6**	**0.014**	**3.7**	**0.016**	**3.6**	**0.018**	**2.05**	**0.008**
Regrowth, treated	19.2	0.091	5.8	0.044	3.7	0.021	3.8	0.023	3.8	0.027	2.04	0.014
Remnant, treated	18.4	0.068	5.9	0.033	3.5	0.017	3.5	0.020	3.4	0.023	2.05	0.009
All plots	17.6	0.056	5.5	0.024	3.4	0.013	3.4	0.015	3.4	0.015	2.00	0.007

Across all stands (treated and untreated), Grimes crown scores also tended to be higher on individual trees that were classified as potential poles or sawlogs than on trees that were classified as unmerchantable (useless) or as being suitable only for fencing products (Table 5.8). This aligns well with the higher growth rates observed on trees classified as poles or sawlogs and the fact that trees classified as potential poles or sawlogs are more likely to be selected for retention in treated plots.

Table 5.8. Grimes crown scores (Total score out of 27) and scores for crown density (maximum score = 9), crown position (maximum score = 5) and crown size (maximum score = 5) for trees classified into different product classes.

	Total crown score		Crown density		Crown position		Crown size	
Product	mean	se	mean	se	mean	se	mean	se
Intermediate	16.9	0.106	5.27	0.048	2.99	0.028	2.94	0.030
Pole	19.3	0.114	6.16	0.059	3.84	0.031	3.70	0.035
Fencing	14.4	0.362	4.34	0.155	2.62	0.089	2.94	0.085
Sawlog	18.3	0.064	5.69	0.029	3.56	0.019	3.64	0.018
Useless	14.1	0.205	4.20	0.089	2.55	0.042	2.62	0.051
All products	**17.6**	**0.056**	**5.49**	**0.024**	**3.36**	**0.015**	**3.40**	**0.015**

The decision support tool

Decision support tool forest growth

The underlying tree growth model was derived from permanent plot data described above. This growth model was based upon DBH periodic annual increments, which differ by treatment and the state of the forest (remnant or regrowth). One of the key aims of the decision support tool was to ensure the inputs required could be easily understood and be readily available to users. The focus of this tool was also to demonstrate the potential of silvicultural treatments to improve tree growth. Hence, separate relationships were derived depending on whether the stand had been thinned and on whether the stand is categorised as remnant or regrowth. As such, we did not want the underlying growth model to be dependent on complex climatic variables or soil type. Although a range of variables (e.g. rainfall and soil type) influence forest growth, we decided to include a productivity modifier in the tool, to allow users to vary the productivity as a percentage (scale bar). Nevertheless, it is recommended that the % productivity change bar is left at zero unless the user has good reason to modify the productivity (e.g. knowledge of local growth rates), or wants to see the range in possible values that might be possible (e.g. to appreciate the uncertainty in growth rates). This modifier allows the user to investigate outputs if the forest is growing at a faster or slower rate than that based on the current dataset used to develop the growth model. The data used to model growth was based primarily on data collected over time in forests dominated by spotted gum. Some forests (e.g. wet sclerophyll forests) might grow at a faster rate, so there is an opportunity to increase productivity (DBH periodic annual increment) here. This should be discussed with a local forestry extension officer.

Decision support tool pasture productivity estimates

The pasture growth information was based on the GRASP (grass production) model (Littleboy and McKeon 1997). We utilised existing relationships between tree basal area and grass biomass growth to determine the utilisable pasture available (i.e. the proportion of average annual pasture growth that can be grazed without leading to a loss of land condition) for a given basal area. These relationships were available for a 135 land types in Queensland. To allow prediction of livestock value, the model assumes an average daily intake throughout the year of 10 kg (this is a standard value for an adult equivalent, AE). Different annual live-weight gains (kg/AE/year) were associated with each land type.

Decision support tool inputs required

Prior to running the decision support tool inventory data should be collected following the PFSQ inventory protocol. Inventory measurements need to include:

1. Tree number, diameter at breast height (cm), and species;
2. Whether each stem should be retained, logged or treated (at the time of the assessment);
3. Product type (pole, sawlog, salvage log, fencing, pile, habitat, required for Code); and
4. Product length (likely merchantable height, m).

In the inventory data it is important to determine which trees should be retained for future logging, or as a requirement under relevant legislation (e.g. ‘Managing a native forest practice: A self-assessable vegetation clearing code’ in Queensland). The trees that could be logged at the time of the inventory should also be recorded (along with likely products) and trees which could be thinned to improve productivity of the stand should be recorded.

Instructions on how to run the decision support tool are provided in Appendix 6. There are a number of options that can be investigated with the tool to allow the user to consider the best management option for the stand (e.g. thinning or no thinning and logging or no logging). These include: (1) whether the stand will be thinned or not. (2) The type of stand needs to be specified as either regrowth forest or remnant forest. (3) The productivity of the site can be modified using the productivity scale bar, but in most cases this should not be adjusted. (4) The number of years between harvests can be modified. (5) The proportion of the future stand that is harvested can also be modified. (6) Maximum basal area for the site can be entered, if known.

There are three options that relate to predictions for pasture growth and associated values. These options do not need to be considered if the user is only interested in timber production values. The first option allows the user to select the most appropriate 'Land type' for the site. Land types (https://futurebeef.com.au/land-types-of-queensland/) determine the amount of pasture that will likely grow on the site. Land type (and region) can be selected from the drop-down menu. The next option is to select the condition of the pasture. The ABCD scale for pasture condition is explained at:
www.healthycountry.com.au/_literature_129384/Grazing_Land_Condition
Condition varies from A (best condition) to D (worst condition), based on factors such as the density of perennial grasses, soil exposure (bare ground), weed infestations, etc. The final option involves providing a current market value ($ per kilogram) for the livestock that are run on the site.

Predictive outputs from the decision support tool (timber and pasture values)

The tool provides a summary of the existing stand and predicts the production of different forest products over time. As well, the expected gross financial returns from both timber production and livestock production are provided. The current stand is described in the inventory tab and future timber outcomes are reported under the 'Future' tab. This includes a table that reports dollar per hectare values for different timber products in different diameter (DBH) classes, as well as a total value across all diameter classes. Two figures are also reported in the 'Future' tab that summarise standing volumes (trees with DBH >20 cm). The first figure shows products for stems that are grown forward for the selected period of time that were assessed to be 'retained' at the time of the inventory. A total volume of the stems assessed as available for logging (at the time of the inventory) is also provided when 'logging' is not selected in the options before growing the stand. The second figure shows products (grown forward) for those assessed as 'to be logged' at the time of the inventory. When 'logging' is selected as an option before growing the stand, these products will not be included in the second figure (as they are logged, and show up in the values based on the current inventory). The second figure also shows a total volume of all stems that are retained in the stand.

The 'Pasture' tab shows outputs associated with livestock grazing. A graph is presented to show the change in utilisable pasture available as tree basal area increases over time (as the stand grows). A table is also provided which lists for each year of the simulation the utilisable pasture (dry matter kg/ha), standing basal area of trees (m^2/ha), animal stocking rate (animal equivalents /ha), and the gross dollar value per hectare for livestock grazing.

An example of the outputs from one randomly selected property, in the Wide Bay region (north-west of Gympie) is provided here for demonstration purposes. The tool has developed to for demonstration purposes (to show the influence of forest management) and it should be pointed out that the values obtained are from a single run of the model are unlikely to be accurate for a given site, given the uncertainties involved. This demonstration output below covers two scenarios: (1) initial logging, but no thinning of the stand; and (2) initial logging and thinning of the stand. While logging does effectively 'thin' the stand, we refer here to thinning as silvicultural thinning (where thinned products have no dollar value) carried out in addition to logging. For this demonstration we know that the forest is mapped as remnant. The following options were selected: (1) the productivity scale bar was not modified; (2) a 20 year interval between harvests was selected; (3) 30% of the stand is harvested at the time of the future harvest; and (4) maximum basal area for the stand is 40 m^2/ha. For pasture growth we have assumed: (1) the ‘Coastal Burnett Ironbark and spotted gum on duplexs and loams (Childers)’ land type; (2) the pasture is in ‘A condition’; and (3) that the price per kilo for cattle is $2. Further example outputs from the decision support tool are provided in case studies in Chapter 8.

The initial value of this stand was estimated at $391 per hectare (Table 5.9). In this case, some smaller DBH stems were selected for removal as valued products (e.g. for fencing products) to help improve the future value of the stand. In scenario 1, after initial logging and no thinning, the future value of the stand (in terms of timber products) was $809 per hectare (Table 5.10). Most of this value was in sawlogs in the 30–40 cm DBH class (Table 5.10, Figure 5.3a). Figure 5.3a shows that a significant volume was present in trees that could have been thinned (i.e. 6.7 m^3 in the 20–30 cm DBH class, 1.4 m^3 in the 30–40 cm DBH class and 3.5 m^3 in the 40–50 cm DBH class). Approximately 2.3 m^3 was stored in trees marked as habitat trees in the 40–50 cm DBH class. In scenario 2, after initial logging and thinning, the future value of the stand (in terms of timber products) was $1030 per hectare (Table 5.11). Most of this value came from sawlogs that had predicted DBH values of 30–50 cm (Figure 5.3b).

Table 5.9. Dollar outputs ($/ha) expected from the stand in different product types, based on the inventory data (inventory data in this case was collected by PFSQ).

DBH class	Sawlog	Salvage	Pole	Pile	Fence	Habitat	Code	Total
D<10	0	0	0	0	0	0	0	0
D10–20	0	0	0	0	0	0	0	0
D20–30	0	0	0	0	95	0	0	95
D30–40	79	0	0	0	78	0	0	157
D40–50	139	0	0	0	0	0	0	139
D50–60	0	0	0	0	0	0	0	0
D60–70	0	0	0	0	0	0	0	0
D>70	0	0	0	0	0	0	0	0
Total	**218**	**0**	**0**	**0**	**172**	**0**	**0**	**391**

Table 5.10. Dollar outputs ($/ha) expected from the stand in different product types, 20 years after logging, but with no thinning applied.

DBH class	Sawlog	Salvage	Pole	Pile	Fence	Habitat	Code	Total
D<10	0	0	0	0	0	0	0	0
D10–20	0	0	0	0	0	0	0	0
D20–30	0	0	0	0	0	0	0	0
D30–40	579	0	0	0	86	0	0	666
D40–50	143	0	0	0	0	0	0	143
D50–60	0	0	0	0	0	0	0	0
D60–70	0	0	0	0	0	0	0	0
D>70	0	0	0	0	0	0	0	0
Total	**723**	**0**	**0**	**0**	**86**	**0**	**0**	**809**

Table 5.11. Dollar outputs ($/ha) expected from the stand in different product types, 20 years after logging, where thinning was applied.

DBH class	Sawlog	Salvage	Pole	Pile	Fence	Habitat	Code	Total
D<10	0	0	0	0	0	0	0	0
D10–20	0	0	0	0	0	0	0	0
D20–30	0	0	0	0	0	0	0	0
D30–40	556	0	0	0	192	0	0	747
D40–50	283	0	0	0	0	0	0	283
D50–60	0	0	0	0	0	0	0	0
D60–70	0	0	0	0	0	0	0	0
D>70	0	0	0	0	0	0	0	0
Total	**838**	**0**	**0**	**0**	**192**	**0**	**0**	**1030**

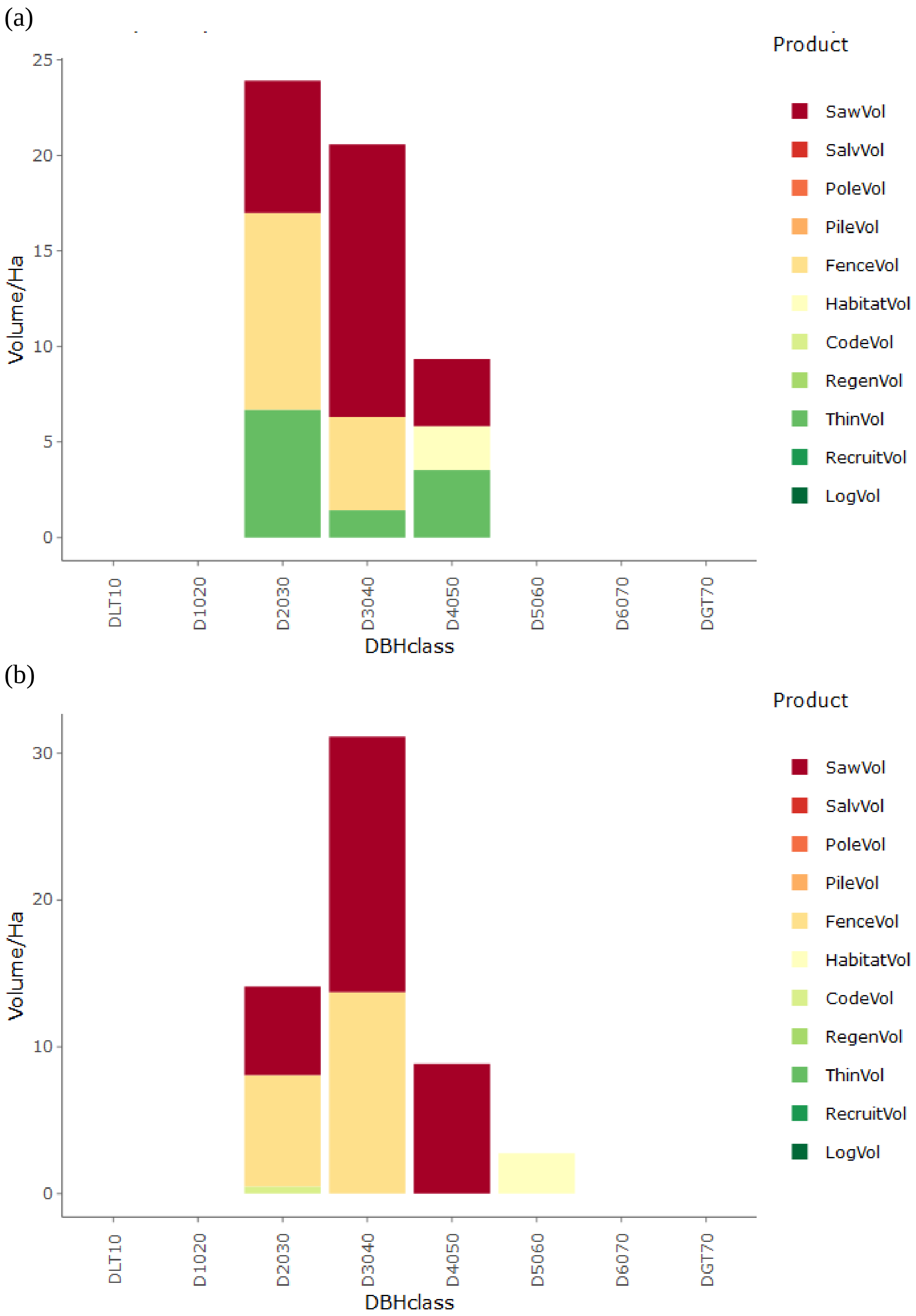

Figure 5.3. Volumes of timber (m^3/ha) expected after 20 years in different products and DBH classes. Scenario 1 (a) shows volumes expected where no thinning was applied (the green bars in this case shows the volume in trees that could have been thinned) and Scenario 2 (b) shows volumes were thinning was applied.

Under scenario 1 (no thinning), grazing value declined from $31/ha in the first year after logging, to $20/ha in year 20 (Figure 5.4). The total grazing value over the 20 year period was $494/ha. Under scenario 2 (thinning), grazing also value declined over time, from $45.7/ha immediately after logging and thinning, through to $27/ha in year 20. The total grazing value over the 20 year period was $711/ha.

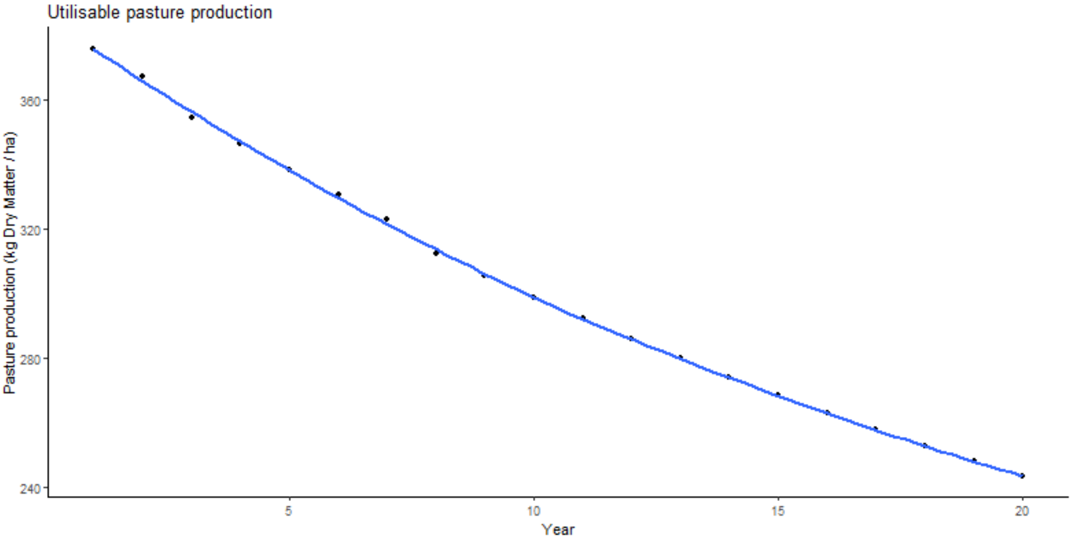

Figure 5.4. Change in the biomass of utilisable pasture (y axis, kg dry matter / ha) over the 20 year period considered, in this case in scenario 1, where the stand was initially logged, but not then silviculturally thinned.

Summing the total timber and grazing values over the 20 year period allows some gross assessments of the effects of thinning (total of $1741/ha in the thinned scenario compared with a total of $1303/ha in the unthinned scenario) in this remnant stand.

Discussion

The effect of silviculture on growth rates

Our analysis has revealed the important influence of silvicultural treatment of individual tree growth. On average, silviculturally treated plots had DBH growth increments that were approximately four times more than those on trees in plots that had not been treated. As this growth is concentrated on merchantable trees in treated stands, merchantable volume growth increments on individual trees were also significantly greater in such stands (five times that of untreated stands). Merchantable volume growth was also significantly higher at a plot-level in treated plots, but the differences were less pronounced. Plot-level basal area PAI did not differ between treated and untreated stands. This suggests that most of the untreated sites utilised in this study had not reached a maximum basal area (i.e. the site carrying capacity). As such, growth rates in the untreated remnant plots on private land (mean increment of 0.26 cm/yr) tended to be growing at a faster rate than that expected in remnant State Forest plots in the region (Ngugi et al. 2015). For example, moist open-forests to woodlands dominated by *Corymbia citriodora* on undulating to hilly terrain (BVG 10b) had an average DBH growth rate of 0.20 cm/yr. In comparing untreated plots on private land, with long untreated plots in State Forest utilised in the current study, there were significant differences in DBH growth rate (State Forest had a DBH increment of 0.15 cm/yr and remnant private native forest plots that had not been treated had an increment of 0.26 cm/yr). Given that standing basal area (and stocking) was similar in such plots across both tenures, this difference in growth rates was unexpected. It is possible that management on private land (e.g. frequent fire and grazing regimes) that often result in low densities of smaller size class stems (regeneration <10 cm DBH) has improved diameter growth in the privately owned stands. Thus an additional thinning benefit might be attained through management activities that reduce stocking of smaller DBH classes than we investigated here.

Lewis et al. (2010) summarised silvicultural treatment experiments from spotted gum forests in State Forests within the study area, and that summary has been adapted for this report in Table 5.12. As was the case for the private native forest plots, the untreated control plots in Crown forests in Table 5.12 have still been 'treated' by logging prior to establishment of the experiments. Individual tree DBH growth in treated State Forest plots ranged from 0.31 to 0.78 cm/yr (Table 5.12). The mean DBH PAI in treated remnant private native forest plots falls within this range (0.59 cm/yr) and was very similar to the DBH increment (0.56 cm/yr) reported by Grimes and Pegg (1979) for State Forest plots (across all species) subject to silvicultural treatments. The higher overall mean for treated plots from the private native forest trial data reported on here (0.76 cm/yr) reflects the inclusion of regrowth forest (which had a faster growth rate than remnant forest) and might also reflect the relatively short period of time that these plots have been monitoring for. Most of the thinning trials in State Forest (all except experiment 165DBY in Table 5.12) were not well maintained over time, so it is likely that recruitment will have had a competitive influence over time, reducing DBH growth on the retained trees. Standing merchantable volume PAI was quite similar in the treated Crown forests (0.88 to 1.44 m^3/ha/yr) and remnant treated private native forest (Table 5.3, average of 1.25 m^3/ha/yr).

The effect of silvicultural treatments on growth can be seen clearly in the individual tree growth and increment factor columns in Table 5.12. Mean DBH growth ranged between 0.15 cm/yr and 0.29 cm/yr for long unmanaged and untreated plots. Similar DBH increments (mean of 0.34 cm/yr) were reported by Grimes and Pegg (1979) for trees considered 'unacceptable' from a merchantability perspective in State Forests in the Maryborough region of Queensland. In Table 5.12, mean DBH growth over 30 years was 4.5 cm in the long unmanaged stands, but typically between about 10 cm and 20 cm for treated stands. That is, individual trees in treated forests increased in diameter two to four times faster than trees in long unmanaged forests. Along with the results presented here, this demonstrates the strong merchantable growth impact of silvicultural treatment and the potential to generate earlier returns for forest owners. It is also worth pointing out the quality of the retained stand, both in terms of wood quality and of product classes is likely to be greater in silviculturally treated forest. However, further work is needed to quantify such additional benefits.

Table 5.12. Summary of spotted gum silvicultural treatment experiments in State Forests conducted between the 1960s and 1990s.

Treatment (m spacing)[a]	Experiment name	State Forest	Stocking (SPH > 10 cm)	Years of data	Stand volume growth		Individual tree growth			Increment factors	
					PAI (m^3/ha/yr)[e]	Total (m^3/ha)[f]	Mean DBH (cm/yr)	30-year DBH (cm)[g]	30-year volume (m^3)[h]	DBH[i]	Vol[j]
Long unmanaged[k]	na	Throughout the Queensland part of the study area	314	7.64	0.35	40.8	0.15	4.5	0.033	1.0	1.0
Control	263HWD	Gundiah (Maryborough region)	359	27	0.97	26.2	0.29	8.7	0.081	1.9	2.4
Control	165DBY	302 Ballon (Dalby region)	352	20	1.00	20.0	0.20	6.0	0.085	1.3	2.5
Control	258HWD	Tiaro (Maryborough region)[b]	266	33	1.03	34.0	0.20	6.0	0.116	1.3	3.5
8 × 8	265HWD	Tiaro (Maryborough region)[c]	156	20	1.35	27.0	0.63	18.9	0.260	4.2	7.8
8 × 8	165DBY	302 Ballon (Dalby region)	137	20	1.30	26.0	na	na	0.285	na	8.5
9 × 9	262HWD	Tiaro, St Mary and Gundiah (Maryborough region)	118	31	1.21	37.5	0.39	11.7	0.308	2.6	9.2
7.6 × 7.6	263HWD	Gundiah (Maryborough region)[d]	108	27	1.44	38.9	0.38	11.4	0.400	2.5	12.0
"Thinned"	258HWD	Tiaro (Maryborough region)[b]	80	33	1.03	34.0	0.31	9.3	0.386	2.1	11.6
12 × 12	262HWD	Tiaro, St Mary and Gundiah (Maryborough region)	68	31	0.98	30.4	0.51	15.3	0.432	3.4	12.9
12 × 12	263HWD	Gundiah (Maryborough region)	68	27	1.14	30.8	0.43	12.9	0.503	2.9	15.0
12 × 12	265HWD	Tiaro (Maryborough region)[c]	69	20	1.35	27.0	0.78	23.4	0.587	5.2	17.6
14 × 14	165DBY	302 Ballon (Dalby region)	51	20	0.88	17.6	0.57	17.1	0.518	3.8	15.5

Notes: a. Long unmanaged plots have not seen harvesting or silviculture for at least 20 years. Control plots were not silviculturally treated, but within harvested forests.

b. Even-aged regrowth following heavy logging. Reported stocking (SPH) are the middle of the reported range: untreated control 235–297; thinned 50–111.

c. Coppice and seedling regrowth experiment commencing 15 years after complete overwood removal.

d. Planned spacing was not achieved.

e. Periodic annual increment is only for stems retained at time of treatment (i.e. excludes subsequent recruitment). In control plots, PAI is likely to include substantial non-merchantable volume increment. Given the intensity of silvicultural treatments, a high proportion of PAI in treated stands is merchantable volume. PAI for long unmanaged plots is merchantable volume only.

f. PAI multiplied by years of data.

g. This is mean DBH (cm/yr) multiplied by 30. For some case numbers, this is an extrapolation from fewer than 30 years of data.

h. This is PAI (m^3/ha/yr) divided by SPH, multiplied by 30. For some case numbers, this is an extrapolation from fewer than 30 years of data.

i. How much faster mean DBH (cm/yr) grew at the control or treatment plot relative to the long unmanaged plots.

j. How much faster individual tree volume (PAI divided by SPH) grew at the control or treatment plot relative to the long unmanaged plots.

k. This is the mean of 40 spotted gum plots.

Source: Adapted from Lewis *et al.* (2010)

The effect of other variables on stand and tree growth rates

Rainfall and moisture related variables (e.g. wetness index and evapotranspiration) were significant, but only modest predictors of plot-level and tree-level growth. Rainfall was a much stronger predictor of stand growth in the earlier study that focussed on State Forest monitoring plots (Lewis et al. 2010). This difference is likely at least partly related to the range in annual rainfall between the two studies. The previous study included annual rainfall values of between 558 and 1662 mm, and included are greater number of plots in drier regions (further west) while the current study included annual rainfall that ranged from 545 and 1245 mm. Ngugi et al. (2015) considered an even greater range in mean annual rainfall and also demonstrated the importance of rainfall as a key driver of DBH growth and standing basal area. Accordingly, the tall open forest types, which were not well represented in the private native forest data, are likely to grow at a greater rate than reported here. Growth rates of 0.29 cm/yr were recorded for such forest types by Ngugi et al. (2015), and assuming a similar growth response to silvicultural treatment to that observed in the current study, it is quite realistic to expect DBH growth rates of greater than 1 cm/yr in such forest types that are treated. While data collected from private forest sites examined here was not representative of woodland environments to the west of the study area (with lower rainfall), the Ngugi et al. (2015) study shows reasonable DBH growth rates (i.e. around 0.2 cm/yr) in such remnant woodland environments where commercial timber species are dominant.

Soil type also had some influence of plot-level basal area and volume growth rates. The effect of soil types (and associated water holding and capacity and nutrient status) on forest growth rates has been widely reported (Vanclay 1992; Paul et al. 2003; Kesteven and Landsberg 2004), particularly in plantation environments, where soil amendments are frequently applied (Morris and Lowery 1988; Sánchez-Rodríguez et al. 2002; Turner et al. 2002; Smith et al. 2008). While most of the private native forest growth plots are located on relatively low productivity soil types (e.g. Kurosols), this is reasonably representative of where private native forests occur in the study region, with more productive soil types being cleared for other agricultural land uses. Typically native forests on a given property are found from mid-slope to ridge-top locations, on shallower soil types often with a clay subsoil, where clearing was uneconomical. Timber production when combined with grazing is often the most viable land use option for these positions in the landscape (Schulke 2012). Nevertheless, encouraging regrowth on alluvial flats (e.g. those typically dominated by forest red gum woodlands, where soils are more productive) also provides great potential for combined timber and grazing production (Schulke pers. comm. 2019).

Tree crown health is an important indicator of likely growth rates and thus can be used in the field to determine trees to be retained during silvicultural management (Grimes 1987). Total Grimes crown score was significantly higher in treated stands than in untreated stands (Table 5.7). This probably reflects the selection of healthier trees when the stand was thinned, but there was also evidence of improved crown health of retained trees following silvicultural treatment. Interestingly, total average scores for a plot were generally quite low (e.g. average of 18.7 out of 27 across all treated plots). Based on this mean score in the treated plots, predicted growth rates, based on Grimes 1987, would be considered ‘average’. That is, according to Grimes (1987) total scores of between 16 and 19.9 would result in DBH increments for spotted gum of 0.42 cm/yr. However, across all treated plots in the current study average DBH increment was 0.76 cm/yr. Grimes crown scores are somewhat subjective, and although most scores in the current study were recorded by one of three observers, it is possible our scoring was consistently lower than that in the Grimes (1987) study. Further the Grimes (1987) study focussed only on spotted gum and ironbark dominated forest in the Bauple region (between Gympie and Maryborough) of Queensland. Despite the potential differences in scoring, there was still a clear relationship observed between total crown score and DBH growth in both studies. The importance of crown position was also recognised in the work by Jay (2009) and is incorporated into the EUCAMIX growth model (crown vigour classes of suppressed, intermediate, codominant or dominant).

This analysis has shown that a range of factors influence plot-level and tree-level growth. However, the effect of silvicultural treatment (or initial plot basal area) had a stronger influence on individual tree growth rates than the climatic and environmental variables investigated here. When carrying out silvicultural treatments, selecting trees with health crowns is important, and this is recognised in the existing silvicultural guidelines for dry eucalypt forest (Appendix 7).

Use of the decision support tool

Based on the randomly selected inventory plot data presented in the results, thinning the stand after logging resulted in a greater value of timber products and a greater cumulative grazing value over the 20 year simulation period. The combined timber plus grazing value over the 20 years was $1303/ha in the scenario with no thinning and $1741/ha in the scenario with thinning, a net increase of $439/ha. This demonstrates the potential of silvicultural thinning treatments to improve the value of such stands. However, this is based on a single run of the decision support tool. To appreciate the variability in the tool outputs, we recommend that the tool be run multiple times for a given set of initial inventory data. A table of outputs could be created by the user, to help realise the variation in the model outputs (e.g. by changing log prices, productivity, time between harvests etc, on each different model run). Table 5.13 shows an example of the different outputs obtained for timber values, based on the example above, where productivity (growth rate) is modified and when the proportion of the stand harvested is modified. In this case, stand values were more sensitive to the proportion of the stand that was harvested than to variation in tree growth rates. Use of different inventory data across a property (e.g. a few different locations) would provide an even better understanding of the variation in the values that could be obtained from the forest on a given property. In addition, further analysis is needed to consider the costs of silvicultural treatments to a landholder. Chapters 7 and 8 provide such analysis.

Table 5.13. Total dollar outputs ($/ha) from timber products alone, expected from a randomly selected stand, 20 years after logging, with and without thinning. This example output shows a range in potential values associated with the stand, where productivity (growth rate) is increased and decreased in 5% increments, and where the proportion of the area harvested is either 30% or 20%.

	Default	+5%	+10%	+15%	-5%	-10%	-15%
No thinning							
30% removal at harvest	809	821	832	828	798	787	776
20% removal at harvest	540	547	555	552	532	525	517
Thinning applied							
30% removal at harvest	1030	1061	1087	1112	1004	980	955
20% removal at harvest	687	708	725	741	670	653	636

The decision support tool was developed primarily as an extension tool, for groups such as the Private Forestry Service Queensland (PFSQ) to demonstrate the influence of stand management. It is reliant on inventory input, following the template provided, before any outputs can be predicted. As such, some experience with forest inventory is needed, and it is envisaged that such inventory be carried out by extension groups like PFSQ. Given the varied ‘starting condition’ of private native forest (depending on growth stage and management), including inventory data in the tool was deemed necessary. This will likely limit how widely the tool is used.

Providing accurate inventory data is critical to ensure valid predictions of forestry value. While collecting inventory data is time consuming, this is a critical step to ensure accurate assessment of current and future products available from the stand. Further work could be carried out to analyse future volumes and associated uncertainties, predicted from the decision support tool, based on a series of randomly located private forests in the region. A number of scenarios could be considered, based on whether the forest is managed (with thinning) or largely unmanaged (with occasional harvests). Existing strip data collected by PFSQ could provide a useful starting point for better understanding potential wood volumes that might be available from the private resource.

Future work

There are limitations with the data used to generate the DBH growth model. Most of the growth data utilised is based on dry eucalypt forest, usually with spotted gum (*Corymbia citriodora* subsp. *variegata*) as one of the dominant species. Additional thinning trials should be established across other forest types and in parts of the study area where such trials are lacking (western Queensland and northern NSW). The growth data utilised here also covers only a relatively short period of time. As further growth data is collected the growth models should be updated to improve the prediction of future outputs from the stand. There are also many other variables that could be refined (for example, using volume equations for individual species, varying productivity by DBH) in future versions of this decision support tool. Linking the tool to spatially explicit productivity layers to directly impact productivity modifiers and identify land-type for pasture predictions would also be desirable. The decision support tool developed here could be made readily available to users on the internet. Making the source code available online could also encourage further improvements and development of this product.

Further modifications to the decision support tool might include: (1) using species specific volume equations; (2) providing options to select different growth relationships (e.g. that account for different growth rates on different product classes or size classes); (3) adding additional growth relationships based on inventory data for different forest types (when data becomes available); and (4) developing an optimisation summary, to allow a user to simply determine the best management option without the need for comparing results from numerous model runs. There is also potential for further work to validate the GRASP model outputs that influence grazing values reported by the tool.

Chapter 6: The effect of recent forest management on ecological condition (BioCondition) attributes and carbon stocks

Tom Lewis, Tracey Menzies, Sean Ryan and Annie Kelly

Introduction

In addition to the values associated with wood products that can be harvested from private native forest, these forests also provide other important benefits to society. This chapter focuses on some of the ecological values and carbon values associated with private native forest. In particular, the chapter aims to determine the impacts of different silvicultural treatments and forest maturity (i.e. regrowth forests *vs* remnant forest) on forest ecological condition attributes, and standing forest carbon stocks based on existing monitoring plots (outlined in Chapters 2 and 5). Thinning of a forest can have potentially positive impacts on carbon sequestration and biodiversity values (Dwyer e al. 2009), particularly through encouraging more diversity in the ground-layer vegetation in certain forest types (e.g. Price and Morgan 2008; Jones et al. 2015). However, restorative thinning is rarely practiced in Australia. This may be largely due to uncertainty around the impacts of thinning on a range of biodiversity attributes. Clearly, further research is needed, because if restorative thinning has a positive impact on biodiversity values, this will encourage future policy development and incentives for improved management. For example, Vanclay (2007) proposed an incentive system allocated on the basis of standing basal area to encourage improved management of private forests for multiple outcomes.

It was beyond the scope of the current study to determine the impacts of thinning treatments on biodiversity. However, the current study did utilise the BioCondition framework (Eyre et al. 2015b) for assessing the impact of silviculture on several important ecological attributes. BioCondition is one of three commonly used ecological condition metrics in Australia, the others being the Biodiversity Assessment Method (BAM) in NSW (which has replaced BioMetric; Gibbons et al. 2009; https://www.environment.nsw.gov.au/Research-and-publications/Publications-search/Biodiversity-Assessment-Method-Operational-Manual-Stage-1) and Habitat Hectares in Victoria (Parkes et al. 2003). BioCondition was developed specifically for Queensland regional ecosystems, so was considered most appropriate for this study. This framework has been proven reliable, transparent and repeatable (Kelly et al. 2011; Neldner and Ngugi 2014). The BioCondition framework measures site and landscape-scale attributes and compares these to values expected from benchmark sites (referred to as best-on-offer sites) to come up with a total score for the site. To date, there are limited Australian studies that have assessed the impacts of native forest thinning treatments, on condition metrics, or specifically BioCondition, in forests managed for production. Jay (2009) investigated the impact of forest management on ecological condition metrics, but did not include BioCondition assessment. This study reported that selective harvesting, and other forest management activities (including livestock grazing and fire), had little impact on condition scores across a wide range of stand structures in spotted gum dominated forest. Several other Australian studies have investigated the impacts of thinning or selective logging on various ecological attributes that are considered as part of condition metrics (e.g. Eyre et al. 2010; Eyre et al. 2015a; Gonsalves et al. 2018; Waters et al. 2018). Gonsalves et al. (2018) investigated the impacts of thinning on coarse woody debris (CWD) and habitat structure in *Eucalyptus camaldulensis* forest, and found that while thinning increased the density of CWD, the volume of CWD was not impacted. Waters et al. (2018) determined the influence of historic thinning on structural attributes in forest dominated by white cypress pine (*Callitris glaucophylla*) and reported that volumes of CWD were greater in areas that had been thinned. However, for many of the variables assessed by Waters et al. (2018), such as bare ground cover and litter cover, there were no significant differences between thinned and unthinned stands. Studies in Queensland by Eyre et al. (2010; 2015a) found that selective harvesting, thinning and other forest management activities had a discernible and cumulative impact on features known to be important to biodiversity. Eyre et al. (2010) found that logged stands have a lower abundance of live trees with hollows and that hollow-bearing tree numbers in these forests were below current timber harvesting prescriptions. This may reflect the lack of prescriptions encouraging habitat retention prior to the 1990s. The Eyre et al. (2010) study also found that the density of dead trees with hollows was greatly influenced by fire, and that grazing related management reduced shrub cover. Eyre et al. (2015a) investigated the impacts of thinning and logging in cypress pine forest, with a focus on habitat attributes. They found that thinning and logging altered the forest structure and thinning (approximately 30 years previous) specifically reduced the density of large living eucalypts and litter cover.

In the current study, silvicultural treatments in most cases involve leaving residue *in situ* (e.g. standing dead trees or felled dead trees). This is somewhat different to selective harvesting, where some biomass (and carbon) is removed from the site. A key aim of this chapter was to focus on the on-site carbon stocks in private native forests. It is acknowledged that further work is needed to determine the fate of the carbon that is removed from the site (e.g. mill residues and carbon stored in long-life wood products). Nevertheless, few studies have thoroughly investigated on-site carbon stocks, including debris and soil carbon pools, in native forest managed for timber production in the region. Existing studies have focused on plantation forest (e.g. Lewis et al. 2016), model validation (Moroni and Lewis 2015) or have focussed on tree carbon pools (e.g. Ngugi et al. 2014). Due to the creation of coarse debris through silvicultural treatments, we hypothesised that debris stocks would be greater in treated areas. However, the effects of forest management on soil carbon stocks are likely to be more complex (Jandl et al. 2007). The main source of soil organic carbon is derived from root biomass (Jackson et al. 2017; Kogel-Knabner 2017). Thus, soil carbon stocks may be decreased if a reduction in above-ground biomass during thinning, results in lower inputs to the soil carbon. Nevertheless, as fine grass roots add significantly to the soil carbon stocks (Neill et al. 1997), there is potential for an increase in soil carbon associated with increased grass biomass in areas that are silviculturally treated.

The effect of native forest harvesting and silvicultural treatments on carbon stocks and fluxes has been widely studied elsewhere (e.g. Balboa-Murias et al. 2006; Roxburgh et al. 2006; Finkral and Evans 2008; Sorensen et al. 2011; Ximenes et al. 2012; Keith et al. 2014). In Queensland, Ngugi et al. (2014) provided estimates of tree carbon stocks for a range of native forest ecosystems based on permanent growth plots. This comprehensive study, which included data from 641 plots on Crown land, provides a good point of comparison to estimates from the private resource. Other relevant studies that have reported on tree biomass or carbon stocks include those by Burrows et al. (2000) and Burrows et al. (2002) who focussed on grazed woodlands in central Queensland. In the current study we hypothesized that tree carbon stocks would be lower in silviculturally treated plots as the effects of tree culling have been relatively recent (mostly within 10 years) and it is unlikely that enough time has gone by to allow carbon accumulation on the remaining trees to reach levels similar to untreated plots. Nevertheless, as treated stems are usually left *in-situ*, we expected overall ecosystem carbon stocks to be similar in treated and untreated stands. In this chapter we investigated carbon stocks in trees and coarse woody debris across a number of existing silviculture trial sites (Chapters 2 and 5). We investigated detailed carbon stocks, including fine debris, ground-layer plant carbon and soil carbon at four sites with a history of timber management, where forest maturity varied from relatively young regrowth through to remnant forest.

Methods

BioCondition attributes

This analysis used a sub-set of the trial plots on privately owned land that were introduced in Chapter 5. BioCondition attributes were assessed within trial plots that were large enough in area, and BioCondition scores were calculated. Due to the limited areas of different treatments at the trial plots, full BioCondition transects (0.5 ha) could not be established at these plots. Therefore BioCondition assessment areas were modified to fit existing plots for trial sites with plots ≥0.16 ha in area. Trials with plots that were less than 0.16 ha in area (e.g. some of the sites with circular plots) could not be reasonably assessed for BioCondition. This is because some of the attributes assessed in BioCondition (e.g. density and richness of large trees, CWD) are unlikely to be accurately reflected in smaller plots (Annie Kelly pers comm.).

BioCondition attributes were assessed at 94 of the trial plots (out of the 158 trial plots) across 13 properties. Of these plots, 52 were mapped as remnant forest and the remaining 42 were considered regrowth forest. All of the plots (including silviculturally treated plots) had a history of forest management and in many cases plots were harvested prior to establishment of the trials. Plots were located in the Wide Bay-Burnett region (69 plots) and the south-east Queensland region (25 plots).

Scores for the following attributes were assigned in accordance with methods outlined in the BioCondition assessment manual (Eyre et al. 2015b).

1. Number of large trees. This was assessed based on tree growth data for the plot. Large trees were defined as those with a diameter at breast height (DBH) greater than the DBH threshold provided in the benchmark document. Native trees larger than the DBH threshold were counted within the measure plot and scaled up to a per hectare basis.

2. Tree canopy height. Tree canopy height (measured to the top of the highest leaves) refers to the median canopy height in metres, estimated for the trees in the ecologically dominant layer (EDL) or canopy layer within the measure plot. The median canopy height (the height that has 50% of canopy trees higher and lower than it) was calculated from total height measurements on trees within the plot.

3. Recruitment of dominant canopy species. The presence of regeneration (i.e. individuals with a DBH <5 cm) of the dominant canopy species in the monitoring plot was recorded. The canopy equates to the EDL for forests and woodlands, plus the emergent and sub-canopy layers if they contribute a significant amount of biomass (e.g. mid-storey wattles).

4. Richness of native tree species. Tree species richness was based on a count of the number of native tree species occurring within the monitoring plot.

5. Coarse woody debris. Assessment of CWD was conducted by measuring the length of all fallen woody logs and other coarse woody debris (>10 cm diameter and >0.5 m in length) within a given area of the monitoring plot. Where possible a 50 × 20 m plot area was assessed, however in many cases a 40 × 20 m area was assessed, to fit existing plots. Smaller plot areas (e.g. 25 × 25 m) were assessed where control plots (unthinned) were a smaller size.

The area of the plot assessed was recorded to allow calculation of total length of CWD per hectare.

6. Tree canopy cover. This attribute was estimated based on plot basal area, rather than by using the transect method in BioCondition. A significant linear relationship was determined between tree canopy cover and plot basal area ($F_{1,27} = 35.5$, $P<0.001$, adjusted $R^2 = 0.55$) based on the full BioCondition plots surveyed as part of this project (Chapter 3). This relationship was used to predict tree canopy cover in the trial plots.

7. Non-native plant cover. The percentage cover of the total vegetation cover that was comprised of exotic and non-indigenous species, was assessed within the monitoring plot. Where there were non-native plants present in more than one layer, such as grasses in the ground layer and shrubs in the shrub layer, then the cover in each layer were added together.

8. Native perennial grass cover. Perennial grass cover (%) was assessed within five 1 × 1 m quadrats (Figure 6.1) and averaged to give a value for the plot. Cover was measured estimated by vertical projection downwards of the living and attached plant material.

9. Cover of organic litter. Litter is defined as including both fine and coarse organic material such as fallen leaves, twigs and branches <10 cm diameter. Organic litter cover refers to the average percentage cover assessed within the five 1 × 1 m quadrats (Figure 6.1).

Perennial grass and litter cover were assessed 5 m from the corner of each trial plot and in the centre of the plot (Figure 6.1).

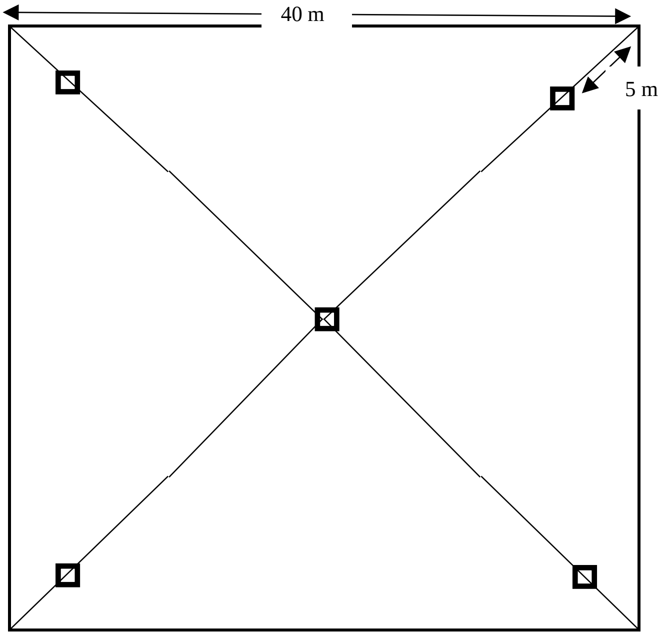

Figure 6.1. Locations of the 1 × 1 m quadrats used for assessing perennial grass cover and litter cover, within an existing 40 × 40 m monitoring plot. Diagonal lines were used to locate position of the quadrats.

10. Landscape metrics. Size of patch, patch context and connectivity were determined proximal to the site being assessed as per the BioCondition framework. This information was obtained post-field assessment, using GIS layers.

Table 6.1. Weights for the different attributes assessed at BioCondition plots, to give a total score for each plot out of 80.

Site based attributes:	**Weighting**
Large trees	15
Tree canopy height	5
Recruitment of canopy species	5
Richness of native tree species	5
Coarse woody debris	5
Tree canopy cover	5
Non-native plant cover	10
Native perennial grass cover (%)	5
Litter cover (%)	5
Landscape attributes:	
Size of patch	10
Patch context	5
Patch connectivity	5
TOTAL	**80**

Scores were derived for each attribute and a total BioCondition score out of 80 was derived for each plot, based on available benchmark data for the relevant ecosystems. A weighting based on the BioCondition Framework was applied to the site-based attributes and the landscape attributes according to Table 6.1. BioCondition attributes that were not measured in trial plots included shrub cover and the native species richness of shrubs, grasses and other plant groups. These attributes generally required more specialist skills (e.g. botanical knowledge of native species) or were time consuming to assess. While it is acknowledged that they are important attributes in BioCondition scoring, some compromise had to be made to allow assessment of BioCondition at 94 of the trial plots.

For each plot sampled, the regional ecosystem was assigned based on available mapping layers (i.e. remnant and regrowth forest mapping and the likely ecosystem prior to clearing) and plot species composition data. Where necessary, an equivalent regional ecosystem was determined based on pre-clearing mapping and the plot species assemblage. This was necessary for BioCondition scoring. Benchmarks for each relevant ecosystem were sourced through collaboration with the Department of Environment and Science (DES). As per the BioCondition assessment (Chapter 3), plots that scored between 64 and 80 (i.e. 0.8 or better) were considered to be in ‘very good condition’, and are likely to be functioning in a similar manner to the relevant benchmarks. Sites that scored between 48 and 64 (i.e. 0.6–0.79) were considered to be in ‘good condition’ and show a strong potential to be recovered to a benchmark condition. Sites that scored between 32 and 48 (moderate condition) or less than 32 (poor condition, less than 0.4) were likely to be highly degraded through management, or in earlier stages of regrowth.

Carbon stocks

Methods for determination of carbon stocks are outlined in Chapter 2. Data availability varied between different carbon stocks assessed. In this chapter we considered the following stocks: (1) living tree above-ground carbon; (2) CWD carbon; (3) litter debris carbon (which includes both fine and coarse litter debris); (4) ground-layer plant carbon (which was usually just herbaceous species); and (5) soil carbon in the upper 30 cm of the soil profile. A total of 203 (living tree), 93 (CWD), 170 (litter debris), 110 (ground-layer plant) and 170 (soil) plots were used in our analysis of carbon stocks. However, measurement of litter debris, ground-layer plant and soil carbon pools was carried out at four sites with a range of forest management treatments. At these sites an estimate of total ecosystem carbon was made by summing the different carbon pools. An estimate of carbon stored in tree roots was also added, based on the above-ground tree carbon (assuming tree root biomass is equivalent to 35% of above-ground biomass). Carbon stocks in trees and CWD debris were determined across a broader range of silviculturally treated and untreated sites (53 and 13 sites, respectively).

Analysis

The effect of silvicultural treatment (treated *vs* untreated) and vegetation state (i.e. whether it was remnant or regrowth forest) on the BioCondition attributes and total BioCondition score was assessed using ANOVA. This analysis was carried out across all plots (94 in total). Treatment by vegetation state interactions were not reported due to non-orthogonality. There are some important caveats with this analysis. Firstly, there was relatively low replication of untreated plots; as most sites included a range of treatments there were often only a couple of untreated control plots per site. Secondly, often the untreated plots did have a history of forest management, so they were likely harvested at some point in the last 20 years. Thirdly, the latest thinning treatments were usually carried out within 10 years of the measurements made in this study. Time since thinning is likely to have an important influence on certain BioCondition attributes. Time since thinning was not analysed here, due to the small range of times since thinning in the dataset and the lack of information of time since last thinning for the ‘untreated’ plots (which may have been treated historically in some cases).

The effect of silvicultural treatment (treated *vs* untreated) and vegetation state (i.e. whether it was remnant or regrowth forest) on standing tree C stock and CWD C stock was assessed using ANOVA. Analysis of the additional carbon stocks focussed on four sites with detailed measurements of all carbon pools. All four of these sites had been managed for forest production with cattle grazing in the understorey. Across these sites we did not investigate the effects of ‘treatment’ because the effect of treatment was confounded by the influence of recent logging (all sites had either a history of recent logging and or silvicultural treatment). However, we could investigate the effect of treatment alone at one regrowth site (NFQ 2), where all plots received the same management with only treatment varying between plots. For the analysis across the four sites we investigated the approximate age (or growth stage) of the vegetation, which was classified as ‘young regrowth’ (<20 years since clearing), ‘old regrowth’ (≥20 years since clearing) and ‘mature’ (remnant, or more than 50 years since clearing). ANOVA was used to compare the different carbon pools among the different growth states of vegetation. In this analysis tree basal area (at the time of carbon assessments) was included as a covariate (where significant). These relationships with basal area give some indication of a potential treatment effect (as treated sites will have lower basal areas than untreated sites). Change in tree carbon stocks over time was assessed, using the biomass growth rates reported in Chapter 5.

Results

BioCondition attributes

Large trees, canopy cover and height

There was no significant difference in the number of large trees (defined based on DBH thresholds for different Regional Ecosystems) between treated and untreated plots ($F_{1,91}$ = 0.37, P >0.05; Table 6.2). Regrowth stands tended to have a lower number of ‘large trees’, most likely due to the history of clearing trees at such sites ($F_{1,91}$ = 5.25, P = 0.024; Table 6.2). Average scores (out of 15) for this variable were generally low (3.8 for untreated and 4.4 for treated stands). Of the 94 plots included, 47 plots had a score of zero for the number of large trees and 11 plots received the maximum score of 15.

Tree canopy height ranged from 11.3 m to 36.5 m. Median canopy heights were marginally higher in treated stands than in untreated plots ($F_{1,91}$ = 3.32, P = 0.072; Table 6.2) and were higher in remnant plots than regrowth plots ($F_{1,91}$ = 4.36, P = 0.040; Table 6.2). Most plots scored highly for this variable (means of 4.5 and 4.9 out of five, for untreated and treated stands, respectively).

Tree canopy cover, which was estimated based on plot basal area, was higher in untreated plots than in treated plots ($F_{1,91}$ = 11.06, P = 0.0001; Table 6.2) and regrowth plots tended to have lower tree canopy cover than remnant plots ($F_{1,91}$ = 3.98, P = 0.049; Table 6.2). Most plots received high scores for this variable (means of 5 and 4.5 out of five, for untreated and treated stands, respectively).

Table 6.2. Means and standard errors for the number of 'large' trees per hectare, median tree canopy height and estimated tree canopy cover, for silviculturally treated and untreated plots that were classified as either regrowth or remnant forest.

	Large trees per ha		Tree canopy height (m)		Canopy cover (%)	
	mean	se	mean	se	mean	se
All untreated	**7.4**	**2.6**	**21.1**	**1.5**	**49.0**	**4.2**
Regrowth, untreated	3.2	1.8	18.4	1.8	44.2	6.9
Remnant, untreated	12.3	4.7	24.2	1.9	54.3	4.0
All treated	**10.6**	**1.7**	**24.8**	**0.5**	**40.7**	**1.2**
Regrowth, treated	7.1	2.6	24.1	0.9	38.7	1.8
Remnant, treated	13.2	2.2	25.3	0.6	42.1	1.6
All plots	**10.0**	**1.5**	**24.1**	**0.5**	**42.2**	**1.3**

Most sites had a high proportion of recruitment of dominant canopy species (Table 6.3). There was no significant effect of treatment or whether the stand was regrowth or remnant on recruitment of the canopy species (P >0.05 in both cases). All untreated sites received the maximum score of 5 for this variable, and treated sites also scored highly (average of 4.9 out of five).

Richness of native tree species did not differ in response to treatment ($F_{1,91}$ = 1.78, P >0.05). However, untreated remnant plots had marginally higher tree species richness than treated plots ($F_{1,91}$ = 3.07, P = 0.083; Table 6.3). Modest scores were received for this attribute, although it should be noted that this is likely a function of the smaller areas assessed in these plots than in the standard BioCondition plots. Nevertheless, average scores of 3.5 and 2.8 out of five were obtained for untreated and treated plots, respectively.

Table 6.3. Means and standard errors for percentage recruitment of the dominant canopy species and tree species richness per plot for silviculturally treated and untreated plots that were classified as either regrowth or remnant forest.

	Recruitment of canopy species (%)		Tree species richness	
	mean	se	mean	se
All untreated	**97.6**	**1.6**	**4.0**	**0.4**
Regrowth, untreated	97.8	2.2	3.4	0.5
Remnant, untreated	97.5	2.5	4.6	0.6
All treated	**95.6**	**1.3**	**3.6**	**0.2**
Regrowth, treated	95.7	2.1	3.4	0.3
Remnant, treated	95.6	1.6	3.8	0.2
All plots	**96.0**	**1.1**	**3.7**	**0.2**

Coarse woody debris and organic litter cover

Length of coarse woody debris per hectare did not differ in response to treatment ($F_{1,91}$ = 0.55, P >0.05) but regrowth plots had lower levels of CWD than remnant plots ($F_{1,91}$ = 18.96, P <0.001; Table 6.4). Scores for CWD were generally good. An average score of 3.4 out of five was obtained across all plots. In some cases in the treated plots, scores for CWD were lower than the maximum due to an over-abundance of CWD relative to benchmark levels.

Organic litter cover was good across most plots and scores were high for this attribute. An average score of 4.8 out of 5 was received across all plots. Average litter cover was higher in untreated plots than in treated plots ($F_{1,91}$ = 6.56, P = 0.012) and was higher in remnant plots than in regrowth plots ($F_{1,91}$ = 45.9, P <0.001; Table 6.4).

Table 6.4. Means and standard errors for the length of coarse woody debris and percentage cover of organic litter, for silviculturally treated and untreated plots that were classified as either regrowth or remnant forest.

	Coarse woody debris length (m)		% cover of organic litter	
	mean	se	mean	se
All untreated	**818.7**	**123.8**	**61.1**	**4.3**
Regrowth, untreated	514.0	56.8	53.5	6.9
Remnant, untreated	1161.5	196.6	69.7	3.3
All treated	**938.7**	**69.2**	**51.3**	**2.3**
Regrowth, treated	683.8	83.3	37.4	3.1
Remnant, treated	1134.3	94.8	61.7	2.3
All plots	**916.8**	**60.9**	**53.1**	**2.1**

Non-native plant and native perennial grass cover

The cover of non-native species was generally low at the sites assessed and as such, most plots scored well for this attribute (average score across all plots of 9.4 out of 10).

Silvicultural treatment and whether the stand was remnant or regrowth had no significant influence on the percentage cover of non-native species (P >0.05; Table 6.5).

The cover of native perennial grasses was marginally higher in treated plots than in untreated plots ($F_{1,91}$ = 3.87, P = 0.052) and was significantly higher in regrowth plots than in remnant plots ($F_{1,91}$ = 32.6, P <0.001; Table 6.5). This attribute scored well, with an average score of 4.1 out of five across all plots. Scores were higher in regrowth plots (average score of 4.9) than in remnant plots (average score of 3.4).

Table 6.5. Means and standard errors for the percentage cover of non-native species and the percentage cover of native perennial grasses in silviculturally treated and untreated plots that were classified as either regrowth or remnant forest.

	% cover of non-native species		% cover of native perennial grasses	
	mean	se	mean	se
All untreated	**2.2**	**0.6**	**24.5**	**3.4**
Regrowth, untreated	1.4	0.2	31.0	4.9
Remnant, untreated	3.0	1.2	17.2	3.4
All treated	**2.1**	**0.2**	**32.8**	**2.4**
Regrowth, treated	2.0	0.2	45.2	3.4
Remnant, treated	2.2	0.3	23.4	2.5
All plots	**2.1**	**0.2**	**31.3**	**2.1**

Landscape metrics

Scores for patch size were not significantly different between treated and untreated plots (P> 0.05), but regrowth plots had lower patch size scores than remnant plots ($F_{1,91}$ = 8.44, P = 0.005; Table 6.6). This attribute scored well on average (7.9 out of ten, Table 6.6).

A similar pattern was observed for both patch context and connectivity scores. That is, there was no effect of treatment in either case (P> 0.05), but regrowth plots had significantly lower scores than remnant plots in both cases ($F_{1,91}$ = 21.4, P <0.001, and $F_{1,91}$ = 47.3, P <0.001, respectively). Average score out of five was higher for patch context than it was for connectivity (Table 6.6).

Table 6.6. Means and standard errors for the landscape attribute (patch size, patch context and connectivity) scores determined for silviculturally treated and untreated plots that were classified as either regrowth or remnant forest.

	Patch size score (10)		Context score (5)		Connectivity score (5)	
	mean	se	mean	se	mean	se
All untreated	**8.3**	**0.8**	**3.6**	**0.3**	**2.5**	**0.4**
Regrowth, untreated	7.4	1.4	3.0	0.4	1.8	0.4
Remnant, untreated	9.3	0.5	4.3	0.2	3.3	0.5
All treated	**7.8**	**0.4**	**4.3**	**0.2**	**2.8**	**0.2**
Regrowth, treated	6.6	0.8	3.3	0.3	1.7	0.2
Remnant, treated	8.8	0.4	5.1	0.3	3.7	0.2
All plots	**7.9**	**0.4**	**4.2**	**0.2**	**2.8**	**0.2**

Influence on BioCondition score

Proportional BioCondition scores ranged from 0.41 to 0.92 with an average score of 0.73 (i.e. 73%, Table 6.7). Twenty-five plots were considered to be in very good condition (class 1), 59 plots were in class 2 and considered to be in good condition and 10 plots were in poorer condition (class 3). Silvicultural treatment had no significant influence on the total condition score (P> 0.05; Table 6.7). Remnant sites had greater total condition scores than regrowth plots ($F_{1,91}$ = 24.1, P <0.001). However, regrowth plots still had reasonable scores (Table 6.7) reflecting the fact that all regrowth plots were relatively mature (more than 15 years since clearing).

Table 6.7. Means and standard errors for the BioCondition scores calculated as a proportion (1 = score of 80/80) for silviculturally treated and untreated plots that were classified as either regrowth or remnant forest.

	mean	se	minimum	maximum
All untreated	**0.73**	**0.02**	**0.58**	**0.90**
Regrowth, untreated	0.70	0.02	0.58	0.74
Remnant, untreated	0.77	0.04	0.61	0.90
All treated	**0.72**	**0.01**	**0.41**	**0.92**
Regrowth, treated	0.67	0.02	0.41	0.88
Remnant, treated	0.77	0.01	0.63	0.92
All plots	**0.73**	**0.01**	**0.41**	**0.92**

Living tree above-ground carbon stocks

Average living carbon stored in the above-ground tree biomass varied from 4.0 to 103.9 t/ha with an average of 34.7 t/ha. There was significantly higher tree carbon in the untreated plots than in the treated plots at the time of this assessment ($F_{1,201}$ = 65.6, P <0.001) and tree carbon stocks were higher in remnant plots than in regrowth plots ($F_{1,201}$ = 39.2, P <0.001; Table 6.8). The higher living tree carbon stocks in untreated plots reflects the relative recent effect of treatment, which moves some of the living tree carbon to other carbon pools (e.g. CWD, fine debris and to the atmosphere). However, the rates of stand carbon accumulation in living trees was marginally higher in the treated plots than in the untreated plots ($F_{1,196}$ = 3.32, P = 0.070; Table 6.8) suggesting an improved sequestration capability following silvicultural treatment. Regrowth plots also had statistically higher carbon accumulation rates in living trees than remnant sites ($F_{1,196}$ = 28.5, P <0.001; Table 6.8). As outlined in Chapter 5, biomass, and hence carbon accumulation were strongly influenced by climatic variables such as evapotranspiration (adjusted R^2 = 0.25), maximum daily temperature (adjusted R^2 = 0.24) and wetness index (rainfall divided by evaporation, adjusted R^2 = 0.23).

Table 6.8. Living tree above-ground (AG) carbon stocks (t/ha) and annual carbon accumulation increment (PAI, t/ha/year) in treated and untreated plots across regrowth and remnant forest.

	Living tree AG carbon		Living tree AG carbon PAI	
	mean	se	mean	se
All untreated	**47.4**	**2.1**	**1.0**	**0.07**
Regrowth, untreated	31.2	5.7	1.5	0.16
Remnant, untreated	51.8	1.9	0.8	0.06
All treated	**26.4**	**1.6**	**1.1**	**0.05**
Regrowth, treated	21.8	2.0	1.3	0.09
Remnant, treated	30.7	2.2	1.0	0.05
All plots	**34.7**	**1.5**	**1.1**	**0.04**

Coarse woody debris carbon stocks

Carbon stored in CWD varied from 0 to 24.2 t/ha (average of 7.1 t/ha) and was not significantly influenced by forest management treatments (P> 0.05; Table 6.9). In some cases logging or treatment resulted in an increase in CWD (through thinned material and tree heads being left on the ground), but in other cases debris was retained in standing dead trees. As most of the plots included in this dataset had some history of logging, it is likely that this influenced the variability in CWD stocks (i.e. time since logging). Regrowth plots had a lower CWD stock than remnant plots ($F_{1,92}$ = 4.60, P = 0.035; Table 6.9). This is likely to be related to removal of CWD during clearing of the vegetation and the lack of time available to rebuild the CWD stocks.

Table 6.9. Coarse woody debris carbon stocks (t/ha) in treated and untreated plots across regrowth and remnant forest.

	Coarse woody debris carbon	
	mean	se
All untreated	**5.1**	**0.68**
Regrowth, untreated	5.1	1.11
Remnant, untreated	5.1	0.90
All treated	**7.7**	**0.66**
Regrowth, treated	6.4	0.99
Remnant, treated	8.8	0.85
All plots	**7.1**	**0.53**

Soil, fine debris and ground-layer plant carbon stocks

At the four sites where detailed assessments of carbon stocks were carried out, soil carbon to 30 cm depth varied from 20 to 134 t/ha with an average of 56 t/ha (Table 6.10). The growth stage of the forest had no significant influence on 0–30 cm soil carbon stocks ($P > 0.05$) and there was no significant relationship between this soil carbon stock and standing basal area ($P > 0.05$). However, in the 0–10 cm topsoil the growth stage did have a significant influence on the soil carbon stock ($F_{2,166} = 3.24$, $P = 0.042$); with higher soil carbon in more mature forest than young regrowth (Table 6.10). Soil type also had a significant influence on 0–10 cm, 10–30 cm and 0–30 cm soil carbon stocks. Of the four soil types represented, Dermosols had the highest carbon stock, followed by Kurosols, Kandosols and Rudosols (predicted means of 35.8, 28.7, 23.2 and 16.8 t/ha, respectively in the 0–10 cm soil horizon).

Table 6.10. Soil carbon stocks (soil organic carbon, SOC, t/ha) in the 0–10 cm horizon, the 10–30 cm horizon and the 0–30 cm horizon across four sites where plots (170 in total) were categorised as young regrowth, old regrowth and mature (remnant) vegetation.

	0–10 cm SOC		10–30 cm SOC		0–30 cm SOC	
Stand growth stage	mean	se	mean	se	mean	se
young regrowth	24.0	1.25	29.8	1.70	53.8	2.83
old regrowth	27.4	1.35	31.2	2.12	58.6	3.06
mature	26.2	1.11	30.3	1.37	56.5	2.17
All plots	**25.6**	**0.74**	**30.4**	**1.04**	**56.0**	**1.63**

Across these four sites, total tree carbon stock was higher in more mature forest (old regrowth and remnant forest) than young regrowth ($F_{2,166} = 33.4$, $P < 0.001$; Table 6.11). This is to be expected given the relatively smaller DBH distribution in young regrowth stands. Coarse woody debris carbon stocks tended to be marginally higher in the mature forest ($F_{2,166} = 2.49$, $P = 0.086$; Table 6.11) and basal area of trees had a significant positive influence of CWD carbon ($F_{1,166} = 16.3$, $P < 0.001$). Ground-layer plant carbon stock was also significantly influenced by stand growth stage ($F_{2,106} = 11.2$, $P < 0.001$); being higher in the older regrowth than in the young regrowth or mature forest (Table 6.11). Standing basal area had a significant negative influence on ground-layer plant carbon stock. Litter carbon stock did not differ significantly between the different growth stages, and there was no significant influence of basal area on litter carbon at these sites ($P > 0.05$; Table 6.11).

Table 6.11. Carbon stocks (t/ha) for litter carbon, coarse woody debris, ground-layer plants and trees across four sites where plots (170 in total) were categorised as young regrowth, old regrowth and mature (remnant) vegetation.

	litter carbon		CWD carbon		ground-layer plant carbon		tree carbon	
Stand growth stage	mean	se	mean	se	mean	se	mean	se
young regrowth	3.2	0.31	4.2	0.24	0.8	0.08	19.5	1.39
old regrowth	2.9	0.29	4.2	0.56	1.2	0.13	32.4	4.54
mature	3.8	0.34	5.8	0.73	0.6	0.14	29.4	3.18
All plots	**3.2**	**0.18**	**4.6**	**0.28**	**0.9**	**0.06**	**26.2**	**1.81**

The effect different levels of thinning on carbon stocks was investigated at one trial site, were four different thinning treatments were applied across two soil types (replicates). At this site soil carbon stocks (0–30 cm) differed between different treatments ($F_{3,32}$ = 7.19, P <0.001; Table 6.12) and there was a significant interaction between thinning treatment and soil type ($F_{3,32}$ = 7.56, P <0.001). That is, soils classified as Kurosols showed no difference in soil carbon between thinning treatments, but soils classified as Kandosols had lower soil carbon in the untreated and 120 SPH plots than in the 75 and 200 SPH plots. Lower soil carbon stocks in the 120 SPH treatment is not easily explained, as this treatment is intermediate between the lowest and higher stocking treatments.

At this site litter debris and coarse woody debris had similar carbon stocks and the ground-layer plant carbon stocks were relatively low (Table 6.13). Litter carbon stocks did differ among the different thinning treatments ($F_{3,32}$ = 4.52, P = 0.009); the 120 and 200 SPH treatments had lower litter carbon than the unthinned treatment, and the 75 SPH treatment had an intermediate litter carbon stock (Table 6.13). Ground-layer plant carbon stocks (made up mostly of herbaceous vegetation) also differed among thinning treatments ($F_{3,32}$ = 4.90, P = 0.006); all thinned treatments had more carbon stored in ground-layer plants than the unthinned treatment (Table 6.13). There was a weak, but statistically significant relationship between ground-layer plant carbon and soil carbon to 30 cm depth ($F_{1,38}$ = 5.77, P = 0.021, adjusted R^2 = 0.10), suggesting that higher levels of grass biomass in treated plots have resulted in increases in soil carbon. Coarse woody debris carbon stocks did not differ significantly among treatments at this trial site (P >0.05, Table 6.13).

Table 6.12. The effect different thinning treatments (75, 120, 200 stems/ha, SPH, and unthinned) and soil type (Kandosol or Kurosol) on soil carbon (SOC) stocks (0–10, 10–30 and 0–30 cm depths) at one trial site. This trial was established in small even-aged spotted gum regrowth in 2006 near Esk.

	0–10 cm SOC		10–30 cm SOC		0–30 cm SOC	
Treatment	mean	se	mean	se	mean	se
75 SPH Kandosol	25.7	0.83	38.2	2.55	64.0	2.88
75 SPH Kurosol	36.0	2.37	45.5	3.58	81.5	5.18
120 SPH Kandosol	16.8	1.29	19.5	2.39	36.3	3.58
120 SPH Kurosol	36.1	1.84	41.0	2.10	77.0	3.05
200 SPH Kandosol	32.0	3.16	48.2	4.95	80.2	8.01
200 SPH Kurosol	33.9	2.60	43.6	2.75	77.4	5.17
unthinned Kandosol	19.6	0.95	28.2	1.51	47.8	2.44
unthinned Kurosol	35.9	1.50	47.4	1.09	83.2	1.31
All plots	**29.5**	**1.47**	**38.9**	**1.99**	**68.4**	**3.31**

Table 6.13. The effect different thinning treatments (75, 120, 200 stems/ha, SPH, and unthinned) on litter, coarse woody debris, ground-layer plant carbon stocks at one trial site. This trial was established in small even-aged spotted gum regrowth in 2006 near Esk.

	litter carbon		CWD carbon		ground-layer plant carbon	
Treatment	mean	se	mean	se	mean	se
75 SPH	5.0	1.04	6.3	0.46	1.1	0.24
120 SPH	2.5	0.37	3.6	0.21	0.7	0.16
200 SPH	3.0	0.68	4.2	0.37	0.6	0.17
unthinned	6.2	0.84	4.2	0.67	0.3	0.10
All plots	**4.1**	**0.44**	**4.6**	**0.28**	**0.7**	**0.10**

Ecosystem carbon stocks

Based on the four sites, where detailed assessments of carbon stocks were made, a total ecosystem carbon stock was calculated by summing soil carbon (0–30 cm), litter debris carbon, CWD carbon, ground-layer plant carbon and total tree carbon (with an estimate for carbon stored in tree roots added to the above-ground tree carbon). Total ecosystem carbon varied from 40 to 158 t/ha, with an average of 91 t/ha. Total ecosystem carbon stocks were lower in young regrowth sites, but did not differ between older regrowth and mature forest sites ($F_{2,167} = 5.36$, $P = 0.006$; Figure 6.2).

Most carbon was stored in the soil pool (Figure 6.2). Soil carbon decreases with depth, but it should be pointed out that sampling in this project focussed on the top 30 cm of soil. Even so, across the four sites sampled, soil carbon made up 61.8% (on average) of the total ecosystem carbon. Trees were the next highest contributor, making up 28.9% of the ecosystem carbon, followed by debris carbon (litter and CWD combined) making up 8.7% and ground-layer plant carbon, making up 1%.

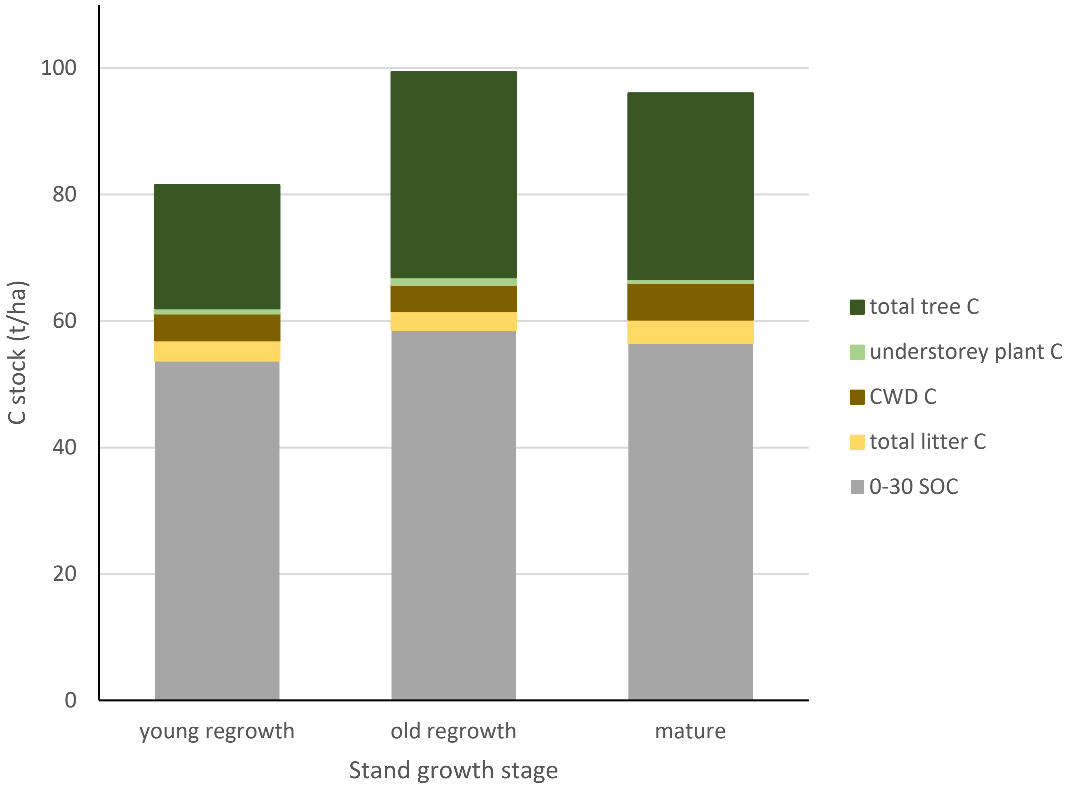

Figure 6.2. Carbon (C) stocks in the different carbon pools assessed (0–30 cm soil, litter debris, coarse debris, ground-layer plant and tree carbon) across four managed forest sites in the differing stages of stand growth (young regrowth, older regrowth and mature forest).

Discussion

BioCondition

Large tree density was an attribute that scored poorly across the managed forest sites assessed in the current study. This was partly due to the fact that many plots were considered regrowth forest and due to recent harvesting activities across most sites. Large tree densities at these trial sites are unlikely to be representative of the broader resource, where a greater range of harvesting histories can be seen, and where silvicultural treatments are uncommon. Nevertheless, the impact of harvesting and thinning activities on the density of large trees has been reported elsewhere, and can be long-lasting (Eyre et al. 2015a). While there was no difference in the density of large trees between treated and untreated plots in the current analysis, the greater diameter growth rates in treated plots (Chapter 5) suggests that large tree density may recover more quickly in such plots. Thus restorative thinning treatments could play a role in encouraging tree diameter growth even in forests managed for conservation, where large trees are lacking. Such management could potentially be applied in State Forests in the South East Queensland bioregion where DBH limit harvesting has reduced the density of large trees (e.g. Norman et al. 2004), prior to conversion to conservation estate under the South East Queensland Forestry Agreement (Commonwealth and Queensland Regional Forest Agreement Steering Committee, 1999). However, further studies are needed to better understand the impacts of thinning on fauna and conservation values (e.g. recent work in NSW by Gonsalves et al. 2018). A review carried out by Venn (Chapter 10) suggests that not all native forest management activities in the region have an adverse impact on forest fauna and that forest management activities have a much lesser influence relative to broad-scale clearing for agriculture. It is well documented however, that an overall reduction in large hollow-bearing trees across the landscape is detrimental to a range of species (Eyre et al. 2009; Goldingay 2009; Smith et al. 2007; Eyre and Goldingay 2005; Lindenmayer 2016), and hence the legislation (e.g. the Code) that requires a certain density of habitat trees to be retained.

For most site-based attributes, the condition scores were high irrespective of treatment history. This was the case for median tree height, tree canopy cover, recruitment of dominant canopy species, organic litter cover, non-native plant and native perennial grass cover. This suggests that silvicultural treatment is unlikely to have a deleterious impact on these attributes, despite some attributes having significantly higher values in untreated plots than in treated plots (e.g. tree canopy cover and organic litter cover). That is, while silvicultural treatments had an influence on certain variables, the influence was not strong enough to result in lower condition scores. As pointed out by Jay (2009) it is possible that existing condition metrics, when looked at as a single score, are not sensitive enough to detect differences in environmental attributes between forest sites with varying management history. The BioCondition framework is most commonly used in assessing habitat for environmental offsets (Biodiversity Integration and Offsets, Ecosystem Outcomes, Department of Environment and Heritage Protection, 2017), mine-site revegetation (Neldner and Ngugi 2014) or in the assessment of grazing lands (Eyre at al. 2011). Nevertheless, the individual site-based attributes assessed in this framework are commonly measured ecological attributes, and differences in these attribute values between silviculturally treated and untreated plots provide important information with regard to positive and negative effects. As such, we have focused our summary of the results in this chapter on individual attribute values, rather than total scores.

Not surprisingly, regrowth plots often had lower attribute values and condition scores than remnant plots. The density of large trees, median canopy height, tree canopy cover, CWD length and organic litter cover were all lower in regrowth plots than in remnant plots, while perennial grass cover was higher in regrowth plots. Landscape scores were also lower in regrowth plots than in remnant plots, particularly in terms of landscape connectivity. While biodiversity values in regrowth vegetation are often lower than in mature forest (e.g. Bowen et al. 2007; Bowen et al. 2009; Peeters and Butler 2014), it is important to consider the likely improvements in condition and biodiversity that take place over time. Although not specifically addressed in our study, regrowth forest is likely to have higher ecological condition than adjacent pasture that has been cleared of trees and shrubs. For example, a perennial pasture dominated by native herbaceous species that has developed after clearing in an area that is mapped as a forested regional ecosystem, could only attain a maximum BioCondition score of 0.37 (assuming maximum scores for grass and herb richness, non-native cover, native grass cover, litter cover and connectivity). This is significantly lower than the scores reported for regrowth forest in the current study (Table 6.7). In this regard, encouraging development of regrowth forest, for multiple management outcomes (e.g. grazing, timber production and conservation) is a much better alternative than continued clearing of regrowth vegetation for grazing production alone. Unfortunately, due to perceived risks associated with allowing development of regrowth forest, many landholders opt to control regrowth and retain open pastures for grazing production alone.

Despite the sometimes negative impact of treatment or historical clearing on some attributes, overall condition scores that considered all attributes assessed, were generally quite good (average proportional score of 0.73). This is encouraging, as it is likely that condition scores at most of these sites will increase over time as the forest matures following clearing, harvesting or thinning treatments. Further assessments of condition variables would be worthwhile every 5 to 10 years at these sites to document changes in condition attributes following forest management activities.

Forest carbon

While silvicultural treatments result in an immediate reduction in the on-site live tree carbon stocks, through a reduction in live-tree biomass, these carbon stocks are likely to recover relatively rapidly. Tree carbon stocks made up a relatively lower proportion of the site carbon at the four detailed assessment sites investigated here (Figure 6.2). Studies elsewhere suggest carbon stored in living trees often contributes a higher proportion of ecosystem carbon in forest growing regions (e.g. closer to 50% of the site carbon, Lewis et al. 2016; Lewis et al. 2019). The relatively low tree carbon stocks at these sites reflects the forest management history. Young regrowth sites tend to have less carbon stored in living trees, simply due to the size of the trees. Such sites have great potential for carbon sequestration, as they should accumulate carbon in tree biomass until they near the carrying capacity of the site. Of the mature forest sites assessed in this dataset (i.e. the four sites where detailed assessments were made), tree carbon stocks were low due to recent reset harvest (approximately 2 years prior to assessment) at one site, and regular selective harvesting at another site. Thus, even the mature forest sites have the potential to sequester carbon in living trees and were a long way from the estimated carrying capacity values (i.e. 45.1 t C/ha for spotted gum broad vegetation group 10a, and 80.6 t C/ha for the *Corymbia* woodland broad vegetation group 9f) reported by Ngugi et al. (2014).

In the broader dataset, tree carbon stocks were in the range of those reported in similar forest types. Ngugi et al. (2014) reported that live above-ground tree carbon stocks ranged from 20.8 (± 4.3) t/ha in inland eucalypt woodlands to 146.4 (± 11.1) t/ha in coastal wet tall eucalypt forests. In the timber production forests studied here, live tree above-ground carbon stocks were at the lower end of the range reported by Ngugi et al. (2014) reflecting the relatively recent thinning and or harvesting treatments at many of these plots. Live tree carbon stocks were highest in the untreated remnant forest plots (Table 6.8). Mean above-ground tree carbon stock in the untreated remnant forest was 51.8 t/ha, which was still lower than the mean values reported for the 800–1000 mm (60.8 t/ha) and the 1000–1200 mm rainfall zones (57.4 t/ha) by Ngugi et al. (2014). The lower values reported here most likely reflect the fact that even in the untreated plots, maximum basal area (and biomass carrying capacity) has not been reached. Assuming a maximum (carrying capacity) above-ground live tree carbon stock of between 67.8 and 78.8 t/ha for the 800–1000 and 1000–1200 mm rainfall zones (as reported in the Ngugi et al. (2014) study), the treated plots still have a lot of potential for carbon accumulation.

The Ngugi et al. (2014) study also highlights the greater potential for carbon sequestration in trees in the higher rainfall zones (e.g. 138.1 t/ha in the 1200–1600 mm rainfall zone). Their study reported that annual live above-ground net carbon flux (C-flux) across all forests types ranged from 0.46 to 2.92 t C/ha/yr with an overall mean of 0.95 t C/ha/yr (n = 2067). This average rate of carbon accumulation was very similar to that reported for the private native forests investigated here (mean of 1.1 ± 0.04 t/ha/yr). The use of silvicultural treatments to encourage carbon sequestration has merit, given the importance of sequestering carbon in larger diameter trees. Peeters and Butler (2014) demonstrate that a regrowth stand with a high number of small trees will store less carbon than a mature stand with a low density of large diameter trees, irrespective of the two stands having the same basal area. Thus silvicultural management, even in areas not managed for timber production, can have benefits associated with encouraging growth on larger diameter trees for carbon storage.

The current study backs up the work of Ngugi et al. (2018) that demonstrated the potential for silvicultural treatments to supply biomass for bioenergy in the South East Queensland bioregion. Most silvicultural treatments carried out by landholders in the study region currently leave debris in-situ where it eventually decays. This is reflected in the relatively high CWD stock (7.7 t C/ha) in treated plots surveyed across the study region. Further, selective harvesting leaves a high proportion of the biomass on-site (mean biomass removed for sawlog was 41.4% of the whole tree biomass in the Ngugi et al. 2018 study). Ngugi et al. (2018) report an average of 4.3 (±1.0) t/ha of biomass could be used for bioenergy production following a sawlog harvest and state that private native forest management in the South East bioregion alone could produce a substantial amount of biomass for bioenergy (13,575,000 t).

Most of the carbon at the sites studied here was stored in the soil. In fact, the soil carbon pool is likely much greater than that reported here, as a significant soil carbon stock occurs beyond the 30 cm depth that we sampled to (Gál et al. 2007; Harrison et al. 2011; Ngo et al. 2013). We focussed this study on the top 30 cm of soil, as most soil carbon occurs in the top soil horizons and most changes in soil carbon are likely to take place to this depth (e.g. this is the Intergovernmental Panel on Climate Change (IPCC) reference depth, IPCC, 2006). A previous study by Bai et al. (2017) at the same Esk site utilised here to compare between thinning treatments, reported no difference in percentage carbon content in the topsoil (0–5 cm depth) between the different thinning treatments. However, it was not clear in the Bai et al. (2017) study how the different blocks (soil types) were accounted for. The significant interaction between soil type and treatment in our current analysis highlights the potential differences in soil carbon response on different soil types. The effect of thinning treatment was only significant for Kandosols, however, there is no clear explanation as to why the 120 SPH treatment had lower soil carbon stocks than in the 75 and 200 SPH treatments. While the soil carbon pool represents an important and relatively stable pool, most of the ecosystem sequestration potential is in the living tree biomass (Paul et al. 2002; Peichl and Arain 2006; Lewis et al. 2019). The relationship between grass biomass (and fine root biomass) and soil carbon requires further investigation, given the significant negative relationship between increasing tree density and ground-layer plant biomass.

The effects of thinning treatments on debris carbon stock were variable. There was a lack of clear difference in CWD carbon stocks between the treated and untreated plots at the regional scale and at the individual Esk site. Coarse woody debris stocks did tend to be higher in remnant forest than in regrowth forest, reflecting a likely higher degree of CWD inputs in more mature forest and removal of CWD from cleared sites. The lack of a silvicultural treatment response was however unexpected. This may be partly due to the silvicultural treatments focussing on smaller stems (<10 cm DBH) or due to other management activities, such as stick raking and prescribed fire. Eyre et al. (2015a) also reported no effect of thinning, approximately 30 years post thinning in cypress pine forest. However, Waters et al. (2018) reported a clear increase in CWD volume in thinned areas. Fire history is likely to have a strong influence on CWD stocks in these forests, through consumption of at least a proportion of the CWD stocks (Aponte et al. 2014; Stares et al. 2018; Collins et al. 2019) that are produced through thinning. Prescribed fire is a common management tool in eucalypt forests and woodlands in Queensland that are managed for timber and grazing (Debuse and Lewis 2007). Fine debris (i.e. litter carbon) stocks are even more likely to be consumed by fire and are therefore likely to be highly dynamic in many private native forests due to the frequent occurrence of fire. Litter carbon stocks did differ between the different thinning treatments at the Esk site. However, there was no clear relationship between stocking and litter carbon stock (that is, it is not clear why the treatment with the lowest stocking had a higher litter carbon stock than the other thinned treatments). Despite this, there was a tendency for higher litter cover (%, recorded in condition assessments) in untreated plots than in treated plots (P = 0.012).

Further work is needed in Queensland on the fate of carbon removed from a site during harvest operations and to determine the long-term carbon balance of production forests relative to those not managed for timber production. In a comprehensive study in NSW, Ximenes et al. (2016) assessed the net carbon implications of native forest management for wood products relative to conservation (no harvesting). Their study accounted for total carbon stored on-site in the above ground forest biomass and coarse woody debris, as well as off-site in products in service, landfill, avoided fossil fuel emissions due to using woody biomass for energy, and wood product substitution effects (e.g. the net carbon benefit of using a timber electricity distribution pole versus a concrete or steel pole). A key finding of this study and the earlier study by Ximenes et al. (2012) was that native forests managed for timber production provide the greatest greenhouse gas benefits, when storage of carbon in long-term wood products and the product substitution effects are considered.

Conclusions

For most site-based attributes assessed in this study, the condition scores were relatively high (compared to recently cleared land), irrespective of treatment history. Historic clearing had a greater impact on condition attributes, such that regrowth sites had lower BioCondition value than remnant sites. However, even regrowth areas still had reasonable total condition scores, reflecting the likely improvements in ecological condition that take place when cleared pasture areas are allowed to regenerate and develop a forest canopy.

Soil carbon stocks made up the greatest component of ecosystem carbon at the sites assessed in this study. However, the greatest potential for carbon sequestration at a site is in the living trees. Live tree carbon stocks were lower in treated plots, reflecting the relatively recent thinning and harvesting treatments. However, these plots have greater potential for carbon sequestration, and it is likely that carbon stocks could double in treated plots before these plots start to approach the carbon carrying capacity. Previous chapters have outlined the important contribution that private native forests make in terms of their grazing and timber production values. This chapter highlights that their values from an ecological condition and carbon storage perspective are not likely to be drastically influenced by silvicultural management treatments. In fact, restorative silvicultural treatments offer some potential benefits, particularly in terms of encouraging growth of large trees.

Chapter 7: Financial performance of silvicultural thinning treatments in private native forests in Queensland

Ben Francis, Tyron Venn, Tom Lewis and Jeremy Brawner

Introduction

Private native forests currently supply between 50 and 70% of native hardwood timber to sawmills in Queensland (Queensland Department of Agriculture and Fisheries 2015; Leggate et al. 2017; ABARES, 2017). There has been a decline in timber supplied from State-owned forests in Queensland in recent decades (Aenishaenslin et al. 2007), and hardwood plantations are unlikely to provide a replacement resource. As such, it is anticipated that the timber industry will be increasingly reliant on private native forests to supply timber over the next decade. However, this is problematic for the timber industry because, despite their large geographic extent, private native forests are generally in poor productive condition. In remnant forests, low productivity is due to a century of periodic 'high-grading'[10] without follow-up silvicultural treatment, while 'overstocking' (i.e. a high density of trees) is often the key cause of low tree growth rates in regrowth forests on formerly cleared agricultural land.

It is generally acknowledged within the timber industry that silvicultural treatments could substantially increase the productivity of private native forests. Thinning, harvesting and burning practices that aim to remove non-productive stems, reduce competition and promote regeneration have the potential to increase the productive capacity of native forests (Ryan and Taylor 2006).

Re-measurement of permanent monitoring plots has revealed that the DBH growth of silviculturally treated plots was on average four times greater than in untreated plots (Chapter 5). Private Forestry Service Queensland (PFSQ) has suggested that if private native forests were managed according to best practice, they could sustainably produce greater volumes of hardwood timber than is currently demanded in Queensland (Leggate et al. 2017). However, although studies have shown that the diameter growth of retained trees in thinned native forest stands is higher than unthinned stands (Forrester et al. 2010; Bai et al. 2013; Chapter 5), information about the financial performance of silvicultural treatments is scarce.

Ryan and Taylor (2006), found that harvest revenues exceeded the cost of silvicultural treatments in a case study of overstocked spotted gum in private native forests in south east Queensland, describing the operation as profitable. However this assessment did not carry out a discounted cash flow analysis, and therefore did not consider whether future financial benefits exceeded the costs of treatment. Northern New South Wales has been the focus of several investigations into the financial performance of silvicultural treatments (Jay 2009; Jay et al. 2009; Jay and Dillon 2016). These studies overcame limited data by using the EUCAMIX model to simulate growth of merchantable log volume in uneven-aged, mixed species native hardwood forests under a variety of management scenarios. Jay et al. (2009) found silvicultural treatments returned a NPV over 30 years of $448/ha at a 5% discount rate, whereas high-grading with some culling of low quality stems generated a NPV of $554/ha over 30 years. Jay and Dillon (2016) also found that high-grading was likely to be financially optimal for landholders over a 30-year simulation period. However, in year 30, the silviculturally treated forest had greater standing value ($9480/ha versus $2730/ha).

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[10] High-grading involves the harvesting of commercially valuable trees, while leaving unmerchantable and damaged trees standing.

The objective of this chapter is to assess the financial performance of several silvicultural thinning treatments in private native forests in Queensland.

Silvicultural treatments evaluated

The financial performance of silvicultural treatments that aim to increase the value of the log at harvest (stumpage price) to landholders in private native forest has been evaluated. These treatments aim to maximise profits obtained from high value timber products including sawlogs (log that will be milled into dimensional timber) and electricity distribution poles. A variety of silvicultural thinning methods have been recommended by PFSQ (Ryan 2017, personal communication) to improve the productive potential of private native forests. Three are examined in this study:

- brushcutting, where trees to be removed are small in diameter (i.e. <15cm diameter at breast height, DBH), but not in large groups and on terrain suited to chopper-rolling (see below). Herbicide is often used immediately on cut stems, or on coppice regrowth one year after brushcutting;
- an axe and stem injection system to poison pre-selected trees via chemical treatment, typically with herbicide like Glyphosate or Tordon®. This treatment method will subsequently be referred to by the industry term, 'tordoning'. There is no tree diameter limit with this method; and
- chopper-rolling, which uses a heavy (e.g. 9 tonne) roller that is towed by a skidder or tractor to remove pre-selected groups of trees typically up to about 10 cm DBH.

In preparation for thinning, a stand should ideally have trees marked with spray paint for retention at an appropriate spacing (e.g. 6 to 10 m between trees), depending on the forest type (PFSQ 2017). The density of retained trees will vary depending on stand characteristics, including species, height, diameter, and product mix. Prescribed fire and follow up chemical treatments are often used to control the density of woody regeneration after silvicultural treatment. In Queensland, silvicultural treatments must adhere to the native forest practice code, 'Managing a Native Forest Practice: a Self-Assessable Vegetation Clearing Code' (Department of Natural Resources and Mines 2014).

Financial analysis of silvicultural treatments

The financial performance of three silvicultural treatment scenarios were assessed: (1) brushcutting; (2) tordoning; and (3) chopper-rolling. The aim of all treatment scenarios is to reduce stocking to a total of about 250 stems per hectare (SPH), where typically 100 to 150 SPH would be at least 10 cm DBH[11]. Table 7.1 summarises the silvicultural treatment regime for the three scenarios. A spreadsheet model was developed to estimate the net present value (NPV) of each silvicultural treatment scenario. This required estimation of:

- labour and non-labour costs for the first silvicultural treatment in year zero;
- the present value of re-treatment costs; and
- the present value of the expected net increase in harvest revenues attributable to the treatment.

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[11] Tree stocking in native forests in Australia is often reported only for trees ≥10cm DBH. This assessment has included trees less than 10 cm DBH, because these smaller stems typically account for a large proportion of the silviculturally treated stems.

Table 7.1. Silvicultural treatment regime for the three treatment scenarios.

Year	Description
0	First silvicultural treatment for all treatment scenarios
1	Re-treatment for the chopper roller scenario only (F_{ty1})
10	Re-treatment for all treatment scenarios (F_{ty10})
20	Timber harvest for all treatment scenarios (HY)

Time and motion studies were carried out on four brushcutting and four tordoning treatment plots to estimate costs for the first silvicultural treatment in year zero. Factors collected for the time and motion studies were variables identified to be important time related labour costs and non-labour costs such as fuel and chemical consumption associated with each treatment. Trees to be retained were paint marked, allowing before and after treatment stocking to be determined. Table 7.2 summarises stand characteristics for the brushcutting and tordoning plots. All four plots in the brushcutting treatment are located in regrowth forests at Boomerang, a site near Gin Gin, in Queensland. For the tordoning treatments, plots 3 and 4 are located at Boomerang, and plots 1 and 2 are in regrowth forest at Mundubbera, Queensland. Plot locations are illustrated in Figure 7.1. The plots at Mundubbera are dominated by spotted gum (*Corymbia citriodora*) and narrow-leaved ironbark (*Eucalyptus crebra*) and the plots at Boomerang are dominated by spotted gum, narrow-leaved ironbark and yellow stringybark (*Eucalyptus acmenoides*).

Table 7.2. Stand characteristics for brushcutting and tordon treatments.

Treatment type	Plot num.	Plot area (ha)	Pre-treatment SPH (IS)	Post-treatment SPH	Treated SPH (CT)	Distribution of treated stems by DBH (cm) (SPH)		
						<5	5 to 9.9	10 to 15
Brushcutting[a]	1	0.05	3500	420	3080	1700	1220	160
	2	0.05	1800	240	1560	820	360	380
	3	1.37	3335	212	3123	2671	361	91
	4	0.55	2430	259	2171	1451	350	370
	Mean		2766	282	2483	1660	573	250
Tordoning[b]	1	0.16	1475	100	1375	-	988	388
	2	0.16	1006	175	831	-	656	175
	3	0.05	1120	260	860	740	120	0
	4	0.05	580	140	440	340	20	80
	Mean	-	1045	168	877	-	716[c]	161

Notes:

a Stems >15cm DBH were not included in the brushcutting analysis, as they accounted for less than 1% of the total stems across the four sites.

b No pre-treatment estimates for SPH <10cm DBH were collected for plots 1 and 2. For these two plots the initial stocking of trees <10cm DBH has been assumed to be equal to the number of treated stems <10cm DBH (which was recorded). All treated stems <10 cm DBH have been counted in the 5 to 9.9 cm DBH class, because whether treated stems were < 5 cm DBH was not recorded.

c The mean DBH for the 5cm to 9.9cm category column for tordoning reflects the mean for stems <10cm DBH. The stems <5cm DBH in plots 3 and 4 have been included in this value.

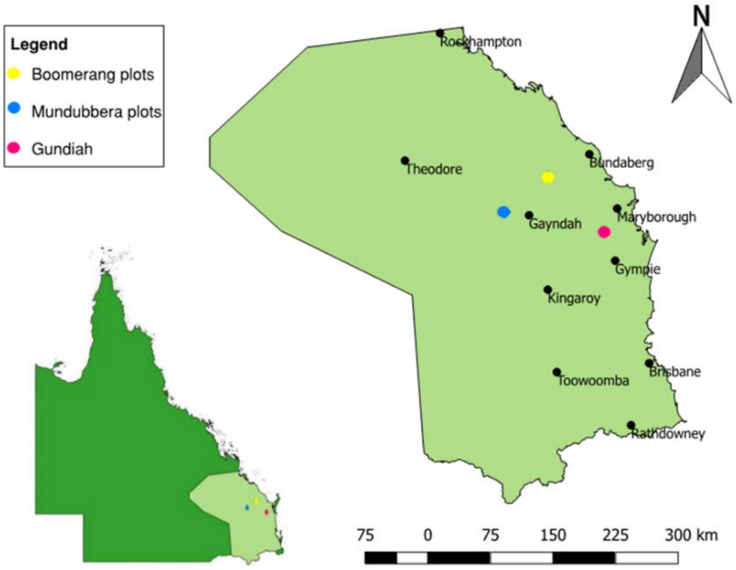

Figure 7.1. Brushcutting and tordoning plot locations and the PFSQ chopper-rolling site at Gundiah.

PFSQ have provided average fuel, transport and productivity costs for the chopper-rolling treatments. PFSQ collected the chopper-rolling treatment data over 70 days at both Boomerang and Gundiah, which included 1200 ha of spotted gum dominated forest. In stands suitable for chopper-rolling (i.e. <10cm DBH), the chopper-rolling process is not affected by tree stocking or size. In contrast, labour and non-labour costs for tordoning and brushcutting are affected by tree stocking and size. As such, the chopper-rolling data provided by PFSQ is appropriate for financial analysis.

Labour costs for the first treatment

All treatment scenarios (brushcutting, tordoning and chopper-rolling) have their first treatment in year zero, as described in Table 7.1. Contractors were filmed carrying out treatments in the brushcutting and tordoning plots, and the footage was reviewed to determine the time for activities described in Table 7.3 for both treatment scenarios.

Cut and poison time per tree with brushcutting was found to increase substantially with DBH. From the film recording, mean cut and poison times have been calculated for three tree size classes. Three other labour activities associated with the brushcutting treatment were found to be related to pre-treatment stocking (SPH), namely: (1) walking between trees; (2) pumping tordon; and (3) putting down hung-up trees and untangling the brushcutter from trees. Time spent pumping tordon was positively related to pre-treatment stocking, while time spent on the other two activities was negatively related to pre-treatment stocking. Linear regression models were fitted to the data with pre-treatment stocking as the independent variable. Because sharpening the brushcutter blade occurred infrequently during treatments on the small plots, the average time per hectare across the four plots has been adopted. In reality, blade sharpening time is likely to increase with DBH of treated stems and with pre-treatment stocking.

In the tordoning scenario, cut and poison time for individual trees is expected to increase with tree DBH. However, insufficient data was available to estimate cut and poison time by DBH size class. A linear regression model was fitted to the time to cut, poison and walk between trees, where the independent variable was pre-treatment stocking. As indicated in Table 7.3, this model explains almost all the variation in time in this scenario. This may be because there was a negative correlation between pre-treatment stocking and mean DBH on the plots, such that pre-treatment stocking was acting as a proxy for DBH and thus accounting for higher cut and poison times with larger trees.

Based on prior experience, PFSQ asserted chopper-rolling treatments progress at the rate of about 0.5 hours/ha. It has been assumed that tree stocking does not impact chopper roller productivity, provided the treated trees are less than approximately 10 cm DBH.

Table 7.3. Labour costs and productivity of labour for the first silvicultural treatment in the three treatment scenarios.

Item	Acronym	Unit of measure	Mean	Linear regression model. Pre-treatment stocking in SPH is the independent variable		
				Intercept	Slope	R^2
All treatments						
Labour rate	LR	$/h	50			
Tree marking for retention	TM	h/ha	2			
Brushcutting						
Cut and poison time						
<5 cm DBH	CPT1	s/treated stem	1.8			
5 to 9.9 cm DBH	CPT2	s/treated stem	4.2			
10 to 14.9 cm DBH	CPT3	s/treated stem	9.3			
Walking between trees	OLA1	s/treated stem		4.41	–0.00095	0.74
Pump tordon	OLA2	s/treated stem		–0.069	0.00022	0.39
Trees or brushcutter caught up	OLA3	s/treated stem		0.444	–0.00006	0.35
Sharpening brushcutter blade	BS	s/hectare	240			
Tordoning						
Cut, poison and walk time	CPWT	s/treated stem		31.18	–0.0132	0.99
Chopper-rolling						
Chopper-rolling time	CRT	h/ha	0.5			

The productivity (P) of labour for each silvicultural treatment scenario is the person hours required to treat one hectare. P for the brushcutting (Pb), tordoning (Pt) and chopper-rolling (Pc) treatments has been calculated with the following equations.

$$P_b = \frac{\left(\left(\sum_{c=1}^{3} CPT_c \times CT_c\right) + \left(\left(\sum_{i=1}^{3} InterceptOLA_i + \sum_{i=1}^{3} SlopeOLA_i \times IS\right) \times CT\right)\right)}{3600} + TM \qquad \text{(eq. 7.1)}$$

$$P_t = \frac{\left((InterceptCPWT + SlopeCPWT \times IS) \times CT\right)}{3600} + TM \qquad \text{(eq. 7.2)}$$

$$P_c = CRT + TM \qquad \text{(eq. 7.3)}$$

Where IS is initial or pre-treatment stocking in SPH;

CPT_C is the cut and poison time per tree for brushcutting for DBH class c, as listed in Table 7.3;

CT_c is the number of cut trees in DBH class c;

$InterceptOLA_i$ is the intercept for the linear regression model for other labour activity i, as listed in Table 7.3;

$SlopeOLA_i$ is the slope for the linear regression model for other labour activity I, as listed in Table 7.3;

InterceptCPWT is the intercept for the linear regression model for cut, poison and walk time for tordoning, as listed in Table 7.3;

SlopeCPWT is the slope for the linear regression model for cut, poison and walk time for tordoning, as listed in Table 7.3;

TM is tree marking time in hours; and

3600 is the number of seconds in one hour.

Productivity of the brushcutting and tordoning treatments are a function of the pre-treatment stocking and the number of cut trees. Productivity of brushcutting is also related to the distribution of cut trees by diameter class. Chopper-rolling is not affected by pre-treatment stocking, number of cut trees or diameter distribution of cut trees. With productivity determined for each treatment, labour cost per hectare (LC) of for the first treatment in each treatment scenario was calculated with equation 7.4.

$$LC = P \times LR \qquad \text{(eq. 7.4)}$$

Where P is productivity of labour in hours per hectare for brushcutting (Pb), tordoning (Pt) or chopper-rolling (Pc); and

LR is the labour rate in dollars per hour as specified in Table 7.3.

Non-labour costs for the first treatment

Non-labour unit costs and use of equipment and supplies such as tordon, brushcutter blades and fuel (i.e. consumption rates) have been collected for each treatment. The non-labour unit costs and consumption rates observed in the brushcutting and tordoning plots, and reported by PFSQ for chopper-rolling are reported in Table 7.4.

For tordoning, a linear regression analysis was carried out with pre-treatment stocking as the independent variable to determine tordon consumption per treated stem. For chopper-rolling, the cost of transporting the tractor and skidder was quoted at $180/h, and transport time for the base case analysis has been set at two hours. PFSQ asserted that 50 hectares is the minimum viable area to treat with a chopper roller. As such, 50 hectares has been applied as the base treatment area (TA) for the chopper-rolling scenario.

Table 7.4. Non-labour unit costs and consumption rates.

Item	Acronym	Unit of measure	Level	Linear regression model. Pre-treatment stocking (SPH) is the independent variable		
				Intercept	Slope	R^2
Unit costs						
Fuel costs	FC	$/l	1.5			
Tordon costs	TC	$/l	57.8			
Blade costs	BC	$/blade	20			
Chopper roller transport costs	TRC	$/h	180			
Brushcutting consumption rates						
Fuel	FCR_b	l/treated stem	0.0003			
Tordon	TCR_b	l/treated stem	0.0005			
Blades	BCR	blades/treated stem	0.0001			
Tordoning consumption rate						
Tordon	TCR_t	l/treated stem		0.003	–0.0000009	0.87
Chopper-rolling consumption rate						
Fuel	FCR_c	l/ha	4			
Chopper roller transport time		h	2			
Minimum treatment area	TA	ha	50			

Note: For the brushcutting treatments, the contractor mixed the herbicide at a rate of 20:1, water to Tordon, and for the axe and stem-injection system tordoning treatments, the contractor mixed the herbicide at a rate of 4:1, water to Tordon.

Total non-labour costs per hectare (NLC) for the brushcutting (NLC_b), tordoning (NLC_t) and chopper-rolling (NLC_c) treatment scenarios were calculated with equations 7.5 to 7.7.

$$NLC_b = ((TC \times TCR_b) + (BC \times BCR) + (FC \times FCR_b)) \times CT \quad \text{(eq. 7.5)}$$

$$NLC_t = TC \times TCR_t \times CT \quad \text{(eq. 7.6)}$$

$$NLC_c = (FC \times FCR_c) + (\frac{TRC}{TA}) \quad \text{(eq. 7.7)}$$

All variables are as previously defined.

Present value of re-treatment costs
Re-treatment will be required for all silvicultural treatment scenarios in year 10, with chemical control to maintain stocking in the desired range of 100 to 150 SPH of trees of at least 10 cm DBH. Since the first treatment in the chopper-rolling scenario does not include chemical control, vigorous coppice regrowth is likely to follow treatment. Chopper-rolling will therefore require a chemical treatment in year one as well as year 10. Depending on stand structure, the re-treatment method employed could be any one of the three treatment scenarios examined. It is expected that the re-treatment will be less costly than the first treatment, because larger diameter trees would have been treated in year zero, and there would likely be fewer trees for treatment. In the absence of empirical data about re-treatment costs (RTC), expert opinion was sought from industry, and a rate of \$250/ha recommended. The present value of RTC has been estimated for all treatment scenarios as follows.

$$PVRTC = \frac{RTC}{(1+r)^{Fty}} \quad \text{(eq. 7.8)}$$

Where Fty is the re-treatment year, as indicated in Table 7.1; and r is the real discount rate. A base case rate of 5% has been adopted in this analysis.

Present value of the expected net increase in harvest revenues
The native forest silvicultural treatment response model developed as part the larger project (Chapter 5) was used to estimate the growth response to silvicultural treatments. This model was used to simulate forest growth with and without silvicultural treatment over 20 years on four case study sites in southeast Queensland for which detailed stand data was available and with rainfall ranging from 600 to1000 mm/yr (Chapter 8). The average silvicultural treatment growth response simulated for the four case studies over 20 years was 1.3 m^3/ha/yr greater than what could have been achieved if the forest was not silviculturally treated. This level has been adopted as the base case increase in mean annual increment (MAI) in response to the silvicultural treatment[12].

Table 7.5 reports average stumpage prices paid to landholders for the two log types that the silvicultural treatment aims to maximise production of – electricity distribution poles (poles) and sawlogs. The same case study data used to estimate the increase in mean annual increment (MAI) was also used to estimate the proportion of the harvest volume in 20 years that will be poles (10%) and sawlogs (90%) for the analysis.

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[12] The adopted base case level of net increase in MAI over 20 years may be conservative, because the native forest silvicultural treatment growth response model presently cannot simulate a re-treatment. Consistent with forest stand growth theory, the silvicultural treatment growth response model predicts annual growth declines with time since treatment. However, it is expected that re-treatment in year 10 will free up site resources and facilitate increased growth on retained stems. At the time of publication, this is not accommodated in the silvicultural treatment growth response model.

Table 7.5. Stumpage prices, pole proportion of harvest volume and MAI response to treatment.

Parameter	Acronym	Unit of measure	Level
Sawlog stumpage price	SP	$\$/m^3$	100
Pole stumpage price	PP	$\$/m^3$	150
Proportion of pole volume in harvest	PV	%	10
Increase in MAI relative to no treatment	MAI	m^3/ha/yr	1.3

The present value of the expected net increase in harvest revenue (PVIHR) per hectare was then estimated with equation 7.9. PVIHR was determined to be the same for all treatment scenarios, as the future product values, the harvested product proportions, the discount rate and the increase in growth rate was assumed to be the same given all treatments reduced the stand to the same post-treatment stocking.

$$\text{PVIHR} = \frac{\left(\left(MAI \times SP \times HY \times (1 - PV)\right) + (MAI \times PP \times HY \times PV)\right)}{(1 + r)^{HY}} \qquad \text{(eq. 7.9)}$$

Net present value of treatments

The present value of total silvicultural treatment cost (PVSTC) was estimated for each scenario with equation 7.10.

$$\text{PVSTC} = \quad (LC + NLC + PVRTC) \qquad \text{(eq. 7.10)}$$

The net present value of each treatment was calculated with equation 7.11.

$$NPV = \quad PVIHR - \text{PVSTC} \qquad \text{(eq. 7.11)}$$

Sensitivity analyses

Extensive sensitivity analyses were performed to determine the impact of independent variables on the NPV of treatment scenarios. The six most important parameters are reported in Table 7.6, along with the alternative parameter levels examined. Note that because of the interaction of labour productivity (P) with labour rate, the sensitivity of NPV to labour rate can also be interpreted as the sensitivity to labour productivity (when labour cost is $50/h).

With empirical data collected on different size classes of treated stems in the brushcutting treatments, sensitivity analyses were also performed to assess the impact of stem size class on the financial performance of the brushcutting treatment.

Table 7.6. Parameters assessed in sensitivity analysis.

Parameter	Base case level	Alternative levels
Labour rate ($/h)	50	35, 65 (±30%)
Increase in growth rate following treatment, relative to no treatment (m^3/ha/yr)	1.3	0.65, 1.95 (±50%)
Discount rate (%)	5	3, 7
Proportion of poles at future harvest (%)	10	0, 20
Stumpage price for (1) pole and (2) sawlogs ($/$m^3$)	(1) 150; (2) 100	(1) 105, 195 (±30%); (2) 70, 130 (±30%)
Re-treatment costs ($/ha)	250	175, 325 (±30%)

Results and Discussion

Financial performance of silvicultural treatments

Figure 7.2 provides the present value of treatment costs (PVSTC) and revenues (PVIHR) per hectare, and the NPV per hectare for each of the three treatment scenarios by pre-treatment stocking. The brushcutting and tordon treatments are not represented at all stocking levels due to the limited data. These treatments were only assessed at stockings within 30% of the highest and lowest pre-treatment stocking rates observed at the field sites (Table 7.2) to avoid unreasonable extrapolation. The reported stocking levels for each treatment also reflect what sort of treatments are applied at different levels of stocking in an operational setting.

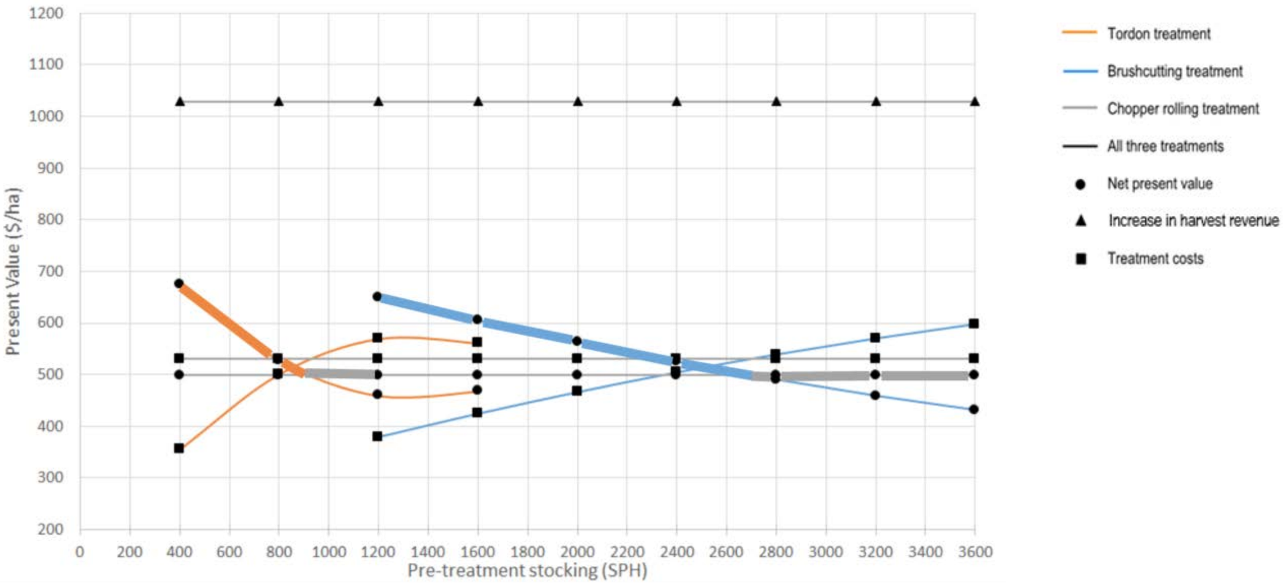


Figure 7.2. Net present value of silvicultural treatment scenarios by pre-treatment stocking.

Note: The bolded sections of the NPV estimates represent the highest NPV at a particular pre-treatment stocking.

All three treatment scenarios returned positive NPVs. For example, brushcutting at 1600 SPH made 5% (the discount rate) per annum on funds invested in the silvicultural treatment, plus an additional $600/ha. Figure 7.2 reveals how the financially optimal silvicultural treatment varies with pre-treatment stocking. In stands with stocking lower than approximately 900 SPH, the tordon treatment was found to produce the highest NPV. At stocking between 1200 SPH and 2800 SPH, brushcutting was found to have the highest NPV, and where stocking is greater than 2800 SPH, the chopper-rolling treatment was found to have the highest NPV. Figure 7.2 highlights that chopper-rolling also has the highest NPV between about 900 and 1200 SPH, although this is likely only because of scarce brushcutting data. At a pre-treatment stocking level of 1600 SPH, brushcutting resulted in a more favourable NPV than tordoning and chopper-rolling, by margins of \$139/ha, and \$108/ha respectively.

The cost of treatment was highest for the tordon treatment when compared to brushcutting and chopper-rolling at pre-treatment stockings between approximately 900 SPH and 1600 SPH. This resulted in lower NPVs for the tordon treatment at those pre-treatment stocking rates. This appears to be associated with the tordon treatment requiring higher non-labour costs associated with significantly ($P \leq 0.05$) higher chemical consumption per cut tree than the brushcutting treatment. The chopper-rolling treatment is not optimal until pre-treatment stocking reaches 2800 SPH. This is largely due to the costs of the re-treatment in year one.

The effect of the proportion of cut trees by DBH class on the NPV of the brushcutting treatment scenario

Figure 7.3 illustrates the sensitivity of the NPV of the brushcutting treatment scenario to the proportion of cut trees at least 10 cm DBH. For reference, the base case NPV for the tordoning and chopper-rolling silvicultural treatment scenarios as illustrated in Figure 7.2, are also illustrated in Figure 7.3. The negative relationship between the brushcutting NPV and the proportion of cut trees with a DBH of at least 10 cm was expected, because larger trees take considerably longer to fell with a brushcutter than small trees. The proportion of cut trees greater than 10 cm DBH was found to substantially alter the efficient treatment type for a given pre-treatment stocking. At zero stems greater than 10 cm DBH, brushcutting outperforms chopper-rolling for pre-treatment stocking levels up to 3600 SPH. At 20% of cut trees at least 10 cm DBH, chopper-rolling is financially superior to brushcutting when pre-treatment stocking exceeds 2400 SPH.

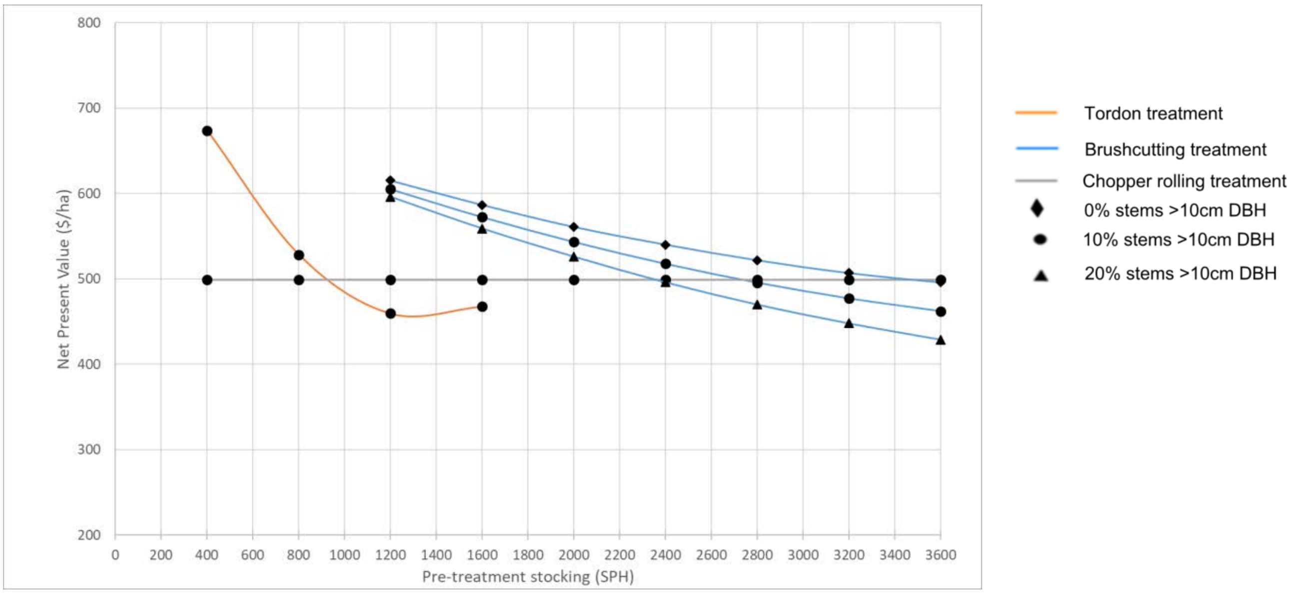


Figure 7.3. NPV of the brushcutting scenario when proportion of stems treated that are >10cm DBH represent 0%, 10% and 20% of the total treated stems.

Note: The tordoning and chopper-rolling scenarios are presented for comparison. No assessment was made at for different size classes in these scenarios.

Impact of discount rate on the financial performance of treatments

The NPV of all treatments remained positive at discount rates of 3%, 5% and 7%, for all pre-treatment stocking rates assessed (Figure 7.4). While NPV is substantially affected by the discount rate, the relative performance of each silvicultural treatment scenario was not sensitive to the discount rate. This is because the discounted re-treatment costs and harvest revenues for the three treatments are identical, with the exception of the re-treatment in year one for chopper-rolling. At a pre-treatment stocking of 400 SPH, the tordoning treatment generated a NPV that ranged from $376/ha at a 7% discount rate to $1124/ha at a 3% discount rate. At a stocking of 1200 SPH, the NPV of the brushcutting treatment ranged from $308/ha at a 7% discount rate to $1055/ha at a 3% discount rate.

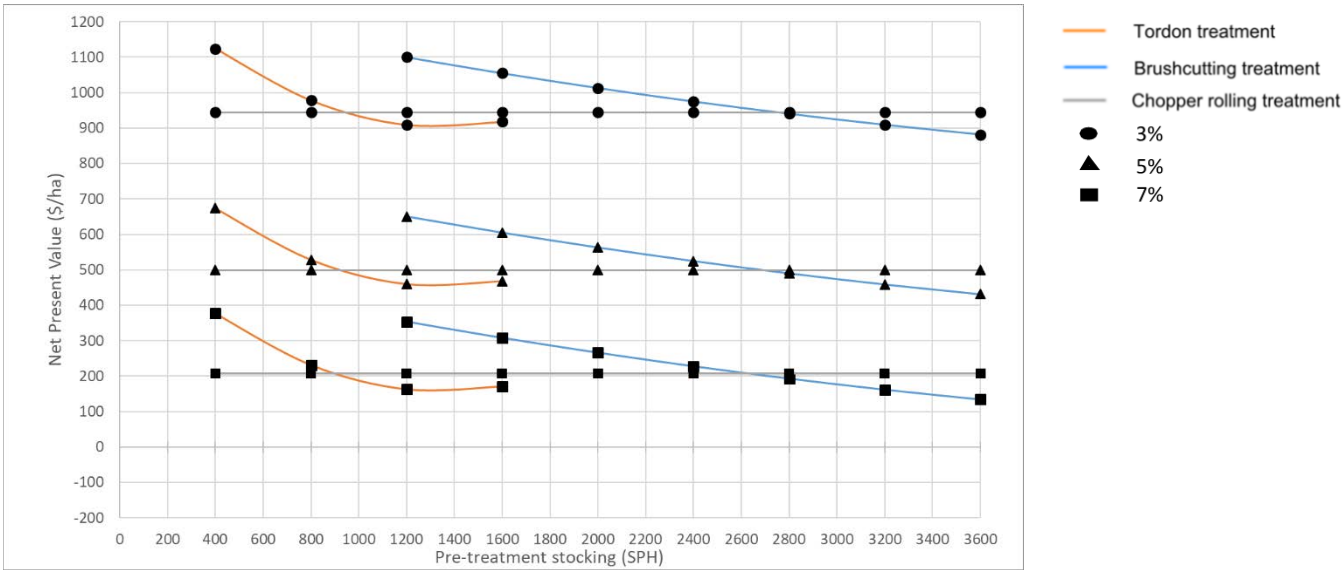


Figure 7.4. Sensitivity of the NPV of brushcutting, tordoning and chopper-rolling treatment scenarios to discount rates of 3%, 5% and 7%.

Sensitivity of NPV of silvicutural treatment scenarios to changes in MAI due to the treatment

As indicated in Figure 7.5, the NPV of all silvicultural treatment scenarios are highly sensitive to changes in MAI; however, the relative performance of the treatments are not affected. As such, at any particular initial stocking rate, the optimal treatment remains consistent irrespective of MAI growth rates following treatment. Notably, the increase in MAI due to the treatment needs to be at least about 0.65 m^3/ha/yr for any silvicultural treatment to be financially viable. A 50% increase over the base case MAI to 1.95 m^3/ha/yr approximately doubled the NPV of all silvicultural treatment scenarios irrespective of pre-treatment stocking.

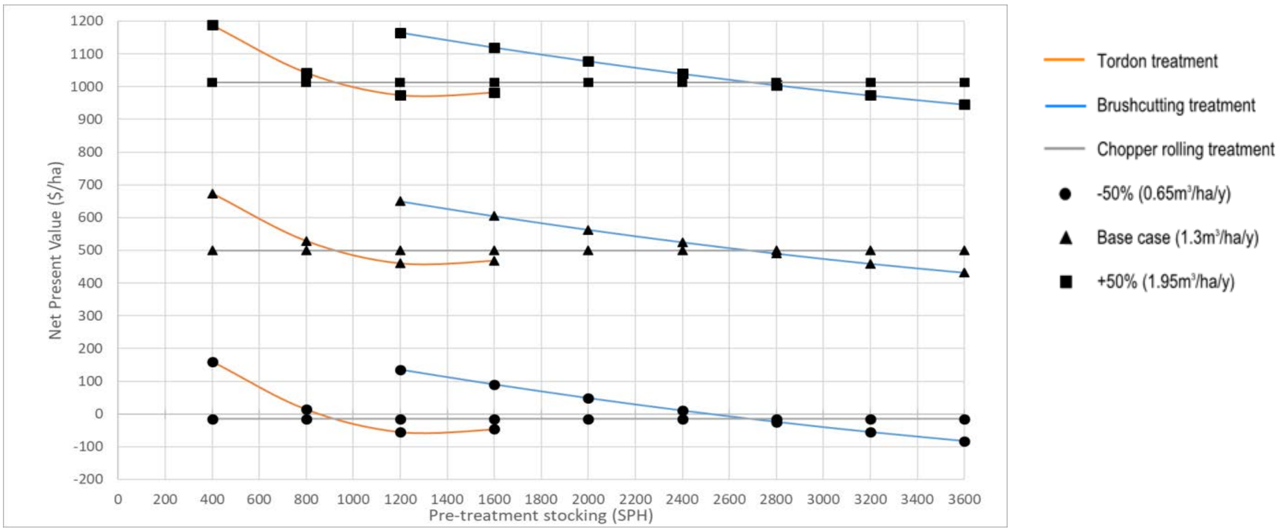


Figure 7.5. Sensitivity of the NPV of brushcutting, tordoning and chopper-rolling treatments to changes in MAI due to the silvicultural treatment.

Sensitivity of NPV of silvicultural treatment scenarios to log stumpage prices
Figure 7.6 indicates that increasing or decreasing the future stumpage prices by 30% results in the NPV of all treatments increasing or decreasing by around 50%, or \$310/ha. Therefore, if silvicultural treatments are able to improve the quality of log products at harvest, attracting a higher stumpage price, the overall financial performance of the treatments improves greatly. The NPV for all treatments remains positive when conservative future pole (\$105/m^3) and sawlog (\$70/m^3) values are applied.

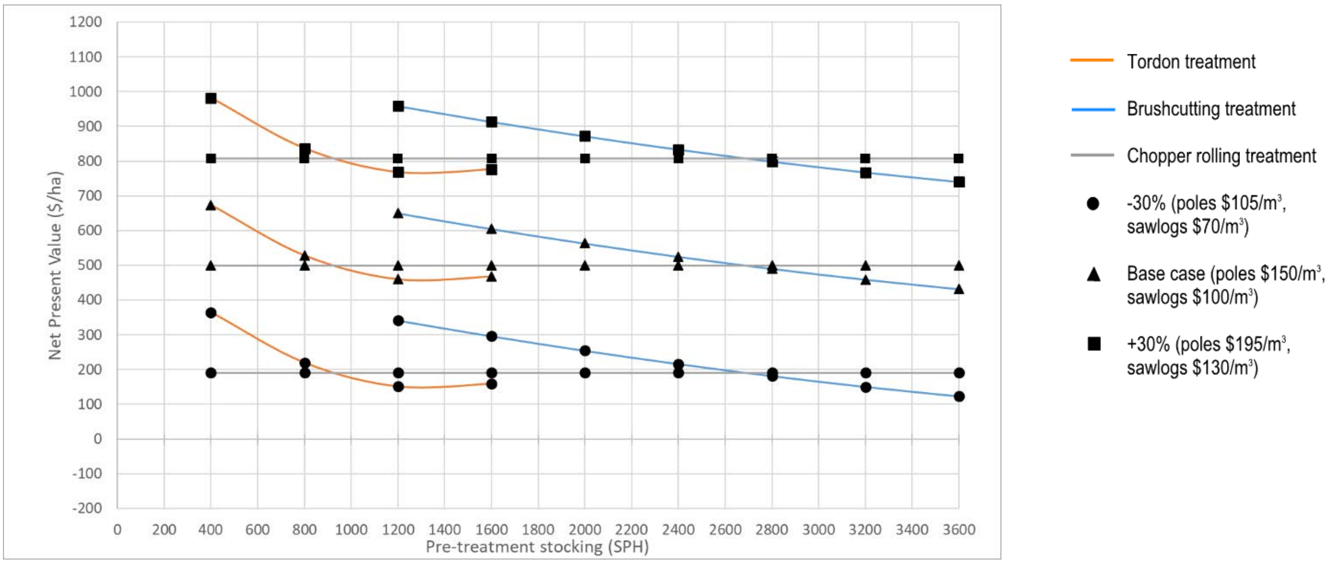


Figure 7.6. Sensitivity of the NPV of brushcutting, tordoning and chopper-rolling treatment scenarios to pole and sawlog stumpage price.

Sensitivity of NPV of silvicultural treatment scenarios to pole proportion at harvest
Figure 7.7 reveals that doubling the pole proportion to 20% of harvested volume and reducing pole proportion to 0% of the harvest volume changed the NPV of each silvicultural treatment scenario by ±\$50/ha. This suggests log prices and increase in MAI due to the treatment are likely to have a greater impact on NPV of silvicultural treatments than the proportion of the harvest that is poles.

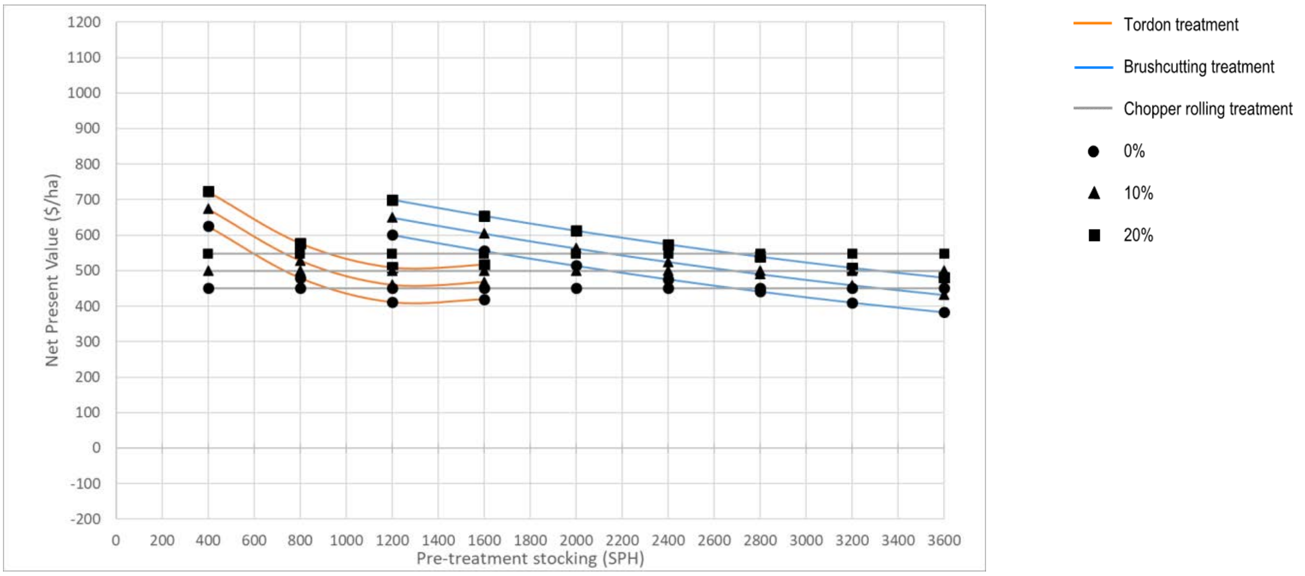


Figure 7.7. Sensitivity of the NPV of brushcutting, tordoning and chopper-rolling treatment scenarios to the proportion of poles at harvest.

Sensitivity of NPV of silvicultural treatment scenarios to labour rate in the first treatment

Figure 7.8 highlights that changing the labour rate of the initial treatment has a greater impact on the NPV of the tordoning and brushcutting treatment scenarios than chopper-rolling, because chopper-rolling uses substantially less labour time. The brushcutting treatment NPV is less sensitive to labour cost than the tordoning treatment, when compared at the same pre-treatment stocking. This is because the productivity of labour in the first treatment is lower for the tordoning treatment than the brushcutting treatment. At the labour rate of $35/h, chopper-rolling is never the financially optimal treatment for a landholder. At the high labour rate of $65/h, chopper-rolling is often the financially optimal treatment for the landholder (given the available data). At the high labour rate, chopper-rolling is superior to tordoning at pre-treatment stocking of between 800 and 1200 SPH, and is also superior to brushcutting when pre-treatment stocking exceeds 2000 SPH.

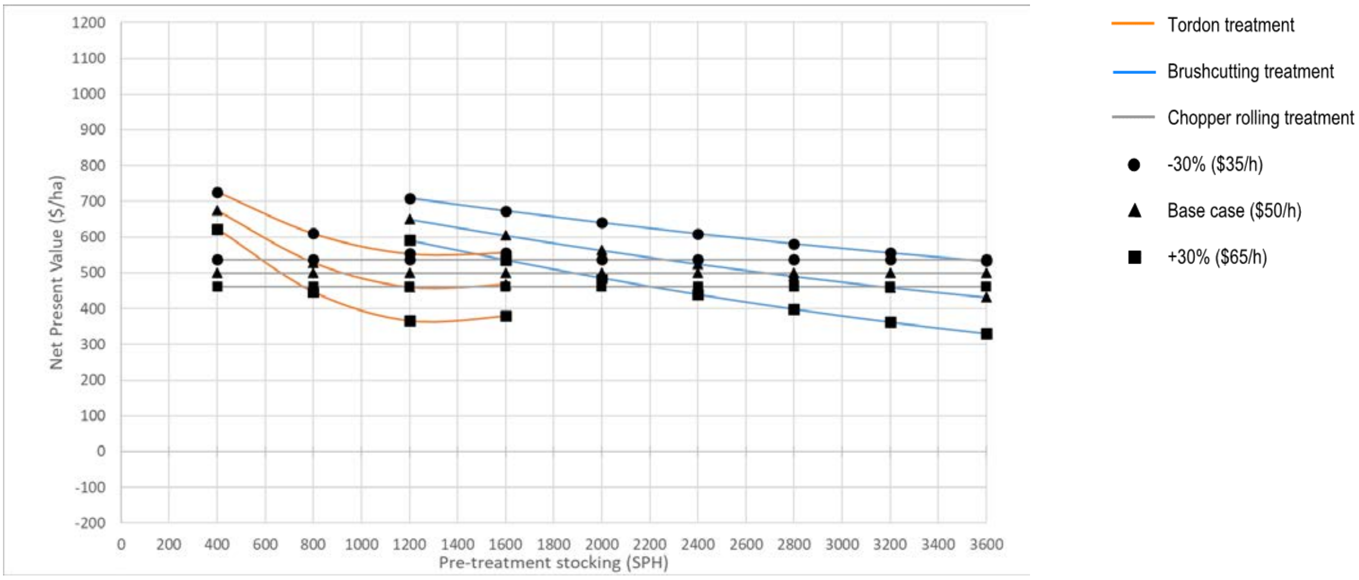


Figure 7.8. Sensitivity of the NPV of brushcutting, tordoning and chopper-rolling treatment scenarios to labour rate ($/h) in the first treatment.

Sensitivity of NPV of silvicultural treatment scenarios to re-treatment costs
The chopper-rolling treatment scenario has two re-treatments. Hence, the NPV of chopper-rolling is expected to be the most sensitive to re-treatment costs, as illustrated in Figure 9. A 30% change in chopper-rolling re-treatment costs represents a $117/ha change in NPV. If the chopper-rolling re-treatment costs could be reduced by 30%, chopper-rolling would be the financially optimal silvicultural treatment at most pre-treatment stocking levels assessed. Conversely, if the base case re-treatment costs for chopper-rolling have been underestimated by 30%, chopper-rolling is never the financially optimal silvicultural treatment. Re-treatment costs are less important for the brushcutting and tordoning scenarios and their financial performance relative to each other is not affected by changes in re-treatment costs.

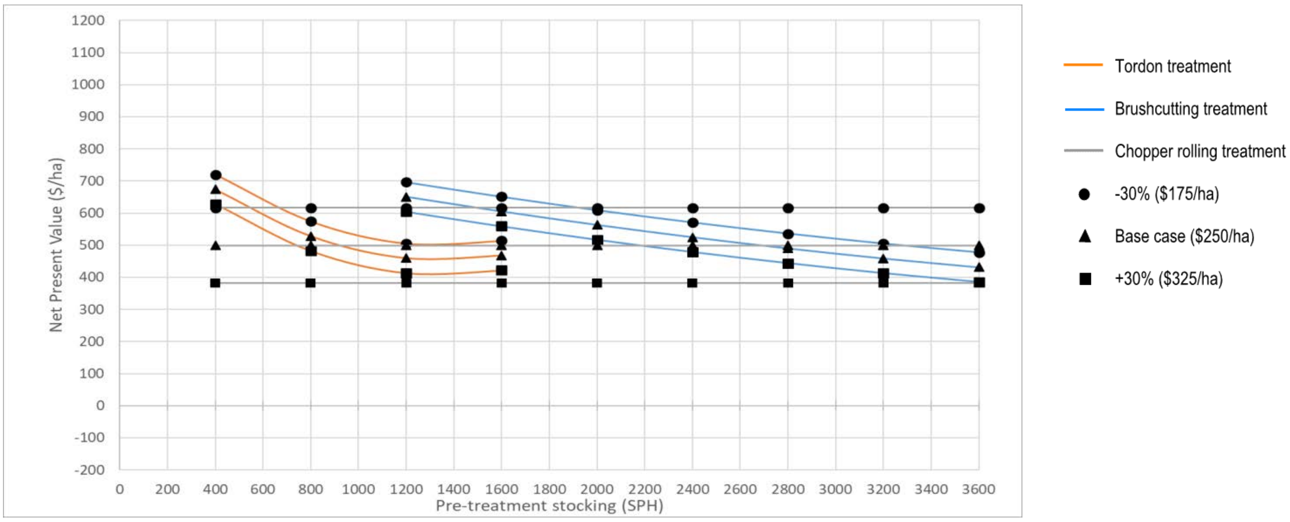


Figure 7.9. Sensitivity of the NPV of brushcutting, tordoning and chopper-rolling treatments to future re-treatment costs.

Summary of key findings

Findings need to be interpreted cautiously given limitations outlined in the following section. Nevertheless, the analysis has revealed that silvicultural treatments are financially viable, even at a 7% discount rate, so long as growth following treatment is at least about 0.65 m^3/ha/yr greater than for no-treatment. In forest stands where the pre-treatment stocking is low (i.e. <600 SPH), tordoning appears to be financially optimal. Although the financial performance of brushcutting has not been estimated for stocking levels less than 1200 SPH due to limited data, it is conceivable that the financial performance of brushcutting will exceed that of todoning from a pre-treatment stocking of somewhere between 600 and 1200 SPH until about 2800 SPH. Chopper-rolling becomes financially optimal at stocking levels greater than 2800 SPH.

The financial performance of tordoning relative to brushcutting and chopper-rolling was similar, irrespective to level of the model parameters investigated. However, the relative performance of brushcutting and chopper-rolling are sensitive to changes in particular parameter estimates. For example, if all treated stems are less than 10 cm DBH, brushcutting appears to be financially superior to chopper-rolling at stockings up to 3600 SPH. If the labour rate is lower or the re-treatment cost higher than the base case levels examined in this study, the financial performance of brushcutting will exceed that of chopper-rolling for all stocking levels examined.

From all the sensitivity analyses performed, the most financially favourable outcome recorded was for the tordoning treatment at a pre-treatment stocking of 400 SPH, when the increase in MAI was 1.95 m^3/ha/yr, which resulted in an NPV of $1188/ha. The worst was brushcutting at a pre-treatment stocking of 3600 SPH when the increase in MAI was only 0.65 m^3/ha/yr, with an NPV of –$82/ha.

Limitations and further work

With data collected at only four plots for the brushcutting and tordoning treatments, limited variation in pre-treatment stocking was available. Further plot data would increase the precision of treatment cost estimates and allow better comparison between treatment scenarios at alternative pre-treatment stocking levels. Ideally tordoning treatments could be assessed at sites with higher stocking levels (e.g. up to 2000 SPH) while brushcutting treatments could be assessed at sites with lower stocking levels (e.g. down to 600 SPH). As additional plot data are collected over time, it is anticipated that the spreadsheet model will be further developed.

At the time of publication, scarce silvicultural treatment data means there are important limitations to the assessment. Only the brushcutting treatment data facilitated an assessment of how tree size class affects treatment costs and NPV. Therefore, it has not been possible to empirically evaluate which treatment scenario is optimal based on the DBH distribution of cut stems within a stand. Further fieldwork in plots with alternative tree size distributions would be beneficial for further model development. For example, the financial model presently cannot directly account for what typically occurs in operational settings, where tordoning is the financially optimal treatment in stands dominated by large (i.e. >20 cm DBH) stems. Forests with lower tree stocking do tend to have a higher proportion of larger trees, so the model may be indirectly accounting for the effect of tree size with tree stocking, but further research is necessary. While the models account for pre-treatment stocking, some other environmental factors, such as topography, can affect the technical feasibility of treatment methods, and this has not been accommodated in the analysis. Hence, practitioners should determine the most appropriate treatment option feasible for a site.

Currently, the native forest silvicultural treatment response model developed as part of the larger project is parameterised for spotted gum forests only. Thus, the analyses presented in this report are most applicable to spotted gum forests. It would be useful to further develop the silvicultural treatment response model to accommodate other forest types. Another limitation with the response model is that it cannot account for the re-treatment at year 10 and is therefore likely to underestimate growth response to the silvicultural treatment scenarios examined.

Conclusions

The aim of this chapter was to assess the financial performance of three silvicultural treatment scenarios in private native forest. The three treatment options, brushcutting, tordoning and chopper-rolling, are typically used in different situations, depending on the size class distribution of the stand (and other factors such as topography). Investment in all three treatment scenarios was found to be profitable over a 20-year harvest period. The growth response to treatments had the largest impact on NPVs, but other factors including the discount rate, labour costs, future stumpage price and re-treatment costs were also important. The collection of additional plot data will allow for further development of the silvicultural treatment growth response model and the financial performance spreadsheet model. In particular, it will be helpful to collect silvicultural treatment costs data for a greater range of pre-treatment stockings.

Chapter 8: Economic case studies for individual properties

Ben Francis, Tyron Venn, Tom Lewis and Jeremy Brawner

Introduction

Private native forests contribute an important source of timber to the timber processing industry, and if well managed they will likely provide ongoing resources to the timber industry and strong financial returns to landholders. It is generally acknowledged within the timber industry that silvicultural treatments could substantially increase the productivity of private native forests. Re-measurement of permanent monitoring plots has revealed that silvicultural treatment can enhance the growth of retained trees (Chapter 5). Other studies have also shown that the diameter growth of retained trees in thinned native forest stands is higher than un-thinned stands (Forrester et al. 2010; Bai et al. 2013), but information on the financial performance of silvicultural treatments is scarce.

Ryan and Taylor (2006), found that harvest revenues exceeded the cost of silvicultural treatments in a case study of overstocked spotted gum in private native forests in south east Queensland, describing the operation as profitable. However this assessment did not carry out a discounted cash flow analysis, and therefore did not consider whether the upfront cost of investment in silvicultural treatment provided a sound return over time. Additionally, it is anticipated that potential returns to silvo-pastoral systems, where grazing and timber production occur concurrently, are greater than grazing or timber alone in the medium and long-term (discussed further in chapter 4 and 9). However, the financial performance of silvo-pastoral systems in the sub-tropics and tropics of Australia is poorly understood (Donaghy et al. 2010) and literature on the financial performance of silvo-pastoral systems in Queensland is scarce.

This chapter assesses the potential financial performance of silvicultural treatments in private native forests, in terms of increased timber and cattle production for four case study properties.

Methods

Case study properties were selected based on forest type and available forest inventory data. Properties dominated by spotted gum forests were selected, because the silvicultural treatment response model (see Chapter 5) has been largely developed from spotted gum forest data. Inventory data utilised in this assessment was collected by PFSQ and DAF. This inventory data classifies logs to industry product standards. The properties are situated at Gayndah, Doughboy, Glenbar and Rathdowney in the South East Queensland and Wide Bay-Burnett regions as illustrated in Figure 8.1.

Interviews were conducted with each landholder to determine historic and current forest management. The properties vary in terms of their primary enterprise, with the property at Rathdowney focusing on dairy, the property at Gayndah focusing on beef cattle grazing, and the properties at Doughboy and Glenbar focusing on timber production, with the latter being a self-managed superannuation investment. The Doughboy and Rathdowney properties also graze beef cattle in their native forests, although this is not the primary focus of their enterprise. The owner of the Glenbar property is interested in incorporating beef cattle grazing in the future.

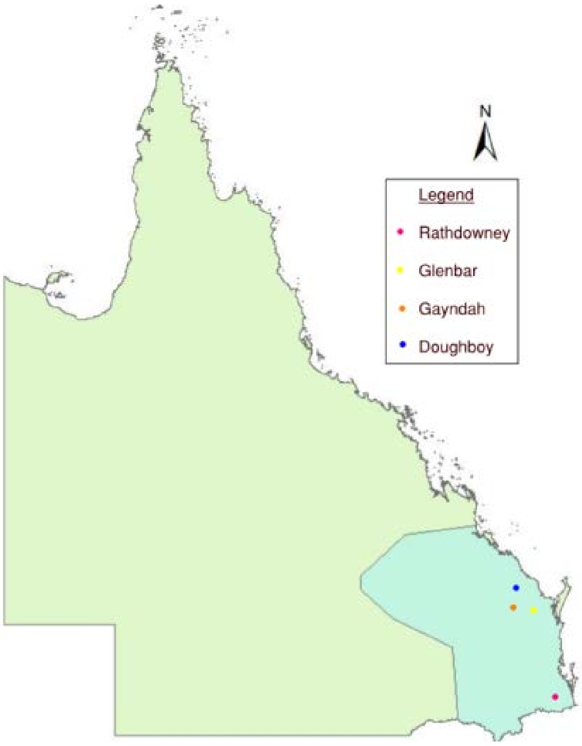


Figure 8.1. Case study locations.

Five forest management scenarios were assessed for three of the case study properties over a 20 year investment period.

1) Clear forest for grazing;
2) No silvicultural treatment or harvesting in 2019, followed by a harvest in 2038;
3) Silvicultural treatment in 2019, and harvest in 2038;
4) Harvest in 2019, and harvest in 2038; and
5) Silvicultural treatment and harvest in 2019, followed by a harvest in 2038.

There was insufficient merchantable timber identified during the inventory at the Rathdowney property to support a harvest in 2019. As such, only the above scenarios 1 to 3 were assessed for that site.

The assessment was restricted to regrowth forest, as there is presently greater confidence in the projected growth response of regrowth forests to thinning treatments within the decision support tool used for analysis. The financial performance of each management scenario for the regrowth (Category X) forest on each property was evaluated utilising the decision support tool described in Chapter 5. It is assumed that cattle are grazed in all scenarios, and grazing is assessed concurrently with timber production in scenarios 2 to 5.

The inventory data collected on each property determined what forest would be silviculturally treated, harvested or retained in 2019 depending on the forest management scenario. Then the decision support tool was used to simulate the growth of the stand for 20 years to 2038. The outputs from the decision support tool provided anticipated merchantable timber volumes by product for each scenario in 2038. For analysis purposes, it has been assumed that up to 80% of the standing volume of the regrowth forest greater than 30 cm diameter at breast height

(DBH) could be harvested in 2038, given that the simulations are for Category X (unregulated) regrowth forest.

The effect of each of management scenario on cattle carrying capacity was assessed over a 20 year period with the decision support tool, which has inputs from the Queensland Government grass production model (GRASP). The selection of land type, which is necessary for parameterisation of the GRASP model, was determined by FORAGE Property Reports for each case study property through the Queensland Government Long Paddock website.

A discounted cash flow analysis to assess the financial performance of each management scenario was conducted using a discount rate of 5%. The timber product and volume outputs from the decision support tool were adopted to assess 2019 and 2038 timber revenues, and the potential cattle carrying capacity estimated by the decision support tool was adopted to estimate potential grazing revenues. Key cost and revenue parameters utilised in this analysis, and the justification of each parameter are detailed in Table 8.1. The analysis has not accommodated income taxes and tax deductions. Forest management recommendations have been made on the basis of this analysis.

Key characteristics for the four case study properties are presented below in Table 8.2.

Table 8.1. Parameters utilised in the financial analysis of forest management scenarios.

Parameter	Year	Level
Discount rate		5%
Forestry		
Paint marking of retained trees not (silviculturally treated) in 2019 $(\$/\text{ha})$[a]	0	100
Contract tordoning silvicultural treatment cost $(\$/\text{ha})$ [a]	0	350
Stumpage prices $(\$/\text{m}^3)$ [a]	20	
Sawlog 2019 and 2038 (no silvicultural treatment)		80
Sawlog 2038 (following silvicultural treatment in 2019)		100
Pole $(\$/\text{m}^3)$		150
Other $(\$/\text{m}^3)$		
Salvage class logs		20
Pile		30
Fencing		35
Grazing		
Land clearing and pasture establishment costs ($/ha [a])	0	500
Cattle annual feed requirement (kg/adult equivalent) [a]	Every year	3650
Liveweight gain per adult equivalent (kg/yr) [a]	Every year	100 – 150[b]
Liveweight farmgate price ($/kg)[c]	Every year	2.54

Notes: a. Expert opinion from project partners

b. Varies for each site based on pasture quality. Glenbar 130 kg/yr, Gayndah 150 kg/yr, Doughboy 150 kg/yr and Rathdowney 100 kg/yr.

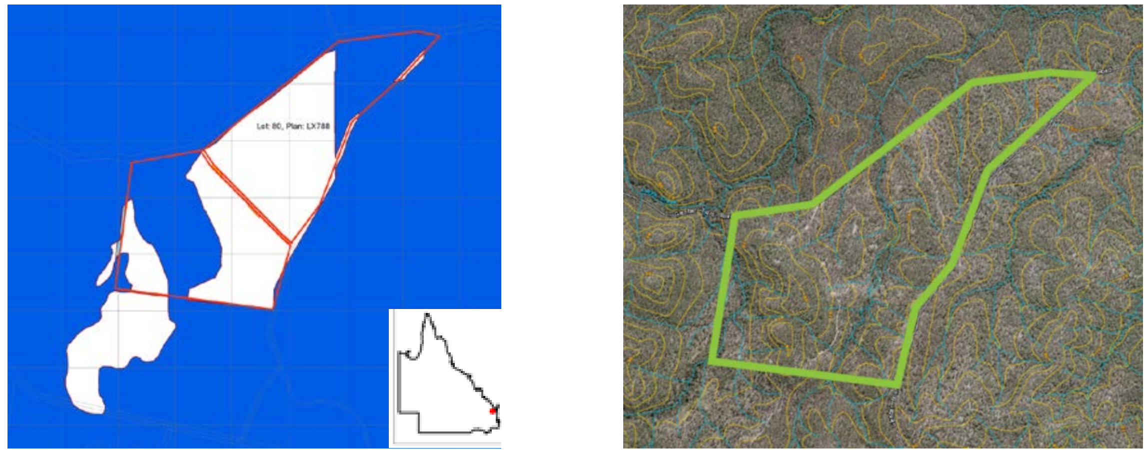
c. Weighted average price derived from meat and livestock saleyard reports for Manufacturing Steers, Grown Heifers, Vealer Heifers, Vealer Steers, Yeerling Steers, Yearling Heifers, Bulls and Cows between 2015 and 2018 for Rockhampton and Toowoomba markets (https://www.mla.com.au/prices-markets/market-reports-prices/).

Table 8.2. Characteristics for the four case study properties.

Property Characteristic	**Glenbar (Case Study 1)**	**Gayndah (Case Study 2)**	**Doughboy (Cast Study 3)**	**Rathdowney (Case Study 4)**
Property size and composition	303 ha, comprising approximately 187 ha of regrowth forest (category X), 116 ha remnant forest (category B)	10,000 ha, comprising approximately 3,050 ha of regrowth forest (category X), 450 ha cleared for grazing, 6,400 ha remnant forest (category B), and 100 ha of high value regrowth (category C)	1500 ha, comprising approximately 680 ha of regrowth forest (category X), 760 ha remnant forest (category B) and 60 ha of high value regrowth forest (category C)	455 ha, comprising around 303 ha categorised as category X, with around 133 ha of that area cleared for grazing and 170 ha as regrowth forest, as well as 152 ha of remnant forest (category B)
Management objective	Long-term returns from timber production to support a self-managed superannuation investment	Long-term returns from timber production to supplement grazing	Long-term returns from timber production, with a focus on pole production	Long-term returns from timber production to supplement dairy and grazing enterprise
Mean annual rainfall	968 mm	613 mm	958 mm	906 mm
Terrain and elevation	Predominantly flat to gently undulating. 50 to 90 m above sea level	Gently undulating with some hilly areas, from around 200 m to 400 m above sea level	Undulating, ranging from 170 m to 500 m above sea level	Predominantly flat to gently undulating ranging from approximately 80 m to 200 m to above sea level
Landuse	Formerly grazed and harvested for timber production. The property is not presently generating an income stream	The property is primarily run as a cattle grazing enterprise, with supplementary timber production	Formerly grazed and harvested for timber production. The property is primarily run as timber production enterprise with supplementary grazing	The property is primarily run as a dairy enterprise. Outside the cleared and irrigated area, the property is managed for beef cattle grazing and timber
Dominant timber species	Spotted gum (*Corymbia citriodora*), grey ironbark (*Eucalyptus siderophloia*), narrow-leaved red ironbark (*Eucalyptus crebra*), yellow stringybark (*Eucalyptus acmenoides*), and forest red gum (*Eucalyptus tereticornis*)	Spotted gum, narrow-leaved red ironbark, yellow stringybark, gympie messmate (*Eucalyptus cloeziana*), yellow bloodwood (*Corymbia trachyphloia*), gum-topped box (*Eucalyptus moluccana*) and forest red gum	Spotted gum, narrow-leaved red ironbark, yellow stringybark, pink (*Corymbia intermedia*) and yellow bloodwood, gum-topped box and forest red gum	Spotted gum, narrow-leaved red ironbark and gum top box

Case study 1. Self-managed superannuation investment

The Case Study site is located within the Gympie region. The property layout, as well as vegetation mapping, topography and drainage is presented below in Figure 8.2.



🟦 Category B area (Remnant vegetation)

☐ Category X area (Exempt clearing work on Freehold, Indigenous and leasehold land)

Figure 8.2. Property map, showing regulated (Category B) and unregulated (Category X) areas.

Financing the purchase of forest land with superannuation

The property was purchased by the current landholder in 2016 as a long term superannuation investment. The property was set up as a self-managed superannuation fund (SMSF) with the assistance of the landholder's accountant. The SMSF purchased the property, which is in turn held by a property trust that the property owner is the trustee of. The property trust leases the property to a separate sole trader forestry business set up by the landholder. The regulatory requirements of a SMSF are that a property can only be purchased in this way where it produces income at a commercial rate. The current arrangement is that the SMSF earns a commercial income from the lease to the sole trader forestry business.

The landholder's sole trader forestry business carries out forestry operations on the leased land to generate future income from the sale of logs. Provided these operations are financially viable in the long term, forest management expenses incurred can be deemed tax deductable by the Australian Taxation Office (ATO). Private Forestry Service Queensland (PFSQ) provided an independent forestry assessment that was used the landholder's sole trader business to successfully apply for an ATO ruling that allows any costs associated with timber production on the property (e.g. silvicultural treatment) as a tax deduction against the landholder's off-farm income.

Forest condition

Under previous owners, timber has been periodically harvested without follow-up silvicultural treatment. The most recent harvest was probably between about 2007 and 2010, and removed most available merchantable logs that could be harvested within the regulations. This resulted in an open forest canopy and significant regeneration with a current stocking of around 540 to 750 stems per ha (SPH). About 80% of the stems are less than 15 cm diameter at breast height (DBH). At this level of stocking, competition for soil moisture and nutrients will substantially inhibit the timber production potential unless silvicultural treatments are conducted. Some silvicultural treatments have since been applied on the property (Figure 8.3).

Figure 8.3. A regrowth stand on the property that hasn't been silviculturally treated (left), and a treated stand (right)

Projected financial performance of forest management scenarios

Figure 8.4 illustrates the projected cattle carrying capacity for regrowth forest for each management scenario over the period 2019 (year 1) to 2038 (year 20). As expected, carrying capacity (stocking rate) is maximised by clearing the forest, and declines over time as the trees grow in the other scenarios. Silvicultural treatment and harvesting together in 2019 approximately doubles the cattle carrying capacity relative to no silvicultural treatment and no harvest in 2019, with the difference decreasing over time.

Figure 8.5 illustrates current and projected regrowth forest structure and volumes. The first row of charts describes the distribution of stems in 2019 by DBH class and management scenario. The second and third rows of charts indicate retained, thinned and harvested volumes in 2019 and 2038. The third row of charts also includes the simulated mean annual increment (MAI) of merchantable timber between 2019 and 2038, which indicates that silviculturally treated stands on the Glenbar property will grow timber at about twice the rate of untreated stands. This is evident in substantially higher projected pole and sawlog volume in 2038.

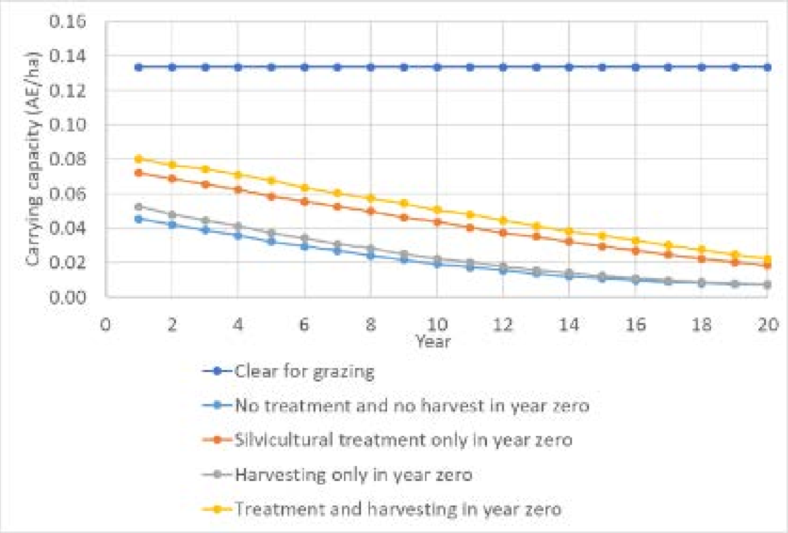
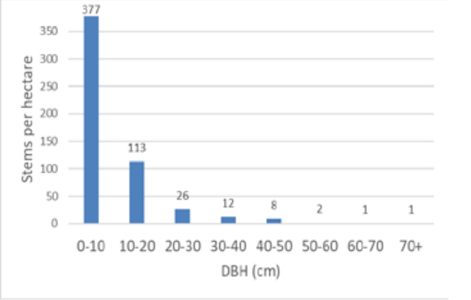
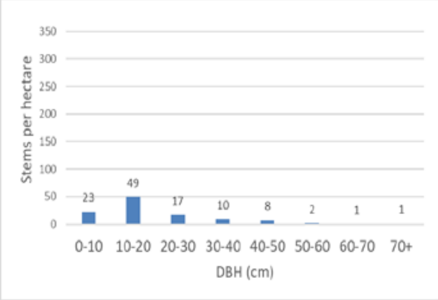
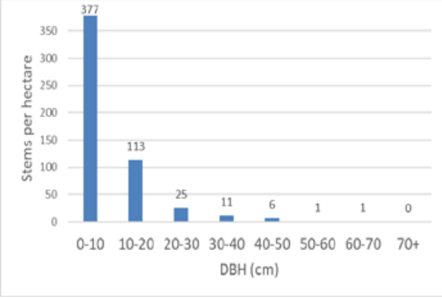
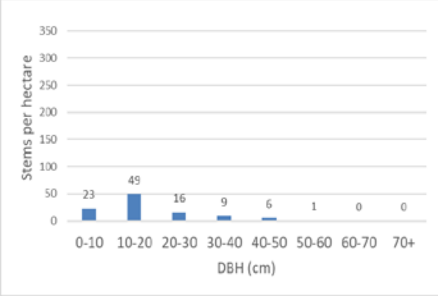
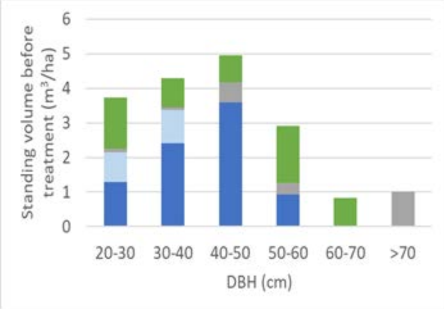
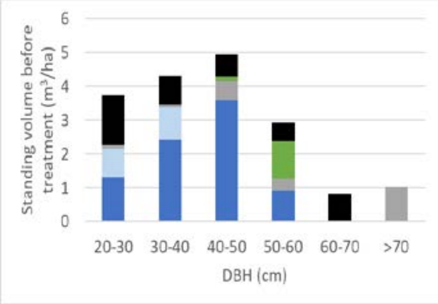
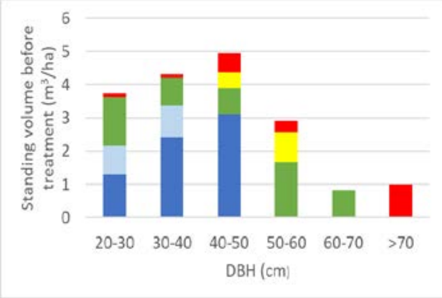
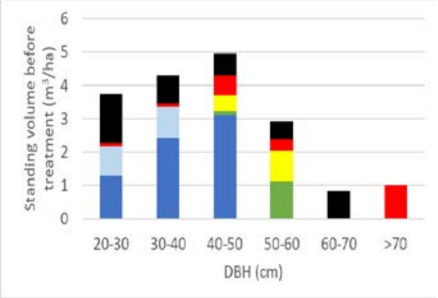
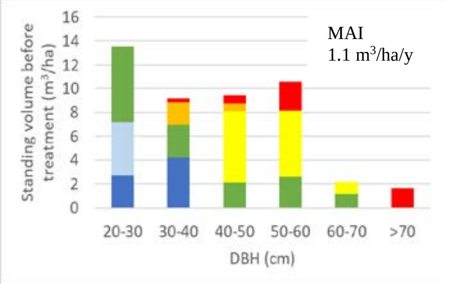
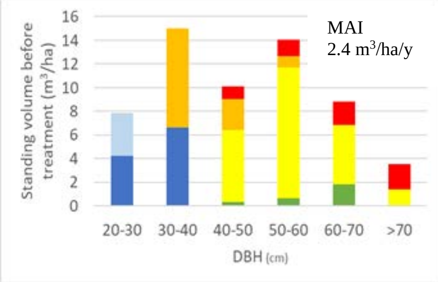
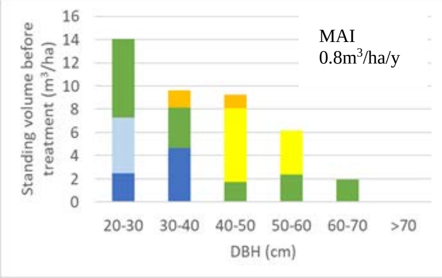
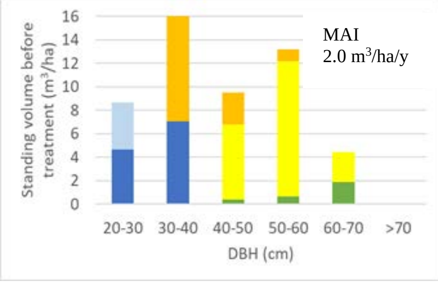


Figure 8.4. Projected cattle carrying capacity in regrowth forest between 2019 (year 1) and 2038 (year 2038).

	Forest management scenario			
	Scenario 2. No silvicultural treatment and no harvest in 2019	Scenario 3. Silvicultural treatment only in 2019	Scenario 4. Harvest only in 2019	Scenario 5. Silvicultural treatment and harvest in 2019
DBH distribution after management in 2019				
Retained, thinned and harvested volume in 2019				
Retained and harvested volume in 2038	 MAI 1.1 m^3/ha/y	 MAI 2.4 m^3/ha/y	 MAI 0.8m^3/ha/y	 MAI 2.0 m^3/ha/y

■ Retained sawlog
■ Retained pole
■ Retained other merchantable
■ Retained unmerchantable
■ Harvested sawlog
■ Harvested pole
■ Harvested other merchantable
■ Thinned unmerchantable

Figure 8.5. Current and projected stand structure and product volumes in regrowth forest on the Glenbar property.

Notes: The legend applies to the bottom two rows of charts only. "Other merchantable" are piles, fencing and salvage logs. MAI is for retained stems over the period 2019 to 2038.

Figure 8.6 illustrates the present values (PV) of costs and revenues per hectare for a real (net of inflation) discount rate of 5% per annum. The net present value (NPV) for each management scenario is equal to the sum of the present values of grazing and timber costs and revenues for that scenario. Table 8.3 reports total projected cash flows and NPV for the regrowth forests on the property. The treatment and harvest in 2019 scenario was found to have the highest NPV at $1432/ha. This result is interpreted as follows. The investment in silvicultural treatment and a harvest operation 2019 yielded a real 5% per annum rate of return, plus $1432/ha on top of that in the regrowth vegetation. In contrast, clearing for grazing alone generated a NPV of only $49/ha, thus being substantially less profitable over the 20-year period than managing the regrowth forest for mixed grazing and timber production.

Table 8.3. Cash flow over 20 years and net present value (NPV) by management scenario for 187 ha of regrowth forest.

Financial performance criterion	Cash flow 2019–2038 and NPV by management scenario				
	1. Clear for grazing	2. No treatment and no harvest in 2019	3. Silvicultural treatment only in 2019	4. Harvest only in 2019	5. Treatment and harvest in 2019
Cash flow	71,000	316,000	786,000	339,000	803,000
NPV	9,000	128,000	260,000	138,000	269,000

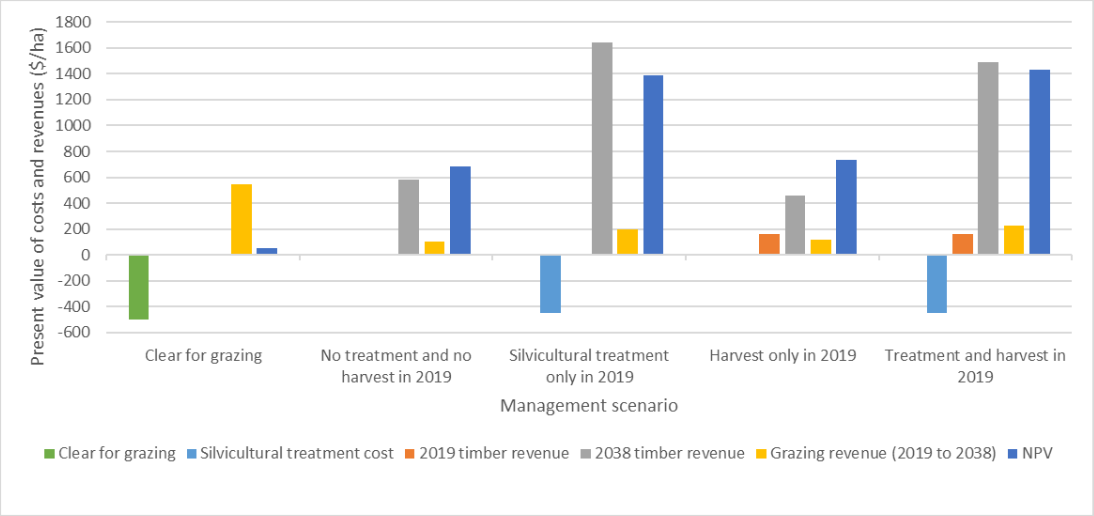


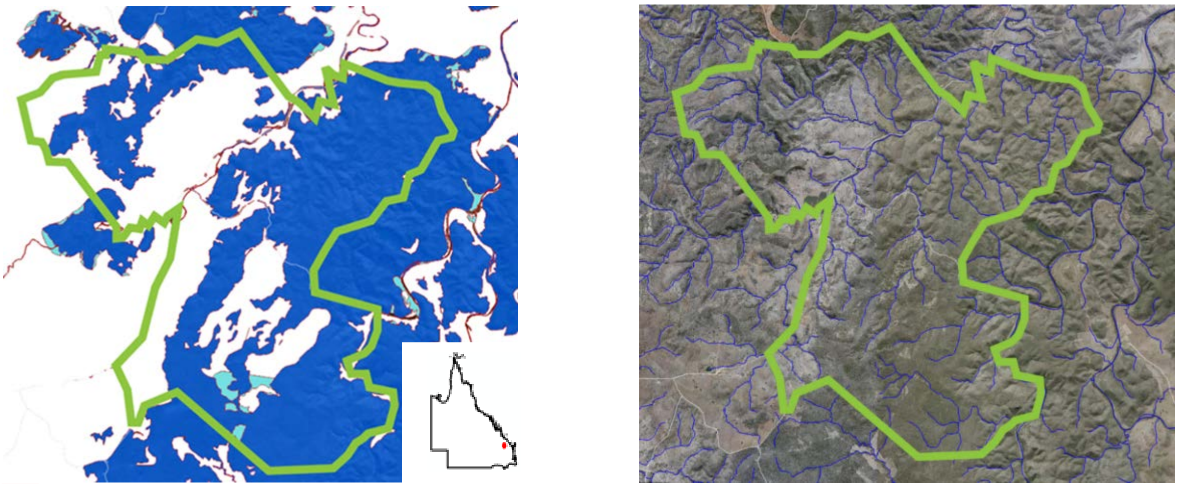
Figure 8.6. Present value of costs and revenues per hectare by management scenario for regrowth forest.

Property management recommendation

Both forest management scenarios with investment in silvicultural treatment in 2019 are expected to generate substantially higher returns for the landholder over the next 20 years in the regrowth forest than the remaining scenarios. However, almost all of the revenues will be received in 2038. The two forest management scenarios that do not include a silvicultural treatment in 2019 are expected to generate substantially less revenue over 20 years because of the residual stocking of non-merchantable stems in 2019, which is projected to reduce MAI. Clearing regrowth for grazing will generate modest annual income, although it is the least financially rewarding management scenario over 20 years. The landholder does not rely on the regrowth forest for an annual income, so the optimal management strategy is to harvest and silviculturally treat the forest in 2019. Proceeds from the harvest in 2019 can be utilised to offset silvicultural treatment costs. This option will also facilitate future grazing on the property, if desired by the landholder, by increasing available grass under more widely spaced trees.

Case study 2. Supplementary income

The Case Study site is located in Gayndah, North West of Gympie. The property layout, as well as vegetation mapping and drainage is presented below in Figure 8.7. The property has been managed by the same family for around 100 years.



🟦 Category B area (Remnant vegetation)
☐ Category X area (Exempt clearing work on Freehold, Indigenous and leasehold land)
🟦 Category C (High-value regrowth)

Figure 8.7. Property map for case study 2, showing regulated (Category B and C) and unregulated (Category X) areas.

Forest condition

Timber has been periodically harvested with follow-up silvicultural treatment to retain quality trees and reduce competition for water and nutrients. The most recent harvests were between 2001 and 2003, and in 2007, with a total of about 4000 ha harvested. This resulted in an open forest canopy in the harvested areas and significant regeneration response.

In 2008, AgForests and the Department of Agriculture and Fisheries (DAF) established silvicultural thinning treatment trials on the property. The landholder then engaged a tordon contractor to treat more of their forest for timber production. Between 2009 and 2010, 500 ha of regrowth forest was treated though tordon stem injection. On average, the forest was thinned from between 350 and 400 stems per hectare (SPH) to around 120 stems per hectare (Figure 8.8). In 2016, DAF remeasured the trial plots and found that the treated plots were growing at a substantially faster rate than untreated plots. The landholder is very happy with the outcomes of the thinning treatments. He has noticed an improvement in the tree crowns, increased growth rates compared with the untreated areas, and that the general quality and straightness of the trees in treated areas is superior to untreated areas. Acknowledging the benefits of the thinning treatments, the landholder intends to utilise a portion of the profits from their grazing enterprise to fund further treatments in the near future.

Figure 8.8. Forest regrowth stand that has not been silviculturally treated (left), and a stand treated with tordon (right).

Projected financial performance of forest management scenarios

Figure 8.9 illustrates the projected cattle carrying capacity (stocking rate) for regrowth forest for each management scenario over the period 2019 (year 1) to 2038 (year 20). As expected, carrying capacity is maximised by clearing the forest, and declines over time as the trees grow in the other scenarios. Silvicultural treatment and harvesting in 2019 approximately doubles the cattle carrying capacity over both the no treatment and no harvest scenario and the harvest only in 2019 scenario. This trend continues over the 20 year period, with the difference decreasing over time as the trees grow in the treated scenarios.

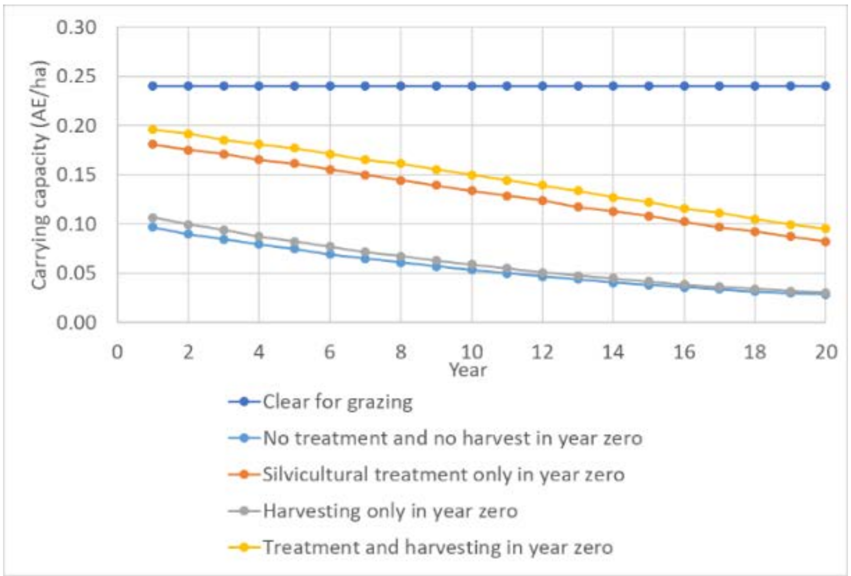
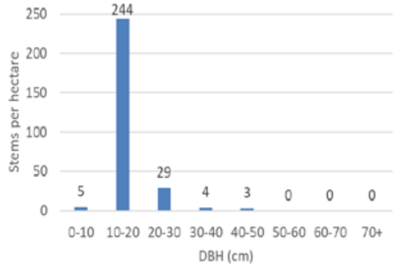
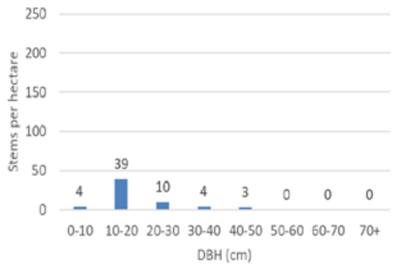
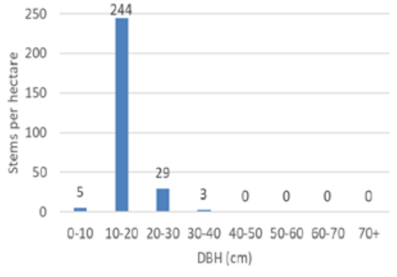
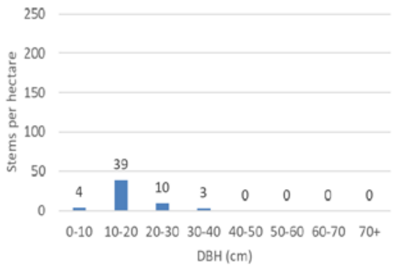
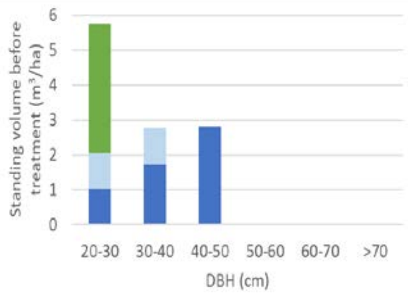
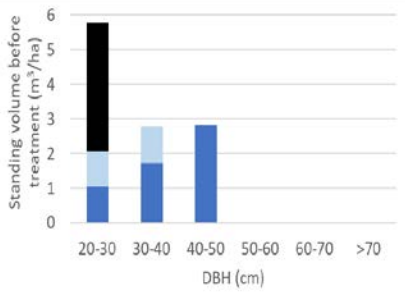
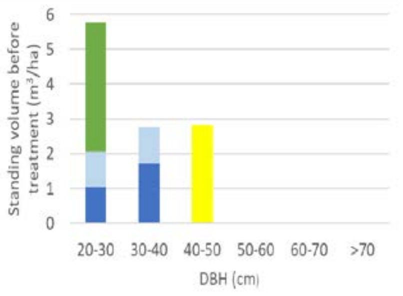
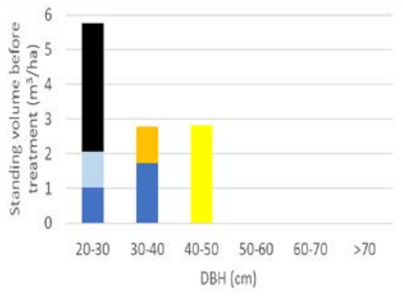
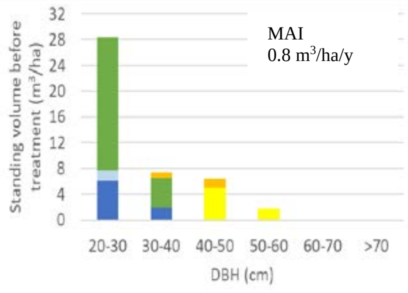
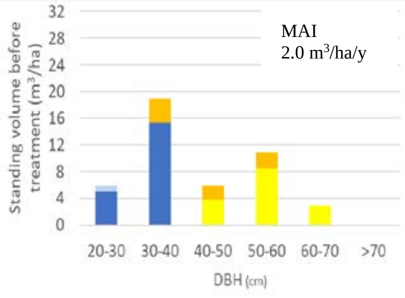
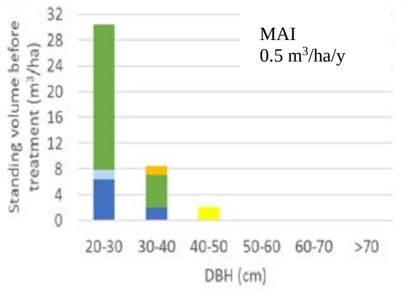
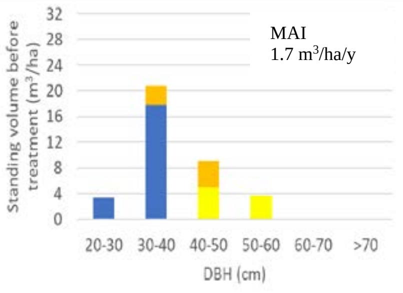


Figure 8.9. Projected cattle carrying capacity in regrowth forest between 2019 (year 1) and 2038 (year 20).

Figure 8.10 illustrates current and projected regrowth forest structure and volumes. The first row of charts describes the distribution of stems in 2019 by DBH class and management scenario. The second and third rows of charts indicate retained, thinned and harvested volumes in 2019 and 2038. The third row of charts also includes the simulated mean annual increment (MAI) of merchantable timber between 2019 and 2038, which indicates that silviculturally treated stands on the property are anticipated to grow timber at more than twice the rate of untreated stands. This is evident in substantially higher projected sawlog and pole volumes in 2038.

	Forest management scenario			
	Scenario 2: No silvicultural treatment and no harvest in 2019	Scenario 3: Silvicultural treatment only in 2019	Scenario 4: Harvest only in 2019	Scenario 5: Silvicultural treatment and harvest in 2019
DBH distribution after management in 2019				
Retained, thinned and harvested volume in 2019				
Retained and harvested volume in 2038				

■ Retained sawlog ■ Retained pole ■ Retained other merchantable ■ Retained unmerchantable

■ Harvested sawlog ■ Harvested pole ■ Harvested other merchantable ■ Thinned unmerchantable

Figure 8.10. Current and projected stand structure and log volumes in regrowth forest on the property.

Notes: The legend applies to the bottom two rows of charts only. “Other merchantable” are piles, fencing and salvage logs. MAI is for retained stems over the period 2019 to 2038.

Figure 8.11 illustrates the present values (PV) of costs and revenues per hectare for a real (net of inflation) discount rate of 5% per annum. The net present value (NPV) for each management scenario is equal to the sum of the present values of grazing and timber costs and revenues for that scenario. Table 8.4 reports total projected cash flows and NPV for the regrowth forests on the property. The treatment and harvest in 2019 scenario was found to have the highest NPV in the regrowth forest at $1306/ha. This result is interpreted as follows. The investment in silvicultural treatment and a harvest operation in 2019 yielded a real 5% per annum rate of return, plus $1306/ha on top of that. In contrast, investment in land clearing and pasture establishment for grazing alone returned a NPV of $640/ha, thus making substantially less than scenarios that include forest management for timber production.

Table 8.4. Cash flow over 20 years and net present value by management scenario for 3050 ha of regrowth forest.

Financial performance criterion	Cash flow 2019–2038 and NPV by management scenario				
	1. Clear for grazing	2. No treatment and no harvest in 2019	3. Silvicultural treatment only in 2019	4. Harvest only in 2019	5. Treatment and harvest in 2019
Cash flow	4,053,000	4,441,000	10,003,000	3,585,000	8,794,000
NPV	1,951,000	2,076,000	3,789,000	2,357,000	3,984,000

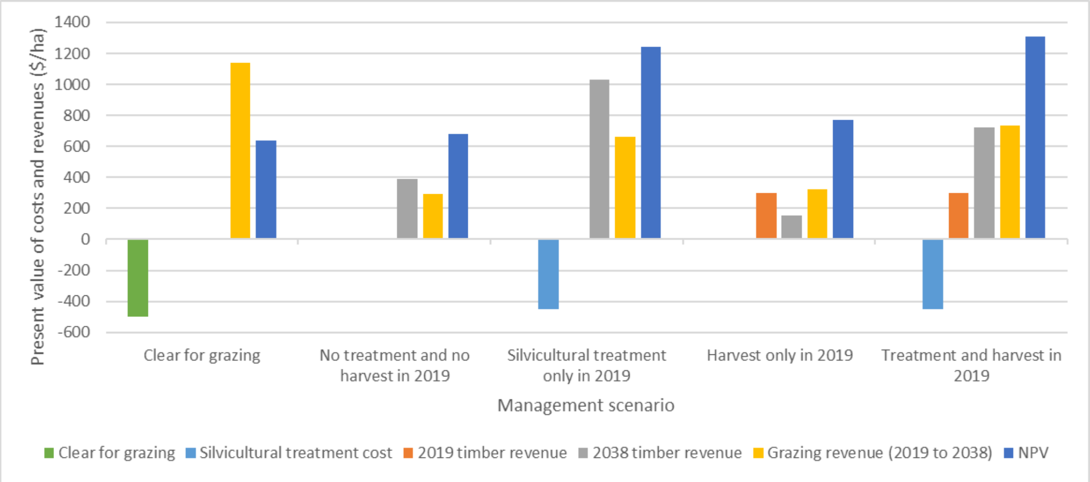


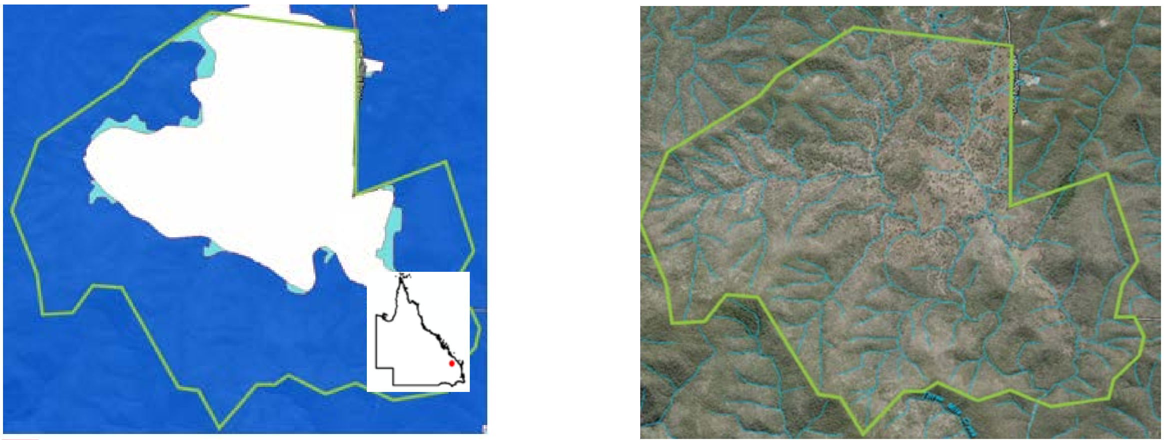
Figure 8.11. Present value of costs and revenues per hectare by management scenario for regrowth forest.

Property management recommendation

Both regrowth forest management scenarios with investment in silvicultural treatment will generate substantially higher returns from the property over 20 years than the remaining scenarios. The two forest management scenarios that do not include a silvicultural treatment in 2019 are expected to generate substantially less revenue over 20 years because the residual stocking of non-merchantable stems in 2019 is projected to reduce MAI of merchantable logs. Figure 8.10 highlights that the productive condition of the forest under these two scenarios in 2038 is poor, with large volumes of unmerchantable trees less than 40 cm DBH. Clearing regrowth forest for grazing will generate a modest annual income stream. This is in contrast to the silvicultural treatment scenarios, where a substantial proportion of all revenues are received in 2038. However, clearing for grazing is the least financially rewarding management scenario over 20 years. The optimal management strategy for the landholder is to harvest and silviculturally treat the forest in 2019, which will enhance grass production under more widely spaced trees, and promote timber production.

Case study 3. Timber production focus

The Case Study site is located in the Gin Gin region. The property layout, as well as vegetation mapping and drainage is presented below in Figure 8.12.



🟦 Category B area (Remnant vegetation)
⬜ Category X area (Exempt clearing work on Freehold, Indigenous and leasehold land)
🟩 Category C area (High-value regrowth)

Figure 8.12. Property map for case study 3, showing regulated (Category B and C) and unregulated (Category X) areas.

Forest condition

In 1963, the property was purchased by an owner with connections to the local timber industry. The potential value of timber was recognised and the owner commenced a long-running timber treatment program. Tree density was reduced to promote grass to run more cattle, and young trees were retained with the potential to grow into sawlogs. Between 1963 and the late 1980s, approximately 650 ha had been treated. Over the period 1970 to 2009, a total of approximately 3000 m^3 was periodically selectively harvested with follow-up silvicultural treatment. The property was sold in 2009, and then again in 2011 to the current owners.

In 2011, Private Forestry Service Queensland (PFSQ) developed a forest management plan for the property to assist landholders in effectively managing the forest for timber production. PFSQ are responsible for the ongoing management of the property and are continuing to carry out silvicultural treatments. Revenues from the harvest of approximately 3000 m^3 between 2013 and 2017 have paid for the ongoing management of the property.

Historically, tree stocking on the property has ranged from 200 stems per hectare (SPH) to 1500 SPH for stems greater than 10 cm diameter at breast height (DBH), and up to 3500 SPH when including stems less than 10 cm DBH. In recent years these stands have been thinned to around 100 to 200 SPH using tordon stem injection, brushcutting and chopper rolling (Figure 8.13). A current focus of property management is to integrate timber production and grazing. Assessments carried out to date have found that thinning practices have increased cattle carrying capacity (stocking rate) of the site, which has subsequently increased grazing profitability by 65% over unmanaged forest stands on the property.

Figure 8.13. Forest regrowth stand on the property that has not been silviculturally treated (left), and a treated (brushcut) stand (right).

Projected financial performance of forest management scenarios

Figure 8.14 illustrates the projected cattle carrying capacity for regrowth forest for each management scenario over the period 2019 (year 1) to 2038 (year 20). As expected, carrying capacity (stocking rate) is maximised by clearing the forest, and declines over time as the trees grow in the other scenarios. Silvicultural treatment and harvesting together in 2019 approximately doubles the cattle carrying capacity relative to no silvicultural treatment and no harvest in 2019, a trend that continues over the 20 years.

Figure 8.15 illustrates current and projected regrowth forest structure and volumes. The first row of charts describes the distribution of stems in 2019 by DBH class and management scenario. This particular stand has a relatively low tree stocking, including scattered large merchantable trees. The second and third rows of charts in Figure 8.15 indicate retained, thinned and harvested volumes in 2019 and 2038. The third row of charts also includes the simulated mean annual increment (MAI) of merchantable timber between 2019 and 2038. Generally, silviculturally treated stands will grow timber at a substantially faster rate than untreated stands. However, the low tree stocking retained in scenario 5 resulted in MAI between 2019 and 2038 being less than scenario 2.

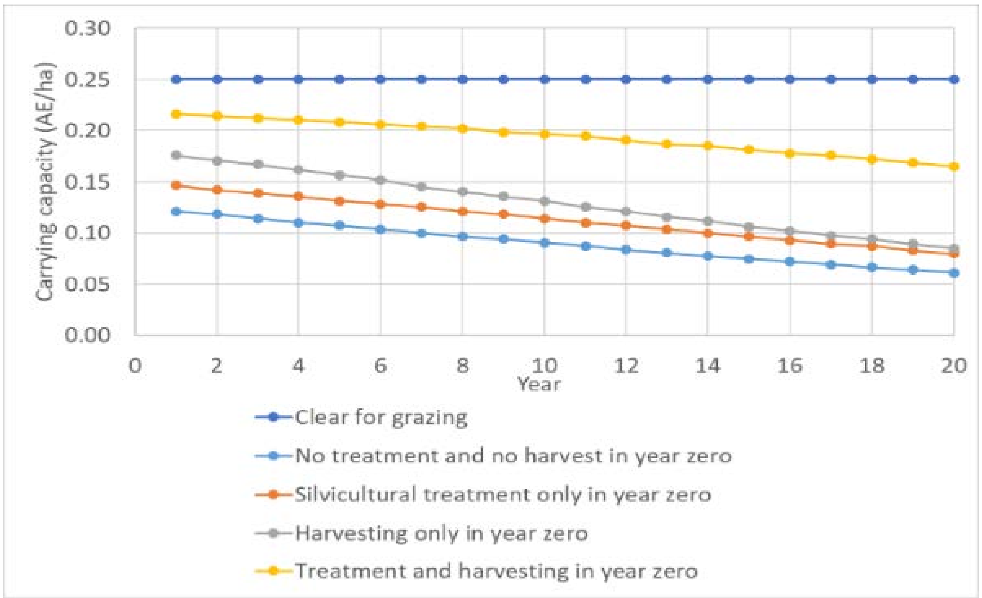


Figure 8.14. Projected cattle carrying capacity in regrowth forest between 2019 (year 1) and 2038 (year 2038).

<table>
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<tr><th></th><th>Scenario 2. No silvicultural treatment and no harvest in 2019</th><th>Scenario 3. Silvicultural treatment only in 2019</th><th>Scenario 4. Harvest only in 2019</th><th>Scenario 5. Silvicultural treatment and harvest in 2019</th></tr>
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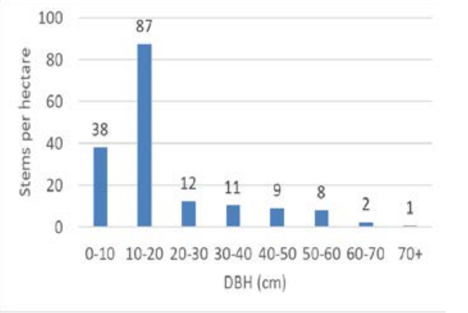
<td>
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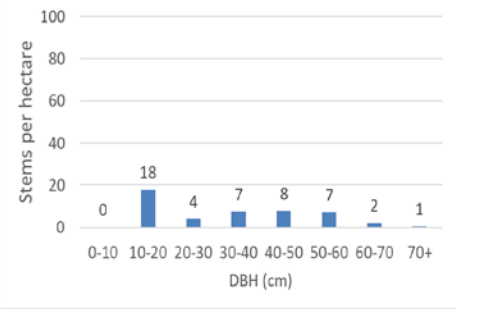
<td>
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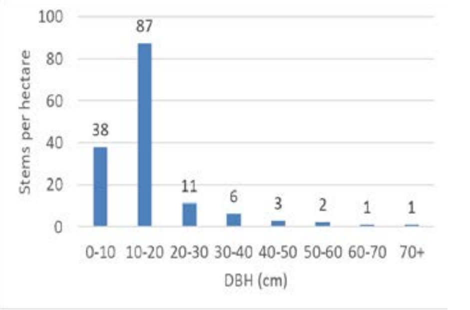
<td>
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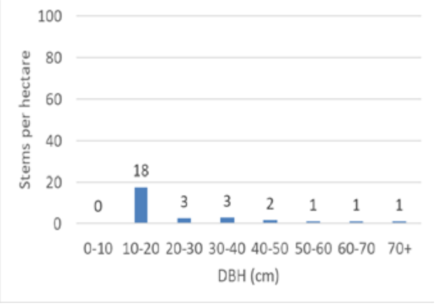
<td>
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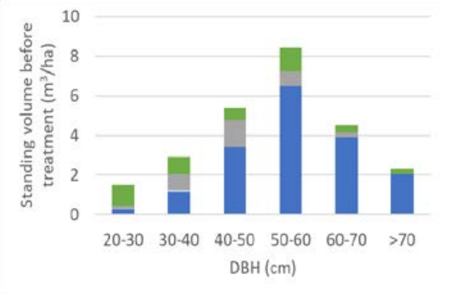
<tr><td>Retained, thinned and harvested volume in 2019</td>
<td>
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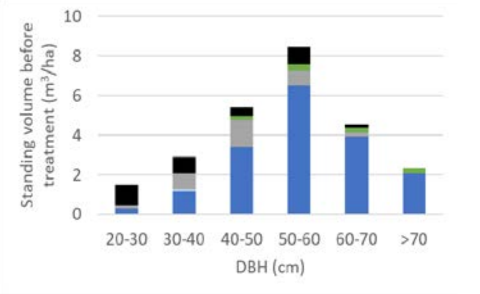
<td>
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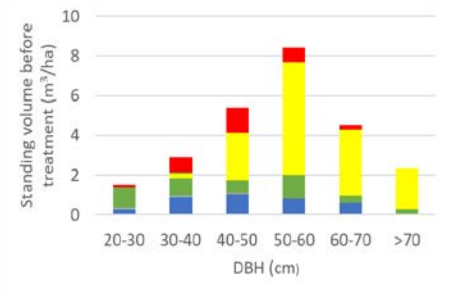
<td>
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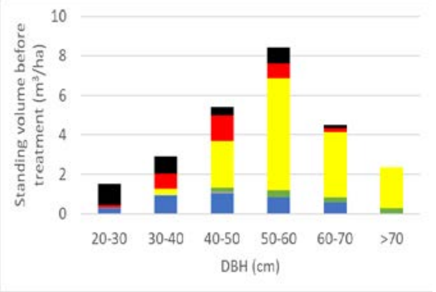
<td>
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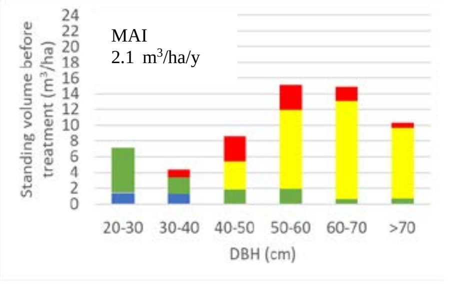
<tr><td>Retained and harvested volume in 2038</td>
<td>
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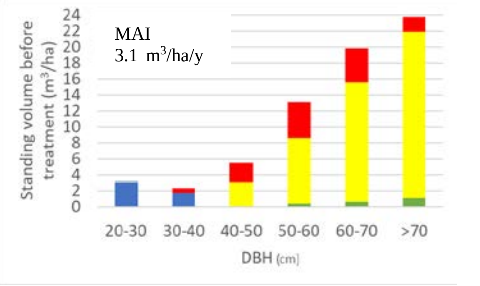
<td>
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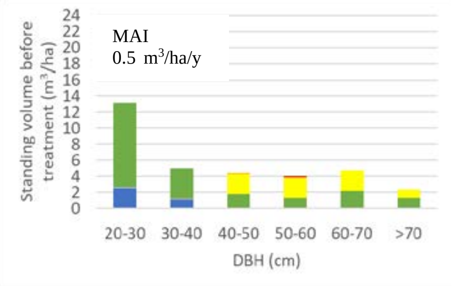
<td>
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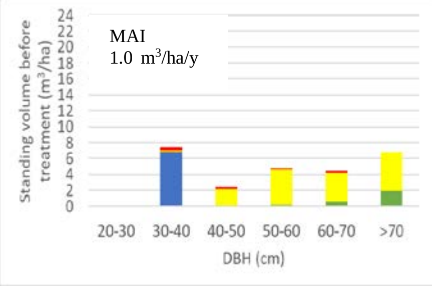
<td>
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🟦 Retained sawlog	■ Retained pole	■ Retained other merchantable	🟩 Retained unmerchantable
🟨 Harvested sawlog	🟧 Harvested pole	🟥 Harvested other merchantable	■ Thinned unmerchantable

Figure 8.15. Current and projected stand structure and product volumes in regrowth forest on the property.

Notes: The legend applies to the bottom two rows of charts only. “Other merchantable” are piles, fencing and salvage logs. MAI is for retained merchantable stems over the period 2019 to 2038.

Figure 8.16 illustrates the present values (PV) of costs and revenues per hectare for a real (net of inflation) discount rate of 5% per annum. Table 8.5 reports total projected cash flows and NPV for the regrowth forests on the property. The treatment and harvest in 2019 scenario was found to have the highest NPV at $2296/ha, because of the up-front timber returns and high projected grazing revenues over time because of the more open forest canopy. The result is interpreted as follows. The investment in silvicultural treatment and harvest in 2019 yielded a real 5% per annum rate of return, plus $2296/ha on top of that. In contrast, clearing for grazing generated an NPV of $687/ha, thus making a substantially lower return on investment than all other scenarios.

Table 8.5. Total projected cash flows and NPV for the 680 ha of regrowth forest.

Financial performance criterion	NPV by management scenario				
	1. Clear for grazing	2. No treatment and no harvest in 2019	3. Silvicultural treatment only in 2019	4. Harvest only in 2019	5. Treatment and harvest in 2019
Cash flow	955,000	2,594,000	3,769,000	3,350,000	3,967,000
NPV	467,000	1,101,000	1,380,000	1,451,000	1,561,000

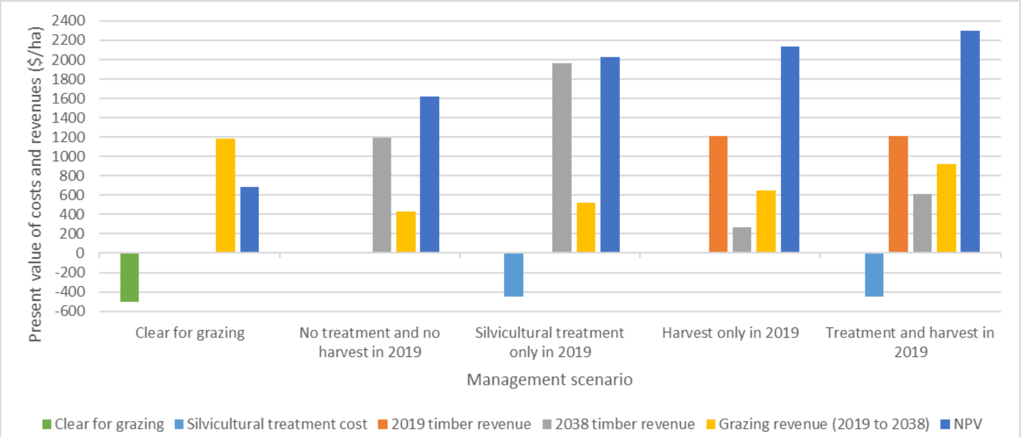


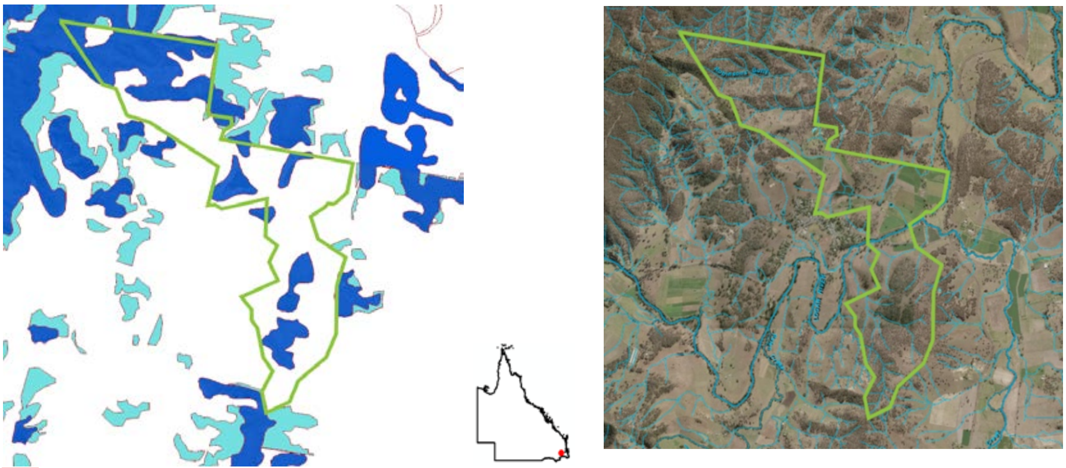
Figure 8.16. Present value of costs and revenues per hectare by management scenario.

Property management recommendation

Silvicultural treatment and harvesting in 2019 will generate the highest returns for the property over the next 20 years. Although MAI in this scenario was projected to be low, by 2038 a cohort of future sawlogs is expected to have developed in the 30 to 40 cm DBH class, and substantial natural regeneration is expected to have established following treatment and harvest in 2019. Post 2038, the timber and grazing productivity of the site in this scenario is expected to be sound. Harvesting only in 2019 was marginally more financially beneficial than silvicultural treatment only in 2019. However, Figure 8.15 highlights the forest in the harvesting only scenario will be in poor condition following harvest in 2038, having been simulated to grow at only 0.5 m^3/ha/yr and with large standing volumes of unmerchantable logs. In contrast, the forest in the silvicultural treatment only scenario will be in excellent condition in 2038, having been projected to grow at 3.1 m^3/ha/yr. Clearing regrowth forest for grazing will generate modest annual income. Nevertheless, it is the least financially rewarding management scenario over 20 years. Since harvest revenues in 2019 are illustrated in Figure 8.16 to be equivalent to the PV of grazing revenues over 20-years in the clear for grazing scenario, performing silvicultural treatment and a harvest in 2019, and operating a mixed forestry and grazing enterprise, is unambiguously better than clearing for grazing on this property.

Case study 4. Supplementary farm income

The property is located at Rathdowney, south west of Beaudesert. The property layout, as well as vegetation mapping and drainage is presented below in Figure 8.17.



🟦 Category B area (Remnant vegetation)
☐ Category X area (Exempt clearing work on Freehold, Indigenous and leasehold land)
🟦 Category C area (High-value regrowth)

Figure 8.17. Property map for case study 4, showing regulated (Category B and C) and unregulated (Category X) areas.

Figure 8.18. The property with the home in the middle, irrigated pasture for the dairy cattle to the left and part of their forested area behind the pasture and the home.

Forest condition

The property has been harvested for timber periodically, with recent harvests taking place in 2007, 2008 and 2014 and prior harvests in 1946, 1960, 1968 and 1970. The property owner noted that revenues received from these harvests have assisted in paying for further forest management, and also contributed to other farm operations such as maintenance of fencing and milking sheds.

The landholder has been involved in active management of the forest on his property for over ten years. There has been a focus on both managing for timber production and keeping the forests open to maintain a herd of beef cattle outside the irrigated dairy cow pasture. Tree stocking on the property varies between 100 stems per hectare (SPH) and 1000 SPH for trees greater than 10 cm DBH.

Private Forestry Service Queensland (PFSQ), carried out the first tordon stem injection thinning on the property in 2008. The landholder has continued tordon treatments since then, such that 25% of the regrowth forest on the property had been treated by 2018. Thinning has typically reduced tree stocking to 150 SPH in the initially more densely stocked areas (Figure 8.19).The land holder has been very happy with the results from the treatments. The aesthetics of his property has improved substantially, the forest is more open for grazing, and the remaining trees will produce more valuable logs.

Figure 8.19. Forest regrowth stand on the property that hasn't been silviculturally treated (left), and a treated stand (right).

Projected financial performance of forest management scenarios

Figure 8.20 illustrates the projected cattle carrying capacity for regrowth forest for each management scenario over the period 2019 (year 1) to 2038 (year 20). As expected, carrying capacity (stocking rate) is maximised by clearing the forest, and declines over time as the trees grow in the other scenarios. Silvicultural treatment in 2019 is projected to increase the cattle carrying capacity by around 30% relative to no silvicultural treatment in 2019, with the difference decreasing over time as the trees grow.

Figure 8.21 illustrates current and projected regrowth forest structure and volumes. The first row of charts describes the distribution of stems in 2019 by DBH class and management scenario. The second and third rows of charts indicate retained, thinned and harvested volumes in 2019 and 2038. The third row of charts also includes the simulated mean annual increment (MAI) of merchantable timber between 2019 and 2038, which indicates that silviculturally treated stands on the property are anticipated to grow timber at more than twice the rate of untreated stands. This is evident in substantially higher projected sawlog and pole volumes in 2038.

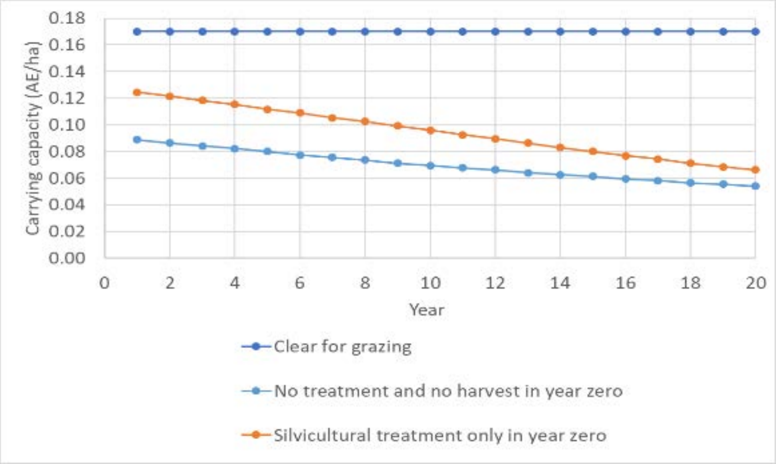


Figure 8.20. Projected cattle carrying capacity in regrowth forest between 2019 (year 1) and 2038 (year 2038).

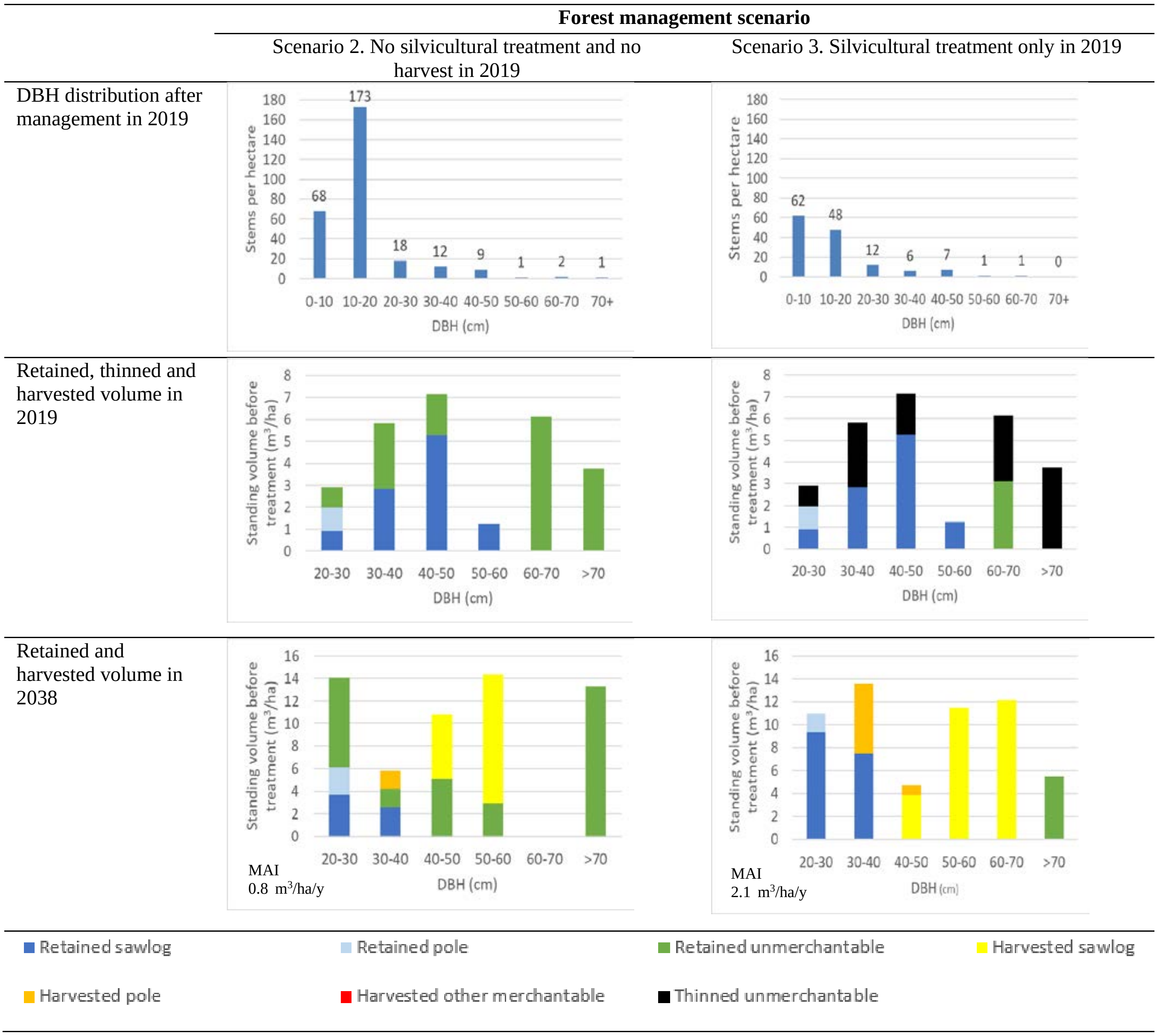


Figure 8.21. Current and projected stand structure and product volumes in regrowth forest on the property. *Notes*: The legend applies to the bottom two rows of charts only. “Other merchantable” are piles, fencing and salvage logs. MAI is for retained merchantable stems over the period 2019 to 2038.

Figure 8.22 illustrates the present values (PV) of costs and revenues per hectare for a real (net of inflation) discount rate of 5% per annum. The net present value (NPV) for each management scenario is equal to the sum of the present values of grazing and timber costs and revenues for that scenario.

The treatment in 2019 scenario was found to have the highest NPV at $1305/ha. This result is interpreted as follows. The investment in silvicultural treatment in 2019 yielded a real 5% per annum rate of return, plus $1305/ha on top of that. Conversely, clearing for grazing generated a NPV of $92/ha, thus making substantially less revenues than investment in managing the regrowth forest for timber and grazing. Table 8.6 reports total projected cash flows and NPV for the 170 ha of regrowth forest outside the grazing areas on the property.

Table 8.6. Cash flow and net present value over 20 years by management scenario for 170 ha of regrowth forest.

Financial performance criterion	Cash flow 2019–2038 and NPV by management scenario		
	1. Clear for grazing	2. No treatment and no harvest in 2019	3. Silvicultural treatment only in 2019
Cash flow	76,000	398,000	652,000
NPV	16,000	168,000	222,000

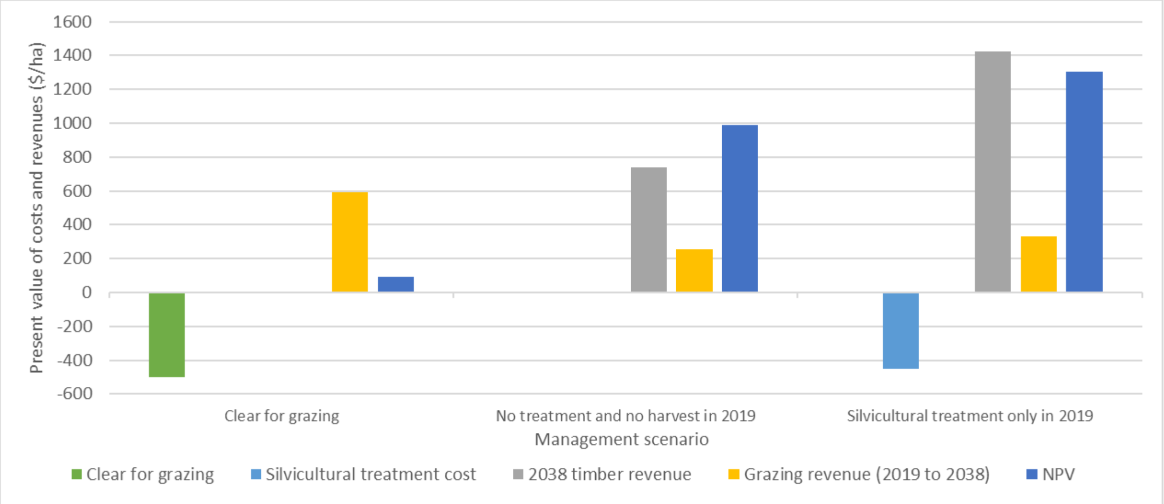


Figure 8.22. Present value of costs and revenues per hectare by management scenario for regrowth forest.

Property management recommendation

The forest management scenario with investment in silvicultural treatment in 2019 is expected to generate substantially higher returns for the landholder over the next 20 years than the other two scenarios. Under this scenario, the forest is projected to be in excellent productive condition following the 2038 harvest, with a large cohort of future sawlogs and poles less than 40 cm DBH (Figure 8.21). In contrast, the no treatment and no harvest in 2019 scenario is projected to have large volumes of unmerchantable trees competing with merchantable trees and grass for site resources. Clearing regrowth forest for grazing will generate a modest annual income, but it is the least financially rewarding management scenario over 20 years. As the landholder’s primary income is from dairy farming, they do not rely on the regrowth forest for an annual income. Therefore, the landholders optimal management strategy is to silviculturally treat the stand in 2019, to maximise future timber returns, while also increasing grass production for beef cattle.

Discussions and conclusions

Forest management scenarios with silvicultural treatments in 2019 were financially optimal for all four case study properties. In the three cases studies where silvicultural treatment and harvest in 2019 was possible, this scenario was financially optimal. The 2019 timber revenues at least partially offset the upfront silvicultural treatment costs. However, at the Rathdowney property, where there was insufficient volume for a harvest in 2019, the silvicultural treatment only in 2019 scenario was financially optimal. The harvest only in 2019 scenario, which was designed to represent a ‘high-grading’ harvest where there was no regard for the forest’s future productivity, always generated lower returns than silviculturally treated forests. The two least financially rewarding scenarios for all case study properties were clear for grazing, and no treatment and no harvest in 2019.

The scenarios with silvicultural treatments always outperformed the remaining scenarios because the treatments improved timber and cattle production. Thinning the forest substantially increased projected timber growth rates, resulting in higher timber revenues in 2038. Indeed, the average simulated mean annual increment (MAI) over 20 years across the four properties when the stand received the silvicultural treatment only in 2019 was 2.4 m^3/ha/yr, which is 1.3 m^3/ha/yr greater than the mean growth rate of the no treatment and no harvest in 2019 scenario. Harvesting only in 2019 did not result in large improvements in MAI because poor management of these forests over time has resulted in stand conditions where there are few merchantable trees to cut. The harvesting only scenario, and the no silvicultural treatment and no harvesting in 2019 scenario, do not provide conditions for vigorous forest growth in private native forests.

The cattle carrying capacity in regrowth forests on the case study farms that had not been harvested or silviculturally treated is estimated to be about 25% of the level achievable if the land had been cleared of trees. Silvicultural treatments resulted in a forest structure with more widely spaced trees, which increased grass production and cattle carrying capacity. All properties were found to generate higher grazing revenues when their forests were silviculturally treated, relative to the no silvicultural treatment and no harvest in 2019 scenario, and the harvest only in 2019 scenario. The grazing revenues in the silvicultural treatment scenarios averaged at least 50% of the grazing revenues in the clear for grazing scenario in three of the four case studies. For business accounting purposes, the up-front investment in silvicultural treatment necessary to achieve this grazing outcome should be shared between the timber and cattle production elements of the business. Therefore, at least 50% of potential grazing revenues can be earned from a fraction of the investment necessary to clear regrowth forest for grazing. The Glenbar case study property was the exception. Clearing regrowth forest for grazing generated the highest average annual income stream for landholders. It is rational that risk averse landholders who are heavily dependent on their property to generate an annual income would seek to clear their regrowth forests. However, all four case studies demonstrated that this is the least financially rewarding management scenario over 20 years. If landholders can manage a lower annual income stream while waiting for their native forest timber crop to mature, the profitability of their enterprise will be substantially increased in the long-term. Chapter 9 describes a financially viable large-scale investment scheme that could provide an income stream to landholders to reduce their reliance on annual cattle sales, while increasing the aggregate value of cattle and timber production in the medium to long-term. Increased farm output can support increases in regional employment opportunities and regional incomes. Grazing enterprises managed as silvo-pastoral systems will have a more diversified income stream and will be more resilient to climate change. For example, established timber trees in native forests look after themselves during drought, flood and fire (in most cases), and timber can provide a financial buffer in years where grazing is less profitable. Trees in managed silvo-pastoral systems are less likely to be impacted by wildfire, once the trees reach a certain size, as fire intensity is likely to be lower where understorey fuels are managed (i.e. a grassy understorey is less likely to encourage a crown fire than a midstorey of dense trees and shrubs).

The case studies highlighted that investment in silvicultural treatment is the financially optimal medium to long-term regrowth forest management strategy for landholders. However, there are limitations with the analysis. First, a typical silvicultural treatment schedule would include a follow up treatment about 10 years after the initial treatment. Presently, the decision support tool does not accommodate this. This follow-up treatment would result in higher costs, but also faster tree growth and increased future timber revenues relative to the case study analyses presented. Second, in the clear for grazing scenario, it was assumed that landholders are disinterested in timber, with the trees cleared with no regard to their value. While this practice is relatively common, it is possible that a timber harvest could occur prior to clearing for grazing, which could increase revenues to the landholder in that scenario. Third, this case study analysis only considered regrowth forests dominated by spotted gum, because the decision support tool is parameterised with data from this forest type. Research into the financial performance of silvicultural treatments in other forest types and remnant forests (Category B) as opposed to regrowth forests (Category X) is warranted.

Chapter 9. The potential for silviculture in Queensland’s private native forests to improve returns to landholders and generate economic benefits in regional communities

Tyron Venn

Introduction

Silvicultural treatments can improve the overall health and productive condition of private native forests. There is a potential opportunity for silvicultural treatments to increase the level of timber available to industry, boost regional employment and increase financial returns to landholders. This chapter evaluates the financial performance of silvicultural treatments for timber only and for silvo-pastoral systems (cattle and timber together) for the six commercial forest types in southern Queensland that were defined in Chapter 4. Potential sustainable yields from private native forests under alternative management scenarios are estimated, and the implications for regional jobs and incomes reported. An investment scheme to finance large-scale silvicultural treatments is proposed and evaluated in terms of the value of future log production, mill gate outputs and regional employment.

Estimates of private native forest growth rates

The long-term sustainability of harvesting in private native forests is constrained by growth rates of trees that are deemed commercial. Table 9.1 summarises published mean annual increment (MAI) estimates for private native forests in the SEQ Forests Agreement region for particular commercial log specifications[13]. The tabulated estimates for wet forests are consistent with net yields from Crown coastal blackbutt forests and mixed hardwood forests in northern New South Wales, being between 0.9 m^3/ha/yr and 2.4 m^3/ha/yr, and 0.2 m^3/ha/yr and 0.5 m^3/ha/yr, respectively (Florence 1996).

The MAIs reported in Queensland CRA/RFA Steering Committee (1997) and Queensland CRA/RFA Steering Committee (1998a) were estimated on the basis of average stand conditions and management regimes on State land, a condition that Bureau of Rural Sciences (2004) asserted is not a plausible approximation of the condition of the resource on private land. Nevertheless, the estimates from Queensland CRA/RFA Steering Committee (1998a) may reflect what could be achieved in private native forest if silviculture was improved to the standards practiced within State Forests[14].

The MAI estimates by forest type in Bureau of Rural Sciences (2004) were ‘based on modelling undertaken by DPI Forestry on the basis of ground assessed plots’ (p. 33). These MAI estimates were intended to reflect actual growth rates in private native forests at that time. For example, the MAI of compulsory (i.e. high quality) sawlogs on private land was estimated to be about half the MAI estimated by Queensland CRA/RFA Steering Committee (1998a) for State Forest. This suggests merchantable volume growth on private land was

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[13] This region was defined for the purposes of forest policy decisions made in 1999 and is no longer a planning region in Queensland. Figure 3.11 defines the SEQ Forests Agreement region.

[14] Since the 1970s, forest managers have relied on harvesting alone for silvicultural treatment in State Forests (Queensland CRA/RFA Steering Committee 1997, Ryan and Taylor 2006). Therefore, although the average productive condition of State Forests is better than private native forests, MAIs estimated from State Forest data are unlikely to fully capture the potential of periodic silvicultural treatments to increase the productivity of private native forest.

about half that on Crown land. These low MAIs on private land are consistent with sawmiller assertions that return periods on private land are most commonly about 30 years in order to achieve a compulsory sawlog harvest of at least 2 m^3/ha (Bureau of Rural Sciences 2004). Nevertheless, Bureau of Rural Sciences (2004) found that, with good management, rates of ‘average [compulsory] sawlog growth of 0.5 to 1 m^3/ha/yr are not inconceivable over a large proportion of forests in SEQ’ (p. vii).

Table 9.1. Published estimates of MAI for private native forests in the SEQ Forests Agreement region.

Forest Type	MAI by source and product (m^3/ha/yr)					
	Queensland CRA/RFA Steering Committee(1997) [a]	Queensland CRA/RFA Steering Committee(1998a) [b]	Bureau of Rural Sciences(2004) [c]			
	Compulsory sawlog	Compulsory sawlog	Compulsory sawlog	Optional sawlog	Girders and poles	Total
Wet forest	0.5 to 5	0.44	0.19	0.07	0.02	0.28
Moist dry forest		0.18				
Dry forest	0.2 to 0.4		0.11	0.03	0.01	0.15
Woodland		0.15				

Notes: a. These estimates are broad ranges of commonly observed MAIs in Crown native forests according to Department of Primary Industries – Forestry experts.

b. These estimates are the weighted (by area of each productivity class) average MAI for each forest type, where the average MAIs for high, medium and low productivity classes were essentially identical for all forest types, and estimated at 1.26 m^3/ha/yr, 0.45 m^3/ha/yr, and 0.05 m^3/ha/yr, respectively.

c. Wet forests (described as moist forests in their report) were defined as broad vegetation groups 2 and 2a (wet tall open forests dominated by *E. saligna*, *E. grandis*, *Lophestemon confertus* and *E. laevopinea*) 3 (moist open forest to tall open forest dominated by *E. pilularis*), and 4a (moist to dry open forest to woodland containing a mix of species including *Corymbia citriodora*, *E. carnea*, *E. propinqua*, *E. siderophloia*, *E. pilularis*, *E. acmenoides*, *E. major*, and *E. microcorys*). Dry forests were defined as broad vegetation groups 6, 7 (dry woodlands to open woodlands mostly dominated by *C. citriodora*) 8 and 8a (dry to moist woodlands and open woodlands dominated by *E. crebra*, *E. cullenii*, and *E. melanophloia*), 9a (open forest and woodlands on drainage lines and alluvial plains dominated by *E. tereticornis* or *E. camaldulensis*), and 11b.

As part of this study, permanent plot data from spotted gum dominant forest within the study area on private land was analysed (Chapter 5). This forest type represents approximately one-third of the commercial and harvestable private native forest in the Queensland part of the study area. The permanent plot data are summarised separately for eastern and western plots in Table 9.2 due to the potential impact of lower rainfall on growth in western parts of the study area. The mean MAI across all plots is 1.3 m^3/ha/yr, and there was not a significant difference in mean MAI between eastern and western parts of the study area. However, the most productive stands in the east have almost double the volume growth of the most productive stands in the west. Differences in standing volumes between the eastern and western parts of the study area are highlighted in Chapter 3. The estimates in Table 9.2 do need to be interpreted with caution, as far fewer plot data (one property only) are available from western parts of the study area.

Table 9.2. Summary statistics for mean annual increment measures from permanent plot data on private land that is dominated by spotted gum forest.

Plot location	Silviculturally treated	No. plots	MAI (m^3/ha/yr) Mean (s.d.)	Min	Median	Max
East	Yes	108	1.31 (0.78)	0.03	1.22	4.52
East	No	28	1.24 (0.79)	0.0	1.23	3.14
West	Yes	6	1.43 (0.60)	0.63	1.41	2.43
West	No	2	1.48 (0.72)	0.97	1.48	1.99

Note: MAI is potentially merchantable volume growth on trees greater than 20 cm DBH

Mean MAI was also found to be not statistically significantly different between treated and untreated private spotted gum forests. However, mean DBH growth of retained trees in treated stands summarised in Table 9.2 were 0.59 cm/yr in remnant forests and 0.95 cm/yr in regrowth forests. These growth rates compare favourably to mean DBH growth in private untreated remnant and regrowth forests of 0.26 cm/yr and 0.37 cm/yr, respectively. Thus, DBH growth rates in treated private stands are at least double untreated stands. Bureau of Rural Sciences (2004) asserted that diameter growth in Queensland’s native forests can be increased by a factor of 2 to 4 with silvicultural treatment, and this is consistent with research conducted as part of this project and reported in Chapter 5. This does suggest the potential for silvicultural treatment to halve the harvest return interval (time required for retained trees to attain merchantable product specifications).

Lewis et al. (2010) summarised data from the Queensland Department of Agriculture and Fisheries on nine silvicultural treatment tree spacing experiments from five Crown spotted gum forests within the study area. Growth data was available for between 20 and 33 years post-treatment (Table 5.12). Retained stems per hectare ranged from 51 to 108, which resulted in the lowest and highest observed MAIs respectively, at 0.88 m^3/ha/yr and 1.44 m^3/ha/yr. The mean MAI across all nine treatment spacing trials was 1.2 m^3/ha/yr. In contrast, MAI in long unmanaged and untreated Crown spotted gum forest was 0.35 m^3/ha/yr.

Table 9.3 summarises the MAIs adopted in this study to estimate private native forest timber productivity with and without silvicultural treatment in each of the commercially important forest types defined in Chapter 4. The moist tall and spotted gum forest growth rates are supported by private forest and State Forest permanent plot data. For the remaining forest types, untreated and treated MAI estimates have been informed by experts at PFSQ and the literature summarised above. The analysis reported in the following sections has adopted the mean MAI estimates.

Table 9.3. Estimates of MAI adopted in this study.

Forest type	MAI in untreated stands (m^3/ha/yr)				MAI in silviculturally treated stands (m^3/ha/yr)			
	Mean	Low	Median	High	Mean	Low	Median	High
Moist tall forest	1.7	0.5	1.7	3.0	3.5	2.0	3.9	7.0
Spotted gum	0.3	0.05	0.6	2.0	1.3	0.5	1.3	4.0
Mixed hardwood	0.3	0.1		1.0	1.0	0.5		2.0
Blue gum	0.3	0.2		1.0	1.0	0.5		2.0
Gum-topped Box	0.15	0.05		0.4	0.8	0.4		1.5
Ironbark [a]	0.15	0.05		0.4	0.6	0.3		1.2

Note: a. As illustrated in Chapter 4, these ironbark forests are in drier, less fertile western and northern parts of the study area. This does not include the coastal ironbarks (such as *Eucalyptus siderophloia* and *E. fibrosa* subsp. *fibrosa*) which often grow within the spotted gum or mixed hardwood forest types. These ironbark trees often exhibit reasonable growth rates (0.45–0.49 cm DBH per year on acceptable trees), but represent only a component of the stand.

Financial performance of silvicultural treatments in commercially important forest types

The net present value (NPV) of perpetual native forest management with and without silvicultural treatment has been estimated for each commercially important forest type defined in Chapter 4. Table 9.4 lists important parameters for the financial analysis of silvicultural treatments. A real (net of inflation) discount rate of 5%, which is equivalent to the real annual rate of return on investment in housing in Brisbane between 1990 and 2015, has been adopted as the base case opportunity cost of capital for landholders. However, landholders face considerable sovereign risk and other risks including bushfire, and the inconvenience of not receiving an annual income from forestry investments (in contradistinction to investments they might otherwise make in cattle or crops). Therefore, this analysis also considers discount rates of 7.5% and 10%.

Table 9.4. Parameters for evaluation of financial performance of silvicultural treatments in private native forests in the study area.

Parameter	Level or description
1. Discount rate (%)	5; 7.5; 10
2. MAI by forest type	Mean untreated and treated MAIs by forest type from Table 9.3
3. Mean stumpage price (\$/m^3) [a]	80 for untreated stands; 100 for treated stands.
4. Harvest return interval for untreated forest (y)	15 for moist tall forest type; 30 for all other forest types
5. Harvest return interval for treated forest (y)	15 for moist tall forest type; 20 for all other forest types
6. Silvicultural treatment costs (\$/ha)	400 in year zero and 250 every 10 years thereafter

Note: a. This is an average stumpage price per cubic metre and accounts for all log types that may be harvested including higher value poles and compulsory sawlogs, as well as lower value optional sawlogs, piles and landscape timbers.

Silvicultural treatment costs are consistent with the analyses in Chapters 7 and 8, and it is assumed that other forest management costs (e.g. track maintenance) are equivalent in silviculturally treated and untreated forests, and are therefore not relevant for the analysis. Harvestable volumes by log type were not available for this broad analysis by forest type. The mean stumpage prices in treated and untreated stands are based on anecdotal information collected by PFSQ personnel over many years. The mean stumpage price for treated stands is higher because silviculture will reduce the proportion of growing stock with lower quality logs. Timber revenue from each harvest is the MAI multiplied by the harvest return interval, multiplied by the mean stumpage price, with a discount rate applied to discount the future value to the present. For silviculturally treated stands, the present value of treatment costs have been subtracted from the present value of harvest revenues to estimate NPV. A sensitivity analysis has been performed to highlight the sensitivity of NPV to changes in stumpage price and MAI.

Figure 9.1 illustrates the NPV of timber production for untreated and treated stands for the six commercial forest types. At a discount rate of 5%, silvicultural treatments are financially viable (NPV > $0) and exceed returns from harvesting without silvicultural treatment for all forest types, except ironbark[15]. For example, in spotted gum forests, landholders can make a 5% per annum rate of return on resources invested in silvicultural treatments, plus $775/ha on top of that. In contrast, harvesting without silvicultural treatment is the financially optimal strategy for ironbark forests because the relatively low growth response due to treatment does not offset the treatment cost. If landholders require higher rates of return, the attractiveness of investments in silviculture are substantially reduced in all forest types. At a 7.5% discount rate, silvicultural treatment is only justified in moist tall and spotted gum forests.

Figures 9.2 and 9.3 illustrate the sensitivity of NPV to a 30% increase in mean stumpage price or MAI, and a 30% decrease in mean stumpage price or MAI, respectively. Figure 9.2 highlights that the financial performance of silvicultural treatments is robust against increases in stumpage prices and MAI. As expected, NPVs for all forest types and discount rates are larger than in the base case (illustrated in Figure 9.1). However, these increases resulted in only one change in the relative financial performance of treated stands to untreated stands; ironbark stands evaluated at a 5% discount rate now have a higher financial performance than untreated ironbark stands. Moist tall and spotted gum forests are still the only forest types where silvicultural treatments make at least a 7.5% rate of return (i.e. positive NPV with a 7.5% discount rate).

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[15] If the slower growth of ironbark forests could permit silvicultural treatments to be performed every 15 years instead of every 10 years, then silvicultural treatments in ironbark forests would be financially viable at a 5% discount rate.

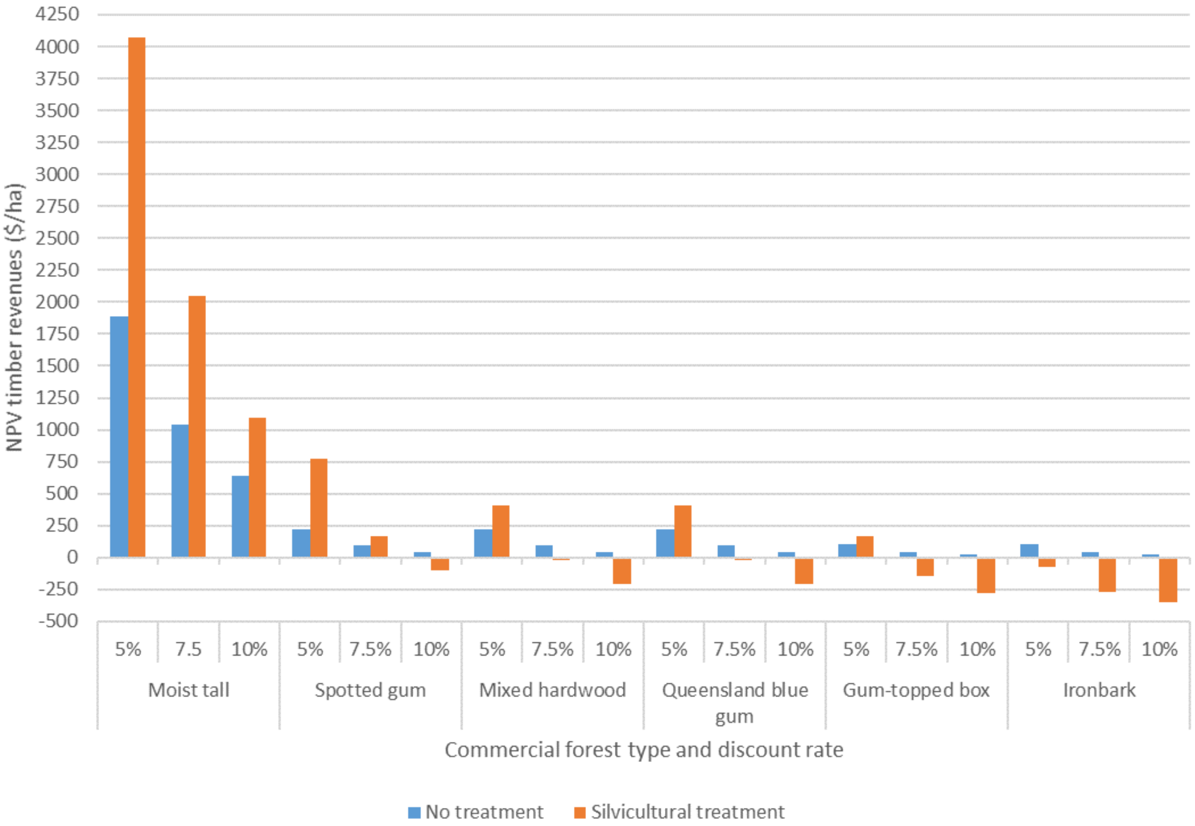

Figure 9.1. Net present value of timber revenues by forest type with and without silvicultural treatment at different discount rates (5, 7.5 and 10%).

Long-term industry experience supports the mean stumpage price estimates used for the base case analysis (and reported in Table 9.4), so Figure 9.3 is perhaps best interpreted as a 30% reduction in the achievable MAI relative to the base case values adopted in Table 9.3. Figure 9.3 indicates that the financial performance of silvicultural treatments in moist tall and spotted gum forest types is robust against a 30% decrease in mean stumpage price or MAI. However, silvicultural treatments are no longer financially viable in gum-topped box forests. While treatments remain financially viable at a 5% discount rate for mixed hardwood and Queensland blue gum forest types, untreated stands of these forest types provide a slightly higher return when MAIs or stumpage prices are reduced by 30%. That is, investment in silvicultural treatment would not be justified in these two forest types if returns were 30% lower than the base case.

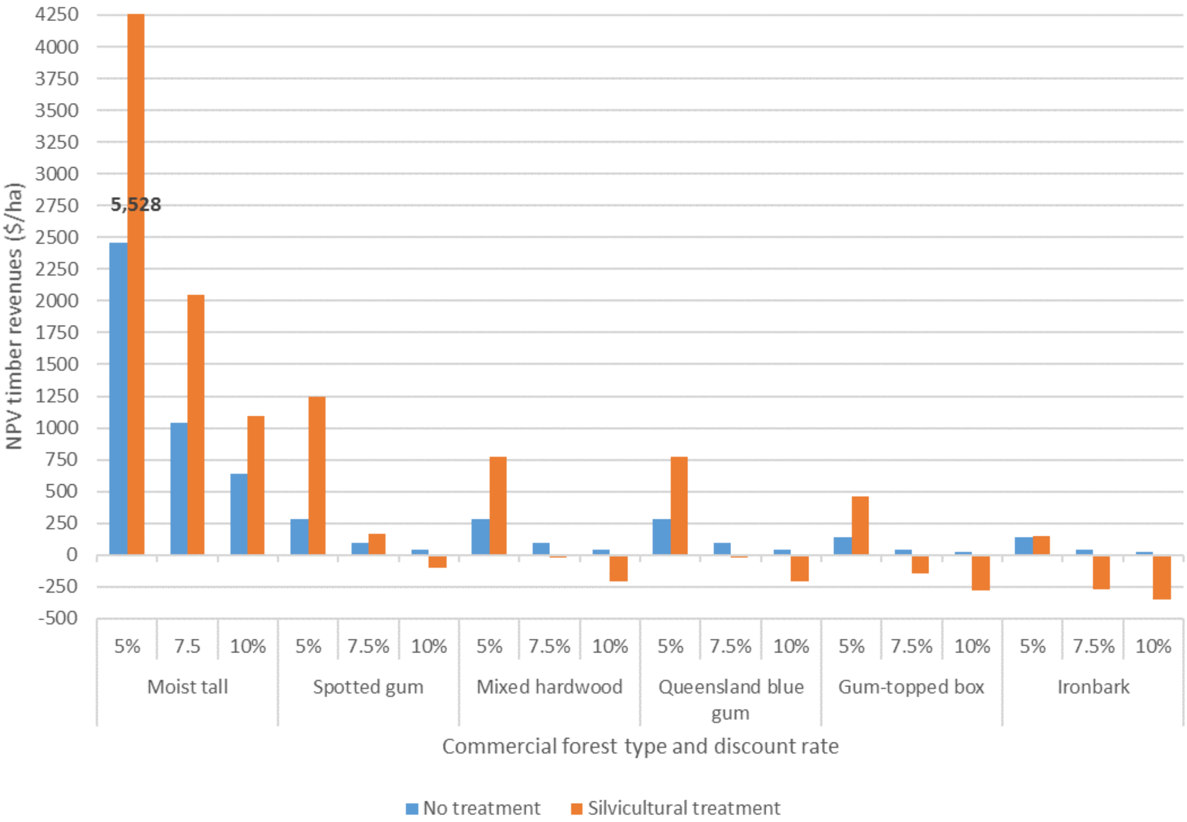

Figure 9.2. Sensitivity of NPV of treated and untreated stands to a 30% increase in mean stumpage price or MAI.

Note: The y-axis has been truncated at $4250 to facilitate comparison with Figure 9.1. The NPV of silviculturally treated moist tall forest at a 5% discount rate is $5528.

Table 9.5 reports the minimum MAI necessary to justify silvicultural treatment costs by discount rate, assuming a harvest every 20 years and mean stumpage price of $100/m^3. This reveals that for the base case silvicultural treatment costs considered in this study, a MAI of at least 0.66 m^3/ha/yr is required in order to make a 5% rate of return. If treatment costs are 30% higher or lower, the MAI would have to be at least 0.86 m^3/ha/yr or 0.46 m^3/ha/yr, respectively, for the landholder to make at least 5% on resources invested in the silvicultural treatment.

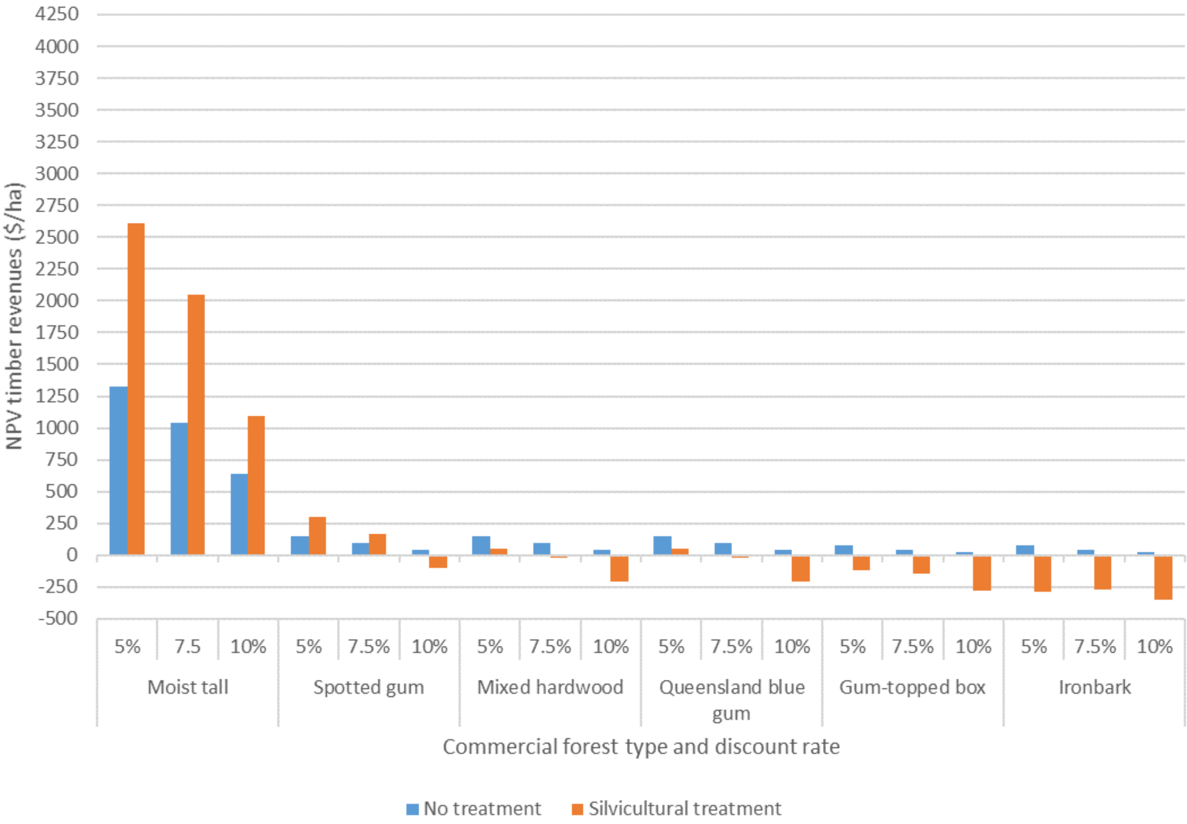

Figure 9.3. Sensitivity of NPV of treated and untreated stands to a 30% decrease in mean stumpage price or MAI.

Table 9.5. Breakeven MAI to justify investment in silvicultural treatment in native forests.

Discount rate (%)	Breakeven MAI (m^3/ha/yr) by silvicultural treatment cost ($/ha)		
	Base case –30%	Base case: $400 in year zero and $250 every 10 years thereafter	Base case +30%
5	0.46	0.66	0.86
7.5	0.72	1.03	1.34
10	1.12	1.59	2.07

Financial performance of silvo-pastoral systems

Silvo-pastoral systems refers to the dual management of land for timber and cattle. For most beef producers in Queensland, there is a trade-off between trees and grass. Although there are many reported benefits of trees within pasture for livestock welfare, as well as pasture quality, the net effect of trees is one of pasture growth suppression and reduced returns per hectare from cattle (Schulke 2017). Chapter 4 presents a literature review on financial returns to grazing on cleared land and under trees, as well as the effects of trees on the productivity of grazing properties. Chapter 10 reviews potential environmental opportunities and impacts of native forest management.

Under vegetation management regulations, landholders are not permitted to clear remnant and high value regrowth forests to create open pasture. However, there are hundreds of thousands of hectares of Category X land in Queensland where landholders can legally clear forest to establish pasture. Alternatively, they could manage these forests under a silvo-pastoral system. The financial performance of silvo-pastoral systems in the sub-tropics and tropics of Australia is poorly understood (Donaghy et al. 2010). This section builds upon the financial performance of forest types in Section 9.3 to estimate potential returns to silvo-pastoral systems in silviculturally treated forests and untreated forests, and compares these with returns from clearing forest land for grazing.

Table 9.6 reports the key parameters in the financial analysis of silvo-pastoral systems. There are few published estimates of land clearing, pasture establishment and water infrastructure costs. Indeed, the only recent published estimate found for Australia in a literature search was $310/ha to clear a 200 ha block of brigalow in Queensland (Donaghy et al. 2010). The level adopted is based on expert opinion from the Queensland Department of Agriculture and Fisheries and Private Forestry Service Queensland.

Table 9.6. Parameters for evaluation of financial performance of silvo-pastoral systems.

Parameter	Level or description
1. Discount rate (%)	5, 7.5, 10
2. Land clearing and pasture establishment and maintenance costs ($/ha)	$400 in year zero and $110 every 15 years thereafter
3. Grazing gross margins on cleared land ($/ha/yr)	15, 30, 50, 75, 100, 200
4. Grazing gross margins in untreated forest (% of cleared land gross margins)	30% of returns on cleared land
5. Grazing gross margins in silviculturally treated forest (% of cleared land gross margins)	48% of returns on cleared land
6. Timber returns by forest type with and without silvicultural treatment (PV $/ha)	Described in the previous section of this chapter and timber returns are illustrated in Figure 9.1 (net of silvicultural treatment costs)

The levels of grazing gross margins on cleared land are taken from studies that have assessed grazing productivity on land where the cleared vegetation consisted of poplar box and silver-leaved ironbark in central Queensland ($15/ha/yr), brigalow ($25/ha/yr to $50/ha/yr), and spotted gum near Gympie and Kingaroy ($40/ha/yr to $185/ha/yr) (Department of Primary Industries and Fisheries 2007; Stephens et al. 2008; Maraseni et al. 2009; Donaghy et al. 2010; Star and Donaghy 2010; Maraseni and Cockfield 2011; Schulke 2012). For completeness, all levels of annual grazing margins are compared against each forest type; however, some pairings are unlikely in practice. For example, moist tall forests are in high rainfall and higher fertility areas that would likely generate grazing returns of at least $75/ha/yr. In contrast, ironbark forests occur in drier, less fertile areas where grazing returns are unlikely to exceed $50/ha/yr.

The grazing gross margin parameter estimates for treated and untreated forest are the means of the four farm case studies reported in Chapter 8. The level of 30% of returns on cleared land for untreated forest is consistent with the three to four-fold increase in pasture production that can generally be achieved in Queensland when trees are removed from the landscape (Scanlan and Turner 1995).

Figures 9.4 to 9.8 provide financial performance estimates for land cleared for grazing, as well as for silvo-pastoral systems in silviculturally treated and untreated stands. Each figure reports NPVs for a different forest type. For example, Figure 9.5 reports findings for spotted gum forests. There are three levels of x-axis headings in each figure. First is the grazing gross margin for cleared land, ranging from \$15/ha/yr to \$200/ha/yr. Second is the discount rate. Third, for each grazing gross margin and discount rate combination, NPVs are reported for three land management types: (i) land cleared for grazing only (GO); (ii) forest land managed as a silvo-pastoral system with no silvicultural treatment (SNT); and (iii) forest land managed as a silvo-pastoral system with silvicultural treatment (SWT).

The stacked NPV bars in Figures 9.4 to 9.8, are the sum of net returns to cattle and timber. There are no timber returns when land is cleared for grazing. By design, Figures 9.4 to 9.8 illustrate identical returns to cattle for any particular combination of grazing gross margin for cleared land, discount rate and land management type. This allows the reader to select the grazing returns considered appropriate for a particular landscape of interest, and these do vary substantially in southern Queensland. The timber returns differ between Figures 9.4 to 9.8 depending on the productivity of the forest type and whether the stand is silviculturally treated. Note that the NPV scale for the y-axis for moist tall forests in Figure 9.4 is different to Figures 9.5 to 9.8, because timber returns for this forest type are much higher than for other forest types.

Three broad conclusions can be drawn from this analysis of silvo-pastoral systems. First, clearing for grazing (GO) is not financially viable (NPV < \$0) when the grazing gross margin for cleared land is \$15/ha/yr. Second, for all forest types except ironbark, financial returns to silvo-pastoral systems exceed those from clearing for grazing at all discount rates examined when grazing gross margins do not exceed \$50/ha/yr. In ironbark forests, silvo-pastoral systems are financially optimal when grazing gross margins do not exceed \$30/ha/yr. Third, in moist tall and spotted gum forest types, silvo-pastoral systems with silvicultural treatments always outperform silvo-pastoral systems without silvicultural treatments, irrespective of the discount rate and grazing gross margin. For the remaining forest types, where the timber growth response following treatment is less pronounced, the relative performance of silvo-pastoral systems with and without silvicultural treatments is sensitive to the discount rate and grazing gross margins[16]. Nuanced observations for each forest type follow.

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[16] Higher discount rates favour silvo-pastoral systems without silvicultural treatments because the avoided silvicultural treatment cost in year zero becomes a relatively greater cost saving the more that future revenues are discounted. Higher grazing gross margins favour silvo-pastoral systems with silvicultural treatments because silviculturally treated stands can capture more of the grazing potential of the site than untreated stands.

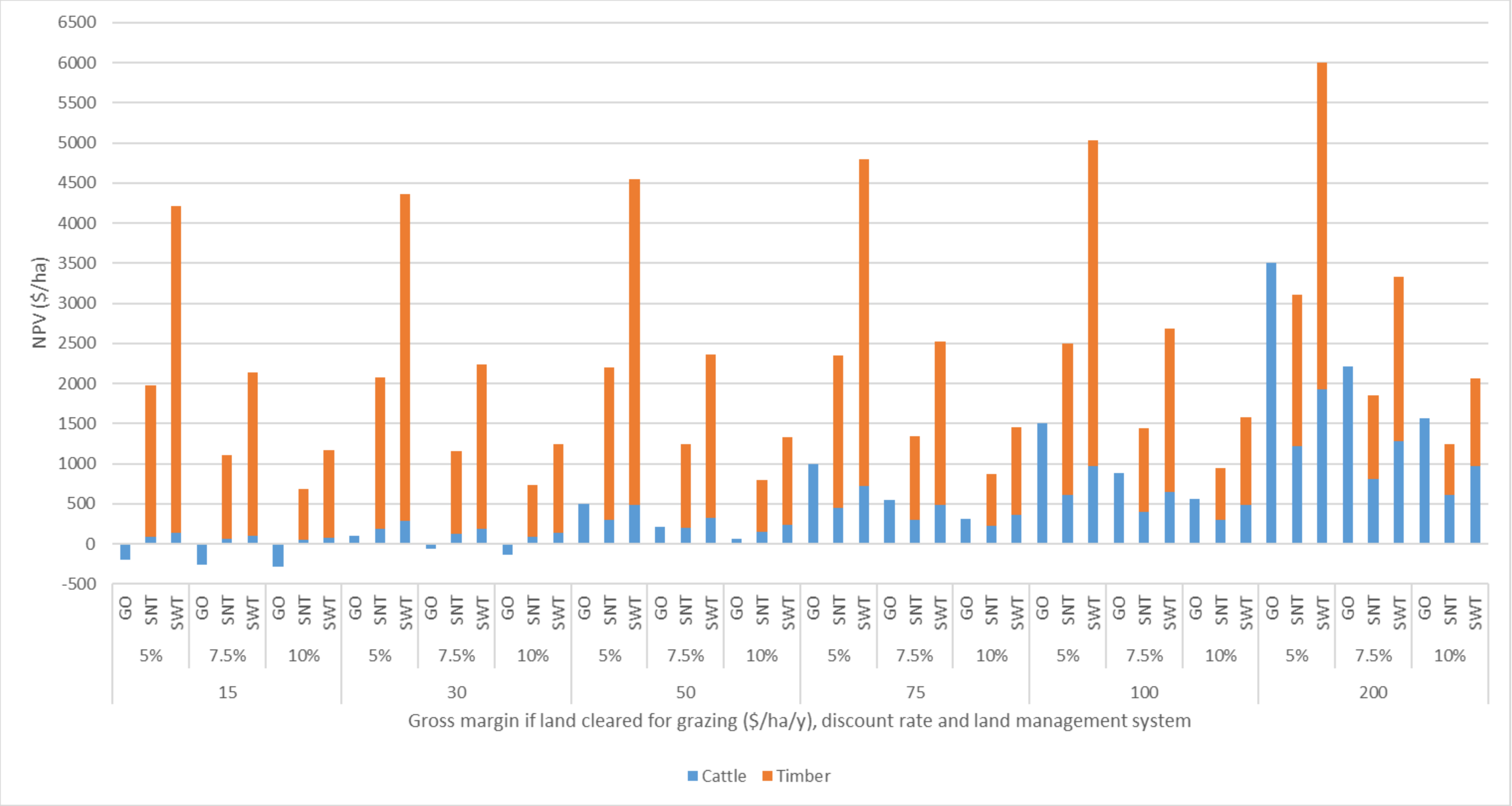

Figure 9.4. Financial performance of grazing only and silvo-pastoral systems in treated and untreated moist tall forests.

Notes: GO is land cleared for grazing only. SNT is forest land managed as a silvo-pastoral system with no silvicultural treatment. SWT is forest land managed as a silvo-pastoral system with silvicultural treatment. Financial performance has been evaluated for discount rates of 5%, 7.5% and 10%, and for grazing gross margins ranging from $15/ha/yr to $200/ha/yr.

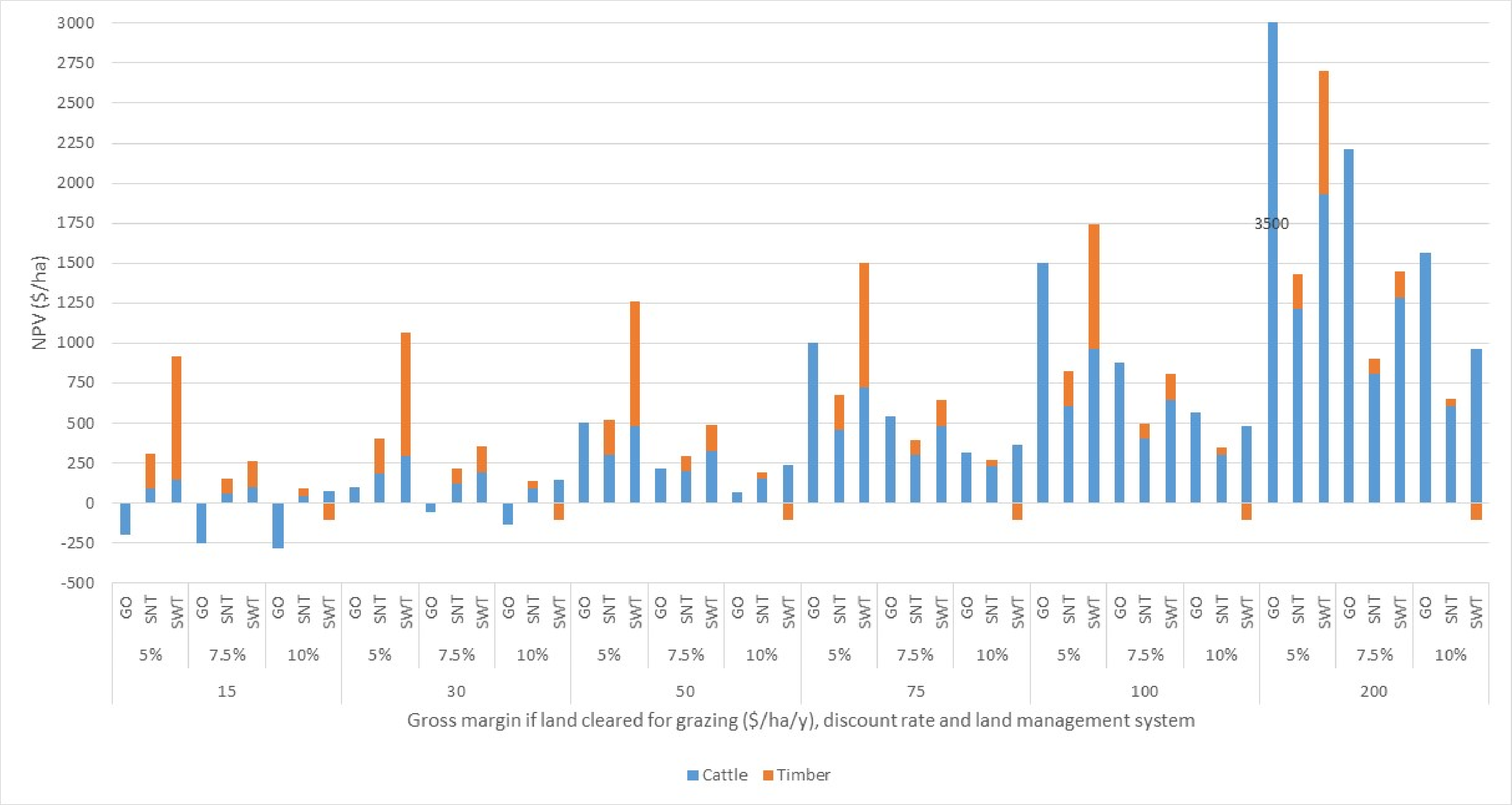

Figure 9.5. Financial performance of grazing only and silvo-pastoral systems in treated and untreated spotted gum forests.

Notes: GO is land cleared for grazing only. SNT is forest land managed as a silvo-pastoral system with no silvicultural treatment. SWT is forest land managed as a silvo-pastoral system with silvicultural treatment. Financial performance has been evaluated for discount rates of 5%, 7.5% and 10%, and for grazing gross margins ranging from $15/ha/yr to $200/ha/yr. The Y-axis has been truncated at $3000 to facilitate comparison of NPVs. NPV of grazing only at a 5% discount rate and a gross margin of $200/ha/yr is $3500.

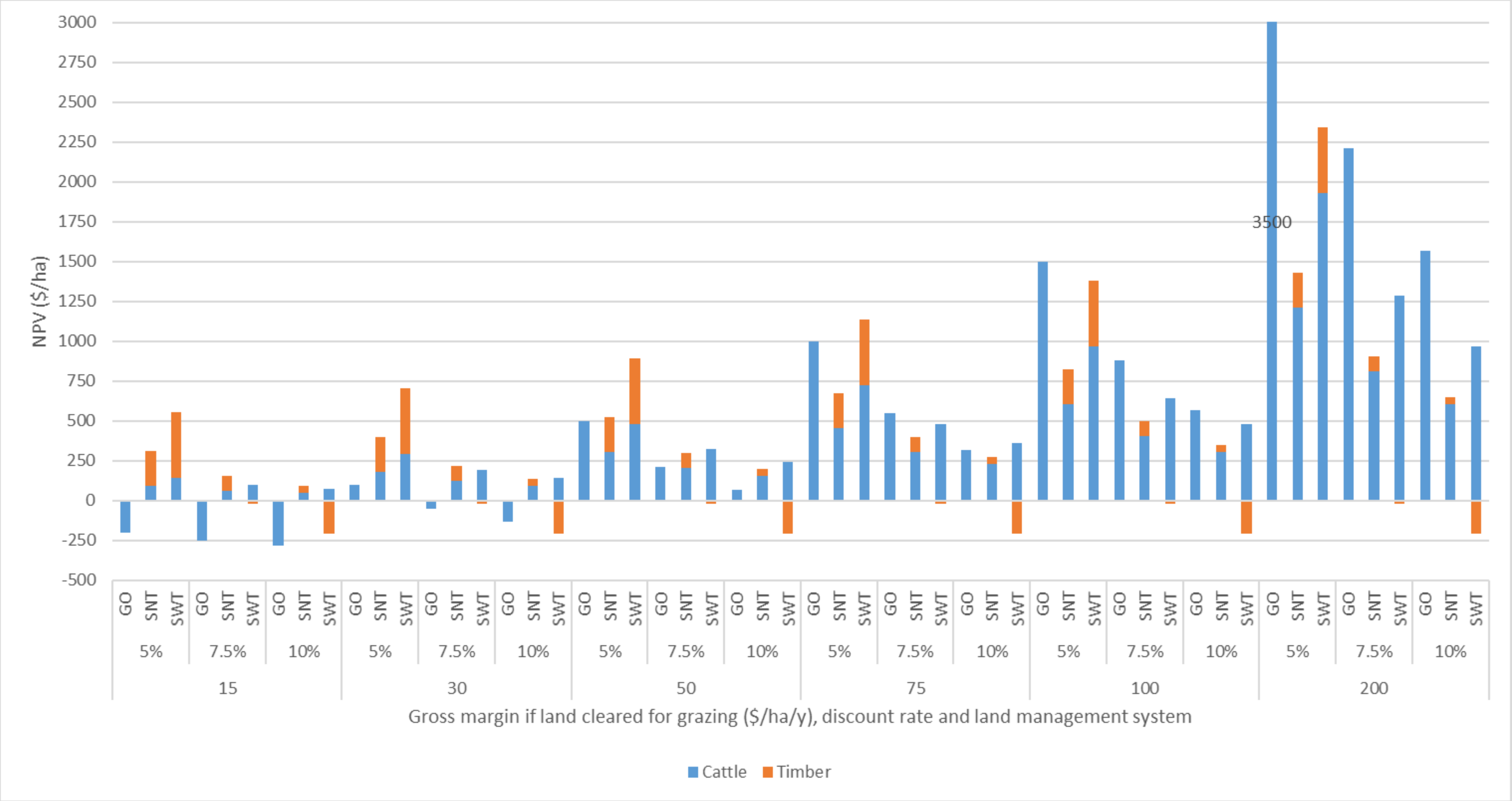

Figure 9.6. Financial performance of grazing only and silvo-pastoral systems in treated and untreated mixed hardwood and Queensland blue gum. forests.

Notes: GO is land cleared for grazing only. SNT is forest land managed as a silvo-pastoral system with no silvicultural treatment. SWT is forest land managed as a silvo-pastoral system with silvicultural treatment. Financial performance has been evaluated for discount rates of 5%, 7.5% and 10%, and for grazing gross margins ranging from $15/ha/yr to $200/ha/yr. The Y-axis has been truncated at $3000 to facilitate comparison on NPVs. NPV of grazing only at a 5% discount rate and a gross margin of $200/ha/yr is $3500.

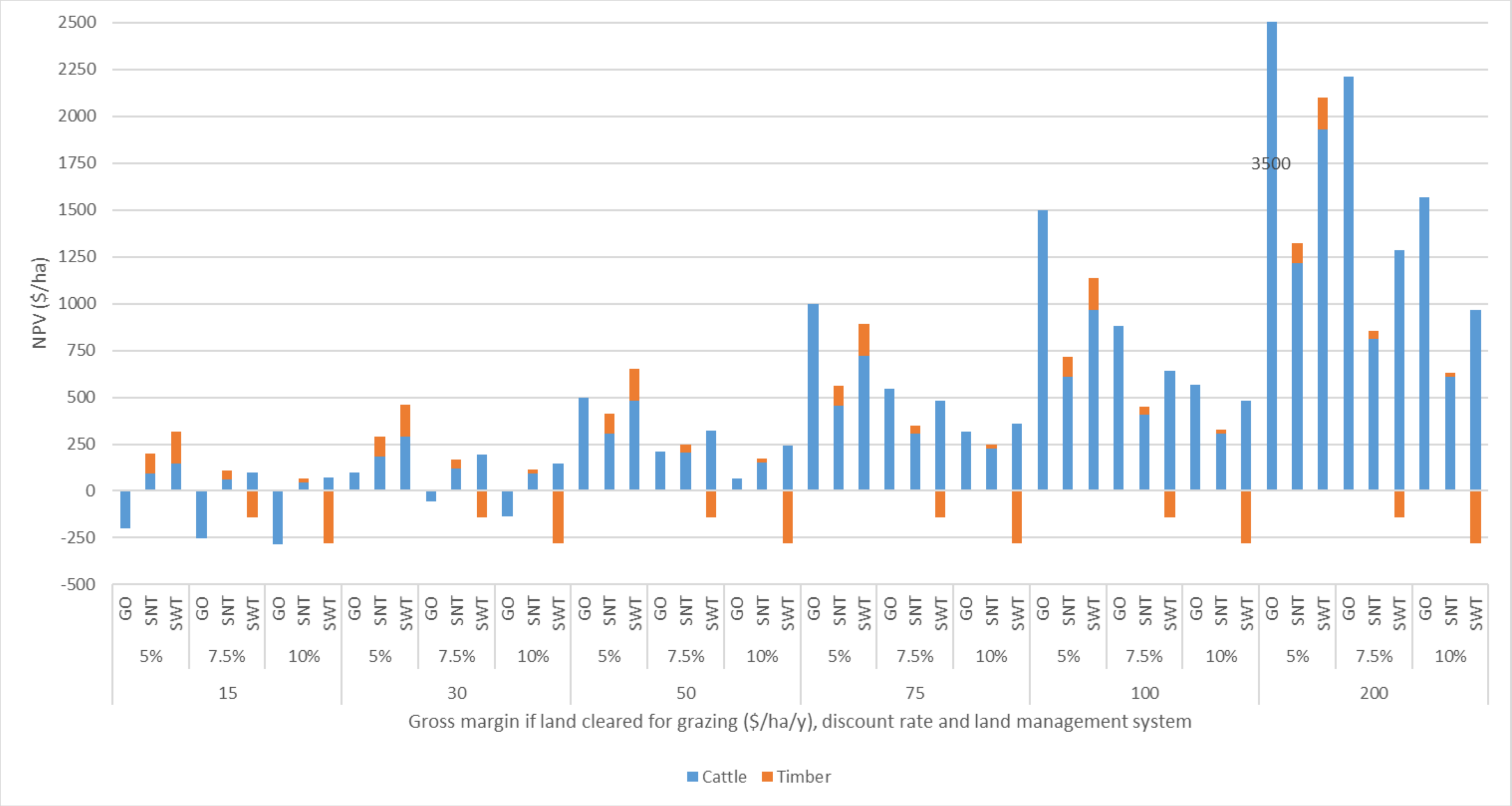

Figure 9.7. Financial performance of grazing only and silvo-pastoral systems in treated and untreated gum-topped box forests.

Notes: GO is land cleared for grazing only. SNT is forest land managed as a silvo-pastoral system with no silvicultural treatment. SWT is forest land managed as a silvo-pastoral system with silvicultural treatment. Financial performance has been evaluated for discount rates of 5%, 7.5% and 10%, and for grazing gross margins ranging from $15/ha/yr to $200/ha/yr. The Y-axis has been truncated at $3000 to facilitate comparison on NPVs. NPV of grazing only at a 5% discount rate and a gross margin of $200/ha/yr is $3500.

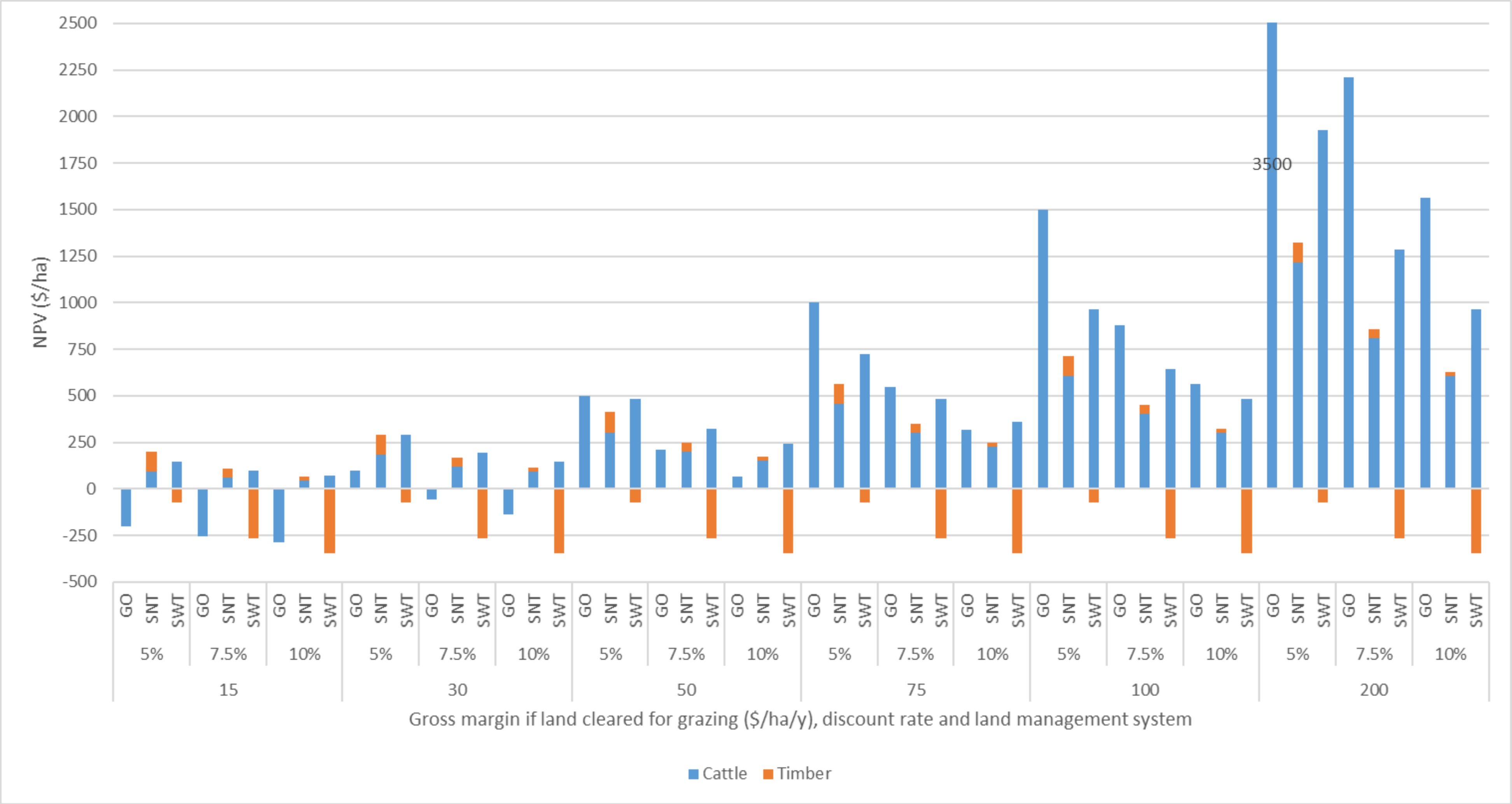

Figure 9.8. Financial performance of grazing only and silvo-pastoral systems in treated and untreated ironbark forests.

Notes: GO is land cleared for grazing only. SNT is forest land managed as a silvo-pastoral system with no silvicultural treatment. SWT is forest land managed as a silvo-pastoral system with silvicultural treatment. Financial performance has been evaluated for discount rates of 5%, 7.5% and 10%, and for grazing gross margins ranging from $15/ha/yr to $200/ha/yr. The Y-axis has been truncated at $3000 to facilitate comparison on NPVs. NPV of grazing only at a 5% discount rate and a gross margin of $200/ha/yr is $3500.

Figure 9.4 shows that moist tall forest managed under a silvo-pastoral system with silvicultural treatments (SWT) always outperforms clearing for grazing and silvo-pastoral systems without silvicultural treatments (SNT). In contrast to the other forest types, the contribution of timber revenues to the NPV of a silvo-pastoral system in moist tall forest always exceeds that from cattle. Land under moist tall forest may have high value under alternative agricultural production not assessed here.

In spotted gum forests – the single largest forest type in the project study area – landholders comfortable with a 5% real rate of return on invested resources would have to have country capable of generating grazing gross margins in excess of \$100/ha/yr before clearing for grazing could generate a better return than managing their forests under a silvo-pastoral system with silvicultural treatments (Figure 9.5). For example, where grazing gross margins are \$50/ha/yr, the NPV of clearing spotted gum for grazing is \$500/ha, but silvo-pastoral systems with silvicultural treatments generates \$1260/ha. Even at 7.5% and 10% discount rates, returns to silvo-pastoral systems with silvicultural treatments in spotted gum exceeds that from clearing for grazing, unless grazing gross margins exceed \$75/ha/yr and \$50/ha/yr, respectively.

In mixed hardwood and Queensland blue gum forest types, silvo-pastoral systems with silvicultural treatments are superior to clearing for grazing at a 5% discount rate when gross margins for cleared grazing land do not exceed \$75/ha/yr (Figure 9.6). At a 7.5% discount rate, returns to silvo-pastoral systems in these forest types exceed clearing for grazing when gross margins for cleared grazing land do not exceed \$50/ha/yr. As indicated in Figures 9.7 and 9.8, clearing for grazing in gum-topped box and ironbark forests is only optimal if grazing gross margins exceed \$50/ha/yr and \$30/ha/yr, respectively, which is unlikely in these forest types.

Potential contribution of private native forests to regional employment and income

This section investigates how adoption of active management in private native forests can sustainably increase harvestable timber volumes, regional employment and regional income. Estimates of sustainable yield (SY, volume of timber available for harvest per annum) in the Queensland part of the study area have been estimated as follows:

$$SY = PNFMT * \left[\sum_{i=1}^{6} \Big(\big((1 - ST) * FA_i * MAINT_i \big) + (ST * FA_i * MAIST_i) \Big) \right]$$

where: SY is sustainable yield (m^3/yr)

PNFMT is the proportion of private native forest managed for timber production (%);
ST is the proportion of private native forest managed for timber production that is also silviculturally treated (%);
FA_i is the area of forest type *i* in the Queensland part of the study area (ha);
$MAINT_i$ is the MAI of forest type *i* when the forest is not silviculturally treated (m^3/ha/yr); and
$MAIST_i$ is the MAI of forest type *i* when the forest is silviculturally treated (m^3/ha/yr)

For the purposes of analysis, PNFMT has been set at the levels of 30%, 40% and 50%, ST has been set at six levels of silvicultural treatment between 0% and 50%, FA_i are the areas of commercial private native forest by forest type reported in Chapter 4, and $MAINT_i$ and $MAIST_i$ are as reported in Table 9.3. The analysis assumes PNFMT and ST are the same for all forest types. Given differences in treatment responses between forest types, if treatments were concentrated on forest types with higher MAIs, sustainable yields could be higher than those reported. The results of these sustainable yield calculations are illustrated in Figure 9.9.

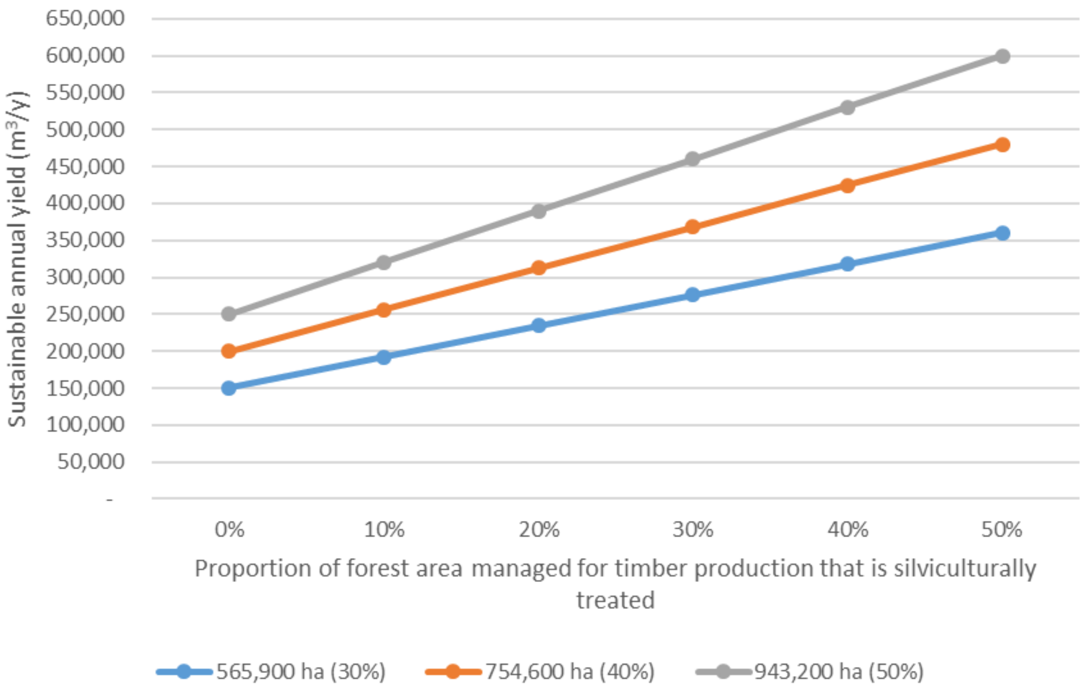

Figure 9.9. Potential annual sustainable yield from private native forests.

Note: The three plotted series are alternative proportions of private native forest managed for timber production (30, 40 and 50%).

Although some forest landowners in the study area do silviculturally treat their forest, the current situation is closely approximated by 0% treatment. From Figure 9.9, the sustained yield with zero silviculture is between 150,000 m^3/yr and 250,000 m^3/yr, depending upon assumptions about the proportion of forest managed for timber production. From the sawmill survey described in Chapter 4, private native forests in the study area presently account for 218,800 m^3 of the sawlog and pole hardwood volume supplied to sawmills in the study area. Although this volume falls in the middle of the range of the illustrated sustainable yields with no silvicultural treatment, it is not possible to comment on the sustainability of the current harvest because the proportion of landholders managing their forest for timber production is unknown[17].

For comparative purposes, previously published estimates of sustainable annual yield from private native forests in the SEQ Forests Agreement region are available from the Queensland CRA/RFA Steering Committee (1998a) and Bureau of Rural Sciences (2004). These publications estimated the area of commercially important private native forest in the SEQ Region at 1.25 M ha and 0.75 M ha, respectively, which are equivalent to 66% and 40% of the commercial and harvestable private native forest in the Queensland part of the study area of this report, respectively. Assuming 50% of these forests are managed for timber and no silvicultural treatment is performed, Queensland CRA/RFA Steering Committee (1998a) estimated the sustainable yield at 108,000 m^3, and Bureau of Rural Sciences (2004) at 50,000 m^3. When scaled up to the private native forest area within the study area for this

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[17] Analyses of sustainable yield from private native forests in the SEQ Forests Agreement region have assumed 50% of private native forest is managed for timber production (Queensland CRA/RFA Steering Committee 1998a, Bureau of Rural Sciences 2004).

report, these sustainable yields are equivalent to 163,000 m^3/yr and 126,000 m^3/yr. These are at the low end of the sustainable yields estimated in this report for zero silvicultural treatment, as illustrated in Figure 9.9.

Figure 9.9 illustrates the potential for silvicultural treatment to substantially increase sustainable timber yields from private native forests. For example, if 40% of private native forests are managed for timber production and 30% of these are silviculturally treated, private native forests could sustainably supply 368,000 m^3/yr. That is 10% more log volume than Crown and private forests combined are supplying to the industry at present.
If 50% of private native forests were managed for timber production, and half of that was managed with silvicultural treatment, the sustainable yield from private land is estimated to be 600,000 m^3/yr. That is a three-fold increase in private hardwood log production over the status quo, and would be equivalent to total Crown and private hardwood log production in Queensland in the 1980s (Queensland CRA/RFA Steering Committee 1998b).

Table 9.7 reports 10 hardwood log supply scenarios for the Queensland part of the study area, and quantifies impacts on regional employment and income levels. Scenario 1 is the status quo derived from the sawmill survey described in Chapter 4. Scenarios 2 to 5 have been developed assuming Crown harvesting continues at its present level in the study area, but for alternative levels of sustainable yield from private land. Scenarios 6 to 10 assume Crown harvesting ceases, but with the same alternative levels of sustainable private harvest as the first five scenarios.

As reported for Scenario 1, current employment in harvesting, haul and milling is 866 FTEs and the mill-gate sales revenue received by sawmills in the study area is $189 M. Changes in industry employment and income have been estimated for each scenario on the basis of current employment levels and value of output at the mill-gate per 1000 m^3 of hardwood log throughput (as derived from the sawmill survey). Thus, a 10% increase in log volume has been estimated to increase regional employment and income by 10%.

The scenarios indicate the substantial opportunity that silvicultural treatment on private land presents for growing regional employment and income. For example, Scenario 3, in which 30% of private native forest is managed for timber production and 40% of that is silviculturally treated (i.e. 12% of the total), is estimated to sustainably increase regional employment and income by 48% relative to the status quo. The flow-on benefits for regional communities of such an expansion would be substantial.

Table 9.7. Log volumes (sawlog and pole) and regional jobs and income under alternative scenarios of private and Crown log supply.

Scenario number and description (%PNF, %ST) [a]	Sustainable PNF log volume (1000s m^3/yr) [c]	Crown log volume (1000s m^3/yr) [d]	Total log volume (1000s m^3/yr)	Δ FTE from SQ	Total FTE	Δ mill sales revenue from SQ ($ M)	Mill sales revenue ($ M)
Harvesting in Crown and private native forests							
1. SQ [b], 0% ST	219	105	323	na	866	na	189
2. 30% PNF, 30% ST	276	105	381	+153	1019	+33	222
3. 40% PNF, 30% ST	368	105	473	+399	1265	+87	276
4. 50% PNF, 30% ST	460	105	565	+645	1511	+141	330
5. 50% PNF, 50% ST	600	105	705	+1019	1885	+222	411
Harvesting in private native forests only							
6. SQ [b] (0% ST)	219	0	219	–281	585	–61	128
7. 30% PNF, 30% ST	276	0	276	–128	738	–28	161
8. 40% PNF, 30% ST	368	0	368	+118	984	+26	215
9. 50% PNF, 30% ST	460	0	460	+364	1230	+79	268
10. 50% PNF, 50% ST	600	0	600	+738	1604	+161	350

Notes: a. %PNF is the percent of commercial and harvestable private native forest that is managed for timber production. %ST is the percent of private native forest that is managed for timber production that is also silviculturally treated. For example, where 30% of private native forests are managed for timber and 30% of these forests are silviculturally treated, this means 9% of the total commercial private native forest is treated.

b. SQ refers to the status quo for private commercial forest land management. It is unclear what proportion of private native forest is presently managed for timber production, so this percentage is not provided. It is reasonable to assume close to zero percent of the forest that is managed for timber production is also silviculturally treated.

c. The log volumes listed for SQ scenarios (1 and 6 only) are not necessarily sustainable, as it depends on what proportion of private native forest is managed for timber production. Figure 9.9 indicates if it is less than 40%, then the current harvest is not sustainable given zero silvicultural treatment.

d. Based on information collected in the sawmill survey described in Chapter 4, 105,000 m^3 of logs supplied from Crown forests to industry was processed in the study area over the year up to the time of the survey. This includes sawlogs, poles, landscape and other logs. By comparison, Leggate et al. (2017) reported that the Queensland Department of Agriculture and Fisheries harvested a total of 132,500 m^3 from Crown forests in the South East forest area (entirely within the study area for this report) and South West forest area (almost all production hardwood forests within the study area for this report). Some of the Central forest area is also within the study area for this report, the harvest being reported by Leggate et al. (2017) as 8000 m^3 in 2016. These volumes include sawlogs, poles, landscape and other logs, and is close to the estimate of the total volume of Crown logs processed in the study area derived from the mill survey.

It is possible that harvesting on Crown land within the study area will cease at some time in the future. Scenario 6 reports the outcome of the continuation of no silvicultural treatment in private native forests and no Crown harvest, indicating this could result in the loss of 281 regional jobs and $61 M in regional income. However, silvicultural treatments in private native forests have the potential to increase sustainable yields to offset reduced timber production from Crown forests. For example, Scenario 8, with 40% of the commercially important private native forest managed for timber production and 30% of that silviculturally treated, is an example of the level of investment in private native forest management necessary to maintain or expand the hardwood timber industry if production from Crown forests declines.

The hardwood employment and income scenarios described are plausible. The sustainable yields are based on empirical forest growth data and expert opinion reported and analysed elsewhere in this report. Silvicultural treatments have been shown to be financially viable for all forest types except ironbark. The private forest land exists. In Chapter 4, it was described how the 2950 LotPlans (and likely fewer individual landholders) that have at least 150 ha of commercial forest in the study area account for 1,235,000 ha (66%) of the private native forest resource in the Queensland part of the study area. It is likely that these large forest landholders have the most to gain from improved silviculture and may be more receptive to extension advice and incentives to manage their land for timber production. If the owners of 60% of LotPlans with at least 150 ha of commercial native forest could be motivated to manage their properties for timber production, and 50% of them could be encouraged to conduct silvicultural treatments, these 1770 LotPlans could sustainably supply about 480,000 m^3/yr to industry in the long-term[18]. Even if Crown timber harvesting ceased, this level of private native forest management could increase regional jobs by 390 FTEs and regional income by $86 M, relative to the status quo.

The next section reports the economics of the kind of large-scale investment in private native forest management that is likely to be necessary to turn the projected potential increases in regional employment and income into reality.

Potential economic benefit to Queensland of investment in private native forest management

Traditionally in Australia, New Zealand, Europe and North America, the timber industry has been supported by government agencies actively managing forests on public land for timber production. The economic rationale for this was that timber, vital for 19th and 20th Century economies, would not be sustainably supplied by the private sector due to relatively low rates of return and long pay-back periods.

Although the direct uses of timber are not as vital to economic activity in Australia today as they once were, the economic value to society of the public good benefits generated by well-managed private native forests are increasing as forest and woodland continues to be fragmented and cleared for urban development, agriculture and mining. These economic benefits include on-site and off-site carbon sequestration (e.g. including through displacement of carbon-intensive substitutes), habitat provision for wildlife, watershed protection and aesthetically pleasing landscapes. In addition, private native forests managed for timber provide important sustainable regional employment and income earning opportunities. Therefore, there are strong social, economic and environmental arguments in favour of support measures for private native forest management.

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[18] Growth rates of trees with commercial logs will increase almost immediately following silvicultural treatments; however, increases in harvestable log volumes will take about 20 years to materialise.

In Queensland, history has demonstrated that the majority of private native forest landholders have not perceived their forests as capable of providing sufficient financial return (given the risks involved) to justify sound forestry management (see Chapter 4). There are four main reasons for this:

i. high sovereign risk – the risk that rules regarding forest management and access to timber will change;
ii. the need for an annual income, which is not provided by trees to the extent that it is by cattle;
iii. landholders do not appreciate how silvicultural treatment can increase the value of their timber, and they have limited knowledge about how to manage their forest for timber production; and
iv. other risk factors, such as severe bushfire, which may reduce the value of their timber crop.

These factors have resulted in land clearing and subdivision (when permitted under the law), and poor management (often only 'high-grade' harvesting) of the remainder. Long-term sustainable management of private native forests for timber and public good benefits will be facilitated by addressing these factors.

One potential way to encourage sustainable private native forest management is through provision of an annuity payment in lieu of timber stumpage and in recognition of the continuous production of non-timber benefits for society[19]. As a condition of the annuity payment, the landholder would transfer their rights to manage timber to a professional forestry management organisation. However, the landholder would retain their rights to access the forest for wood for domestic use and for non-timber purposes, including the grazing of cattle. Some assurance that silvicultural treatments will not reduce the grazing value of the land will be necessary. The minimum duration of the annuity agreement would need to be at least 20 years to ensure the benefits of improved forest management are realised in increased forest growth and timber production. A long-term investor would be required to provide funds to initiate such a private native forest management program. The system would become self-sustaining when harvests commence 20 years after the first silvicultural treatments, and substantial annual dividends to the investor could commence at this time.

Table 9.8 summarises private native forest resource parameters adopted to evaluate an investment scheme to facilitate large-scale private native forest management. It is assumed silvicultural treatments will be focussed on the four most productive forest types in Queensland: moist tall, spotted gum, mixed hardwoods and Queensland blue gum. Together, they account for 60% of the commercially important forest area in the Queensland part of the study area. It is assumed the investment program would silviculturally treat 100,000 ha[20] distributed across the four forest types in proportion to the aerial extent of each forest type. One twentieth of the area (5000 ha) would be treated each year starting today (year zero) and harvesting of the treated forests would commence in 20 years, when the sustainable yield from these 100,000 ha will be 125,580 m^3/yr.

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[19] Vanclay (2007) made a similar proposal for stewardship payments to stimulate management for conservation in private native forests.

[20] Results are scalable, such that a 50,000 ha program would have half the projected costs and benefits, while a 200,000 ha program would have double the projected costs and benefits

Table 9.8. Private native forest resource parameters adopted for evaluation of the silvicultural treatment investment scheme.

Forest type	Harvest-able area (1000 ha) [a]	% harve-stable area	Silvicult-urally treated area (1000 ha)	MAI no treatment (m^3/ha/y) [b]	MAI with treatment (m^3/ha/y) [b]	Sustainable yield in 20 years without treatment (m^3/y) [c]	Sustainable yield with treatment in 20 years (m^3/y) [c]	Increase with treatment (m^3/y) [d]
Moist tall	33.4	2	2.9	1.7	3.5	4,980	10,260	5,280
Spotted gum	693.0	37	60.8	0.3	1.3	18,250	79,080	60,830
Mixed hardwood	159.6	8	14.0	0.3	1.0	4,200	14,010	9,810
Qld blue gum	253.3	13	22.2	0.3	1.0	6,670	22,230	15,560
Other	796.5	40	0	na	na	na	na	na
Total	1886.4	100	100	0.34	1.26	34,100	125,580	91,480

Notes: a. Harvestable area from Table 4.2.

b. MAIs from Table 9.3.

c. Sustainable yields in 20 years with and without treatment have been calculated as the MAI with and without treatment, multiplied by the silviculturally treated area.

d. Increase with treatment is sustainable yield with treatment, minus sustainable yield without treatment.

Table 9.9 reports the financial performance of the private native forest silvicultural investment scheme. Harvest revenues commence in year 20 at $12.6 million per year. For analysis purposes, the annuity for landholders is set at $30/ha/yr[21] indexed to inflation. This may seem low, but is likely to be attractive over large areas of private native forest, because it is a zero-risk annual income stream and the professional forestry management will increase grazing values in the forest. To implement the 100,000 ha program, the total silvicultural treatment and annuity cash costs over the first 20 years (before harvest revenues are earned) is $84 million (or $4.2 million per annum). To help put this in perspective, the cash cost of establishing, weeding, fertilising, pruning and thinning 20,000 ha of hardwood plantations in Queensland for sawlog and pole production would be about $100 million, excluding the cost of land and annuity payments to landholders[22].

The present values of revenues and costs assume perpetual (i.e. not only the first 20 years) private native forest management for timber production. At a 5% real (net of inflation) discount rate, the net present value of this investment in private native forest silviculture is $12.8 million. That is, the investor could earn a 5% rate of return over and above inflation on funds invested in silvicultural treatments and annuities to landholders, plus $12.8 million on top of that.

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[21] More discriminatory approaches to setting annuity levels are possible, such as variable payments according to forest productivity or reverse auctions.

[22] Greenfield Resource Options Pty Ltd (1999) and Venn (2005) estimated plantation establishment and management costs at about $3000/ha in 1999 dollars. These costs become $5000/ha when Inflated by the CPI to 2018.

Table 9.9. Financial performance of an investment to facilitate private native forest management on 100,000 ha.

Revenues and costs	Description	*Annual* cash revenues commencing in year 20 ($ millions)	*Total* cash costs over the first 20 years ($ millions)	Present value of perpetual forest management at a 5% discount rate ($ millions)
Stumpage (return to the investor)	From Table 9.8, 125,580 m^3/yr @ $100/$m^3$ starting in 20 years	12.6		94.7
Less				
Silvicultural treatment costs	5000 ha/yr for 20 years @ $400/ha, plus re-treatments at $250/ha every 10 years thereafter		52.5	41.8
Less				
Annuity payments to landholders	$30/ha/yr, with the treated estate growing 5000 ha/y over the first 20 years		31.5	40.1
Total and **Net Present Value**			84.0	**12.8**

Figure 9.10 highlights that when the annuity paid to landholders is $30/ha/yr, the internal rate of return (IRR) for the investor facilitating private native forest silviculture is 5.8% real (net of inflation). If the annuity was $40/ha/yr, the IRR would be 5%. If the investor is comfortable with a 3% real rate of return, landholders could be paid an annuity of $65/ha/yr.

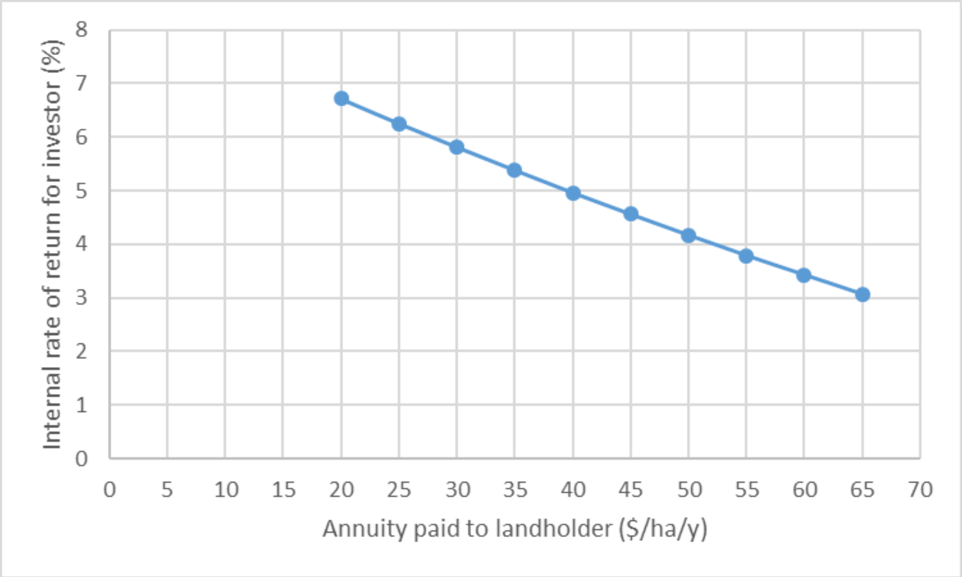

Figure 9.10. Internal rate of return from investment in private native forest management as a function of the annuity level paid to landholders.

Logs from silviculturally treated forests will be processed into value-added products. Silvicultural treatment increases the sustained annual yield by 91,500 m^3/yr relative to no silvicultural treatment (Table 9.8). Findings from the sawmill survey presented in Chapter 4 suggested the average mill-gate sale value of hardwood products was $583/$m^3$ of log harvested, and that every 1000 m^3 of hardwood log processed generates 2.4 full-time equivalent (FTE) jobs in forest management, harvesting, hauling and wood product processing. Using these averages, the investment program in private native forests not only provides an annual revenue stream to landholders, but has the potential to expand the net annual economic value of hardwood production in regional Queensland by $53 M/yr and expand sustainable regional employment by 219 FTEs by year 20 of the program. This net increase in hardwood production at the sawmill has a present value of $402 M at a 5% discount rate[23]. Thus, the flow-on benefits of the investment in silviculture and annuity payments for the regional economy of Queensland are many times greater than the direct returns earned by the investor from the increased value of harvested logs.

In summary, the 100,000 ha private native forest silvicultural treatment program, which will require an average annual investment of $4.2 million for 20 years, will produce the following benefits for regional southern Queensland:

- An immediate risk-free farm revenue stream of $30/ha/yr for silviculturally treated forest. When the project reaches its target of 100,000 ha treated in year 20, regional farm revenues will be increased by $3 million per year;
- Improved cattle carrying capacity in silviculturally treated forest, providing a further increase in farm revenues not accounted for in this analysis (but evaluated in Chapter 8 and the silvo-pastoral systems section in Chapter 4);
- Starting in year 20, an annual sustainable harvest will commence of about 125,580 m^3 logs with a value at the stump of $12.6 million per year for the investor. This return could be shared between the investor and landholders;
- Starting in year 20, the silvicultural treatments will increase the annual sustained hardwood log yield by 91,480 m^3, relative to if the forest was not treated. This will add $53 million per year to regional production at the sawmill gate;
- Starting in year 20, the increased timber harvesting will increase sustainable regional forest industry employment by 219 FTEs, relative to if the forest was not treated;
- Reduced incentives for clearing of regrowth forest on Category X land; and
- Improved condition of some aspects of the forest and forest health (Chapters 5, 6 and 10).

Conclusion

This chapter evaluated the potential for silviculture in private native forests to improve the productivity and value of these forests for landholders and benefit the regional economy of Queensland. Available empirical data and expert opinion on forest growth with and without silviculture suggests the growth rates of private native forests vary substantially by forest type, but that silviculture can generally increase growth by a factor of two to four times their untreated rates. Silvicultural treatments were found to be financially viable at a 5% real (net of inflation) discount rate in all commercially important forest types in Queensland, except ironbark. The returns to silvo-pastoral systems versus clearing for grazing was also examined in the chapter, which revealed clearing for grazing is not financially viable (NPV < $0) when the grazing gross margin for cleared land is $15/ha/yr. Also, for all forest types except ironbark, financial returns to silvo-pastoral systems exceed those from clearing for grazing when grazing gross margins do not exceed $50/ha/yr. In ironbark forests, silvo-pastoral systems are financially optimal when grazing gross margins do not exceed $30/ha/yr.

Potential future sustainable annual yields from private native forests in southern Queensland were estimated at between 150,000 m^3/yr and 600,000 m^3/yr, depending on level of landholder participation in timber production (estimated between 30% and 50% of the

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[23] This increase in present value of hardwood production at the mill is in addition to the values reported in Table 9.9.

mapped available forest) and application of silvicultural treatments within their forests (simulated to range between 0% and 50%). However, significant constraints to landholder participation in forest management include sovereign risk and the need for landholders to generate an annual income. A private native forest silviculture investment program that could at least partly overcome the income constraint by paying landholders an annuity of $30/ha/yr, was evaluated. The program was scaled at 100,000 ha of treated forest and found to be financially viable at a 5% real discount rate. The program was also financially viable at a 5% real discount rate when the annuity payment is $40/ha/yr. Such an investment in private native forests could lead to large flow-on benefits in the medium to long-term including increasing the value of sustainable regional output at mills by about $53 M/yr, and increasing regional employment opportunities by about 219 FTEs. Substantial regional economic opportunities appear to exist with private native forest management.

Chapter 10. Environmental opportunities and impacts of private native forest management in southern Queensland and northern New South Wales

Tyron Venn

Introduction

In contrast to southern states, all native hardwood forest types managed for timber production in Queensland are harvested using a single tree selection system (i.e. selective harvesting). The native forest practice code, which is an accepted development vegetation clearing code in Queensland, sets out required outcomes and practices for a native forest practice in Category B vegetation (remnant forest) (Department of Natural Resources and Mines 2014). The native forest practice code ensures private native forests will be managed using selective harvesting. A limited number of regional ecosystems are permitted to be harvested under a group selection regime. In both cases, the native forest practice code requires minimum tree retention levels, including habitat trees.

There was little regulation of harvesting in private native forests until the late 1990s. The majority of private native forests in southern Queensland and northern NSW are either regrowth forests on formerly cleared agricultural land that was abandoned due to low productivity, or are forests that may never have been cleared, but have been periodically selectively harvested over 100 years in unplanned and largely unregulated, ‘high-grading’ operations to complement farm revenues in periods of reduced cash flow (Parsons 1999; Ryan et al. 2002; Ryan and Taylor 2006; Thompson et al. 2006; Jay and Dillon 2016). Unmanaged regrowth on formerly cleared areas has resulted in high inter-tree competition, and retained non-merchantable overstorey trees have suppressed regrowth in areas that have not been cleared (Ryan and Taylor 2006). A lack of silviculture and natural wildfire disturbance has resulted in forests that are ‘locked up’ with very high stocking of trees. Active silviculture allows suppressed trees to be removed and opens up gaps in the canopy which are required to enable trees to grow to their full potential. In many areas, over-stocked forests have led to high competition for light, water and nutrients, resulting in reduced understorey grass cover (e.g. Chapter 6), and potentially increased erosion during high intensity rainfall events (Timber Queensland 2012)[24]. In this condition, Queensland’s private native forests have low timber production values. As Parsons and Pritchard (2009) found for private native forests in southern Australia, excluding forestry activities in Queensland’s modified natural disturbance landscapes could also reduce the value of private native forests for biodiversity conservation. Despite some negative effects on certain ecological attributes, the overall BioCondition scores in private native forest (most of which had a history of selective harvesting, or were younger regrowth forest) were relatively good (Chapter 3).

The purpose of this chapter is to review the literature on environmental opportunities and impacts of selective harvesting of native forests in southern Queensland and northern NSW. More native forest management literature is available for the south west of Western Australia, Victoria and Tasmania than for Queensland and northern NSW, but literature from those states has been largely excluded from this review because the climate, forest types, species assemblages and native forest silviculture practices in those states are not particularly relevant

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[24] There is not much research to directly support this assertion. However, Scanlan (2002) summarised the Queensland research that shows how increasing tree cover reduces grass biomass, and others have found that, in Queensland, reduced cover of grasses and ground cover vegetation increases runoff and soil erosion (Mullins et al. 1987, Ash et al. 1997, Ludwig and Tongway 2002).

to the project study area. This chapter focusses on eucalypt forest literature from southern Queensland and northern New South Wales. The review considers forest structure and regeneration, fauna, flora, wildfire risk, water yield and carbon sequestration.

Forest structure and regeneration

There is evidence that some of Australia's *Eucalyptus*, *Corymbia* and *Angophora* (hereafter referred to as eucalypt) dominated vegetation at the time of European settlement consisted of relatively wide-spaced, large-crowned, mature to over-mature trees with a more open and grassy understorey than today, and that indigenous Australians burnt eucalypt forests and woodlands[25] (Nicholson 1981; Ryan et al. 1995; Florence 1996; Benson and Redpath 1997; Jurskis 2000; Gammage 2012). Researchers have attempted to determine the ecologically appropriate forest structure for healthy forests and woodlands in Australia, with one focus being to estimate pre-European settlement tree stocking. For example, using data from 1850, Specht and Specht (2007) estimated that tree density of stems at least 30 cm diameter at breast height (DBH) in eucalypt forests around Brisbane averaged 80 stems per hectare (SPH) on soil derived from the Brisbane tuff and 110 SPH on soil derived from Brisbane metamorphics. King (1985) reported that old growth *Eucalyptus microcorys*, *E. saligna* and *Lophostemon confertus* forests on the mid north coast of New South Wales had a stocking of 40 to 65 SPH. Florence (1996) indicated that old growth mixed hardwood forests with a *E. pilularis* (blackbutt) component in northern NSW had an average of 86 SPH over 48 cm DBH. Curtin 1961 (cited in Florence 1996) asserted that the ideal stocking for high quality blackbutt forest for timber production was 120 SPH between 20 cm and 100 cm DBH. Gibbons et al.(2010) provide benchmark stem densities for woodlands and open forest from northern Victoria to north central New South Wales.

Concern has been expressed about the increased density of trees and shrubs in many forest and woodland types that have been developed for pastoralism in eastern Australia (Oxley 1987; Flannery 1994; Lunt 1997; Jurskis 2000; Burrows 2002; Burrows et al. 2002; Martin 2005; Whipp et al. 2012). Negative impacts of dense woody regrowth include suppression of understorey species richness and cover, delayed provision of desirable habitat features (such as hollows) and increased wildfire risk (Price and Morgan 2008; Dwyer et al. 2010; Jones et al. 2015). However, there is not a consensus on the prevalence of the dense woody regrowth issue, with the level of increase in woody vegetation in eastern Australia appearing to be variable (Benson and Redpath 1997; Fensham 2008). For example, 'reconstruction' of the density of pre-settlement stands from early surveys in central NSW by Lunt et al. (2006) revealed that trees of at least 20 cm DBH are about 5 times more common today (mean 198 SPH) than pre-settlement (mean 39 SPH). In addition, they found species composition had changed drastically, with the basal area of central NSW woodland dominated by *Callitris* today, but *Eucalyptus* historically. In contrast, there is perhaps evidence for only minor thickening on the Darling Downs, where stem density is about 12 to 28 SPH of trees at least 20 cm DBH (Fensham and Holman 1998). Nevertheless, Burrows (2002) asserted there is substantial evidence for woodland thickening in Queensland. Jurskis (2000) proposed interventions, such as prescribed fire and silvicultural treatments, to promote development of large and vigorous dominant trees to reverse post-European changes in the character of the native vegetation. Where woody vegetation thickening is of ecological concern, native forest silviculture can be part of the solution.

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[25] While there is irrefutable evidence of the use of fire by indigenous Australians to manage and extract resources, there is debate about the frequency and extent of fire use.

Jurskis (2005) and Close et al. (2009) asserted that exclusion of frequent low-intensity fire from dry sclerophyll forests is contributing to their decline and providing conditions for their arbivores and competitors to proliferate. For example, large areas of Queensland’s dry sclerophyll forests have a high stocking of suppressed trees between 10 cm and 30 cm DBH (MBAC Consulting Pty Ltd 2003a; Ryan and Taylor 2006). These trees had responded to release in the past (e.g. a harvesting operation or wildfire), but in the absence of mechanical thinning or fire that could have removed the weaker of these trees and provided canopy openings, most have persisted below the canopy. These trees will not respond to release if the overstorey is removed, will not become habitat trees and will inhibit regeneration of vigorous regrowth. It would be inappropriate to rely on these trees to restock the forest following a harvest (Florence 1996). The productive health of dry sclerophyll forests can be improved by silvicultural treatments to remove suppressed trees.

Vigorous regeneration of overstorey species in eucalypt forests requires a relatively low stocking of large trees. This is because eucalypts are highly sensitive to competition for light, water and nutrients. Indeed, no eucalypt species is able to establish and develop through the normal development sequence to maturity under a canopy (Florence 1996). Even if there is enough light for tree growth, the buds of the eucalypt are extremely sensitive to abrasion and the tree will not develop into a healthy, mature specimen if it establishes under the crown of remnant overstorey trees. Studies within several forest types on the competition effects of retained trees on eucalypt regeneration indicate that retained trees affect regrowth within a distance of between 1.5 and 6 times the crown radius of retained trees (Florence 1996). Silvicultural trials reported by Florence (1996) that commenced in 1949 within a degraded mixed hardwood forest of northern New South Wales, highlighted the benefit of taking a long-term perspective when evaluating the ecological and economic performance of native forest silviculture, and avoiding overly conservative silvicultural practices. Treatments retained 25, 38 and 100 SPH at least 30 cm DBH. After 40 years, the stand that received the most intensive treatment was the most productive and had a substantially more complex structure, with vigorous, healthy trees of all species in a range of size classes, including large habitat trees.

The conservation of moist and wet sclerophyll forest is also threatened by changed disturbance regimes. These forests depend on large disturbance events for regeneration, due to the forest floor generally having unfavourable conditions for recruitment of eucalypt seedlings (Florence 1996). Early research by van Loon (1966) showed wet sclerophyll forests of New South Wales were not regenerating under the prevailing small group selection system of the 1950s. He demonstrated the need for canopy openings larger than 40 m and a greater level of site disturbance. Where this is not achieved, either the canopy tree species composition will have a substantially reduced eucalypt component or the site will become low viny scrub. Nicholson (1999) reported that in northern New South Wales, sound regeneration of wet sclerophyll forests has required canopy disturbance of about 70%, and that infrequent burning has allowed a rainforest understorey to become the dominant association, generally advancing from gullies towards the ridges. Krishnan et al. (2019) found that more pronounced disturbance regimes (including fire and other management tools) than those that have occurred over the past 65 years may be required to conserve wet sclerophyll forest on Fraser Island and prevent its transition to rainforest.

Fauna

Selective timber harvesting will affect the distribution of suitable habitat for fauna in space and time. Kavanagh et al. (2005) assessed the sensitivity of frequency of occurrence for 227 vertebrate species to selective harvesting on 487 sites in north-eastern New South Wales.

They found most species were widely distributed throughout both logged and unlogged landscapes, albeit at different abundances according to their habitat requirements. They found 147 species (65%) were relatively unaffected by logging, 40 species (17.5%) to be significantly disadvantaged by logging and another 40 species (17.5%) significantly favoured by logging. Because of the diversity of ecological niches filled by species, it was not possible to make broad statements about the positive or negative effects of forestry on wildlife or even for particular taxonomic groups. Although not in sub-tropical eastern Australia, Gonsalves et al. (2018) found that the immediate (<2 years) effect of thinning two-thirds of the stems in dense, young stands of ecologically degraded *E. camaldulensis* forest had neutral or positive effects for birds, bats, non-volant mammals and insects. In North America, a meta-analysis by Verschuyl et al. (2011) to investigate the effects of forest thinning treatments on: (i) species richness, (ii) diversity, (iii) abundance of taxa or groups of species (guilds), and (iv) abundance of individual species for birds, mammals, reptiles, amphibians, and invertebrates, found forest thinning treatments had generally positive or neutral effects across all taxa. This section considers harvesting effects on mammals, birds, reptiles and amphibians in the sub-tropics of Queensland and New South Wales.

Mammals

Kavanagh et al. (2005) found mammals were the taxonomic group containing the largest proportion of species disadvantaged by logging (11) compared to those favoured by logging (4). Effects of forestry on koalas, arboreal hollow-dependent mammals, ground-dwelling mammals, and bats, and implications for conservation are summarised.

Koalas

The only physical demand koalas place on their environment is appropriate feed tree species, which prompted White (1999) to assert that it ‘should be relatively easy to provide habitat for koalas within rural areas’ in southeast Queensland. In northern NSW and southeast Queensland, the major threats to koalas are the fragmentation of eucalypt forests for urban development and farming, the density of sealed roads, and domestic dogs (McAlpine et al. 2006; Kavanagh et al. 2007; Tucker and Wormington 2011). Around 340 koalas struck by vehicles and 100 koalas attacked by domestic dogs are taken to wildlife hospitals in south east Queensland annually, where only 20% and 25% recover from their injuries, respectively. It is thought that total deaths from these causes are considerably higher (Queensland Department of Environment and Heritage Protection 2017). Increasingly fragmented habitat and populations of koalas means that severe bushfire and disease are also becoming important factors for their population viability (Tucker and Wormington 2011; Lunney et al. 2012).

In their review of research into forestry impacts on koalas, Tucker and Wormington (2011) found no evidence that forestry has impacted negatively on koalas. Empirical research in northern New South Wales has revealed koala populations are highest in areas with a long history of logging (Law et al. 2017); indeed in one study, koalas were three-times more likely to be present in heavily logged sites than unlogged sites (Kavanagh et al. 1995). An evaluation of koala survival and fecundity, home-range size and fidelity, movements and tree preferences in a selective harvesting experiment revealed no significant differences between koalas in logged and unlogged areas (Kavanagh et al. 2007).

Law et al. (2018b) deployed acoustic recorders at 171 sites to record male bellows for occupancy modelling and for comparisons of bellow rate. Surveys targeted medium to high quality habitat, with sites stratified by time since logging and logging intensity, with old growth forest as a reference. Neither occupancy nor bellow rate was found to be influenced by timber harvest history or local landscape extent of harvested and old growth forest. Notably, occupancy and bellow rate were not lower in recent, heavily harvested forests (mean of 5 years post-harvest) where a significant component of the canopy had been removed and the sites were dominated by dense regeneration of sapling eucalypts in the understorey.

Consistent with studies elsewhere in Australia, Kavanagh et al. (2012) found koalas often forage in young or small diameter trees in northern New South Wales. They found that koalas began feeding in eucalypt plantations two years after their establishment and began to shelter in them between four and seven years after planting. Furthermore, koalas used the eucalypt plantations more than expected based on the availability of this land cover type within their home ranges (Kavanagh and Stanton 2012), suggesting a preference for young, fast growing trees. According to Jurskis (2018), higher densities of koalas could be sustained in regrowth forests with healthy young trees and well-managed plantations. Silviculture in private native forests will increase the availability of healthy, fast growing trees and therefore is likely to benefit koala conservation.

Hollow-dependent arboreal mammals

Hollow-dependent arboreal mammals can be severely impacted by the removal of large trees with hollows. However, experience suggests few, if any, arboreal hollow-dependent mammals are entirely dependent on undisturbed old-growth forest. They survive where there are sufficient trees with suitable den and nest sites, and appropriate food sources (Florence 1996). So long as there is a continuing availability of trees with hollows, populations of hollow-dependent species should not be disadvantaged by forestry.

Populations of arboreal hollow-dependent mammals have remained high in Kioloa State Forest (now Murramarang National Park) and McPherson State Forest, New South Wales, and 11 State Forests in southeast Queensland after long histories of harvesting (Florence 1996; Eyre and Smith 1997; Wormington et al. 2002; Law et al. 2013). More generally for northern New South Wales, Kavanagh et al. (2005) reported the yellow-bellied glider, the common ringtail possum, and the common brushtail possum are not significantly affected by harvesting, while the greater glider is significantly less common in timber production areas. Law et al. (2013) concluded that the mosaic of disturbance created by selective harvesting in New South Wales did not negatively affect home range, habitat selection or den use by eastern pygmy possums (*Cercartetus nanus*).

The greatest abundance of arboreal mammals in southeast Queensland, including the common brushtail possum (*Trichosurus vulpecula*), greater glider (*Petauroides volans*), yellow-bellied glider (*Petaurus australis*), sugar glider (*Petaurus breviceps*), squirrel glider (*Petaurus norfolcensis*), and the feathertail glider (*Acrobates pygmaeus*) occurred at sites with five to six hollow-bearing trees per hectare (Wormington et al. 2002). Four live hollow-bearing trees are adequate to maintain arboreal mammal species richness and abundance in less productive forests, but six should be retained in habitat suitable for the greater glider (Wormington et al. 2002; Eyre 2005).

In slower growing spotted gum forests in the Western Hardwoods region of Queensland, historic harvesting and silviculture appears to have resulted in the removal of too many hollow-bearing trees. Prescriptive forest management codes requiring the retention of trees with hollows were not introduced in Queensland until the late 1990s. Consequently, the abundance of live trees with hollows in logged areas in the Western Hardwoods region is 2.5/ha, compared to 6.2/ha in unlogged areas, which will likely have conservation implications for hollow-dependent arboreal mammals (Eyre et al. 2010). The native forest practice code in Queensland does require the retention of recruitment habitat trees, which will address this shortfall in the coming decades.

The 1999 South-East Queensland Forests Agreement, to which the Queensland Government and key conservation and timber production stakeholders are signatories, included the immediate transfer of 53% of State-owned timber production forests to protected area status, and the implementation of a new, intensive one-time harvesting of all merchantable trees greater than 40 cm DBH (but maintaining habitat trees) in the majority of the remaining 47% (McAlpine et al. 2005). This was designed to maintain timber supply to the hardwood timber industry until 2024, while a substitute hardwood plantation resource was established (although the plantations have not been successful). Eyre (2006) did express concern about a likely negative response by greater gliders to the more intensive harvesting in State-owned production forests, but also reaffirmed that six habitat trees per hectare should be sufficient for conservation of the species.

Eyre and Smith (1997) concluded long-term conservation of the yellow-bellied glider is compatible with selective harvesting in south east Queensland. Wormington et al. (2002) reported that selective logging in other parts of Australia do not threaten populations of arboreal marsupials, and that this also appears to be the case in the dry sclerophyll forests of southeast Queensland. The native forest practice code does ensure selective harvesting is compatible with the conservation of arboreal hollow-dependent mammals, requiring private landholders to conserve six habitat trees per hectare within the habitat range of the greater glider and four per hectare outside that species habitat range. In addition, landholders must retain recruitment habitat trees, with more recruitment habitat trees required when the number of existing habitat trees is low. For example, landholders with forest within the habitat range for the greater glider that have the target six habitat trees per hectare, must also retain two recruitment trees per hectare. However, if the forest presently only has two habitat trees per hectare, then the landholder must retain eight recruitment habitat trees per hectare.

Ground-dwelling mammals

Complexity of habitat, particularly in the understorey, is known to be a key explanatory variable for the distribution and abundance of many ground-dwelling mammals, and short-term effects on habitat variables caused by prescribed burning, grazing and harvesting can modify habitat sufficiently to change species composition and abundance (Florence 1996; Catling et al. 2000). The observed frequencies of occurrence of some species, such as bandicoots, is the same throughout unharvested, selectively harvested and heavily harvested sites in northern New South Wales (Kavanagh et al. 1995). Other species, such as the red-necked pademelon, are known to be advantaged by harvesting, while some, including the rufous bettong, appear to be disadvantaged by the increased density of the understorey and mid-canopy cover that typically follows harvesting (Kavanagh and Stanton 2005).

Catling et al. (2000) developed statistical models to predict the distribution and abundance of ground-dwelling mammals in northern New South Wales, finding the common wombat, small wallabies, the bush rat, and dingos are not likely to be affected by harvesting, while the eastern grey kangaroo and large wallabies are likely to be favoured by harvesting. However, the models also projected the brown antechinus, yellow-footed antechinus, fawn-footed melomys, and spotted-tailed quoll would be negatively affected by selective harvesting. The projected negative effects of harvesting on some of these species are likely to be short-lived, as selective harvesting will create the structurally diverse forest vegetation favoured by species such as antechinus (Florence 1996; Holland and Bennett 2007). Becher (2008) concluded that a mosaic of age classes can maintain tiger quoll (*Dasyurus maculatus*) habitat. To satisfy the needs of all ground-dwelling mammal species, a mosaic of vegetation at the landscape level is required (Holland and Bennett 2007), and selective harvesting does seem to be compatible with that requirement (Florence 1996).

Bats

Blakey et al (2016, 2017) examined the effect of thinning regrowth native forest on bat communities and found edge-space foraging bats with traits varying from more open-adapted to relatively clutter-tolerant species, benefit from the thinning of dense regrowth. At Chichester State Forest, 200 km north of Sydney, Law et al. (2018a) assessed the effects of timber harvesting on bat populations over a 14-year period. The effect of logging history on apparent survival was minor and species specific, with no detectable effect for two species (*C. morio* and *V. darlingtoni*), a positive effect for one (*V. pumilus*) and negative for another (*V. regulus*). There was no effect of logging history on abundance or body condition for any of these species, leading the authors to conclude population dynamics were not compromised by timber harvesting and thinning.

Birds

In northern New South Wales, more bird species appear to be advantaged by logging (26) than disadvantaged (20) (Kavanagh and Stanton 2005). Examples of those advantaged by harvesting prefer wetter, multi-layered forest with dense ground cover and fallen logs, including the Australian owlet-nightjar, whitebrowed scrubwren, eastern whipbird, brown greygone, Lewin’s honeyeater and wonga pigeon. Bird species disadvantaged by harvesting include the buff-rumped thornbill, white-throated greygone, red-browed treecreeper, satin flycatcher and crimson rosella. Many bird species do not appear to be significantly affected by harvesting, including the nocturnal white-throated nightjar and tawny frogmouth (Kavanagh et al. 1995).

Bird species richness increased significantly with harvesting, relative to unlogged and unthinned forest in the Western Hardwoods region of Queensland; however, some species were disadvantaged by harvesting (Eyre et al. 2015a). That finding is consistent with a study in mixed species forests in Gippsland, Victoria, which found both density and species richness of birds were greater at thinned sites than unthinned sites (Barr et al. 2011). A key threat to birds in fragmented landscapes of eastern Australia is the increasing dominance of a native bird, the noisy miner *Manorina melanocephala* (Eyre et al. 2009). In spotted gum forest in the Brigalow Belt of Queensland, selective harvesting appeared to exert a minimal effect upon noisy miner abundance, whereas clearing for grazing had a profound positive influence (Eyre et al. 2009).

Smyth et al. (2002) found populations of only three out of 11 hollow-nesting bird species studied in dry sclerophyll forests of southeast Queensland were significantly affected by selective harvesting. Out of these three species, the little lorikeet had a statistically significant preference for areas more frequently harvested, while the white-throated treecreeper had a statistically significant preference for areas less frequently harvested. This highlights the challenging trade-offs in developing management guidelines for the conservation of individual species rather than the conservation of ecosystems at the landscape scale.

Harvesting practices in northern New South Wales have had little adverse effect on the regional distribution or occupancy rates of the powerful owl and the sooty owl, although occupancy by the masked owl and southern boobook owl appears to be greatly reduced in heavily harvested forests, possibly because these species are disadvantaged by dense post-logging regeneration (Kavanagh et al. 1995; NSW Department of Environment and Conservation 2006). Nevertheless, all owls are well-distributed throughout managed forests, and have been shown to respond to logging (and wildfire) disturbance by recolonising areas as forest regeneration proceeds (Kavanagh et al. 1995; NSW Department of Environment and Conservation 2006).

Reptiles and amphibians

Kavanagh et al. (2005) found reptiles were the taxonomic group containing the largest proportion (39%) of species where occurrence was either significantly positively or negatively affected by forestry in northern New South Wales. Examples of species negatively affected by logging are White’s skink and nobbi, while the land mullet is an example of a reptile that is advantaged by harvesting (Kavanagh and Stanton 2005). In dry sclerophyll forests of southeast Queensland, Goodall et al. (2004) observed 47 reptile species and found them to be most abundant in stands harvested within the last 10 years and in mature stands that have not been harvested for at least 50 years. They also found species richness was not affected significantly by time since harvest. Hence, all reptile species were present in regrowth areas 10 to 50 years post-harvest. In the Western Hardwoods region, a study of the impact of harvesting and thinning in cypress pine forest found reptile species richness increased significantly with harvesting, relative to unlogged and unthinned forest (Eyre et al. 2015a). However, the study revealed complex, cumulative impacts of thinning and harvesting on reptile assemblages.

Lemckert (1999) examined the effect of selective harvesting on the species richness at sites and abundance individuals breeding for 29 frog species at 212 sites in the Dorrigo Management Area of northern New South Wales. Frog species richness was found to be significantly positively related to the percent of disturbed (harvested) forest. Increasing number of harvesting events increased species richness of tree frogs and generalist species at streams, while recent disturbances increased richness of generalists at ponds. The author commented that this is consistent with other studies. Lemckert (1999) concluded that selective logging does not deleteriously affect species richness of sites, nor the abundance of breeding individuals for 26 of the 29 species studied. Negative effects of selective logging were found for three species, *Mixophyes fasciolatus* (great barred frog), *M. iteratus* (giant barred frog), and *Adelotus brevis* (tusked frog). The giant barred frog will return to logged areas for breeding after a short regeneration period. The great barred frog appeared to sometimes favour harvested areas and other times not, suggesting a need for further research. The tusked frog appears to have a preference for unlogged forest. Kavanagh et al. (2005) also found frog species were generally not negatively affected by selective harvesting in north east New South Wales, with only two species being statistically significantly less common in recently harvested areas relative to unharvested areas, and one frog species displaying a significant increase in abundance in harvested areas.

Flora

Forestry practices can have short to medium-term effects on the structure and floristic composition of the forest, as well as the litter layer and level of coarse woody debris. Florence (1996) described numerous silvicultural treatments performed in eastern Australian sub-tropical native forests, including some where the aim was to shift the species balance in favour of preferred commercial species (not permitted by the native forest practice code in Queensland). Time since treatment, harvest and wildfire has been found to affect the relative abundance of particular understorey and overstorey species, but not species presence or absence (Florence 1996). Furthermore, the ecological sifting of plant species by site consistently recreated the original understorey and overstorey species balance with time since treatment, even in trials with deliberate attempts to alter the species composition. Penman et al. (2008) found that timber harvesting and prescribed fire in dry sclerophyll forests of south east New South Wales resulted in no change or an increase in floristic richness in the shrub and ground vegetation layers at the coupe (30 ha) scale, which they reported was consistent with other similar studies in Australia. Some studies have found that thinning forests and woodlands is beneficial for conservation of the diversity of native flora (Jones et al. 2015). No overstorey or understorey plant species are known to have become locally extinct due to forestry practices (Florence 1996).

Conservation of flora and fauna is achievable at the landscape scale with diverse disturbance regimes

Native forest management to maximize individual flora and fauna species densities would be complicated, probably impossible to implement at a landscape level, and always involve substantial trade-offs with the conservation of other species (McIlroy 1978; Smyth et al. 2002). In contrast, it is technically feasible to aim to avoid local extinctions of all species, while accepting that species populations will fluctuate throughout the landscape over time in response to initiation or resetting of succession of flora and fauna communities due to variable forestry and wildfire disturbances (McIlroy 1978; Smyth et al. 2002).

Given that each hectare of forest differs from all others, and none are ever at a steady-state, Attiwill (1994) argued for diversity in sustainable management practices throughout the entire public and private forest estate to maximise conservation of biological diversity at the landscape level. Maintaining a mosaic of different thinning and harvesting combinations throughout the landscape is beneficial for biodiversity conservation (Florence 1996; Holland and Bennett 2007; Eyre et al. 2015a). The permanent clearing of native forests for urban development and farming, not forestry, is the most significant factor threatening the viability of most native forest flora and fauna (Braithwaite 2004; Jay et al. 2007).

Legislation that encourages or indeed incentivises regrowth forest management as an income generating asset will increase the likelihood that regrowth forest (e.g. on Category X land) will remain forest. This will potentially decrease the degree of fragmentation of forest landscapes, and facilitate greater biodiversity conservation by enabling the retained forest to become more structurally mature and diverse. On the other hand, perceptions of high sovereign risk, reinforced by frequent changes of vegetation management regulations, will continue to encourage clearing of regrowth forest, as it has in the past (Queensland CRA/RFA Steering Committee 1998a; Bureau of Rural Sciences 2004).

Wildfire risk and water yield

Lindenmayer et al. (2009) proposed that harvesting in Australia’s wet forests results in drier forests that tend to be more fire-prone, and this did gain some prominence in policy debate. However, Attiwill et al. (2014a; 2014b) found no evidence to support this argument from considerations of eucalypt stand development, nor from re-analysis of the only Australian study cited by Lindenmayer et al. (2009). Attiwill et al. (2014b) concluded the flammability of stands of different ages can be explained in terms of stand structure and fuel accumulation, rather than a dichotomy of regrowth stands being highly flammable, while mature and old growth stands are not highly flammable. Lack of resources for management of fire-adapted ecosystems has long-term social, economic and environmental consequences. Native forest silviculture and harvesting across a landscape can potentially reduce the extent of wildfires by providing heterogeneity in fuel loads (and fuel composition and structure), and through providing fire breaks and improved access to aid in wildfire control. Studies elsewhere (e.g. in the United States) have shown the important influence of forest structure on the risk of severe wildfire (e.g. Graham et al. 2004).

In south-east Queensland, native forest catchments are relied upon to provide high-quality surface water at low cost to communities for domestic consumption and for irrigation. A combination of a growing population within these water catchments and the projected increasing variability of rainfall suggests water security will become a more important issue in coming decades (Steffen et al. 2018). Several studies throughout Australia have investigated the potential of forestry as a water supply augmentation strategy, and have found that distributing thinning and harvesting treatments in native forests over space and time can significantly increase water catchment yield without compromising water quality, through the patchy reduction of sapwood and leaf area that decreases stand evapotranspiration (Ruprecht et al. 1991; Cornish 1993; Lane and Mackay 2001; Webb 2012; Hawthorne et al. 2013). For example, Stoneman and Schofield (1989) studied the Perth Metropolitan Water Supply catchments and the estimated 1000 km^2 of State Forest suitable for thinning within it. The lowest of four indirect estimates of streamflow increase due to thinning indicated that reservoir inflows could be augmented by 47% or 127 million m^3/yr, of which 48 million m^3/yr could be harnessed by the water supply system.

This literature review revealed no Queensland studies on the effect of forest management on water yield. Given the differences in rainfall seasonality and intensity in Queensland, relative to southern Australia, where the cited studies were performed, it is likely to be inappropriate to transfer these findings to the Queensland context. Further research is necessary to estimate implications of private native forest management for water supplies in Queensland.

Private native forest and carbon opportunities

Queensland’s native forests produce a suite of unique timbers with highly desirable wood properties for flooring and decking, structural uses, furniture, electricity distribution poles, and bridge girders. The native forest wood products industry also provides important sustainable regional employment opportunities. If Queensland does not source these timbers locally, the demand will be met by substitute products with much higher costs to society, either due to high embedded carbon (e.g. concrete, brick, steel, aluminium, and carpet) or because alternative wood products are sourced from regions of the world that do not practice sustainable forestry (Hammond and Jones 2006; Ximenes and Grant 2013).

Yu et al. (2017) asserted that substantial reductions in Australia’s carbon emissions could be achieved by having the construction sector (which accounts for 18.1% of national emissions due to reliance on carbon-intensive construction materials) increase its use of wood products. Australian and international lifecycle of carbon analyses have found forests managed for wood products sequester more carbon than conservation forests where carbon is only stored in biomass on-site (Kaul et al. 2010; Oliver et al. 2014; Ximenes et al. 2016; Gustavsson et al. 2017). The Intergovernmental Panel on Climate Change (IPCC) have long argued that a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fibre and energy, will generate the largest sustained climate change risk mitigation benefit (Metz et al. 2007). Sustainable management of private native forests for timber is likely to positively contribute to Australia’s transition to a low carbon economy.

Conclusion

Silvicultural practice, such as thinning, will almost inevitably alter the structure of a native forest. This review highlighted that many flora and fauna species are not impacted by silviculture. However, many other species are disadvantaged or may benefit from these activities. Projected negative effects of disturbance or a lack of disturbance are short-lived for some species, but long-term for others. The literature has revealed challenging trade-offs associated with the development of management guidelines for the conservation of individual species, as these may be to the detriment of other species. Nevertheless, there will be a need for some species specific management guidelines for conservation of species that are in rapid decline in particular landscapes.

Aiming for a mosaic of disturbance regimes at the landscape scale over time appears to be a more feasible approach for biodiversity conservation in general. This requires an acceptance that individual species populations will fluctuate throughout the landscape over time in response to initiation or resetting of succession of flora and fauna communities in response to variable forestry, wildfire and other disturbances. There is a need for areas to be permanently conserved as long-undisturbed old growth forests, but also a need for a mosaic of forests with a range of disturbance regimes. This will likely create more complex forest structures than unmanaged private native forest, which is necessary to satisfy the habitat requirements of many species in southern Queensland and northern NSW. In this context, the native forest practice code in Queensland (and the relevant Private Native Forestry Codes of Practice in NSW) will be particularly useful to mandate outcomes and activities to avoid long-term impacts on particular species, such as requiring the retention of habitat trees for hollow-dependent fauna.

There is no Australian evidence that selective harvesting and silvicultural treatments increase wildfire risk, but there is substantial evidence from southern Australia that municipal catchment water yields can be increased via native forest management. There is an emerging international consensus, ratified by the IPCC, that production forests generate higher climate change risk mitigation benefits than conservation forests in the long-run. Selective and group selection harvesting permitted by the native forest practice code in Queensland can be regarded as one of the tools available to land managers to implement necessary disturbances to maintain or restore the ecological health and resilience of wet, moist and dry sclerophyll forests in southern Queensland and northern NSW.

Chapter 11. Summary and recommendations

Summary of key findings

Extent and common forest types

Across the study region in northern New South Wales (NSW) and southern Queensland, there is a total of approximately 2,597,700 ha of potentially harvestable (net of all regulations) private native forest. The Wide Bay-Burnett region contained a large proportion of this (1,005,300 ha) and there were approximately 525,600 ha of private native forest in the north-eastern NSW region.

Commercial forest types in the Queensland part of the study area cover an area of approximately 1.9 million hectares. Six key commercial forest types that are harvestable under the native forest practice code have been defined, including moist tall forest, mixed hardwood forest, spotted gum dominated forest, Queensland blue gum dominated forest and ironbark forest. Of these, the spotted gum forest types (693,000 ha) and ironbark forest types (641,500 ha) were most common. There are 2950 private landholdings with unique LotPlans that have at least 150 ha of commercial and harvestable forest, and these properties account for 66% of the commercial and harvestable resource. Sixty-nine percent of the spotted gum forest was on these 2950 properties.

Productive condition and ecological condition

Across all inventory plots assessed in the region (316 plots) the average stocking was 269 stems per hectare and average basal area was 14.4 m^2/ha. Potentially merchantable volume was 28.5 m^3 with 23.1 m^3 of that on trees with a DBH of $\geq$ 30 cm. Potentially merchantable volume includes all stems with a merchantable product, and is not representative of what would be removed at a harvest (i.e. only a proportion of this would be removed in a selective harvest).

Private native forests in the region have a high proportion of trees (78%) that are less than 30 cm in diameter (DBH). A large proportion of trees (54%) were considered unmerchantable (excluding those that are required as habitat trees or for native forest practice code requirements), particularly in the 10–20 cm DBH class (73%). These are trees that could potentially be thinned through silvicultural management. Regrowth forests had a particularly high stocking in the 10–20 cm DBH class, where approximately 76% of stems where assessed as unmerchantable.

Based on 33 BioCondition surveys, the average BioCondition score (as a proportion) was 0.75 (± 0.018). One-third of sites (11) scored 0.8 or more, and thus were considered to be in very good condition. No sites scored less than 0.6. Encouraging forest management in regrowth forests, as an alternative to re-clearing for grazing production alone, represents an opportunity to improve BioCondition across the landscape, whilst providing additional benefits to the forest industry.

Contribution of private native forests to the hardwood industry

Over the last decade private native forests have supplied approximately 55% of the hardwood resource to industry in Queensland. A similarly high proportion (approximately 50%) of hardwood logs processed in northern NSW also comes from private land.

There are currently 40 hardwood sawmills in the Queensland component of the study area and a further 23 hardwood sawmills in the upper north-east region of NSW. It is estimated that the 40 sawmills in Queensland process around 177,800 m^3 (60%) of hardwood annually that is sourced from private native forest. Private native forests within the study area are estimated to supply an additional 22,663 m^3 of pole products that are processed by sawmills annually. In Queensland, the Wide Bay-Burnett and south-east regions contained the largest number of mills and had a proportionally high reliance on private native forest (66% and 72% of throughput was sourced from private land, respectively). A lower proportion of the throughput in the western Queensland region was sourced from private land (33%).

Sixty-two percent of all full-time equivalent employment (within Queensland primary processors, hardwood harvest, snig, haul) in the study area can be attributed to private native forest, and these forests are also an important source of employment in northern NSW (56% hardwood sawmill employment). The Wide Bay-Burnett region appears to be a particularly important region for the hardwood industry, providing 512 jobs, of which 72% can be attributed to private native forests.

Sawmiller and landholder attitudes and perceptions

The survey of sawmillers revealed that only 15% believed the private native forest resource would be adequate to supply future timber industry needs, and with 88% of those surveyed indicating that the productivity of private native forest could be increased through silvicultural treatments. They acknowledged that the capability of the private resource depends on landholder attitudes and knowledge, and government policy. Many sawmillers referred to the need for clarification and certainty around government legislation regarding access to the private native forest resource and State-owned forest allocations into the future.

There are significant challenges associated encouraging improved forest management by individual landholders. Most landholders are not well-informed about how to manage their forests for timber production, are not familiar with timber markets, and do not appreciate the higher timber value of well managed forests. Additionally, it appears that the primary concerns for landholder in regards to forest management is government and regulatory requirements, particularly uncertainty of future legislation. Significant constraints to landholder participation in forest management include sovereign risk (i.e. the risk that rules regarding forest management and access to timber will change) and the need for landholders to generate an annual income. Most private native forest owners consider grazing as their main enterprise because it provides an annual income. Extension activities, such as those carried out by PFSQ, are critical to ensure wider uptake of silvicultural management in privately owned native forest.

The effect of silvicultural treatments on forest growth rates

Permanent monitoring plots (158 plots on private land and 45 plots on State Forest) were utilised to determine growth rates over time. Plot basal area (as a measure of the competition between trees) was a reasonable predictor of individual tree DBH growth (explaining approximately 53% of the variation in DBH growth). On average, silviculturally treated plots had DBH growth increments that were approximately four times more than those on trees in plots that had not been treated. As this growth is concentrated on merchantable trees in treated stands, merchantable volume growth increments on individual trees were also significantly greater in these stands (five times that of untreated stands). At a plot-level, potentially merchantable volume growth was 0.76 m^3/ha/year in untreated forest and 1.45 m^3/ha/year in treated forest (means calculated across remnant and regrowth forest types).

The development of a decision support tool

A decision support tool was developed based on relationships between individual tree growth and plot basal area, to assist PFSQ with extension activities. Based on initial inventory data for the property, this tool allows the growth of trees and pasture in the forest to be simulated under different management scenarios, and provides estimates of timber and grazing values for the site. For example, it allows comparisons to be made in the value of timber products under scenarios of thinning the forest and not thinning the forest. The tool will be used by PFSQ to provide property-based management options for landholders.

The effect of silvicultural treatments on BioCondition attributes

Silvicultural treatment had no significant influence on the total condition score, which incorporated most aspects of the BioCondition assessment framework. While certain condition attributes, such as the number of ‘large’ trees, scored poorly, this did not appear to be related to the relatively recent silvicultural treatments. The density of large trees at a site was more strongly related to the history of the site; with regrowth forest areas having lower densities of large trees than remnant forest areas.

The effect of silvicultural treatments on carbon stocks

Average living carbon stored in the above-ground tree biomass varied from 4.0 to 103.9 t/ha at the monitoring plots assessed. Live tree carbon stocks were lower in treated plots, due to the relatively recent removal of biomass associated with thinning. However, biomass accumulation on individual trees in silviculturally treated plots was much higher than in untreated plots, suggesting that treated plots have greater capacity for carbon sequestration. Coarse woody debris carbon stocks were highly variable, and no difference was detected between the treated and untreated plots analysed. Detailed assessments of carbon pools at four sites suggested that a large proportion (62%) of the site carbon is stored as soil carbon. The effect of silvicultural treatment on soil carbon stocks was not consistent (based on assessments at one site), but further study is warranted.

Financial performance of silvicultural treatments

Financial analysis of three silvicultural treatment methods, namely tordoning (axe and stem injection system), brush-cutting and chopper-rolling, showed that positive net present values are returned. Silvicultural treatments were financially viable over a 20-year harvest period, even at a 7% discount rate, so long as growth following treatment was at least 0.65 m^3/ha/yr greater than the untreated forest. The most efficient method of silvicultural treatment was dependent on the stand density and tree size classes.

Economic case studies for individual properties

The effect of different forest management scenarios on farm financial performance was investigated for four individual case study properties. These focussed on regrowth forests dominated by spotted gum. Analysis revealed that silvicultural treatments are a financially beneficial investment for landholders, particularly when they can be combined with an up-front harvest. Thinning the forest was simulated to increase timber growth rates, which generated substantial timber revenues over a 20 year period. Thinning also increased revenues from livestock grazing by increasing the livestock carrying capacity of the property. Clearing regrowth forest for grazing was shown to generate a modest annual income, but it was the least financially rewarding management scenario over 20 years at all sites.

Financial performance of silvicultural treatments in commercially important forest types

The net present value (NPV) of perpetual native forest management with and without silvicultural treatment was estimated for each of the six commercially important forest types in Queensland. At a discount rate of 5%, silvicultural treatments are financially viable (NPV > $0) and exceed returns from harvesting without silvicultural treatment for all forest types, except the ironbark forest type.

Clearing for grazing was not financially viable (NPV < $0) when the grazing gross margin for cleared land was $15/ha/yr. For all of the commercial forest types except ironbark, financial returns to silvo-pastoral systems exceeded those from clearing for grazing when grazing gross margins did not exceed $50/ha/yr. In ironbark forests, silvo-pastoral systems were predicted to be financially optimal when grazing gross margins did not exceed $30/ha/yr.

Potential annual sustainable yield from private native forests

Potential future sustainable annual yields from private native forests in southern Queensland were estimated at between 150,000 m^3/yr and 600,000 m^3/yr, depending on level of landholder participation in timber production (estimated between 30% and 50% of the mapped harvestable and commercially productive private native forest) and application of silvicultural treatments within their forests (simulated to range between 0% and 50%). As an example, if 40% of private native forests were managed for timber production and 30% of these were silviculturally treated, private native forests are predicted to be able to sustainably supply 368,000 m^3/yr. That is 10% more log volume than Crown and private forests combined are supplying to the industry at present.

Annuity payments and economic benefits to Queensland

A private native forest silviculture investment program could at least partly overcome the constraints associated with forest management (e.g. sovereign risk and the need for landholders to generate an annual income) by paying landholders an annuity in return for allowing the forest to be managed by trained forestry professionals. Silvicultural treatment costs and annuity payments of $30/ha/yr to landholders are predicted to be financially viable at a 5% real discount rate, based on treatment of 100,000 ha of private native forest. Such an investment program could increase the annual sustained yield by 91,480 m^3, and would likely lead to large flow-on benefits including increasing the value of sustainable regional output at sawmills by approximately $53 M/yr and expanding regional employment in harvesting and milling by 219 FTEs.

Environmental opportunities and impacts of native forest management

A review of the literature on environmental opportunities and impacts of selective harvesting in native forests in the study area was carried out. Previous studies suggest that most native fauna and flora will generally not be disadvantaged by selective logging in space and time. However, legislation (e.g. native forest practice code) is important for ensuring important habitat trees are retained (e.g. for hollow-dependent fauna that can be rare in the landscape). There was no evidence that selective harvesting and silvicultural treatments increase wildfire risk, but there was substantial evidence that municipal catchment water yields can be increased with native forest management. There is an emerging international consensus, ratified by the IPCC, that production forests generate higher climate change risk mitigation benefits than conservation forests in the long-run.

Recommendations

This research has shown that silvicultural thinning treatments provide a financially viable mechanism to increase the timber production potential of private native forests. Further research and investment in developing the private native forest resource is recommended to help meet this potential.

Future research

This project has identified key areas where further research is needed.

- *Improved mapping of private native forest and improved estimates of growth rates for different forest types throughout the study area will increase confidence in estimates of sustainable yields, which will support land use policy decision-making of government, and is also necessary to support the decision-making of industry.*

Further mapping could be carried out to determine the potentially productive private native forest and woodland that is beyond the project study area. Hardwood sawmills do occur to the north and west of the study region, but the there is little information available on how important private native forests are outside of the region. The current study has focussed on forests with higher potential productivity, and in doing so has conservatively estimated the area of harvestable commercially important forest. Mapping of productive woodland environments with a projected foliage cover of less than 30% could substantially increase the total area of private native forest that is of commercial value. In addition, field surveys or remote sensing analysis are needed to determine the accuracy of the mapped potentially harvestable forest areas. The mapping carried out in the current study has not be validated at a local scale.

Overlaying a forest productivity layer could assist in determining which private native forests could be sustainably harvested. However, further work is needed to develop a forest productivity layer that is reliable for the study area. A minimum standing basal area or volume could define whether sites (that have not been recently harvested) are productive enough for commercial timber production. Remote sensing imagery (e.g. photogrammetric analysis of satellite-based stereo pair images) and LiDAR (Light Detection and Ranging) has great potential to capture stand information to better understand the current state of the resource. Providing stand information relating to species mix, tree height and stocking would be a good start. The existing network of monitoring plots could be used to test the feasibility of remote sensing methods to improve our estimates of the resource.

Currently most inventory plots are located in forest dominated by spotted gum and the geographic spread is limited (Figure 11.1). There is a need to expand the existing inventory plots to cover remnant and regrowth stands in other forest types and obtain a broader geographic spread. Inventory plots should include a mix of permanent plots to track growth over time and determine growth rates for different forest types and silvicultural treatments; and resource assessment plots to provide more information on the state of the resource (and to test the accuracy of mapping). To be consistent with the current study, it is recommended that permanent plots are at least 0.2 ha in area (preferably 0.4 ha in area), and the PFSQ inventory system is used for resource assessment over a given property.

Assuming further inventory data is collected in the future, there is potential to use the decision support tool developed here for further analysis on a property scale or a landscape scale (through multiple simulations, and permitting re-treatments). As discussed in Chapter 5, there is potential to further develop this tool, so that it can be more widely used (e.g. by adding growth relationships for different forest types). Further features could be developed to allow easy comparison of modelled outputs. This tool could be more widely used to support landholder management decisions if it was developed into a user friendly web application.

- *Estimating the public good benefits for society of well-managed private native forest, including in terms of biodiversity conservation, carbon sequestration, and protecting water catchments.*

The current project has provided limited qualitative data on the impacts of native forest silviculture on environmental values. While this data and a review of published studies provides a good starting point, there is a need to expand on existing surveys over a greater number of sites and forest types. Further, biodiversity monitoring (fauna and flora) is needed to critically evaluate the impacts of native forest management in Queensland. Ideally monitoring programs could be established in young regrowth and remnant forest to follow changes in biodiversity over time, with and without forest management.

- *Further research to validate or improve pasture-tree trade off models, what is the potential for silvo-pastoral systems in the existing study area, and indeed throughout Queensland, to increase and diversify farm incomes?*

Validation of pasture models used to evaluate the potential of silvo-pastoral systems in private native forest is important. There is little ‘field-based’ data on pasture production under varying forest types and levels of tree cover for forests in eastern parts of the study area. Five silvo-pastoral system field studies conducted in south east Queensland between the 1970s and early 1990s examining the effect of tree stocking on pasture production all revealed opportunities for equivalent or increased cattle production with timber trees, relative to land cleared of trees. The GRASP model utilised in the current study has been largely tested on datasets from the woodland areas of the study region. This model needs to be tested for more productive forest types with varying levels of tree basal area. In addition, there is a need to determine the opportunities for ‘improving’ pastures in these forests (e.g. with legumes).

Given the long wait period for returns in forestry, the adoption of efficient silvicultural practices are critical for the financial viability of forest growers and the industry as a whole. Silvicultural treatment costs for tordoning (axe and stem injection system), brushcutting and chopper rolling have been estimated over a range of stand densities and have been found to vary by tree stocking. Further research on the costs of silvicultural treatments would facilitate stronger recommendations about financially optimal treatment regimes for particular stand conditions.

Further research could also determine whether there are improvements in ‘wood quality’ and product classes through silvicultural management. Through repeated silviculture, the harvestable wood volumes (and their mean product value) should increase as trees with higher quality boles are retained over time and come to dominate the stand. However, anecdotal evidence suggests that wood quality might also be improved. Understanding these different ways that silviculture may increase a forest’s timber value is critical for evaluation of the financial performance silviculture. There is also a need to consider additional products that could enhance the value of private native forest. For example, the potential to utilise small-diameter logs through rotary peeling (McGavin and Leggate 2019) that could help make silvicultural treatments more attractive to landholders. The extraction of biomass for bioenergy markets also represents a potential opportunity to help cover the immediate costs of silvicultural treatments (Ngugi et al. 2018).

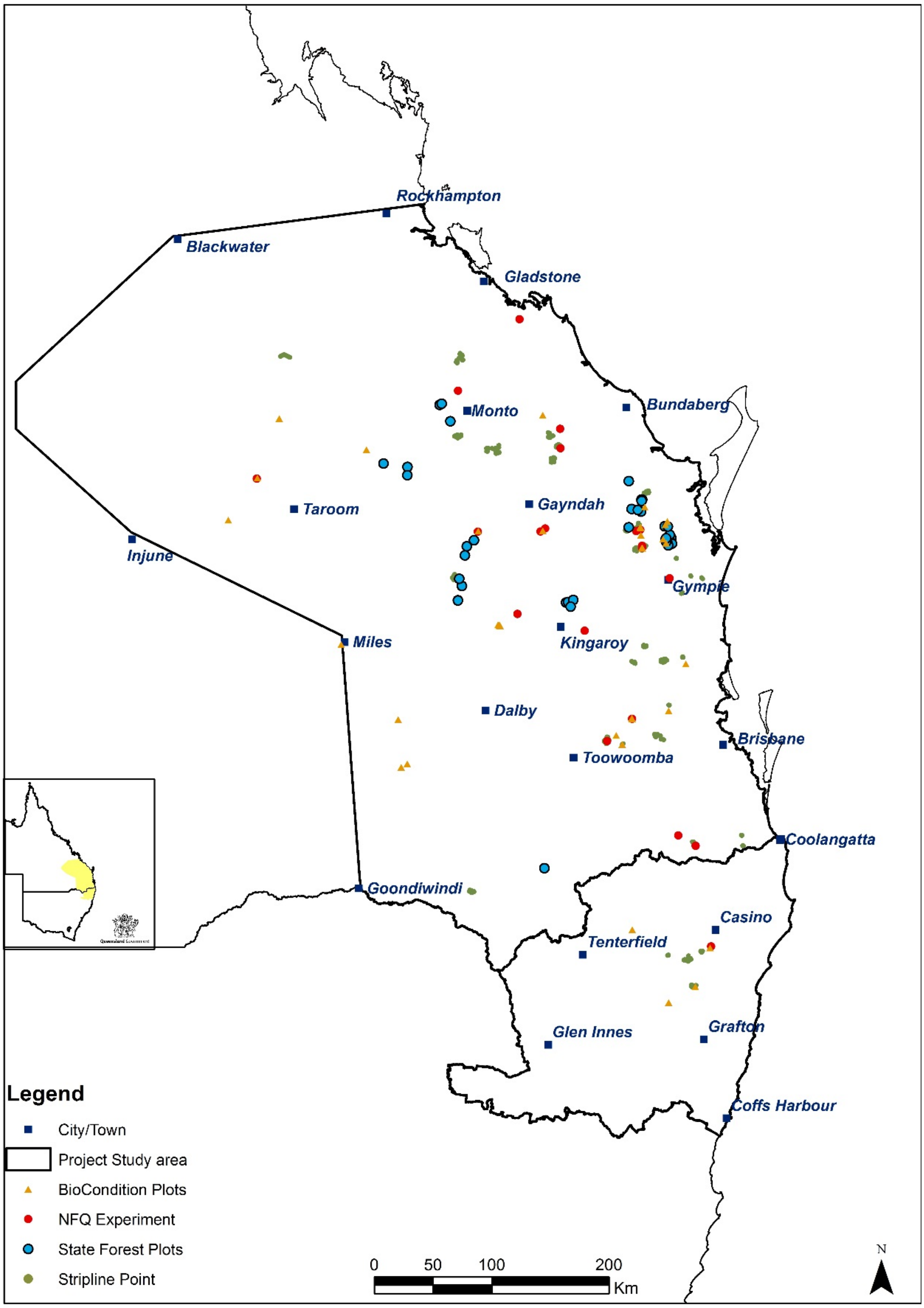

Figure 11.1. Locations of all plots utilised in the current study, including BioCondition plots, silvicultural trial plots (NFQ experiments), selected State Forest permanent sample plots and PFSQ resource inventory plots (Stripline Point).

Maintaining the industry

Further education and extension activities are needed with landholders to help them recognise the potential associated with forest management. Issues such as sovereign risk and lack of annual income provided by forest products are likely to remain drivers for a lack of change in private native forest management. Therefore, although extension activities are important, they are perhaps unlikely to result in changes in private forest management over very large areas. Targeting extension activities with landholders who own large areas of commercial forest might assist in getting broad-scale uptake. Government policy can potentially play a role in reducing the sovereign risk issue for landholders, through providing harvest security for landholders who can demonstrate long-term sustainable forest management practices (e.g. through accreditation schemes).

As discussed in Chapter 9, a native forest silviculture investment program in private native forest should be considered to ensure broad-scale forest management. As a condition of the annuity payment, it was proposed that the landholder would surrender their rights to manage timber to a professional forestry management organisation (over a minimum duration of at least 20 years). An annuity of $30/ha/yr was evaluated and an investment program scaled at 100,000 ha of treated forest and found to be financially viable at a 5% real discount rate. The program was also financially viable at a 5% real discount rate when the annuity payment was $40/ha/yr. Further work could investigate the potential of various incentive schemes, under a range of different scenarios. Such schemes could include values associated with environmental benefits and carbon sequestration. Questions remain over who would pay for such schemes.

Conclusion

In summary, the private native forest resource in southern Queensland and northern NSW has great potential in terms of:

1. Supplying industry with high quality hardwoods into the future.
2. Providing a profitable land management option for individual landholders.
3. Boosting regional employment associated with the timber industry.
4. Encouraging improved ecological condition and associated biodiversity values, particularly when grazing land is converted to managed forest.
5. Providing opportunities for carbon sequestration, particularly through the development of regrowth forest.

Further research and development and investment in private native forest management is needed so that potential of the private native forest resource can better utilised.

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Glossary of key terms used in the report

BioCondition: A measure of ecological condition for terrestrial vegetation at a site that provides a measure of how well an ecosystem is functioning for biodiversity values. Determined through the BioCondition Assessment Manual (Eyre et al. 2015b).

BioCondition benchmark: A reference state for a given Regional Ecosystem that is used in BioCondition scoring. Benchmarks are based on assessments at 'best on offer' sites or sites that are relatively unmodified since European settlement.

Broad vegetation group: A higher-level grouping of vegetation communities, based on the Regional Ecosystem mapping in Queensland (see Neldner et al. 2017a).

Brushcutting: In this report brushcutting refers to a method used for silvicultural treatment (thinning) of small diameter trees (generally <15 cm diameter). Herbicide is usually applied to the cut-stem at the time of brushcutting.

Chopper-rolling: A method used for silvicultural treatment (thinning) of dense homogeneous stands, usually where trees are <15 cm diameter. Chopper-rollers (generally weighing between 7 and 12 tonnes) are towed behind machinery such as a skidder or tractor, and push-over and chop (with angled blades) vegetation.

Discount rate: The interest rate used in financial analysis (discounted cash flow) to determine the present value of future cash flows. Discounted cash flow is a method used to estimate the value of an investment based on its expected future cash flows.

Ecological condition: In this report measurement of ecological condition is based on the BioCondition assessment framework (Eyre et al. 2015b) and provides a measure of the capacity of a terrestrial ecosystem to maintain biodiversity values. In BioCondition, 'condition' refers to the degree to which the attributes of a patch of vegetation, known to be important for biodiversity functioning, differ from the attributes of the same vegetation in a reference ('best on offer') state.

Grimes crown score: A system developed by Grimes (1987) for assessing crown health in spotted gum and ironbark forest. The assessment system includes five factors: position, size, density, dead braches and epicormics growth which are scored to provide a total crown score. Scores are related to diameter growth increment and can be useful for assessing trees to be retained or harvested.

Habitat tree: A tree that is used or potentially used by hollow dwelling fauna. In the 'native forest practice code' there a requirements for retention of habitat trees. In the native forest practice code habitat trees are identified as "a living trees with one or more visible hollows of 10 cm or more in diameter that are position at least 2 m from the base of the tree".

High-grading: A method of harvesting used that removes most trees with potential value at a single harvest or over multiple harvests, leaving a high proportion of non-commercial (unmerchantable) trees in the stand. High-grading often results in long periods of time between harvests.

Lignotuberous regeneration: Tree regeneration that results from a lignotuber (a woody swelling at the base of stem or just below the ground that contains buds and starch reserves). Many eucalypt species occurring in the study region are able to resprout from lignotubers after disturbance such as fire, drought or grazing.

Mean annual increment (MAI): The average annual tree or stand growth rate up to a given age or over a harvest cycle. Note that MAI is used interchangeably with periodic annual increment (PAI) in this report.

Merchantable height: Was defined in this study as the height (in metres) from the ground to the highest merchantable point on the bole (e.g. height to crown break or a heavy branch). This was based on species, straightness and defect, not the size of the bole.

Merchantable volume: A measure of the volume of timber product (of a standard acceptable to industry) that is stored in a tree, expressed on a per hectare basis (m^3/ha). In this study merchantable volume was calculated based on measures of diameter at breast height (DBH) and merchantable height.

Native forest practice code: Queensland legislation for ensuring environmental values are sustained when a forest is managed for timber harvesting under the accepted development vegetation clearing code, 'Managing a Native Forest Practice: A Self-Assessable Vegetation Clearing Guide' (Department of Natural Resources and Mines 2014). The Department of Natural Resources, Mines and Energy (DNRME) is currently responsible for the regulation of private native forest management for timber production in Queensland.

Net present value (NPV): Is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. If the NPV is positive, the investment is considered viable. Present value is the concept that an amount of money today is worth more than that same amount in the future.

Periodic annual increment (PAI): The average annual tree or stand growth increment over some period of time that is longer than one year. PAI is commonly used in uneven aged forest, where growth rates are calculated between two years of measurement.

Potentially harvestable regional ecosystem: A Queensland Regional Ecosystem that it listed in the native forest practice code as an ecosystem where native forest practice is permitted.

Primary processors: Timber processors that convert harvested trees into timber through the process of saw-milling.

Productive condition: Is this report refers to the condition of the forest from a commercial forestry perspective (i.e. availability of merchantable timber volumes, stand structure etc).

Regional ecosystem: Queensland vegetation communities in a bioregion that are consistently associated with a particular combination of geology, landform and soil (Sattler and Williams 1999; https://www.qld.gov.au/environment/plants-animals/plants/ecosystems/about).

Regrowth forest: Is forest that is regrowing on an area after it had been cleared (e.g. for agricultural purposes). There are two types of regrowth forest in Queensland that are referred to in this study: (1) high-value regrowth, which is includes (a) regional ecosystems that are either 'endangered', 'of concern' or 'least concern'; (b) areas that have not been cleared since 31 December 1989; and (c) areas shown on a Queensland Government regrowth vegetation map. (2) woody, non-remnant regrowth, which is regrowth with at least 30% foliage projective cover but is not mapped as either remnant vegetation or high-value regrowth. This second category of regrowth can be managed without following the native forest practice code.

Remnant forest: In Queensland, is forest where the predominant canopy covers more than 50% of the undisturbed predominant canopy; averages more that 70% of the vegetation's undisturbed height; and if the vegetation contains species characteristic of the undisturbed predominant canopy (Accad et al. 2019).

Selective harvesting or single tree selection harvesting: A silvicultural practice that involves selecting single trees for retention or harvesting (e.g. by preliminary selection and marking of trees to meet a certain standard). Selective harvest systems always retain a proportion of the stand basal area and allow multiple size classes of trees to develop. Selecting trees for retention (rather than harvest) is recommended to improve the value of the stand for future harvests.

Silvicultural treatment / silvicultural thinning: Refers to the process of thinning the forest, to reduce the level of competition for resources (sunlight, moisture and nutrients) between the trees, thereby encouraging greater growth rates on the retained trees. Thinning often kills the unwanted or non-productive component of a timber stand.

Silvo-pastoral system: A land-use option that incorporates both trees and cattle (or other livestock) on the same site. When managed carefully silvo-pastoral systems can provide dual incomes from timber production and livestock grazing.

Stumpage price: The price paid for a standing tree (i.e. the price a contractor will pay a landholder) based on the value of the product at the sawmill minus the costs of harvesting and transport.

Sustainable yield: Refers to the yield (i.e. the volume of usable wood fibre that can be harvested per unit area) that can be harvested sustainably through maintaining the regenerative capacities of the system.

Tordoning: A silvicultural treatment method that involves stem injection to poison trees to be thinned. This is usually done with an axe and injection system that applies herbicide like Glyphosate or Tordon®.

Stand basal area: Is calculated as the sum of the cross sectional area of each tree at 1.3 m height (based on diameter at breast height, DBH) and is expressed on a per hectare basis in this report (m^2/ha). It is measure of forest density that incorporates different tree sizes.

Tree stocking: A measure of the density of trees in a stand. This is expressed on a per hectare basis (stems per hectare, SPH) and trees are often divided into diameter classes (e.g. trees with a DBH 10-20 cm) to provide information on the size distributions for a stand.

Unmerchantable tree: A tree that is assessed as being unlikely to ever produce a conventional merchantable product (i.e. sawlog, pole, fencing material etc) that is worth harvesting.

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Researcher’s Disclaimer

This publication has been compiled by Tom Lewis of Agri-science Queensland, Department of Agriculture and Fisheries.