NSW NATIONAL PARKS & WILDLIFE SERVICE

River Red Gum Ecological Thinning Trial

Monitoring report 2021

environment.nsw.gov.au

Cover photo: Peregrine falcon in river red gum forest. Chris Tzaros.

This report should be cited as: Gorrod E, Travers S, Ellis M, Hope B, McAllister D, Val J and O'Kelly T 2021, *River red gum ecological thinning trial: Monitoring report 2021*, NSW National Parks and Wildlife Service, Hurstville.

Acknowledgements

Charles Sturt University supported the vegetation monitoring program. Australian Catholic University assisted with collection of bat data. University of New South Wales provided advice about statistical analyses.

Published by:

Environment, Energy and Science
Department of Planning, Industry and Environment
Locked Bag 5022, Parramatta NSW 2124
Phone: +61 2 9995 5000 (switchboard)
Phone: 1300 361 967 (Environment, Energy and Science enquiries)
TTY users: phone 133 677, then ask for 1300 361 967
Speak and listen users: phone 1300 555 727, then ask for 1300 361 967
Email: info@environment.nsw.gov.au
Website: www.environment.nsw.gov.au

Report pollution and environmental incidents
Environment Line: 131 555 (NSW only) or info@environment.nsw.gov.au
See also www.environment.nsw.gov.au

ISBN 978-1-922672-03-2
EES 2021/0249
June 2021

Contents

Key results

The key results for the effect of ecological thinning on each monitoring variable analysed in this report are listed below. Statistically significant effects of ecological thinning are shaded grey. Where effects of thinning were specific to particular combinations of site quality, pre-thinning stem density or time, they were described.

Tree growth rates	Thinning affected average annual tree growth rates, but effects depended on the size of the tree. Thinning caused the growth rates of smaller trees to increase and the growth rates of larger trees to decrease, with the most likely magnitudes of change being: • a 1.4–2.6 mm per year (30–100%) increase relative to controls for small trees (20 cm diameter at breast height) on some plots • a 2.4–3 mm per year (75–80%) decrease relative to controls for large trees (100 cm diameter at breast height) on some plots.
Tree mortality	Thinning increased the proportion of trees that were dead. Four years after thinning, the most likely magnitude of change was an additional 5–8% dead trees in Site Quality 1 plots that were moderately thinned, approximately double the proportion of dead trees on control plots.
Coppice	Thinning increased the abundance of coppiced stems, particularly in Site Quality 2 plots. The most likely magnitude of increase was: • an additional 7–50 coppiced stems per 0.04 hectare on most plots • an additional 450–550 coppiced stems per 0.04 hectare in Site Quality 2 plots that had very high initial stem density.
Germinants	Thinning initially increased the probability of occurrence of germinants but decreased the probability of occurrence in subsequent years. Four years post-thinning the most likely magnitude of change was an 18–40% reduction in probability of germinants occurring in most Site Quality 1 plots.
Seedlings	Thinning affected seedling abundance, but effects varied with initial stem density and time since thinning. Four years post-thinning the most likely magnitudes of change were: • a 1.5–4-fold increase on moderately thinned Site Quality 2 plots that had very low to moderate initial stem density (3–4 additional seedlings per 0.04 ha) • a 65% reduction on heavily thinned Site Quality 1 plots that had very high initial stem density (15 fewer seedlings per 0.04 ha).
Saplings	Moderate and heavy intensity thinning reduced the abundance of saplings, and this effect was sustained four years post-thinning. Sapling abundance was not modelled because saplings were included in both initial stem density and thinning intensity, and therefore response and explanatory variables were not independent.
Individual tree canopy extent	Thinning affected tree crown extent, but the effects varied with initial stem density, site quality and time. Most commonly, thinning increased tree crown extent and the most likely magnitude of increase four years post-thinning was 5–9% in: • moderately to heavily thinned Site Quality 1 plots that had very high initial stem density • moderately to heavily thinned Site Quality 2 plots that had very low to moderate initial stem density.

Live canopy visual	No statistically significant effects of thinning on visually estimated live tree cover.
Dead canopy visual	The data suggested no effects of thinning on visually estimated dead tree cover. Statistical analyses were not conducted for this variable.
Foliage projective cover	Thinning reduced foliage projective cover. Over time, the magnitude of difference between thinned plots and control plots increased in Site Quality 1 but not Site Quality 2. Four years post-thinning, the most likely magnitude of reduction in foliage projective cover was: • 14–16% lower in moderately thinned Site Quality 1 plots that had moderate to very high initial stem density • 35% lower in heavily thinned Site Quality 1 plots.
Overall fuel hazard	No statistically significant of thinning on overall fuel hazard.
Litter depth	No statistically significant effects of thinning on litter depth.
Litter cover	No statistically significant effects of thinning on litter cover.
Surface fuel hazard	No statistically significant effects of thinning on surface fuel hazard.
Live near surface vegetation	Data suggested that thinning reduced live near surface vegetation cover; however, modelling and statistical analyses could not be performed on these data.
Dead near surface vegetation	Data suggested that thinning did not affect dead near surface vegetation cover; however, modelling and statistical analyses could not be performed on these data.
Near surface fuel hazard	Thinning affected near surface fuel hazard, but the effects differed over time: • initially, heavy thinning decreased risk in Site Quality 1 (by approximately 11%) but increased risk in Site Quality 2 (by approximately 8%) • four years post-thinning, heavy thinning reduced risk on both site qualities by 5%.
Combined surface fuel hazard	No statistically significant effects of thinning on combined surface and near surface hazard.
Live elevated vegetation cover	Data suggested that thinning did not affect live elevated vegetation cover; however, due to time constraints statistical analyses were not performed on these data.
Dead elevated vegetation cover	Data suggested that thinning did not affect dead elevated vegetation cover; however, modelling and statistical analyses could not be performed on these data.
Elevated fuel hazard	No statistically significant effects of thinning on elevated fuel hazard.

Native plant richness	Heavy thinning reduced native plant species richness in Site Quality 1 plots that had very high initial stem density by 4.5 species per 0.04 hectare (a 23% reduction from controls) four years after thinning. No other effects of thinning on native plant species richness were certain to be different from control plots.
Exotic plant richness	Heavy thinning increased exotic plant species richness. The magnitude of increase that was most likely four years post-thinning was: • 4.5 species in Site Quality 1 plots that had very high initial density (70% increase relative to controls) • 4–9 species in Site Quality 2 plots that had low to moderate initial density (55–130% increase relative to controls).
Native plant cover	Thinning may have decreased native plant cover in Site Quality 1 plots, but may have increased native plant cover in Site Quality 2 plots; however, due to time constraints, statistical analyses were not conducted for this variable.
Exotic plant cover	Moderate and heavy thinning may have increased exotic plant cover in Site Quality 1 plots. However, due to time constraints, statistical analyses were not conducted for this variable.
Threatened plants	No threatened plant species were recorded in the 2020–21 monitoring surveys.
Bird species richness	No statistically significant effects of thinning on bird species richness.
Threatened birds	Thinning is unlikely to have affected the occurrence of threatened bird species, although no tests of statistical significance were conducted. Eight threatened bird species were recorded in 2020–21, including the swift parrot, which had not been previously recorded in these surveys.

1. Introduction

1.1 Ecological thinning trial

The aims and details of the experimental design are fully described in *Ecological thinning trial in New South Wales and Victorian River Red Gum forests: Experimental design and monitoring plan* (OEH 2012), which was included in Appendix 1 of *Public Environment Report: Ecological thinning trial in New South Wales River Red Gum forests* (OEH 2014). The experimental design is also detailed in Gorrod et al. (2017) and summarised briefly below.

Aims of the trial

The ecological thinning trial aims to learn about the effectiveness of ecological thinning for addressing a range of conservation concerns associated with widespread high stem density stands and canopy dieback in *Eucalyptus camaldulensis* (river red gum) forests. Conservation concerns in high stem density stands may stem from high competition for water and other resources. Competition can be characterised by stem density and water availability. Within-stand competition is likely to be higher in stands with lower water availability; and is likely to increase with increasing stem density. Ecological thinning may reduce competition by reducing stand density.

The trial's hierarchy of aims are:

- The primary aim for the trial is to determine whether any of several levels of ecological thinning positively affect biodiversity, canopy condition and resilience to epidemic river red gum mortality within all stands of river red gum forests, and whether these effects depend on water availability and initial stem density.
- The secondary aim for the trial is to determine whether any of several levels of ecological thinning positively affect characteristics of the stands that are reasonably expected to lead to the primary aim, and whether these effects depend on water availability and initial stem density. For example: hollow bearing tree recruitment levels, and understorey species diversity.
- The tertiary aim for the trial is to determine whether any of several levels of ecological thinning positively affect characteristics of the trees that are reasonably expected to lead to the secondary aim, and whether these effects depend on water availability and initial stem density. For example: tree diameter growth rates, tree diameter distribution diversity, crown shape and health.

Five years post-thinning, at the conclusion of the 2021–22 financial year, analyses will be undertaken to determine whether the available data supports, contradicts or remains uncertain as to whether ecological thinning may achieve these aims.

Ecological thinning trial sites

The number and locations of ecological thinning trial sites were selected to represent a spectrum of within-stand competition, occurring in a range of stem densities and two levels of long-term water availability. A total of 22 sites are located in the Millewa precinct of Murray Valley National Park in New South Wales (Figure 1).

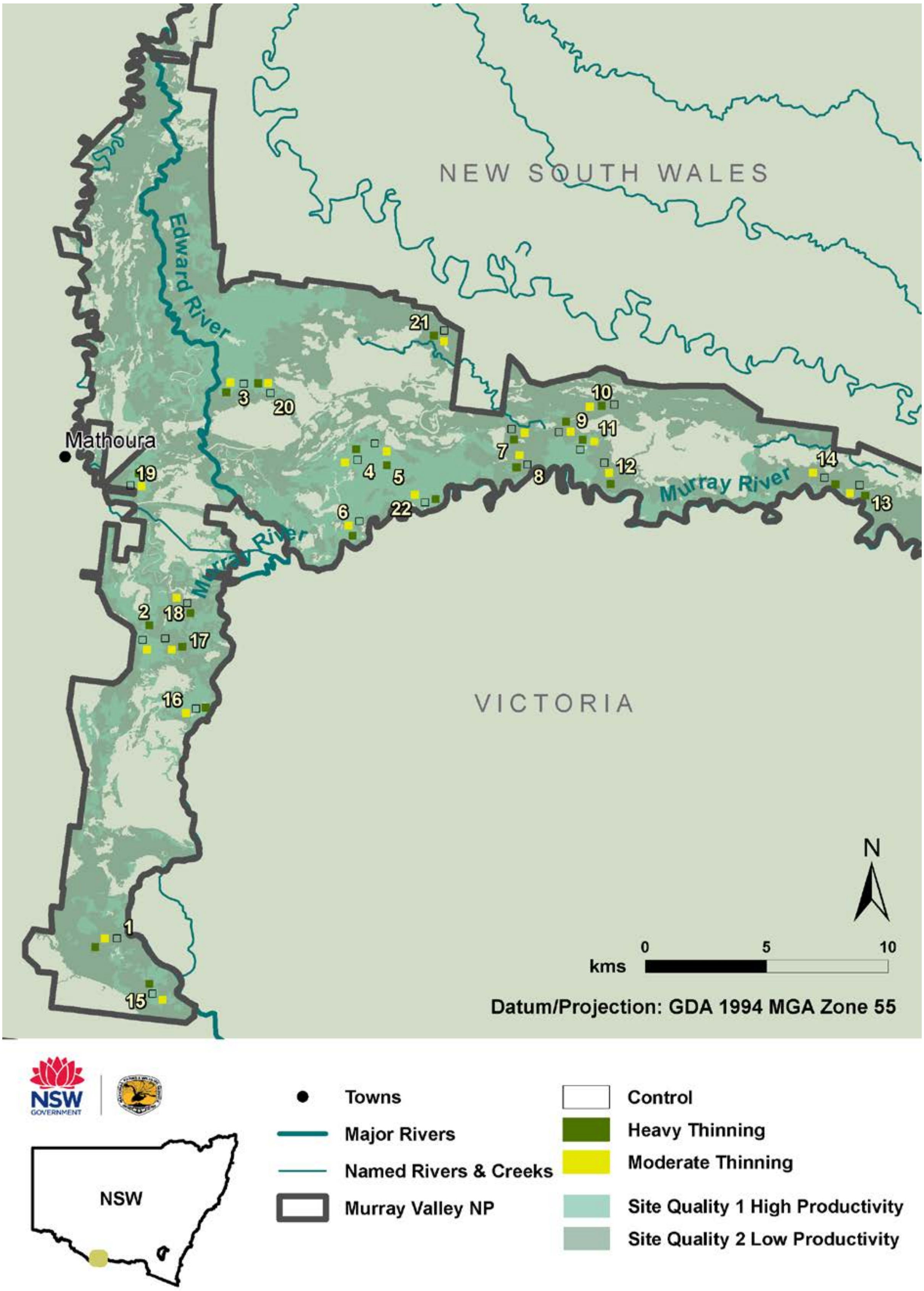

Figure 1 Locations of ecological thinning sites

NP = national park

Sites with a range of pre-thinning stem densities were selected using stem density mapping of Murray Valley National Park (Bowen et al. 2012). More sites were selected in high stem density stands because they are the focus of management interest (Table 1). A surrogate for water availability called 'site quality' was also used to inform the locations of sites. Site quality is derived from tree height mapping (Baur 1984): Site Quality 1 (SQ1) is associated with increased long-term water availability and taller trees than Site Quality 2 (SQ2). Sites were evenly divided among the two site quality classes (Table 1).

Table 1 Intended number of sites across a spectrum of stem density (Bowen et al. 2012) and a surrogate of water availability (site quality)

	<200 stems/ha	200–400 stems/ha	>400 stems/ha	Total
Site Quality 1	2	4	5	11
Site Quality 2	2	4	5	11
Total	4	8	10	22

Each site consists of three 9 hectare (ha) treatment plots. The three treatment plots were intended to be similar to each other prior to thinning. All plots are 300 x 300 metres (m) and the distance between plots within a site is between 100 and 300 metres. The size of the plot minimises edge effects from the surrounding forest and enables detection of responses in all of the vegetation, flora and fauna parameters of interest.

Field data for stem density

Field data for initial (pre-thinning) stem density was collected in 2015, in which all trees >10 centimetres (cm) diameter at breast height (dbh) were counted in two 20 x 50 metre plots in each 9 hectare plot. These data indicated that measured stem density may have poor correspondence with mapped stem density.

Additional field data for stem density were subsequently collected between 2016 and 2017, in which trees of all stem sizes were counted in an additional eight 20 x 50 metre plots in each 9 hectare plot. For some plots (10 out of 44), these data were collected after thinning had been completed, in which case all recent stumps were counted and the height and diameter of each stump was measured. Taper equations were used to allocate stumps to tree size classes.

These data provided estimates of pre-thinning stem density, which indicated that the stem density mapping did not reliably represent on-ground density (OEH 2018).

Pre-thinning stem density

The field data for stem density show that thinning treatment plots are located in a wide range of initial stem densities, from about 250 stems per hectare to 1850 stems per hectare (Figure 2). The majority of plots have stem densities between 400 and 1000 stems per hectare. The average stem density across all plots is 740 stems per hectare.

There are some differences between the site qualities. The majority of plots in Site Quality 1 have stem densities of between about 500 and 1000 stems per hectare, about one-quarter of plots have more than 1000 stems per hectare and very few plots have low stem densities. The average stem density in Site Quality 1 plots is 830 stems per hectare.

The majority of Site Quality 2 plots have stem densities of between about 350 and 800 stems and only four plots in Site Quality 2 have initial stem densities greater than 1000 stems. The average stem density in Site Quality 2 plots is 580 stems per hectare.

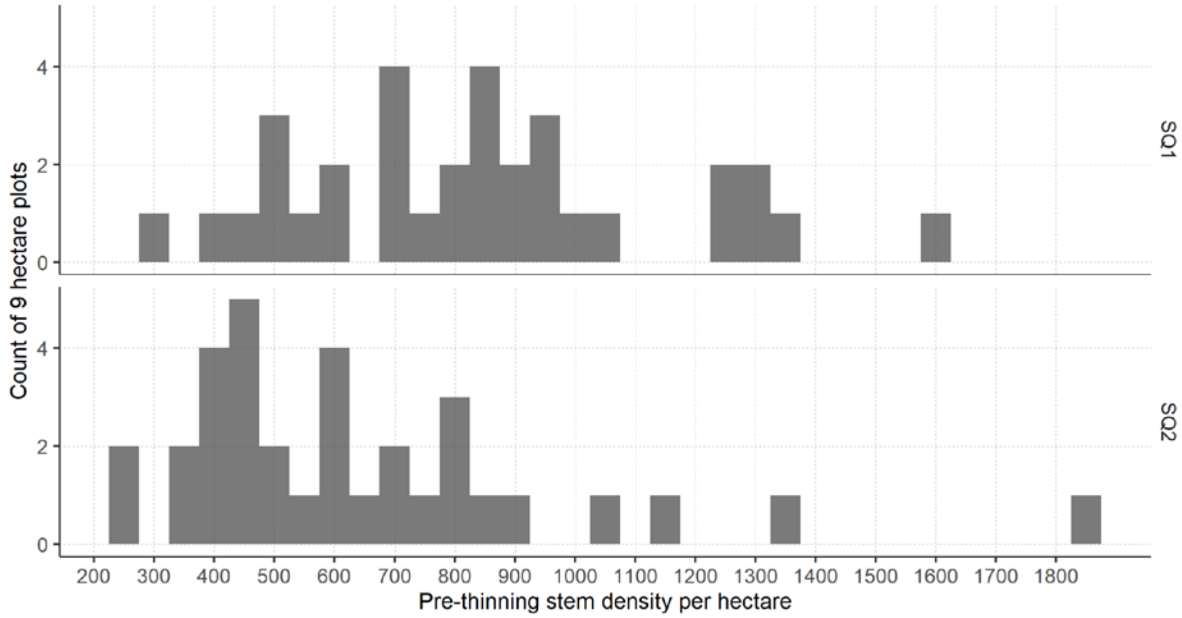

Figure 2 Count of 9 hectare plots with different pre-thinning stem densities per hectare
Each bar represents a range of 50 stems (e.g. the left-most bar in Site Quality 2 represents the count of 9 hectare plots that had pre-thinning stem density of 225–275 per hectare).

1.2 Ecological thinning treatments

Thinning treatments: spacings

Three ecological thinning treatments were planned in the trial (Table 2): control, moderate thinning and heavy thinning. At each site, one 9 hectare plot was assigned to each of the three thinning treatments.

Table 2 Ecological thinning treatments

Treatment	Specifics	Rationale
Control	No action	Enable comparison with thinning treatments.
Moderate thinning	7 m spacings between retained trees	Widest spacings likely to be implemented in commercial silviculture (7.3 m, Baur 1984), and substantially wider than most silvicultural thinning treatments (3–4 m, Schonau & Coetzee 1989).
Heavy thinning	15 m spacings between retained trees	Equivalent to the crown diameter (approximately 17 m) of a large *Eucalyptus camaldulensis* tree (>80 cm dbh*), to facilitate development of branches and spreading crowns that may lead to hollow development.

*diameter at breast height

Thinning prescriptions included a number of environmental protections. The following trees were retained in all treatments:

- all trees with dbh >40 centimetres
- all trees with a visible hollow (minimum opening of 5 centimetres)
- all dead trees with a dbh of >20 centimetres.

Retention of all trees with these properties aimed to maintain the current quantity and distribution of trees with important habitat values, and trees with the potential to develop hollows over the coming decades.

In addition, buffer zones, in which all trees were retained, were placed around drainage lines and cultural heritage features.

No prescriptions were given for the treatment of trees with <10 centimetres dbh and therefore retention was variable among plots.

The spacings method of thinning involved selecting a tree for retention, measuring 7 metres or 15 metres from the trunk of that tree, and selecting another tree for retention, and so on.

Within the 10–40 centimetres dbh size class, trees with the following features were preferentially selected for retention:

- structurally viable trunk and root attachment
- strong lateral branching (that may develop into spreading, branching form)
- healthy crown
- larger dbh.

Thinning using prescribed spacings and retention of all large and habitat trees was selected to increase the proportion of trees in larger size classes, as well as increase the abundance of branching trees that are likely to become hollow bearing in the future.

National Parks and Wildlife Service staff marked-up each 9 hectare plot according to these protections and prescriptions, marking all trees to be retained.

Contractors implemented the thinning operations. Between retained trees all trees with dbh between 10 and 40 centimetres were removed. Following felling, each stump was painted with Roundup Biactive® within five minutes to restrict coppicing. The felling method used minimised damage to retained trees.

Thinning treatments: total stem density change

After thinning operations were completed, stem density surveys were repeated. From the field data, stem density change was estimated for all thinned plots (Figure 3). As noted above, some plots were surveyed only once and stumps were used to estimate the change in density.

Among Site Quality 1 plots, the proportion of trees removed was not dependent on the starting density (indicated by the vertical spread of points for any given pre-thinning density). For example, there were four plots with pre-thinning stem densities of around 500 stems per hectare, which had between 25% and 70% of trees removed by thinning.

Among Site Quality 2 plots, the proportion of trees removed tended to increase with increasing starting density. For example, all plots with starting densities of around 500 stems per hectare had between 55% and 70% of trees removed by thinning.

The proportion of total trees removed was not distinct among the moderate and heavy thinning treatment prescriptions.

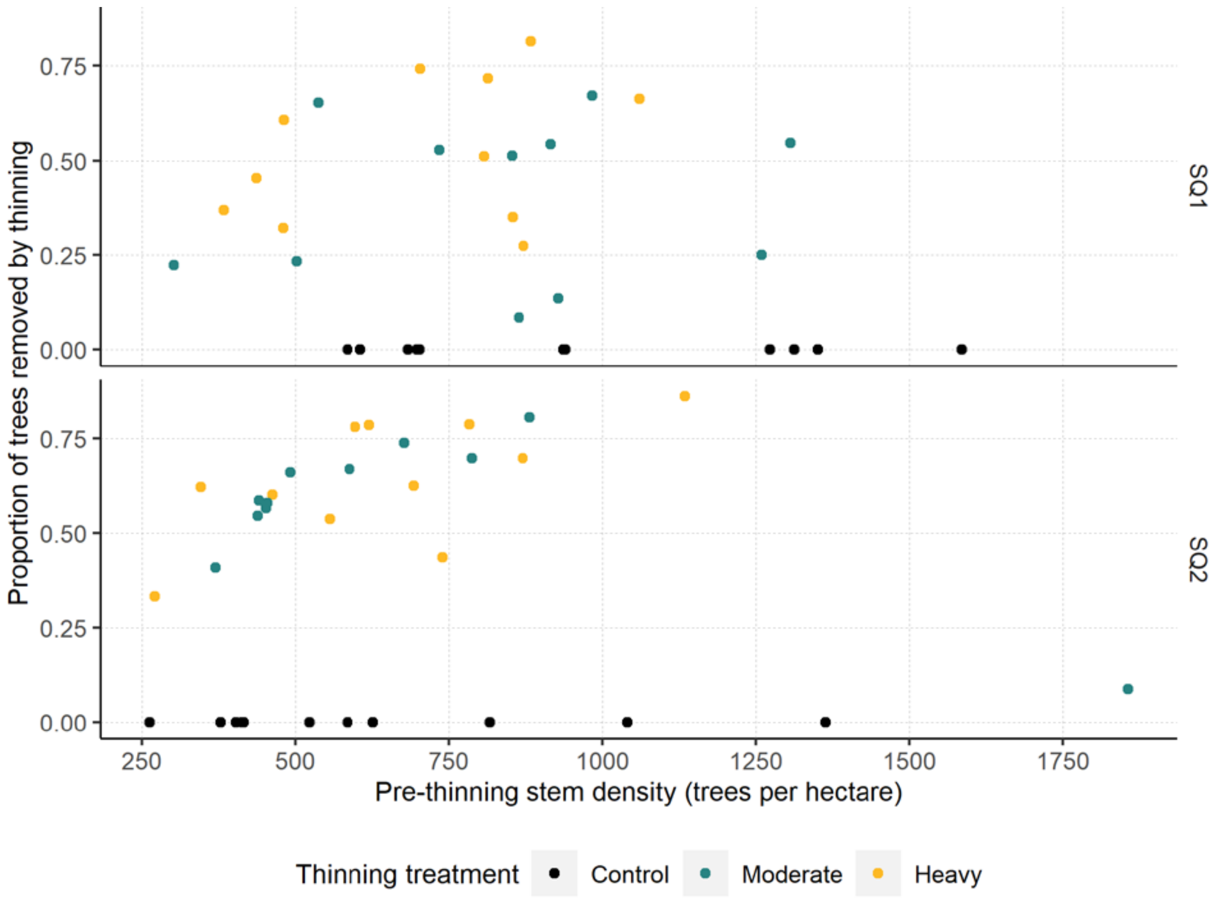

Figure 3 Proportion of trees removed and pre-thinning stem density, by thinning treatment

Thinning treatments: tree size class

The proportion of small (<20 centimetres dbh) trees that were removed did not differ substantially among thinning treatment categories (Figure 4). These size classes were by far the most abundant, contributing substantially to total stem density.

A higher proportion 20–40 centimetres dbh trees tended to be removed in the heavy thinning treatments than moderate thinning treatments (Figure 4).

The proportion of 30–40 centimetres dbh trees that were removed was lower on moderately thinned plots than heavily thinned plots. However, the proportion of smaller trees that were removed was not distinct among treatment protocols, and these smaller trees tended to be the most abundant.

Thinning treatments: thinning intensity

Characterising thinning treatments in terms of the proportional change in total stem density may yield more nuanced information about the effects of thinning in river red gum forest, than the three categories of treatment by spacings. Further, proportional change in total stem density can be coupled with data about pre-thinning stem density to improve understanding of the effects of ecological thinning under different starting conditions.

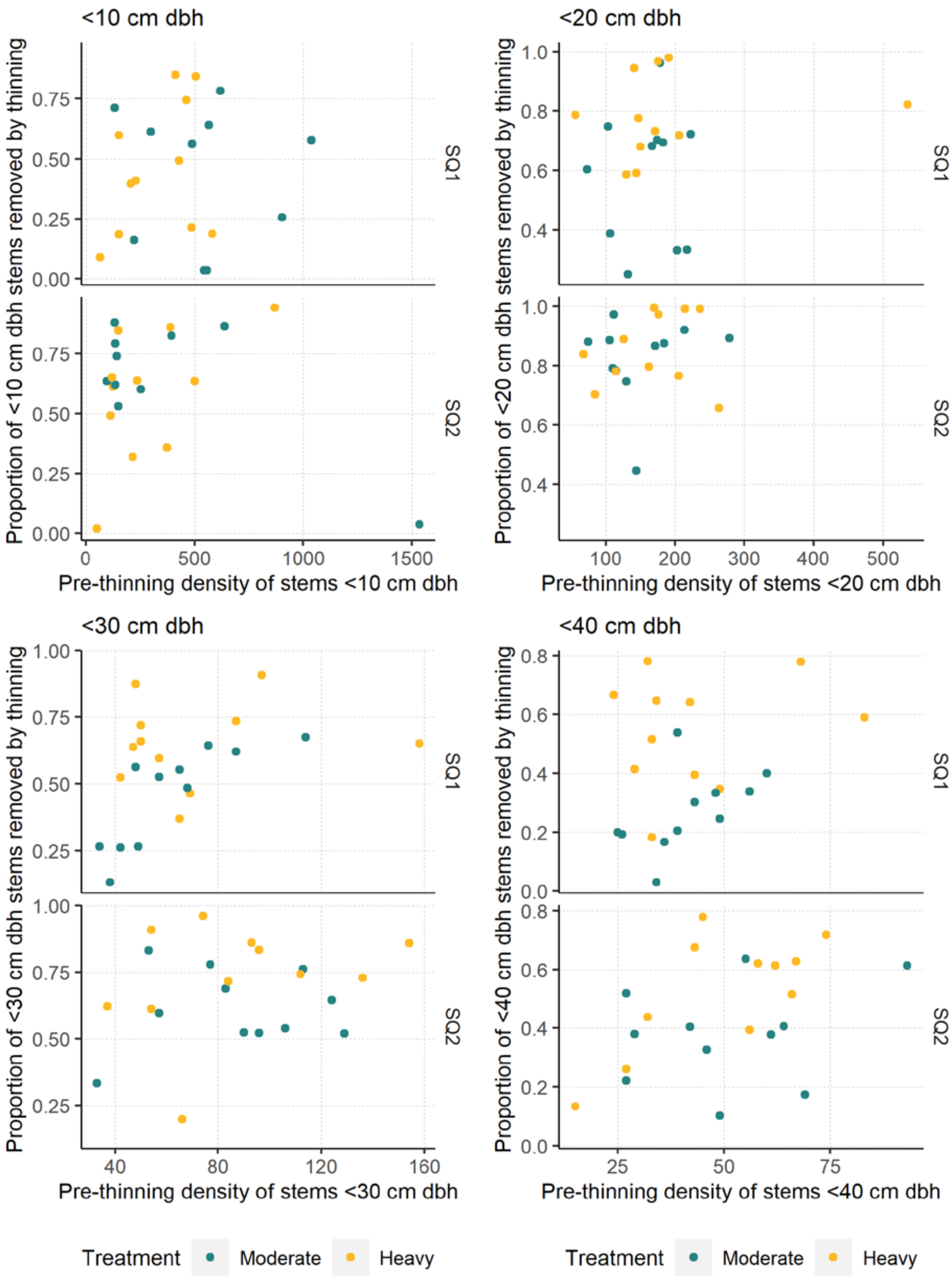

Figure 4 Change in density of different sized trees due to thinning

1.3 Hypotheses

Prior to implementing ecological thinning treatments, a series of hypotheses were specified about: the effects of ecological thinning on individual tree features, tree population characteristics, forest structure and site features; the flow-on effects to indigenous and non-indigenous flora and fauna; and any processes or disturbances associated with implementing the treatments.

It was hypothesised that the effects of ecological thinning would be greatest at plots with high initial stem densities, low post-treatment densities and high levels of water availability. Information concerning the rationale or conceptual process model underpinning each hypothesis, as well as any available published evidence supporting each hypothesis, was provided in the experimental design and monitoring plan (OEH 2012).

Prior to thinning, and for at least five years post-thinning, monitoring data are being collected to evaluate each hypothesis. Each year the trends for each of these parameters are analysed. After the first five years of post-thinning monitoring, at the end of the 2021–22 financial year, analyses will be undertaken to determine whether the available data support or contradict the hypotheses or remain uncertain.

1. **Effects of ecological thinning on tree populations and forest structure:**
    - 1a. Increased survival and growth rates of retained trees
    - 1b. Increased number and proportion of trees occurring in large diameter size classes
    - 1c. Increased spread and hollow development rates of retained trees
    - 1d. Increased tree canopy health (proportion of potential crown that is live) of retained trees
    - 1e. Increased recruitment of tree seedlings in early post-treatment years
    - 1f. Increased survival of seedlings (<1.37 metres) and saplings (>1.37 metres, <10 centimetres dbh)
    - 1g. Increased structural diversity of mid- and under-storey strata
    - 1h. Higher levels of coarse woody debris (45–50 tonnes/hectare) maintained in long term
    - 1i. Increased heterogeneity in cover and depth of forest litter in the long term
    - 1j. Decreased persistence of stags in the short term
    - 1k. Increased fuel and fire risk
2. **Effects of ecological thinning on mammalian and avian diversity:**
    - 2a. Increased diversity of bat species, and increased levels of site utilisation by bat species
    - 2b. Increased abundance and frequency of foraging activity by woodland bird species
    - 2c. Increased abundance of gliders
    - 2d. Increased abundance of predators, in particular foxes
3. **Effects of ecological thinning on vascular plant diversity:**
    - 3a. Increased diversity and cover of exotic plant species in understorey in the short term, decreasing in the long term
    - 3b. Increased diversity and abundance of native plant species

1.4 Monitoring

For each hypothesis, a monitoring variable was defined and a monitoring protocol was designed to survey the variable at an appropriate spatial scale. Consequently, the size and number of monitoring plots within each 9 hectare treatment plot differed for each variable (Figure 5). For example, in each 9 hectare treatment plot birds were surveyed within a single 2 hectare monitoring plot and floristics were surveyed in three 0.04 hectare monitoring plots. Details for each monitoring variable are given in the experimental design and monitoring plan (OEH 2012) and are summarised in the results section for each variable in this report.

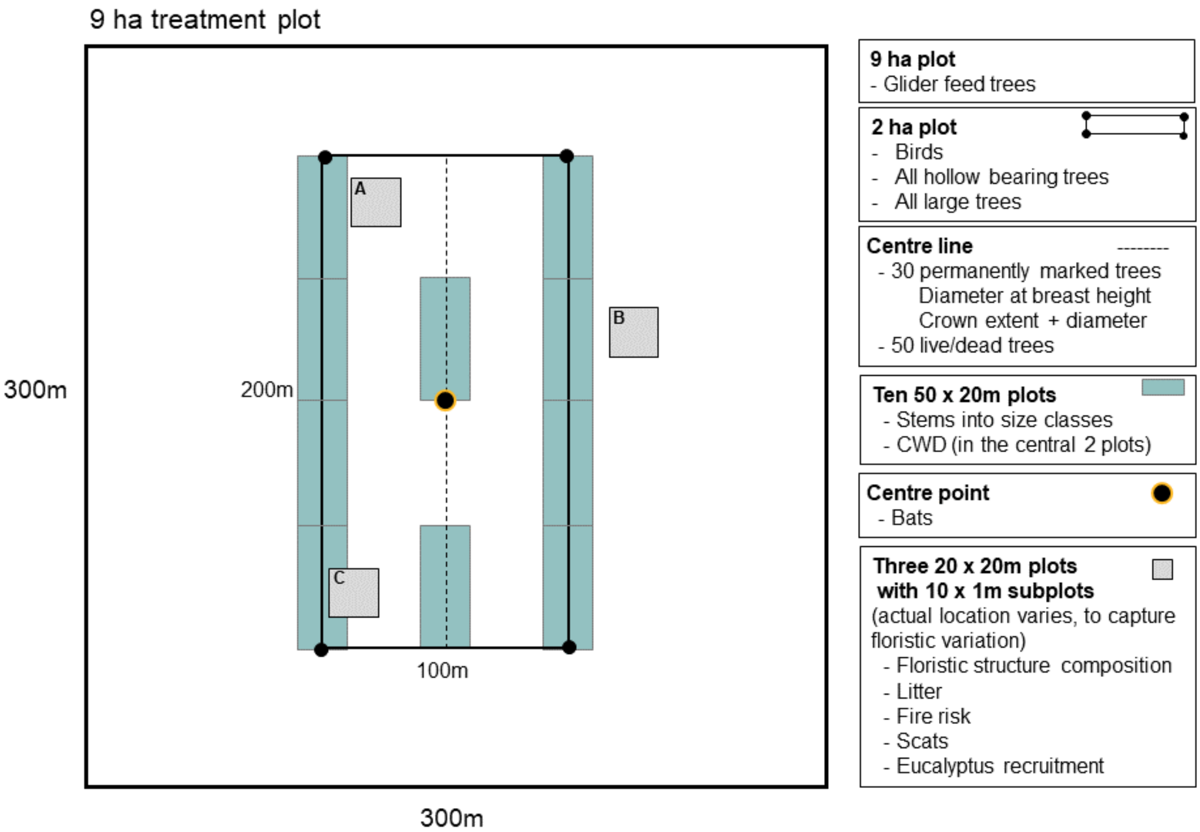

Figure 5 Schematic layout of monitoring subplots within each 9 hectare treatment plot

1.5 Ecological thinning trial to date

Pre-thinning monitoring

Half of the sites (1–12) were monitored in 2012–13. These data are not included in this report.

Pre-thinning monitoring surveys were undertaken on all sites between September 2015 and February 2016. All variables were measured in this survey period. Results were described in the *River red gum pre-ecological thinning monitoring report 2017* (OEH 2017).

These data are referred to as the 2015 or pre-thinning survey period in this report.

Thinning treatments

Thinning treatments commenced in April 2016. Half of the treatment plots were thinned prior to a major flood event in September 2016, in which all control and treatment plots were inundated. Thinning treatments recommenced in February 2017 and were completed in August 2017.

All Site Quality 1 plots that were thinned prior to the flood had a lower proportion of trees removed than Site Quality 1 plots that were thinned after the flood (indicated by the horizontal spread of points in Figure 6).

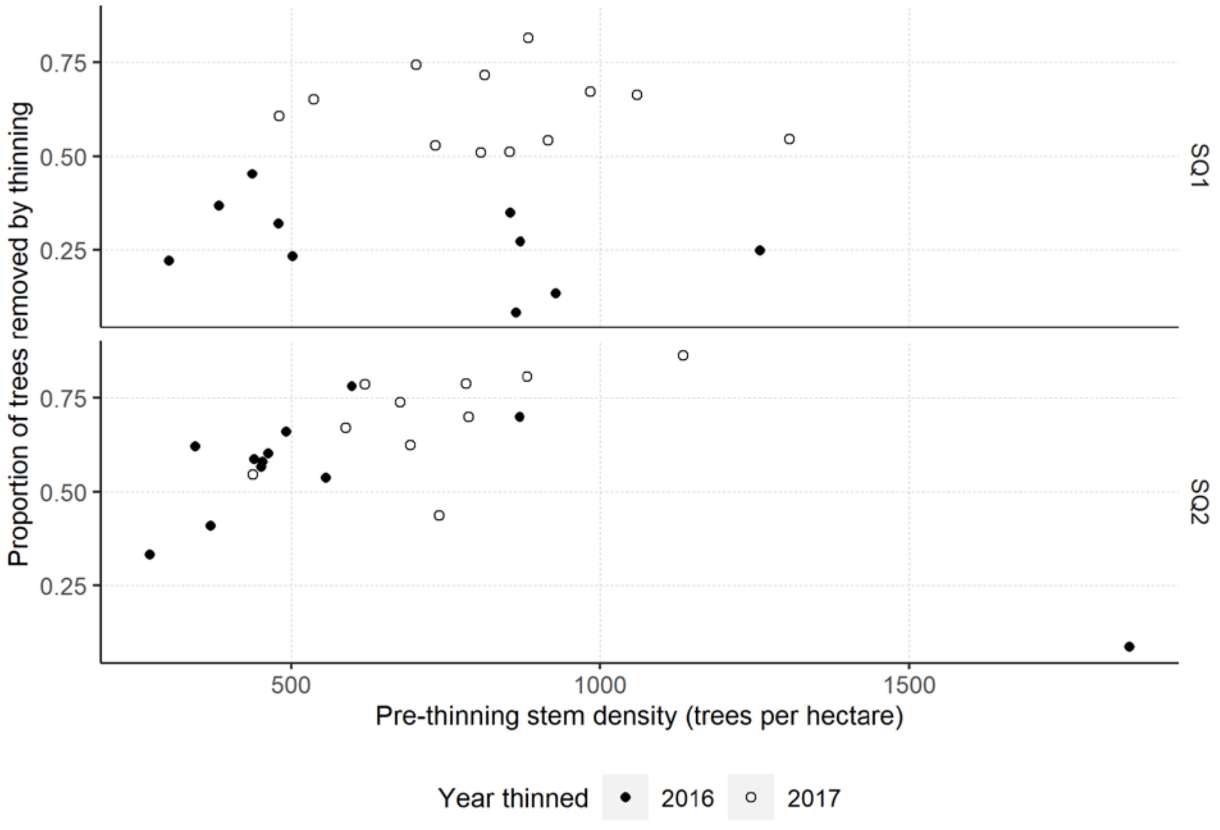

Figure 6 Proportion of trees removed relative to pre-thinning stem density and by year thinned

Post-thinning monitoring

First post-thinning monitoring 2017–18

The first round of post-thinning monitoring commenced in October 2017 and was completed in February 2018. All variables were measured in this survey period. The results of the first post-thinning monitoring are described in the *River red gum ecological thinning trial monitoring report 2018* (OEH 2018).

These data are referred to as the 2017 survey period in this report.

Second post-thinning monitoring 2018–19

The second round of post-thinning monitoring commenced in October 2018 and was completed in February 2019. A subset of variables were measured in the 2018–19 survey period and the results of this monitoring are described in the *River red gum ecological thinning trial monitoring report 2019* (OEH 2019).

These data are referred to as 2018 survey period in this report.

Third post-thinning monitoring 2019–20

The third round of post-thinning monitoring commenced in October 2019 and was completed in February 2020. A subset of variables were measured in the 2019–20 survey period and the results of this monitoring are described in *River red gum ecological thinning trial monitoring report 2020* (Gorrod et al. 2020).

These data are referred to as the 2019 survey period in this report.

Fourth post-thinning monitoring 2020–21

The fourth round of post-thinning monitoring commenced in October 2020 and was completed in February 2021. A subset of variables were measured in the 2020–21 survey period and the results of this monitoring are described in this report

These data are referred to as the 2020 survey period in this report.

Sequence of events

As a result of the 2016 flood event, the sequence of flooding and thinning differed among sites (Figure 7).

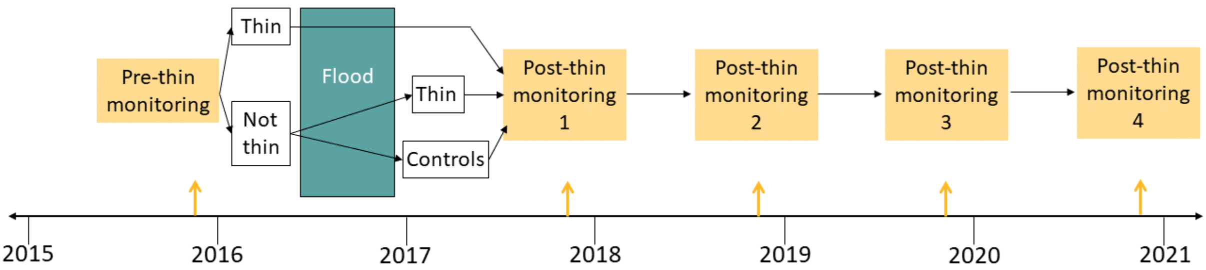

Figure 7 Sequence of monitoring, thinning and flood events

The amount of time that elapsed between thinning implementation and the first post-thinning monitoring varied among sites, and also differed among monitoring variables. For example, time since thinning at the time of survey was between one and 22 months for the tree parameters; and four and 30 months for the floristics. The effect of these differences is taken into account by including a continuous measure of 'time since thinning' (in decimal years) in the analyses.

1.6 Climate and flooding 2020–21

Flooding

No major floods occurred during 2020 (Figure 8).

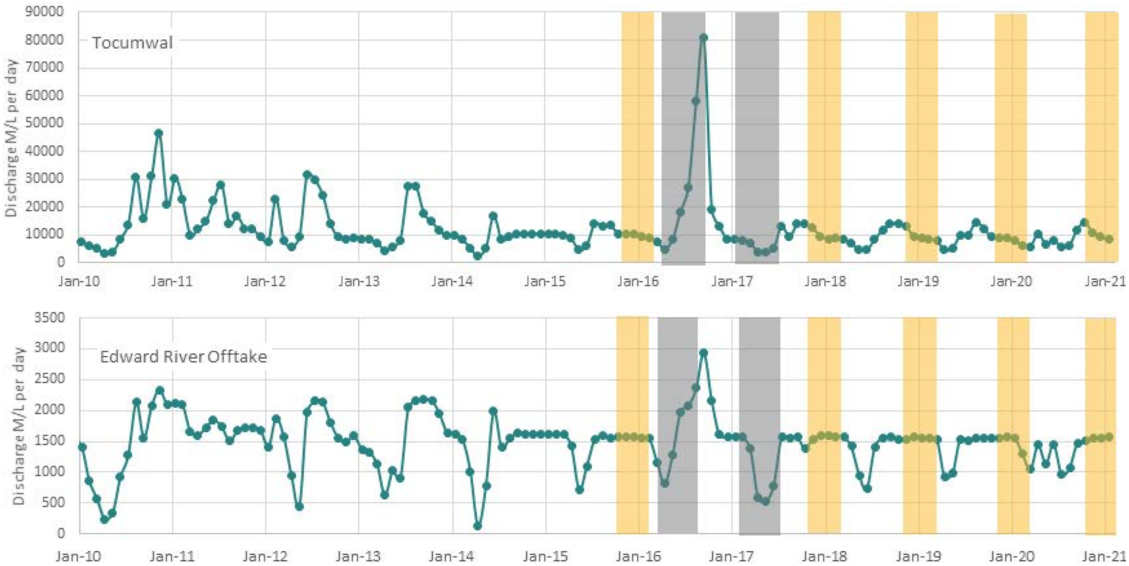

Figure 8 **Average daily discharge (in megalitres) through Tocumwal and Edwards River Offtake, averaged per month**

Source: Murray–Darling Basin Authority, River Murray Data, accessed 31/03/2021.

Rainfall

Rainfall is winter-dominant rainfall at Mathoura. There was a rainfall peak in March 2020 and relatively high rainfall through the autumn and winter of 2020 compared with the preceding 10 years. Spring and summer rainfall was low compared with the preceding 10 years (Figure 9).

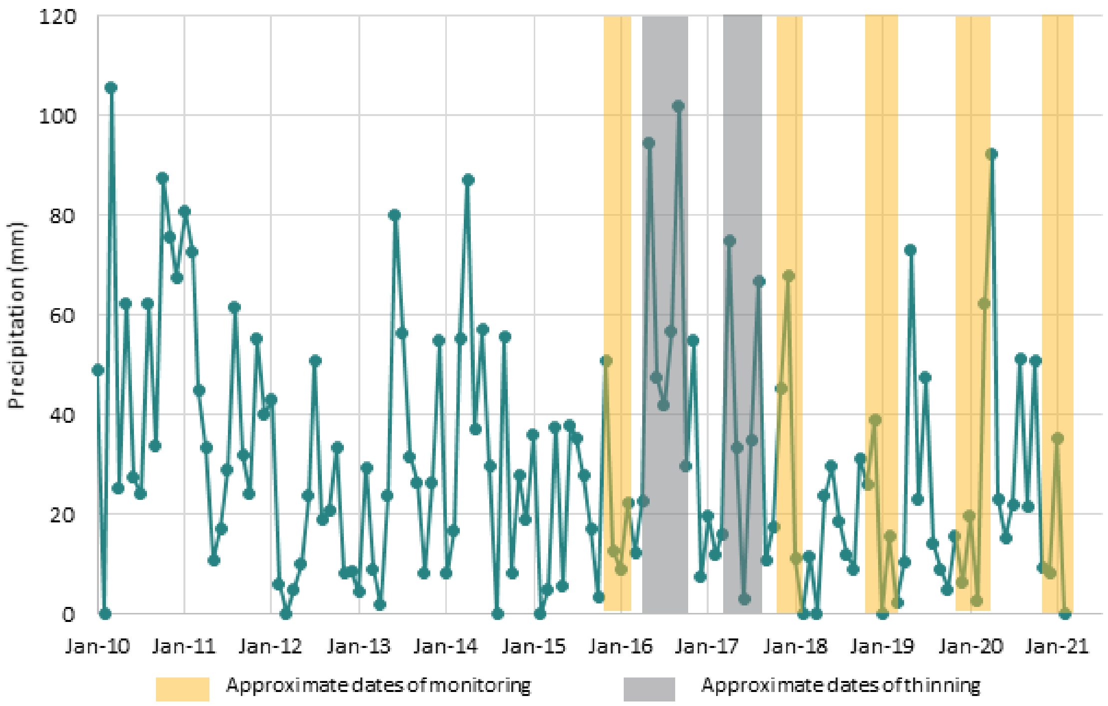

Figure 9 **Total monthly precipitation at Mathoura**

Source: Australian Bureau of Meteorology, gauge no. 074129, accessed 31/03/2021.

Evapotranspiration

Minimum evapotranspiration values in winter 2020 were comparable with the preceding 10 years, and maximum evapotranspiration in summer 2020–21 was lower than the previous five summers (Figure 10).

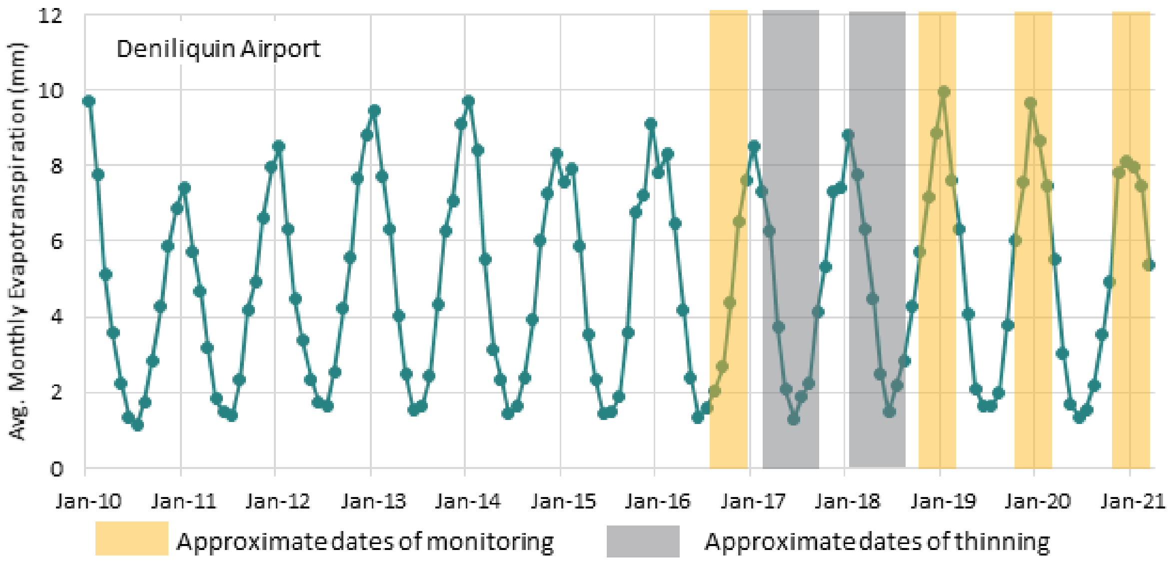

Figure 10 Monthly precipitation minus evapotranspiration at Deniliquin airport
Source: Australian Bureau of Meteorology, gauge no. 074258, accessed 31/03/2021.

1.7 This report

The analyses in this report seek to explore the effects of ecological thinning on a range of variables.

This report describes the fourth post-thinning monitoring data that were collected in 2020–21 and compares them with data collected in previous years.

Monitoring and reporting will continue annually until 2021–22, at which time the monitoring plan will be reviewed.

As specified in the experimental design and monitoring plan (OEH 2012), variables that are expected to change from year-to-year are monitored annually (Table 3).

Photographs of a selection of sites in each survey year are included in the separate Appendices document.

Variables not included in this report

As specified in the experimental design and monitoring plan (OEH 2012), variables that are expected to change over longer timeframes were monitored prior to thinning in 2015–16, in the first year post-thinning in 2017–18, and will not be monitored again until five years post-thinning in 2021–22 (Table 4).

These variables are therefore not included in this report.

Table 3 Variables monitored annually

Variable
Tree diameter at breast height over bark (trees ≥10 cm dbh)
Live/dead status of 50 trees (trees ≥10 cm dbh)
Tree crown extent
Foliage projective cover (Landsat derived)
Occurrence of seedlings
Occurrence of saplings
Cover of litter
Depth of forest leaf litter
*Bat species richness and diversity; use level by individual and all species
Occurrence of woodland bird species
*Fox track or scat evidence
Richness and cover of exotic plant species
Richness and cover of native plant species
Photo points
Fuel assessment

*Due to time constraints, data for fox scats and bat activity and bat species richness were not analysed for this report.

Table 4 Variables monitored five-yearly

Variable
Distribution of trees amongst size classes
Number of trees with hollows
Number of trees with glider notches
Opaque crown (m^2)
Cover, abundance and height of dominant species in understorey strata
Count of standing dead trees (stags)
Volume of coarse woody debris (>10 cm diameter)
Basal area
Survival of trees ≥80 cm dbh
Tree height

2. Methods

2.1 Data analysis approach

An estimation approach to analyses was used to interpret the recorded data and detect effects of thinning.

Data analysis for each monitoring variable was undertaken to estimate the following:

- the direction of change over time
- the magnitude of change over time
- differences in the direction and/or magnitude of change between control plots and plots that were thinned
- the degree to which any effect of thinning was dependent on thinning intensity (the proportion of trees removed)
- the degree to which any effect of thinning depended on the initial density of trees or site quality
- the level of confidence in results.

Confidence about changes in monitoring variables is drawn from the following sources:

- variability in the raw data
- any difficulties in finding relationships between the monitoring variable and the explanatory variables (i.e. model convergence issues)
- how well the model fits all parts of the range of raw data values (i.e. residual tests)
- how likely it is that the data would have occurred by random chance (i.e. p values)
- the width of confidence and prediction intervals.

A separate Appendix document contains information about these sources of information and describes confidence in the model for each monitoring variable.

In this approach, the statistical significance (‘p value’) generated for a regression model is only one piece of information used to draw conclusions about the importance of ecological thinning for the ecological and biodiversity features of interest.

All analyses were conducted in the R statistical environment (R Core Team 2019).

2.2 Data summaries

In this report, raw data are presented in at least one figure, like the example in Figure 11 below. Other summary information is provided in the text where relevant.

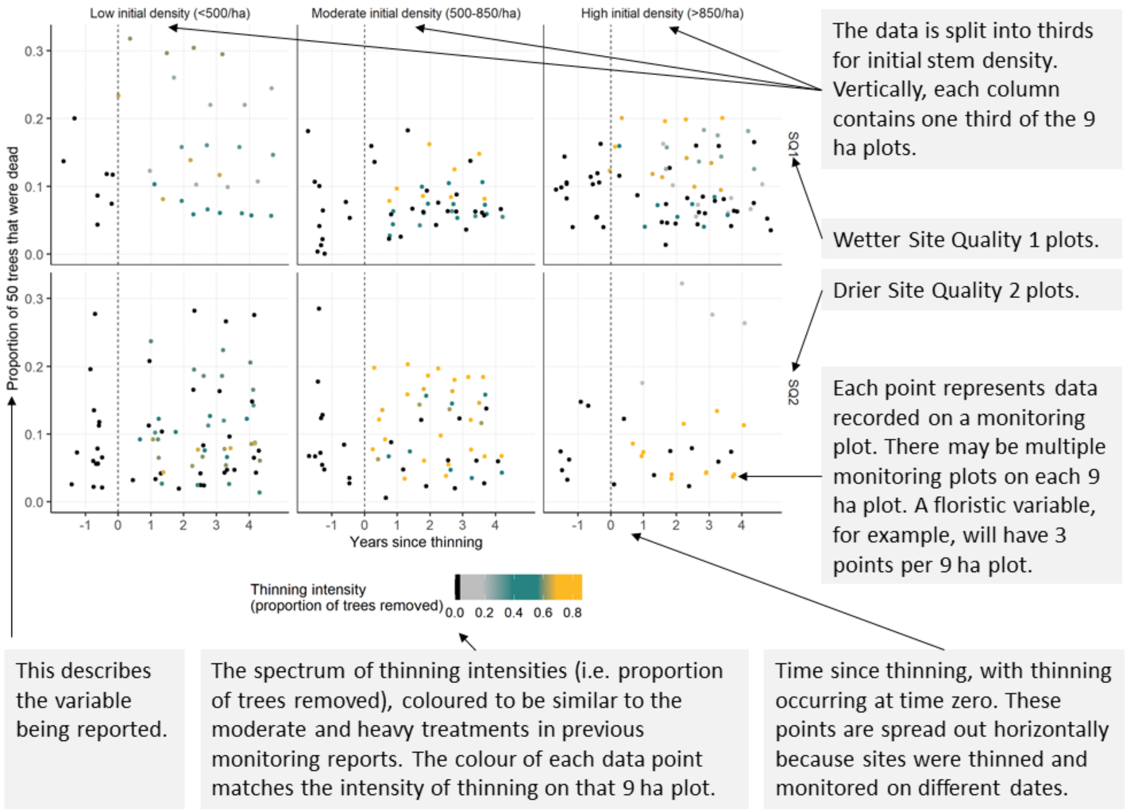

Figure 11 Explanation of raw data figure

2.3 Modelling

Frequentist and Bayesian models

Regression models estimate the extent to which different values of explanatory variables are associated with different values of the response (monitoring) variable, while accounting for known variation in the data.

Regression models calculate the line (or plane) that minimises the distance to each response variable data point. The slope (or shape) and location of the line (or plane) are determined by the values of the explanatory variables. Once the line (or plane) has been calculated, it can be used to predict what the value of the response variable may be for given values of explanatory variables.

Frequentist regression (generalised linear mixed effects models) give a single point estimate for each explanatory variable, by finding the value that minimises the amount of error in the data (called ordinary least squares).

In Bayesian regression modelling, a range of possible fits for each explanatory variable are explored. The result is a **distribution** for the explanatory variables that is proportional to the likelihood of the data. This allows the influence of each explanatory variable on the monitoring variable to be assessed while taking into account background variability. These distributions are called credible intervals.

Frequentist regression results can be re-sampled many times using bootstrapping procedures, also resulting in distributions of explanatory variables. These distributions are called confidence intervals or prediction intervals. Confidence intervals can be used to show the likely range of values that the **average** could take. Prediction intervals show the range of values future **individual observations** could take. Prediction intervals account for the variation in the average plus the variation in individual observations, and thus are always wider than confidence intervals.

While the frequentist and Bayesian estimates are calculated differently, they both provide estimates of uncertainty around the relationship between each explanatory variable and the response variable.

When a credible, prediction or confidence interval for a model coefficient does not include zero, there is high confidence that the explanatory variable has had an effect on the response variable.

Frequentist models were used for most response variables, in conjunction with bootstrapping (1000 simulations) where possible. Bayesian models were used in all cases where the response variable was a category.

Regression models were implemented in the R statistical environment, using the packages lme4 and glmmTMB for frequentist models and brms for Bayesian models.

Response variables

Monitoring (response) variables can be continuous numbers, proportions, counts or categories. Each type of variable differs in terms of the likely spread of values, and the amount of variation expected to occur around each value.

Regression is most useful in detecting the effects of thinning when the likely spread and variation (i.e. distribution) of response variable values are specified.

There are two features of regression models that are used to specify the distribution of the response variable: family and link.

The family specifies the expected relationship between the mean (average) value and the variance of the response variable.

The link function allows the relationship between the response variable and the explanatory variables to be something other than a simple linear form. It is similar to transforming the raw response variable data (for example, taking the log of each response value), but instead transforms the modelled average of the response. Other modelled values are predicted around the mean in accordance with their family characteristics.

In cases where there was uncertainty about which family and link function may have been appropriate, multiple models were run and their performance compared.

Explanatory variables

There were four explanatory variables of primary interest. Three of them were continuous predictors:

- initial stem density – total number of stems (>1.37 metres in height) per hectare (log-transformed)
- thinning intensity – proportion of stems removed (scale of 0–1)
- years elapsed since thinning commenced on the site (i.e. same date for all three 9 hectare plots on the site, including the control). The difference in dates was calculated as the number of years elapsed (as decimal years).

The fourth explanatory variable indicative of long-term water availability, site quality, was a categorical predictor.

All models also included additional explanatory variables that account for the fact that measurements within a given site or plot may not be independent samples (i.e. they may be spatially and/or temporally auto-correlated), which could influence interpretation of the main explanatory variables and their significance. These additional variables are called random effects. Models included random effects across site (where there was one estimate per 9 hectare plot), or site and plot (where there were multiple estimates per 9 hectare plot). A random effect was also included for survey year, to account for the fact that data collected in a particular survey season are more likely to be similar to each other than those collected in other years.

For each response variable, the first model that was attempted included all possible interactions between all main explanatory variables (Table 5). To allow for the effect of the continuous predictors to be relationships other than a straight line, polynomial terms were included.

Table 5 All explanatory variables and interactions for inclusion in regression models

Model term	Effect being tested	Comment
Site quality	Does the value of the response variable depend on whether it is in Site Quality 1 or Site Quality 2?	Each of these terms are independent of all other terms in the model
Initial stem density	Does the value of the response variable differ depending on pre-thinning stem density?	
Initial stem density^2	Does the value of the variable differ depending on pre-thinning stem density, such that the variable does not increase (or decrease) at a constant rate with increasing stem density?	
Years elapsed	Does the value of the response variable change over time? Although this is calculated as time 'since thinning', when it is included in the model on its own (i.e. no interaction with thinning intensity), it is determining whether there is change over time, irrespective of thinning.	
Years elapsed^2	Does the value of the response variable change over time, such that the variable does not necessarily increase (or decrease) at a constant rate as time goes on?	
Thinning intensity	Does the value of the response variable differ depending on the intensity of thinning that was applied?	
Thinning intensity^2	Does the value of the response variable differ depending on thinning intensity, such that the variable does not increase (or decrease) at a constant rate with increasing intensity?	
Initial stem density * site quality Initial stem density^2 * site quality	Does the response variable depend on initial stem density in a way that differs among site qualities?	These terms account for background interactions that are not related to thinning
Years elapsed * site quality Years elapsed^2 * site quality	Does the response variable change over time in a way that differs among the site qualities?	
Initial stem density * years elapsed	Does the relationship between the response variable and initial stem density change over time?	
Initial stem density * years elapsed * site quality	Does the relationship between the response variable and initial stem density change over time in a way that differs among site qualities?	

Model term	Effect being tested	Comment
Thinning intensity * site quality Thinning intensity^2 * site quality	Does the effect of thinning differ among site qualities; and does the effect of increasing thinning intensity in either site quality increase (or decrease) the response variable at a rate that is not constant (for example does moderate thinning lead to a greater increase (or decrease) than either light or heavy thinning)?	These interactions give detailed information about the possible effects of thinning
Thinning intensity * initial stem density	Does the effect of thinning depend on initial stem density?	
Thinning intensity * years elapsed	Does the effect of thinning change over time?	
Thinning intensity * initial stem density * site quality	Does the effect of thinning depend on initial stem density in a way that differs among the site qualities?	
Thinning intensity * years elapsed * site quality	Does the effect of thinning change over time in a way that differs among the site qualities?	
Thinning intensity * initial stem density * years elapsed * site quality	Does the effect of thinning intensity depend on initial stem density and change over time in a way that differs among the site qualities?	
Site	To account for the fact that plots within the same site are likely to be more similar to each other than they are to other sites.	These are random effects to account for temporal and spatial auto-correlation
9 hectare plot, subplot	To account for the fact that sites, plots and subplots are likely to be similar each time they are surveyed.	
Year factor (survey year)	To account for differences across survey seasons – due primarily to different hydro-climatic conditions.	

For some variables, it was not possible to fit a model with all the terms in Table 5. In these cases, simpler models were subsequently attempted by removing one or more interaction terms, or removing the random effect of survey year. The intention was not to find the 'best' model that explained the most variation in the data with the fewest terms, but rather to find the model that could fit the response data and contained as much information as possible about the effects of ecological thinning and the extent to which those effects may be dependent on initial stem density, time since thinning and/or site quality.

Assessing model fit

How well the model fits the raw data can be described in a number of ways, many of which involve looking at the difference between raw values and the model's fitted line (or plane). These differences are called residuals. For example, if the residuals are small for small values of the response variable but large for high values of the response variable, it can indicate that the model might not be a good representation of relationships for the full range of raw response variable data values.

An extension of the comparison of differences between raw and fitted values is to assume that the model is correct and use it to simulate new data with the same mean and variance as the raw data. Simulating many new datasets generates a likely spread of data around the fitted values, which can be compared with the actual spread of data around the fitted values.

The fit of all models was assessed using examination of raw and simulated residuals (using DHARMa package in R) to determine whether they met assumptions of homogeneity of variance, collinearity, and outliers. In cases where two models had similar residuals, they were compared using Akaike information criterion.

The model with the best fit for each response variable is reported in the results section of this report. The Appendix contains details about which models were trialled for each response variable, residual plots for the reported model and a description of the level of confidence in the reported model.

Assessing statistical significance of explanatory variables

Because there were numerous terms in each model that contained information about each explanatory variable, it was difficult to use the model coefficients and estimates of significance to draw conclusions about the strength of relationships between response and explanatory variables. For example, in a model that contained all the terms in Table 5, there were nine terms that included thinning intensity, only some of which may have shown statistical significance. The Appendix contains the coefficients and significance values for each term in each model.

Likelihood ratio tests compare the goodness of fit of two models. If one model is superior at explaining variation in the response data, then its goodness of fit is higher. A model that contains all possible combinations of explanatory variables (full model) can be compared with a model that contains all combinations of explanatory variables **except one** (say, thinning intensity) (null model) via a likelihood ratio test. If there is little difference in the ability of the two models to explain variation in the response data, then the likelihood ratio test will be non-significant. If the test is not significant, then the explanatory variable that was removed is unlikely to be a strong predictor of the response variable. On the other hand, if the explanatory variable was important for explaining variation in the response data then there will be a significant difference between the models.

Null model comparisons were conducted using bootstrapped likelihood ratio tests for each of the main explanatory effects as well as for interactions involving thinning intensity. The significance levels are reported in a table. The actual p values were reported for each null model comparison, and a threshold of $p = 0.05$ was used for ascribing statistical significance.

Instead of likelihood ratio tests, Bayesian models used leave-one-out cross-validation to estimate out of sample prediction accuracy using the log-likelihood evaluations of the posterior simulations to compare the candidate model with null models. These comparisons calculate a difference in expected log-predictive density (ELPD) and a standard error for this difference. Where the difference in ELPD is much larger than estimated standard error of the difference, there is much better predictive performance. We reported the ratio of the ELPD difference to its standard error and used values of five or greater as an indicator of significant change in predictive performance.

Visualising modelled relationships

The modelled relationships between explanatory variables and the response variable are represented in a figure (Figure 12). The figure shows the modelled values of the response variable (on the original scale after removing any link function or transformation that had been applied) for different values of the explanatory variables. The figure also shows bootstrapped 95% prediction intervals (generated from 999 simulations), which were generated from the model for specific values of explanatory variables, generic levels of variation representing differences among site and 9 hectare plot, and specific levels of variation in each survey year (where survey year was included as a random effect).

Note that the figures and text descriptions are on the scale of the response variable. A statistically significant effect may not appear so in the figure, with prediction intervals overlapping all means, particularly where there was a significant interaction but no significant main effects.

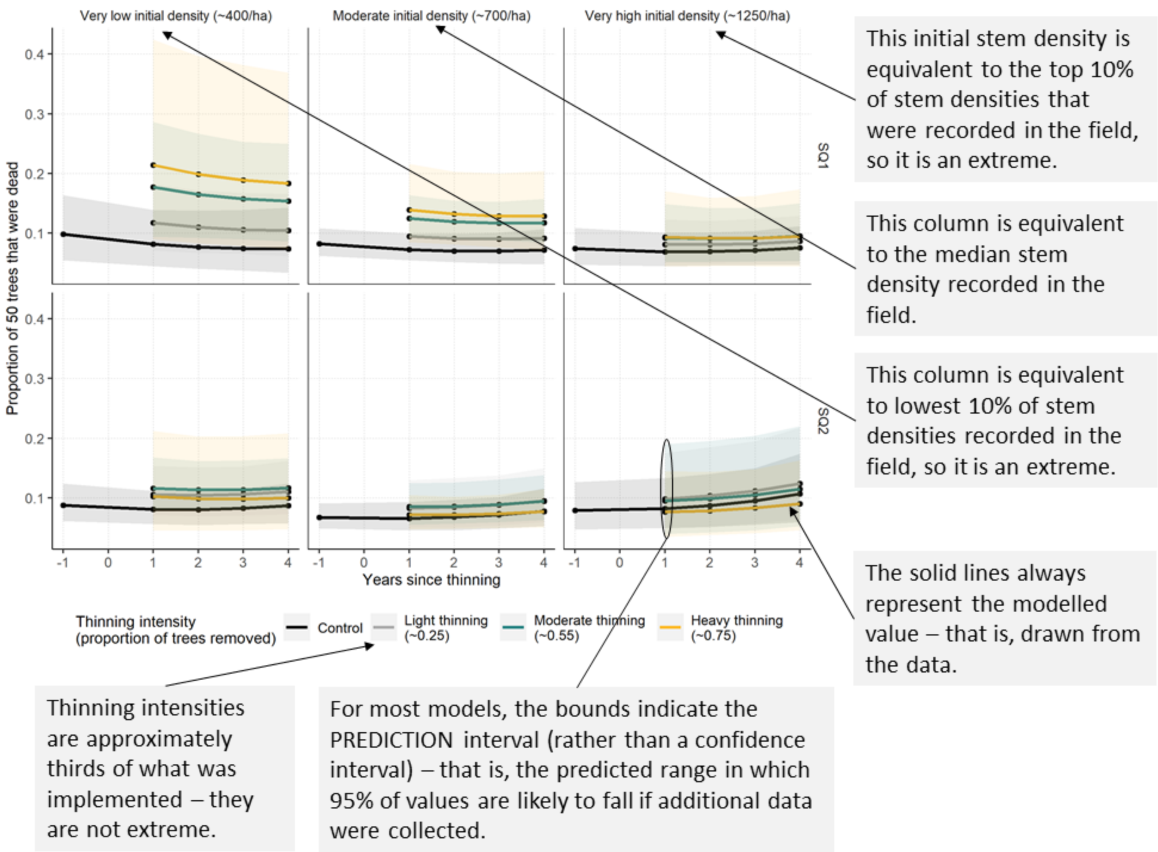

Figure 12 Explanation of model results figure

Assessing magnitude of effects

It may be difficult to determine the exact magnitude of difference between the value of the response variable on control and thinned plots from the model results figure. The exact differences are presented in an effect size table for four years post-thinning (the most recent survey year) only (Figure 13). In cases where the prediction interval for thinned plots does not include the fitted value for control plots, it is likely there has been an effect of thinning. This is indicated by both the interval values being either positive or negative.

Site quality		Site Quality 1			Site Quality 2		
Initial stem density		400/ha	700/ha	1250/ha	400/ha	700/ha	1250/ha
Thinning intensity	Low intensity	+1.5 +0.1 to +3.0	+1.4 +0.3 to +2.4	+1.2 0.0 to +2.5	+0.4 -0.8 to +1.7	+0.5 -1.1 to +2.1	+0.7 -1.2 to +2.6
	Mod intensity	+2.2 +0.3 to +4.2	+1.8 +0.8 to +2.8	+1.5 -0.1 to +3.1	+1.1 0.0 to +2.3	+1.5 +0.2 to +2.7	+1.8 -0.5 to +4.2
	High intensity	+1.7 -1.4 to +4.7	+1.2 -0.6 to +2.9	+0.7 -1.9 to +3.3	+1.7 -1.0 to +4.3	+2.2 +0.9 to +3.4	+2.6 +0.4 to +4.9

For each level of site quality and initial stem density, this is the **difference** between the modelled value of the response variable on **control plots** and the modelled value of the response variable on **plots with different thinning intensities**.

This value is the difference between the modelled value of the response variable on control plots and the lower 95% prediction interval.

This value is the difference between the modelled value of the response variable on control plots and the upper 95% prediction interval.

When the range of predicted values on thinned plots does not include the modelled value for control plots, there is likely to be an effect of thinning and the cell is highlighted. **This is the case when BOTH UPPER AND LOWER predicted values are either positive or negative.**

These values are for FOUR YEARS post thinning – reflecting the most recent surveyed values. This may not be the year in which the greatest effect of thinning was likely to occur.

Figure 13 Explanation of effect size table

Data limitations

Using the available data for initial stem density and thinning intensity (proportion of trees removed) is likely to improve learning about the effects of ecological thinning. However, as the plots in each site quality class were not evenly distributed across the spectrums of initial stem density and thinning intensity, fewer datapoints were available for some combinations of site quality, initial stem density and thinning intensity. Consequently, model predictions for the following combinations were likely to have higher levels of uncertainty:

- control plots in Site Quality 1 with low stem density stands
- low intensity thinning (<40% of stems removed) in stands with moderate to high initial stem density in Site Quality 2.

3. Results: Tree parameters

3.1 Tree growth rates

Key result	Thinning affected average annual tree growth rates, but effects depended on the size of the tree. Thinning caused the growth rates of smaller trees to increase and the growth rates of larger trees to decrease, with the most likely magnitudes of change being: • a 1.4–2.6 mm per year (30–100%) increase relative to controls for small trees (20 cm diameter at breast height) on some plots • a 2.4–3 mm per year (75–80%) decrease relative to controls for large trees (100 cm diameter at breast height) on some plots.

Data collection

Within each 9 hectare treatment plot, 30 trees with >10 centimetres dbh were randomly selected along a north–south transect in the centre of the plot. These 30 trees were permanently marked and surveyed for diameter at breast height to the nearest millimetre (mm) each survey. For multi-stemmed trees a single dbh value was calculated by summing diameters of all stems at breast height. A single observer conducted all measurements on all surveys.

Out of 1980 permanently marked trees, 15 have died since the 2015 surveys. Replacement trees were selected that were a similar diameter to the dead trees. Replacement trees were included in these analyses.

The average annual growth rate (millimetres per year) was calculated for each tree from change in dbh between the first observation date (this was in 2015 prior to ecological thinning for all trees except the replacement trees) until the most recent observation date (in 2020–21).

Data summary

The majority of trees in both site qualities and of all sizes had average annual growth rates of between 0 and 10 millimetres per year (Figure 14).

Trees tended to grow faster in Site Quality 1 than Site Quality 2, with average annual growth rates of 4.3 and 2.6 millimetres per year, respectively.

Tree shrinkage was apparent for approximately 10% of stems, however, only 2.5% of stems shrank by more than 2 millimetres. In some trees, this may be caused by loss of bark or shrinkage in response to water stress.

Fastest growth rates tended to occur on trees that were less than 50 centimetres dbh.

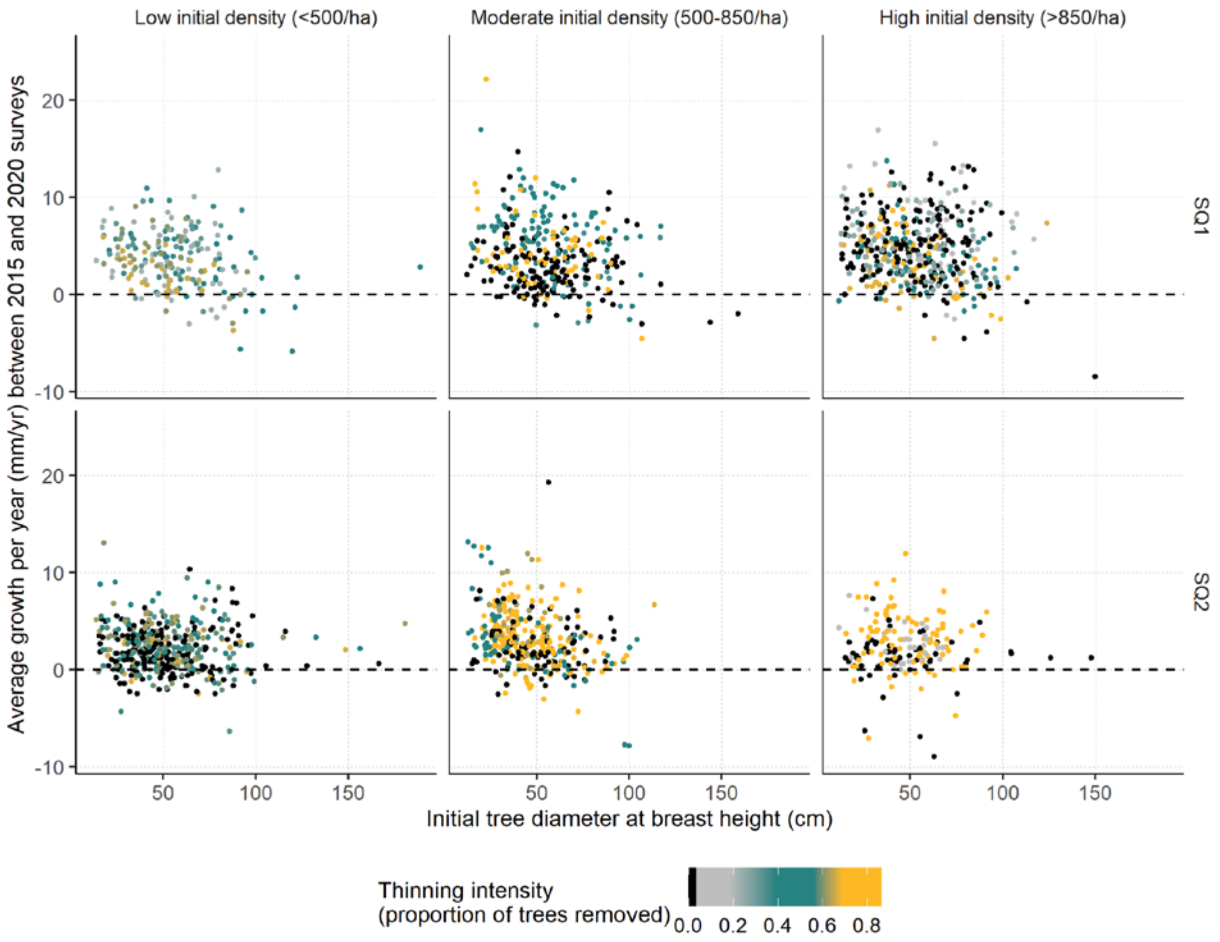

Figure 14 Data for average tree growth per year (millimetres per year) between 2015 and 2020 survey dates

Not showing three values with >25 mm growth; and eight values <–10 mm growth.

Model results

The average annual growth rate of trees between first and last measurements was modelled to determine the likely dependence on site quality, initial stem density, initial tree size and thinning intensity (see Appendix). A four-way interaction between all predictors was included in the model, in addition to all possible two-way and three-way interactions. Time since thinning was not included in this model, as the response variable was an average over time. The random effects in this model were site and 9 hectare plot.

Modelled values of average annual tree growth were higher in Site Quality 1 than Site Quality 2 (Figure 15), and this effect was statistically significant (Table 6). Tree growth rates were higher in very high initial stem density plots in Site Quality 1 (Figure 15), but differences were not statistically significant (Table 6).

In the absence of thinning, tree growth rates depended on tree size (Table 6), with average annual tree growth slightly higher for smaller trees than larger trees in Site Quality 1 and higher than medium-sized trees in Site Quality 2 (Figure 15).

Ecological thinning significantly affected the average annual growth rates of trees, but this effect was dependent on tree size (Table 6). Thinning caused the growth rates of smaller trees to increase and the growth rates of larger trees to decrease relative to control plots (Figure 15).

For smaller trees (20 centimetres dbh at first measurement), thinning generally caused them to grow 0.4–2.6 millimetres per year faster than the small trees on control plots (which grew around 2.5–5 millimetres per year, an increase of 20–50%) (Table 7). Growth rates were most likely to be different from control plots by (Table 7):

- 1.4–2.2 millimetres per year (or 30–75%) increase for low and moderate intensity thinning in Site Quality 1 plots that had low to moderate stem densities prior to thinning
- 1.5–2.2 millimetres per year (or 55–80%) increase for moderate and high intensity thinning in Site Quality 2 plots that had moderate stem density prior to thinning
- 2.6 millimetres per year (or 97%) increase for high intensity thinning in Site Quality 2 plots that had very high stem density prior to thinning.

For large trees (100 centimetres dbh at first measurement), the effect of thinning for which there was the greatest difference from controls was for heavy thinning in Site Quality 1 plots that had moderate to very high stem density prior to thinning. Thinning caused a 75–80% reduction in growth rates of large trees (2.4–3 millimetres per year slower than large trees on control plots, which grew around 3–4 millimetres per year) (Table 8).

The effect of thinning on growth rates did not differ significantly depending on site quality or initial stem density (Table 6).

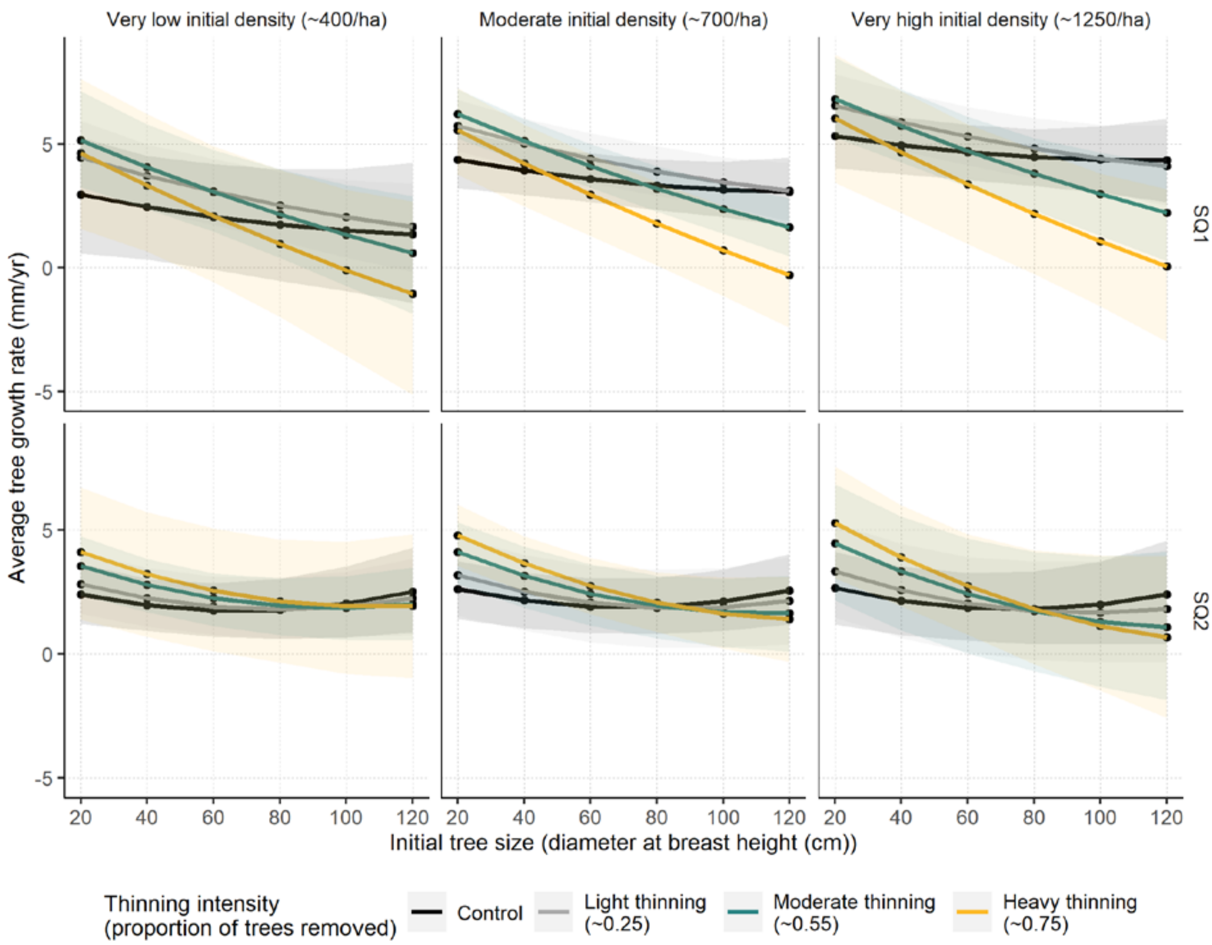

Figure 15 Modelled values and prediction intervals for annual tree growth rates in relation to initial tree size

Table 6 Statistical significance of explanatory variables on average annual tree growth

	Bootstrapped likelihood ratio test significance	Description
Site quality	0.030	Tree growth differed among site qualities
Initial stem density	0.634	Tree growth was not dependent on initial stem density
Initial tree diameter	0.010	Tree growth differed depending on the size of the tree
Thinning intensity	0.010	Tree growth was affected by thinning
Does the effect of thinning intensity vary depending on:		
• Site quality	0.743	Thinning effects on tree growth did not differ among site qualities
• Initial stem density	0.901	Thinning effects on tree growth did not depend on pre-thinning stem density
• Initial tree diameter	0.010	Thinning effects on tree growth depended on the size of the tree
• Site quality **and** initial stem density **and** initial tree diameter	0.851	Thinning intensity effects on tree growth did not vary among all combinations of initial stem density, tree size and site quality

Table 7 Estimated effect sizes four years post-thinning of annual tree growth rates for trees that were 20 centimetres dbh at first measurement

Site quality		Site Quality 1			Site Quality 2		
Thinning intensity		Low intensity	Mod intensity	High intensity	Low intensity	Mod intensity	High intensity
Initial stem density	Very low (400/ha)	+1.5 +0.1 to +3.0	+2.2 +0.3 to +4.2	+1.7 –1.4 to +4.7	+0.4 –0.8 to +1.7	+1.1 0.0 to +2.3	+1.7 –1.0 to +4.3
	Moderate (700/ha)	+1.4 +0.3 to +2.4	+1.8 +0.8 to +2.8	+1.2 –0.6 to +2.9	+0.5 –1.1 to +2.1	+1.5 +0.2 to +2.7	+2.2 +0.9 to +3.4
	Very high (1250/ha)	+1.2 0.0 to +2.5	+1.5 –0.1 to +3.1	+0.7 –1.9 to +3.3	+0.7 –1.2 to +2.6	+1.8 –0.5 to +4.2	+2.6 +0.4 to +4.9

Table 8 Estimated effect sizes of tree growth rates for trees that were 100 centimetres dbh at first measurement

Site quality		Site Quality 1			Site Quality 2		
Thinning intensity		Low intensity	Mod intensity	High intensity	Low intensity	Mod intensity	High intensity
Initial stem density	Very low (400/ha)	+0.5 –1.1 to +2.0	–0.2 –2.2 to +1.8	–1.6 –5.0 to +1.6	–0.1 –1.4 to +1.3	–0.2 –1.5 to +1.1	–0.1 –2.8 to +2.5
	Moderate (700/ha)	+0.3 –0.7 to +1.3	–0.8 –1.8 to +0.2	–2.4 –4.3 to –0.6	–0.2 –1.9 to +1.4	–0.4 –1.8 to +0.9	–0.5 –1.9 to +1.0
	Very high (1250/ha)	0.0 –1.3 to +1.4	–1.4 –3.1 to +0.3	–3.3 –5.9 to –0.6	–0.3 –2.3 to +1.7	–0.7 –3.3 to +1.9	–0.9 –3.5 to +2.0

3.2 Tree mortality

Key result	Thinning increased the proportion of trees that were dead. Four years after thinning, the most likely magnitude of change was an additional 5–8% dead trees in Site Quality 1 plots that were moderately thinned, approximately double the proportion of dead trees on control plots.

Data collection

Dead trees were defined as those with no live foliage and included ringbarked trees.

Tree mortality was surveyed by assessing 50 trees with ≥10 centimetres dbh as live or dead, along a north–south transect in each 9 hectare treatment plot.

Data summary

Prior to ecological thinning, the proportion of dead trees was similar for all treatment types, averaging at about 9% of trees (Figure 16). Three (out of 66) 9 hectare plots had 20–30% dead trees prior to thinning.

After thinning, the proportion of plots with >10% dead trees increased, although the magnitude of change in the average percentage of dead trees was small. The number of plots with 20–30% dead trees remained small over time.

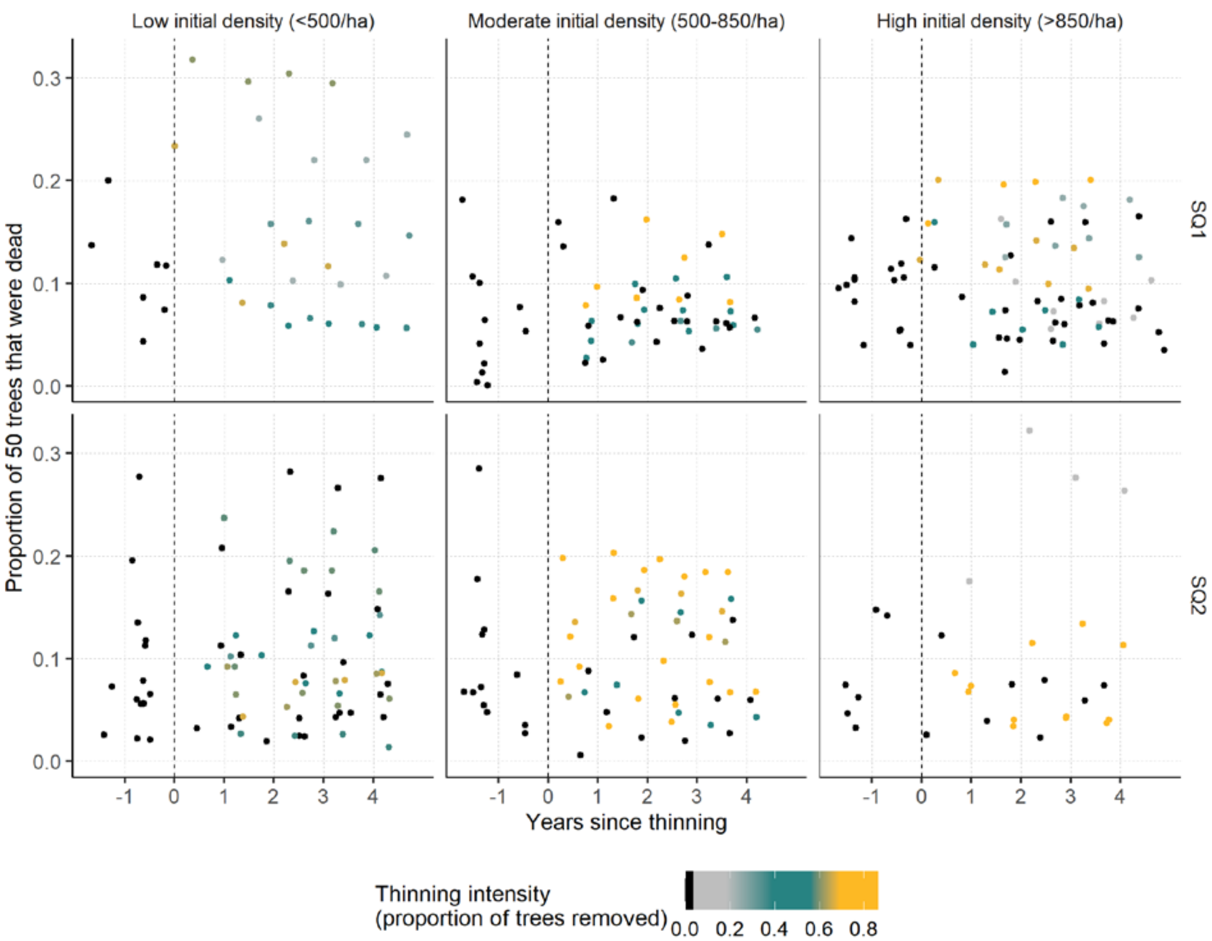

Figure 16 Data for proportion of 50 trees that were dead in each 9 hectare plot

Model results

Tree mortality was analysed as the proportion of trees that were dead (see Appendix). The model for tree mortality did not include a four-way interaction between site quality, initial stem density, time since thinning and thinning intensity, but rather included multiple two-way and three-way interactions. The model did not include a random effect for survey year, so the modelled trend assumes consistent trends among survey years. Confidence in this model was moderate because there were warnings about failure to fit the model in about 10% of the 1000 bootstrapped prediction simulations.

Modelled values of mortality in control plots were between 7 and 10% in all initial stem density and site quality combinations over time. Modelled mortality in control plots in Site Quality 2 increased slightly over time (Figure 17), but this was not statistically significant (Table 9).

Thinning increased the proportion of trees that were dead (Figure 17), and this effect was statistically significant (Table 9). Any differences in the effect of thinning among site qualities and initial stem densities were not statistically significant (Table 9).

Four years after thinning, the effect for which there was most likely to be a difference from control plots was in moderately thinned Site Quality 1 plots that had very low to moderate initial density. The magnitude of increase was 5–8% relative to controls (Table 10). The magnitude of increase in heavily thinned plots was greater, but the prediction intervals included the values for the control plots (Figure 17, Table 10).

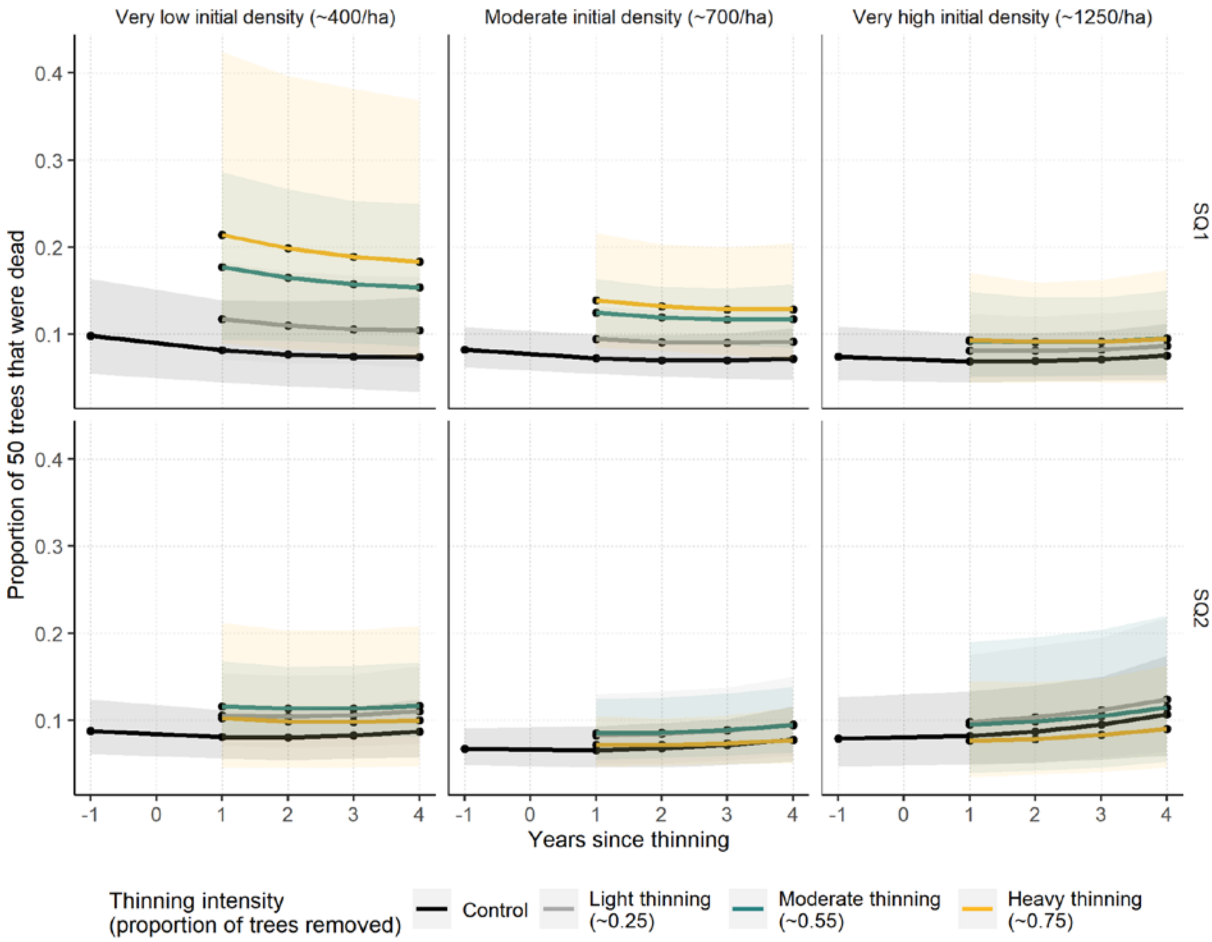

Figure 17 Modelled values and prediction intervals for proportion of 50 trees that were dead in each 9 hectare plot

Table 9 Statistical significance of explanatory variables on tree mortality

	Bootstrapped likelihood ratio test significance	Description
Site quality	0.653	Mortality did not differ among site qualities
Initial stem density	0.663	Mortality did not depend on initial stem density
Time since thinning	0.851	Mortality did not change over time
Thinning intensity	0.050	Mortality was affected by ecological thinning
Does the effect of thinning intensity vary depending on:		
• Site quality	0.436	The effect of thinning on mortality did not depend on site quality
• Initial stem density	0.446	The effect of thinning on mortality did not depend on initial stem density
• Time since thinning	0.851	The effect of thinning on mortality did not change over time
• Site quality **and** initial stem density **and** time since thinning	NA	The four-way interaction was not included in the model

Table 10 Estimated effect sizes for tree mortality (proportion of trees that were dead) four years post-thinning

Site quality		Site Quality 1			Site Quality 2		
Thinning intensity		Low intensity	Mod intensity	High intensity	Low intensity	Mod intensity	High intensity
Initial stem density	Very low (400/ha)	+0.03 –0.01 to +0.09	+0.08 +0.01 to +0.18	+0.11 0.00 to +0.30	+0.02 –0.01 to +0.08	+0.03 –0.01 to +0.08	+0.01 –0.04 to +0.12
	Moderate (700/ha)	+0.02 –0.01 to +0.06	+0.05 +0.01 to +0.09	+0.06 0.00 to +0.13	+0.02 –0.02 to +0.07	+0.02 –0.02 to +0.06	0.00 –0.03 to +0.04
	Very high (1250/ha)	+0.01 –0.02 to +0.05	+0.02 –0.02 to +0.08	+0.02 –0.03 to +0.10	+0.02 –0.04 to +0.11	+0.01 –0.05 to +0.11	–0.02 –0.06 to +0.06

4. Results: Coppice

Key result	Thinning increased the abundance of coppiced stems, particularly in Site Quality 2 plots. The most likely magnitude of increase was: • an additional 7–50 coppiced stems per 0.04 hectare on most plots • an additional 450–550 coppiced stems per 0.04 hectare in Site Quality 2 plots that had very high initial stem density.

Data collection

The number of coppiced stems arising from: a) cut stumps; and b) pushed over saplings were counted in three 0.04 hectare subplots on each 9 hectare plot. For each stump or pushed over stem with coppice, the number of seedling-sized (<1.37 metres in height) and sapling-sized (>1.37 metres in height) stems arising were counted. Coppice often arises in clumps, and in these cases the number of stems was approximated.

Comprehensive data for coppice were collected for the first time in the 2020–21 survey season.

Plate 1 Coppice arising from a pushed over sapling on a thinned plot four years post-thinning

Data summary

On control plots, coppice was the result of previous (historical) logging operations. It was present on 25 out of 66 (38%) subplots. Most commonly the abundance of historical coppice was less than 5 stems per 0.04 hectare (Figure 18).

The proportion of thinned plots with any coppiced stems was 80% (106 out of 132 subplots). In the 2020–21 survey season (3–4 years post-thinning), coppiced stems that were approximately 3 metres in height were observed.

A higher proportion of coppiced stems arose from pushed over saplings than cut stumps, and higher abundances of coppice were observed on heavily thinned plots (Figure 18).

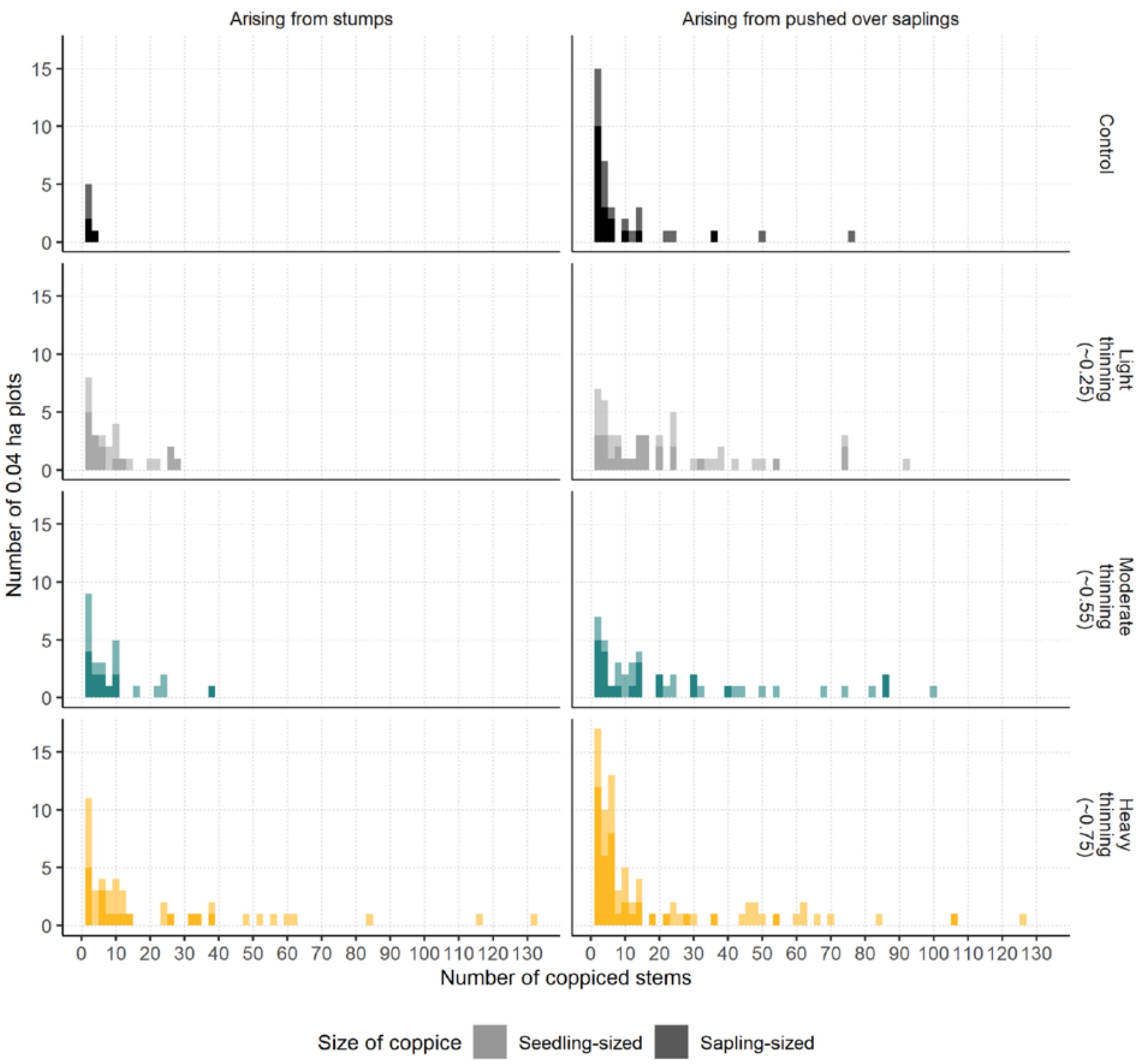

Figure 18 Data for occurrence of different types and sizes of coppice

Each bar represents a range of 2 coppiced stems and the bar for seedling-sized stems is stacked on top of the sapling-sized bar. Figure excludes subplots from which coppice was absent.

The maximum number of coppiced stems recorded (seedling-sized and sapling-sized combined) was 232 per 0.04 hectare (Figure 19).

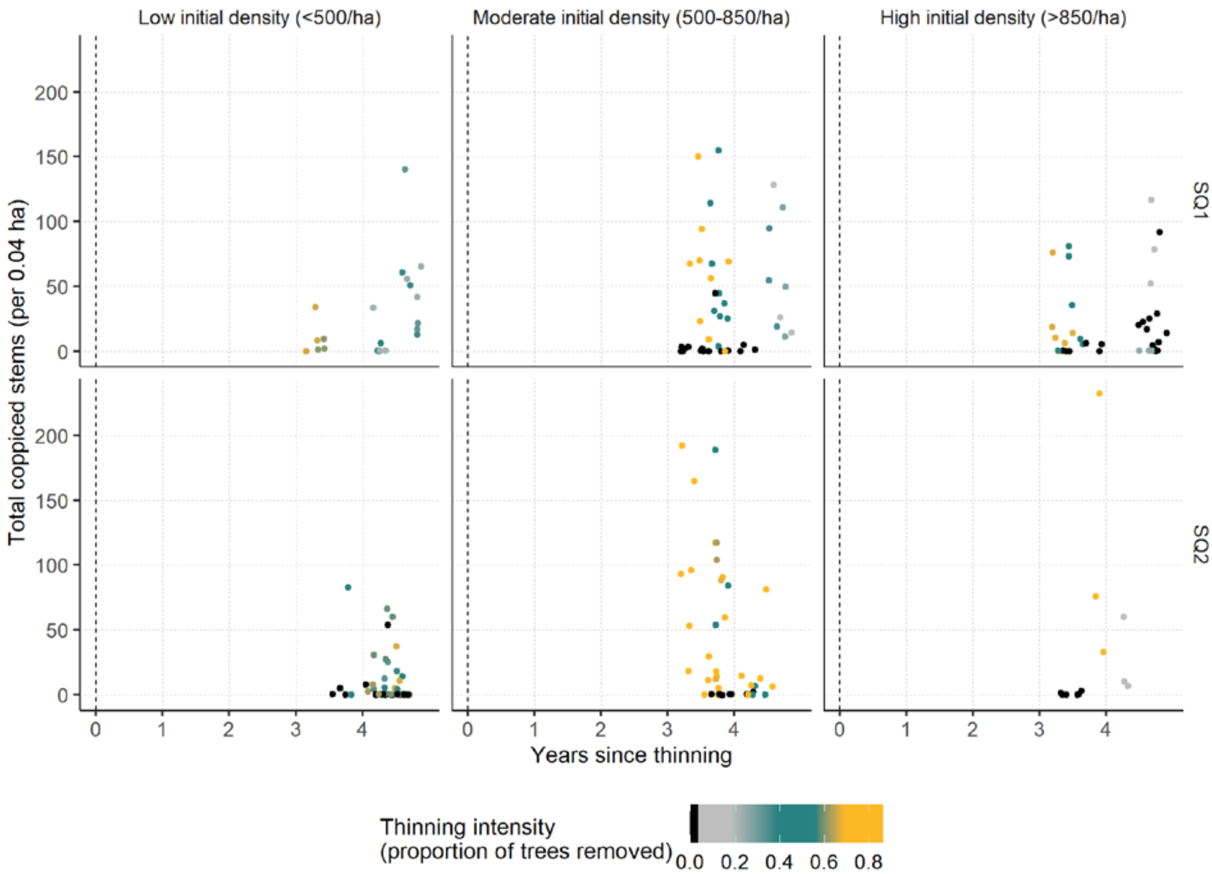

Figure 19 Data for total abundance of coppiced stems (seedling and sapling-sized) arising from stumps and pushed over saplings per 0.04 hectare subplot

Data only recorded in 2020–21 survey season.

Model results

Total abundance of coppiced stems was analysed as a count variable using a negative binomial distribution (see Appendix). The model for abundance of coppiced stems did not include a four-way interaction between site quality, initial stem density, time since thinning and thinning intensity, but rather included multiple two-way and three-way interactions. The model included only the random effect of site and did not include a random effect of year as the data were all collected in the 2020–21 survey season.

In the absence of ecological thinning, the abundance of historical coppiced stems was higher in Site Quality 2 plots and plots that had very high initial stem density (Table 11). The magnitude of these effects was small in comparison to the effects of thinning, and therefore not apparent from Figure 20.

Thinning increased the abundance of coppiced stems, and the effect was greater in Site Quality 2 than Site Quality 1 (Figure 20, Table 11). The effect of thinning may also have depended on initial stem density, but the level of statistical significance was slightly lower than 5% for this interaction ($p = 0.063$, Table 11).

The magnitude of increase in coppice abundance was most likely to be (Table 12):

- an additional 32–53 stems per 0.04 hectare in moderately thinned Site Quality 1 plots that had moderate to very high initial stem density
- an additional 445–545 stems per 0.04 hectare in moderately to heavily thinned Site Quality 2 plots that had high stem density prior to thinning
- an additional 7–36 stems per 0.04 hectare on most other Site Quality 2 plots that were thinned.

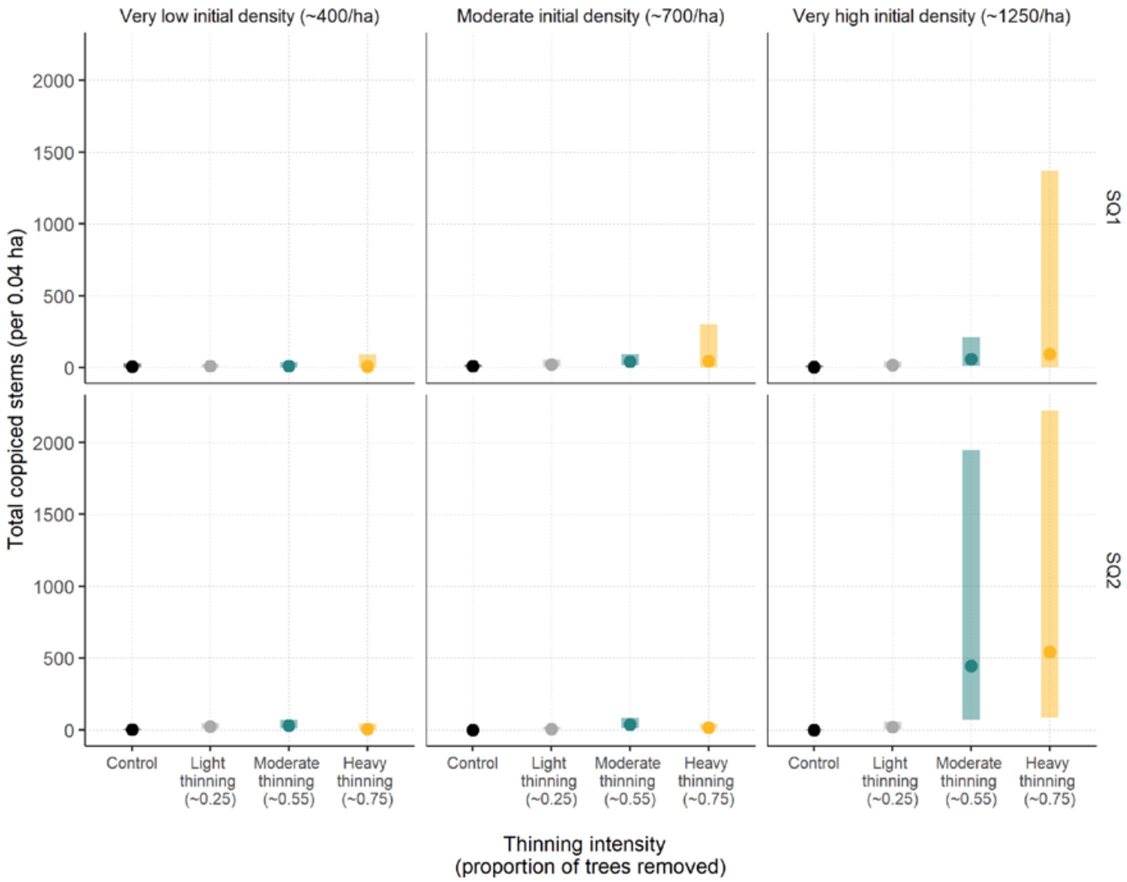

Figure 20 **Modelled values and prediction intervals for abundance of coppiced stems arising from stumps and pushed over saplings**

Table 11 **Statistical significance of explanatory variables on abundance of coppiced stems arising from stumps and pushed over saplings**

	Bootstrapped likelihood ratio test significance	Description
Site quality	0.012	The number of coppiced stems differed among site qualities
Initial stem density	0.021	The number of coppiced stems depended on initial stem density
Time since thinning	0.012	The number of coppiced stems varied over time
Thinning intensity	0.012	The number of coppiced stems was affected by thinning intensity
Does the effect of thinning intensity vary depending on:		
• Site quality	0.039	The effect of thinning on the number of coppiced stems depended on site quality
• Initial stem density	0.063	The effect of thinning on the number of coppiced stems may have depended on initial stem density
• Time since thinning	0.247	The effect of thinning on the number of coppiced stems did not depend on time since thinning
• Site quality **and** initial stem density **and** time since thinning	NA	Not modelled

Table 12 Estimated effect sizes for abundance of coppiced stems arising from pushed over saplings and stumps (difference from fitted control value) four years post-thinning

Site quality		Site Quality 1			Site Quality 2		
Thinning intensity		Low intensity	Mod intensity	High intensity	Low intensity	Mod intensity	High intensity
Initial stem density	Very low (400/ha)	+3.6 –4.7 to +19.2	+4.4 –4.9 to +30.4	+1.6 –6.4 to +84.0	+19.5 +4.5 to +46.0	+27.1 +6.5 to +65.5	+3.3 –2.2 to +41.8
	Moderate (700/ha)	+12.0 –2.3 to +45.3	+32.3 +5.9 to +83.7	+35.9 –4.9 to +290.5	+6.5 +1.6 to +18.4	+35.9 +13.7 to +81.7	+17.6 +5.4 to +43.4
	Very high (1250/ha)	+11.7 –0.5 to +37.5	+53.2 +6.3 to +207.4	+87.7 –0.7 to +1364.3	+20.3 +3.8 to +58.9	+444.7 +67.5 to +1947.7	+544.1 +85.5 to +2220.6

Plate 2 Coppice arising on a thinned plot four years post-thinning

5. Results: Recruitment

5.1 Germinant occurrence

Key result	Thinning initially increased the probability of occurrence of germinants but decreased the probability of occurrence in subsequent years. Four years post-thinning the most likely magnitude of change was an 18–40% reduction in probability of germinants occurring in most Site Quality 1 plots.

Data collection

Germinants were defined as individuals of *Eucalyptus camaldulensis* with cotyledons present.

Germinants were recorded in four quadrants of each 0.04 hectare subplot and summed for each 9 hectare plot.

Presence of germinants tends to be transient in the few weeks after floodwaters recede. If climatic conditions are too dry the germinants die and if climatic conditions are appropriate, they develop into seedlings.

Data summary

The nature of germinant occurrence resulted in their absence from the majority of 0.04 hectare subplots in all survey seasons. The maximum number of subplots with germinants in any one survey season was the 2020–21 season, in which they were observed on 34 subplots in Site Quality 1 (17% of subplots) and 6 subplots in Site Quality 2 (3% of subplots) (Table 13).

Table 13 Count and proportion of 0.04 hectare subplots for which germinants were recorded as present, in each site quality and survey year

Site quality	Survey year	Count of 0.04 hectare subplots with germinants present	Percentage of 0.04 hectare subplots with germinants present
SQ1	2015–16	15	7.6%
	2017–18	24	12.1%
	2018–19	22	11.1%
	2019–20	11	5.6%
	2020–21	34	17.2%
SQ2	2015–16	0	0.0%
	2017–18	9	4.6%
	2018–19	1	0.5%
	2019–20	4	2.0%
	2020–21	6	3.0%

When plots with different thinning intensities were divided into thirds, it appeared as though heavily thinned plots in Site Quality 1 may have fewer occurrences of germinants than other treatments for the three most recent post-thinning surveys (Figure 21).

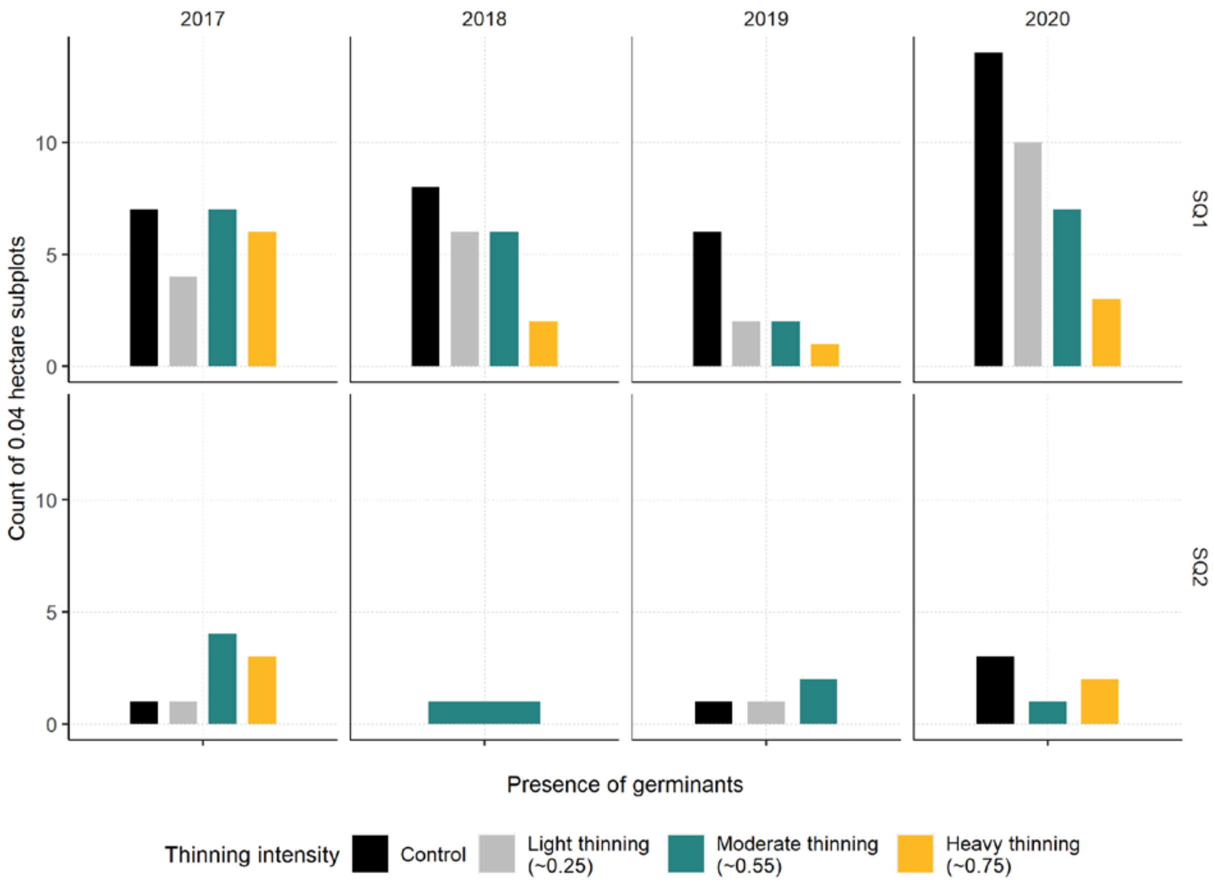

Figure 21 Data for presence–absence of germinants per 0.04 hectare subplot

Germinant abundance data indicated that counts of germinants were most often less than 50 per 0.04 hectare plot, but occasionally between 100 and 950 in Site Quality 1 plots (Figure 22). The data for germinant abundance was not suitable for regression modelling.

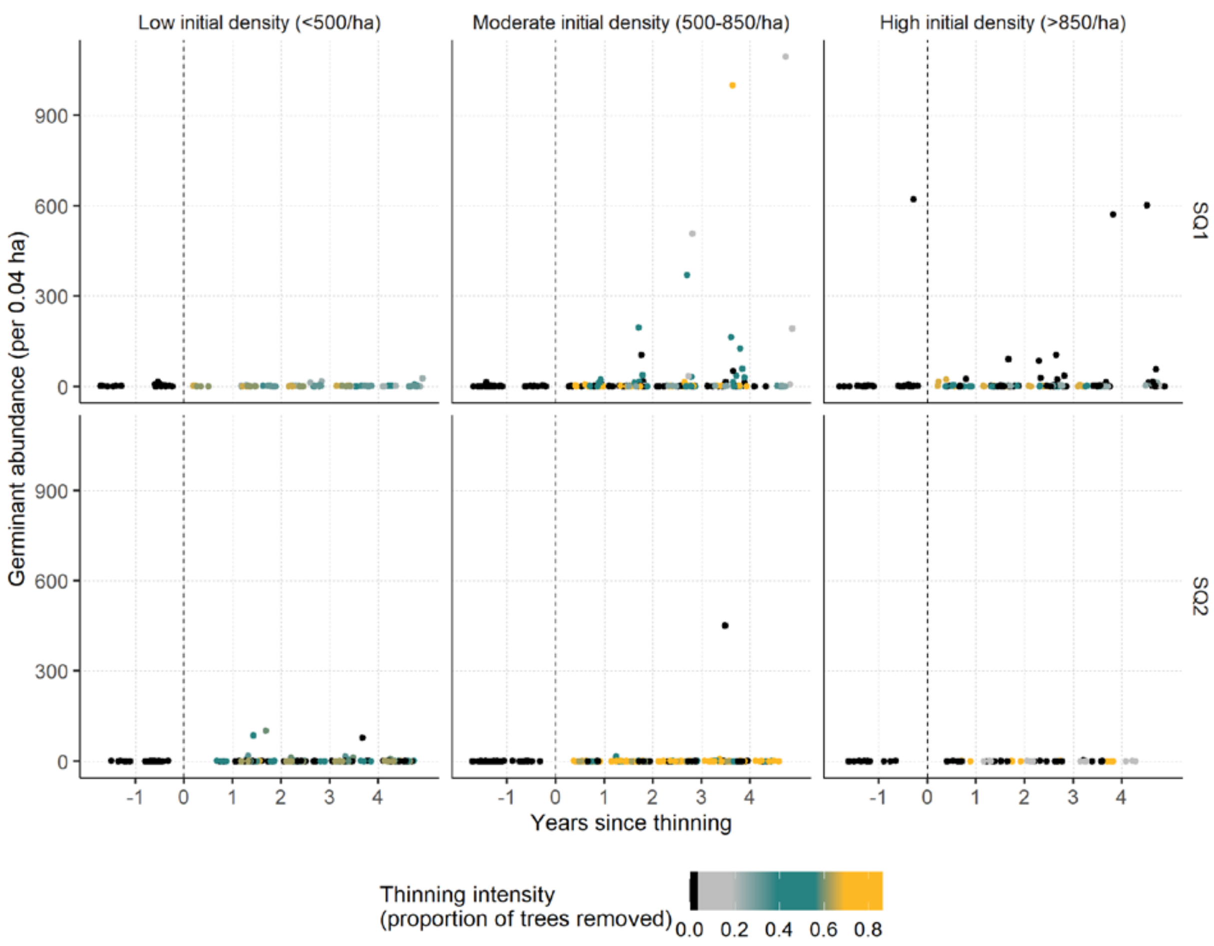

Figure 22 Data for abundance of germinants per 0.04 hectare subplot

Model results

Presence of germinants was modelled as a binary variable (absent or present), using a binomial distribution that generates a model of the probability of germinant occurrence (see Appendix). Due to the large proportion of absences in the data, it was difficult to fit a model that characterised the data well. Explanatory variables were simplified in this model, with a three-way interaction between site quality, time since thinning and thinning intensity (with no polynomial terms to account for potential non-constant relationships), and an additive term for initial stem density. This model assumes that the way initial stem density may modify the effect of thinning was of the same nature among site qualities. All four random effects were present in the model: survey year, site, 9 hectare plot and 0.04 hectare subplot. Confidence in this model was low to moderate, due to the difficulty of fitting a model to data with 88% absences.

On control plots, probability of germinant occurrence was higher in Site Quality 1 than Site Quality 2 and changed over time, with a peak in the most recent survey year (Figure 23). These differences were statistically significant (Table 14). Initial stem density did not affect germinant occurrence, although note that it was modelled differently for germinants than for other response variables.

Thinning affected the probability of germinants occurring, but the nature of the effect changed over time (Table 14). Thinning promoted the presence of germinants one year post-thinning (Figure 23) but the magnitude of the increase was very small (<5%). In other post-thinning years, the probability of germinants occurring was lower on thinned plots than control plots, with the greatest decrease on heavily thinned plots. Four years post-thinning, the most likely magnitude of change was an 18–41% reduction in probability of occurring on moderately and heavily thinned Site Quality 1 plots relative to control plots (Table 15).

The effect of thinning was much more substantial in Site Quality 1 plots than Site Quality 2 plots (Figure 23). However, differences in the effect of thinning among site qualities was not statistically significant (Table 14).

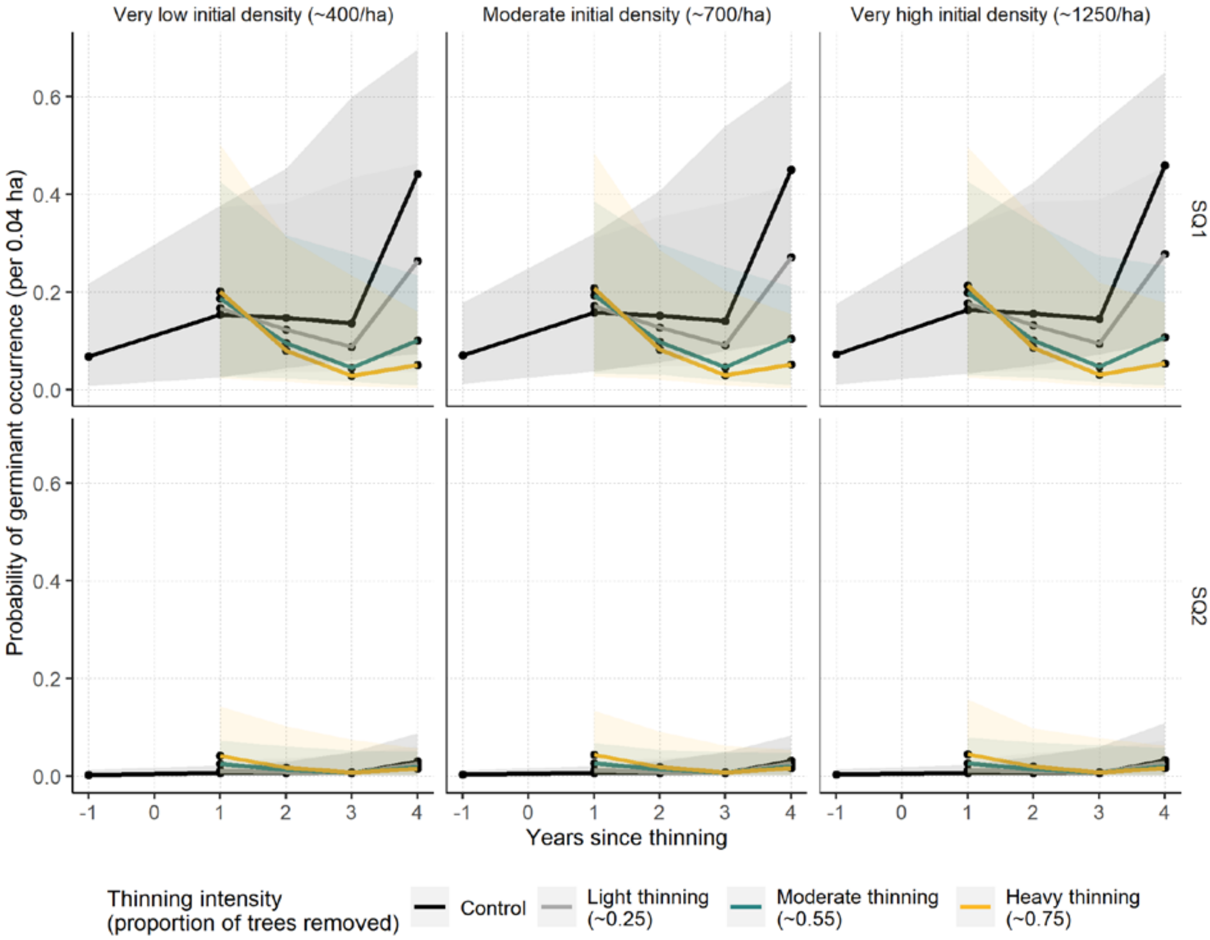

Figure 23 Modelled values and prediction intervals for likelihood of occurrence of germinants in each 0.04 hectare subplot

Table 14 Statistical significance of explanatory variables on the occurrence of germinants

	Bootstrapped likelihood ratio test significance	Description
Site quality	0.010	The likelihood of germinants occurring depended on site quality
Initial stem density	0.891	The likelihood of germinants occurring did not vary with stem density
Time since thinning	0.030	The likelihood of germinants occurring changed over time
Thinning intensity	0.010	The likelihood of germinants occurring was affected by thinning

	Bootstrapped likelihood ratio test significance	Description
Does the effect of thinning intensity vary depending on:		
• Site quality	0.356	The effect of thinning on the likelihood of germinants occurring did not vary between site qualities
• Initial stem density	NA	A model without this interaction term could not be fitted to the data. Therefore, the effect of thinning may vary by initial stem density
• Time since thinning	0.030	The effect of thinning on the likelihood of germinants occurring varied with time since thinning
• Site quality **and** initial stem density **and** initial tree diameter	Not modelled	This was not modelled

Table 15 Estimated effect sizes for likelihood of germinant occurrence four years post-thinning

Site quality		Site Quality 1			Site Quality 2		
Thinning intensity		Low intensity	Mod intensity	High intensity	Low intensity	Mod intensity	High intensity
Initial stem density	Very low (400/ha)	–0.18 –0.41 to +0.02	–0.34 –0.43 to –0.21	–0.39 –0.44 to –0.28	–0.01 –0.03 to +0.03	–0.01 –0.03 to +0.02	–0.02 –0.03 to +0.03
	Moderate (700/ha)	–0.18 –0.40 to –0.03	–0.35 –0.44 to –0.24	–0.40 –0.45 to –0.30	–0.01 –0.03 to +0.03	–0.01 –0.03 to +0.02	–0.02 –0.03 to +0.02
	Very high (1250/ha)	–0.18 –0.42 to 0.00	–0.35 –0.45 to –0.21	–0.41 –0.46 to –0.28	–0.01 –0.03 to +0.04	–0.01 –0.03 to +0.03	–0.02 –0.03 to +0.03

5.2 Seedling abundance

Key result	Thinning affected seedling abundance, but effects varied with initial stem density and time since thinning. Four years post-thinning the most likely magnitudes of change were: • a 1.5–4-fold increase on moderately thinned Site Quality 2 plots that had very low to moderate initial stem density (3–4 additional seedlings per 0.04 ha) • a 65% reduction on heavily thinned Site Quality 1 plots that had very high initial stem density (15 fewer seedlings per 0.04 ha).

Data collection

Seedlings are defined as *Eucalyptus camaldulensis* recruits that are less than 1.37 metres in height. Seedlings did not include coppiced stems that were seedling-sized but emerging from cut stumps or pushed over stems. Seedlings were counted in each of the three 0.04 hectare subplots in the 9 hectare treatment plots.

Data summary

Seedling counts were highly variable (Figure 24). Across all surveys, approximately 20% of records were zero counts. Average counts per year (across all thinning treatments and initial stem density) were between 13 and 28 per 0.04 hectare subplot. Occasionally between 200 and 1000 seedlings were recorded (maximum of three records in any particular survey year).

Site Quality 1 sites tended to have higher abundances of seedlings, and fewer zero counts, than Site Quality 2 sites (Figure 24).

The raw data suggests that ecological thinning may stimulate recruitment in some circumstances. Relatively high abundances of seedlings were apparent in low–moderate stem density plots in Site Quality 1; and in low stem density plots in Site Quality 2. However, high abundances were also apparent for some control plots, particularly where stem density was high in Site Quality 1.

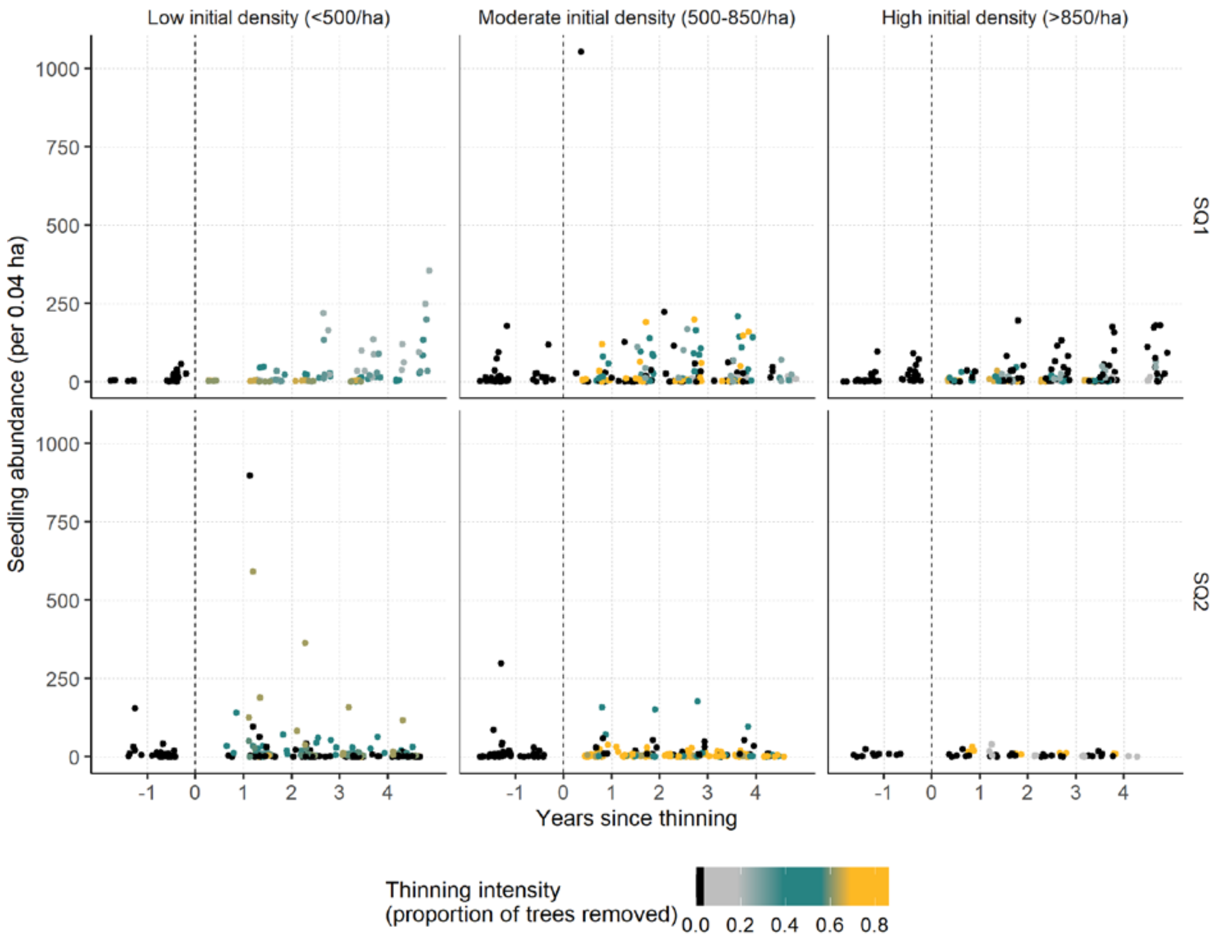

Figure 24 Data for abundance of seedlings in each 0.04 hectare subplot

Model results

The model for seedling abundance was difficult to fit because of the relatively high proportion of zeroes in the data (20%), as well as the presence of very high abundances (see Appendix). A negative binomial distribution was used to represent this count variable, and data greater than 250 seedlings per 0.04 hectare were excluded (six values). The combination of explanatory variables was altered by assuming the effect of initial stem density was consistent in both site qualities. This model was also simplified by removing the random effects of survey year; therefore not capturing year-to-year variation around general trends.

Seedling abundance was higher in Site Quality 1 plots than Site Quality 2 plots, and changed over time (Figure 25), and these differences were statistically significant (Table 16). Seedling abundance also varied with initial stem density (Figure 25), however, differences were not statistically significant (Table 16).

Thinning affected the abundance of seedlings, but the effect of thinning varied with initial stem density and changed over time (Figure 25, Table 16):

- Light and moderate thinning initially increased seedling abundance on plots that had very low initial stem density in both site qualities, with mixed trajectories over time (Figure 25).
- Heavy thinning reduced seedling abundance on plots that had moderate initial stem density in Site Quality 1, and the effect was sustained over time (Figure 25).
- Heavy thinning initially increased seedling abundance on plots that had very high initial stem density in both site qualities, but this effect declined over time (Figure 25).

Four years post-thinning, the most likely magnitudes of change in seedling abundance were (Table 17):

- 15 fewer seedlings per 0.04 hectares in moderately thinned Site Quality 1 plots that had very high initial density
- 3–4 additional seedlings per 0.04 hectares in moderately thinned Site Quality 2 plots that had very low to moderate initial density.

The effect of thinning may also have differed among site qualities, as a model was not able to be fitted without an interaction between site quality and thinning (Table 16).

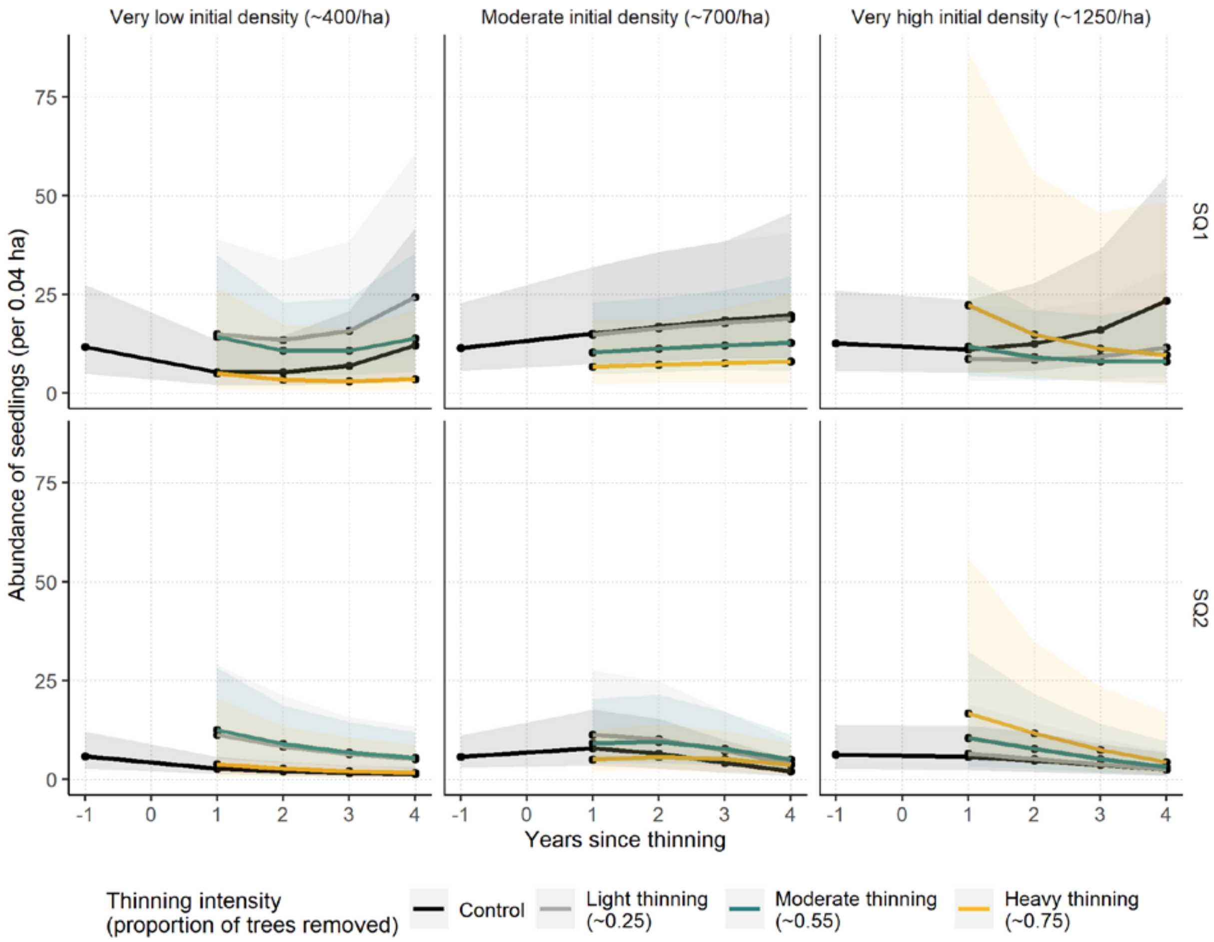

Figure 25 Modelled values and prediction intervals for abundance of seedlings per 0.04 hectare subplot

Table 16 Statistical significance of explanatory variables on seedling abundance

	Bootstrapped likelihood ratio test significance	Description
Site quality	0.010	Seedling abundance varied by site quality
Initial stem density	0.178	Seedling abundance did not vary by initial stem density
Time since thinning	0.010	Seedling abundance changed over time
Thinning intensity	0.010	Seedling abundance was affected by thinning intensity
Does the effect of thinning intensity vary depending on:		
• Site quality	NA	A model without site quality as an explanatory variable could not be fitted to the data. Therefore, the effect of thinning on seedling abundance may have differed among site qualities
• Initial stem density	0.106	The effect of thinning on seedling abundance did not depend on initial stem density
• Time since thinning	0.033	The effect of thinning on seedling abundance changed over time
• Site quality **and** initial stem density **and** time since thinning	Not modelled	

Table 17 Estimated effect sizes for seedling abundance on thinned plots relative to control plots, four years post-thinning

Site quality		Site Quality 1			Site Quality 2		
Thinning intensity		Low intensity	Mod intensity	High intensity	Low intensity	Mod intensity	High intensity
Initial stem density	Very low (400/ha)	+12.3 –2.2 to +48.5	+1.9 –6.6 to +23.4	–8.5 –11.5 to +9.0	+3.8 +0.7 to +12.0	+4.1 +1.2 to +10.7	+0.3 –1.0 to +7.4
	Moderate (700/ha)	–0.8 –11.2 to +20.8	–7.0 –14.1 to +9.8	–11.8 –17.3 to +5.6	+1.9 –0.4 to +7.5	+2.9 +0.1 to +9.2	+1.5 –0.8 to +7.0
	Very high (1250/ha)	–11.8 –19 to +7.9	–15.3 –20.7 to –1.1	–13.7 –21.3 to +25.1	0.0 –1.7 to +4.7	+0.7 –1.6 to +7.1	+1.9 –1.5 to +14.3

5.3 Sapling abundance

Key result	Moderate and heavy intensity thinning reduced the abundance of saplings, and this effect was sustained four years post-thinning. Sapling abundance was not modelled because saplings were included in both initial stem density counts and thinning intensity, and therefore response and explanatory variables were not independent.

Data collection

Saplings are defined as *Eucalyptus camaldulensis* individuals that have generated from seed (not coppice) and are greater than 1.37 metres in height with a diameter at breast height of less than 10 centimetres.

Some saplings were removed as part of the thinning operations.

Data summary

Saplings were included in total stem density counts. Data indicate that saplings were most abundant in plots with high initial stem density, in both site qualities (Figure 26).

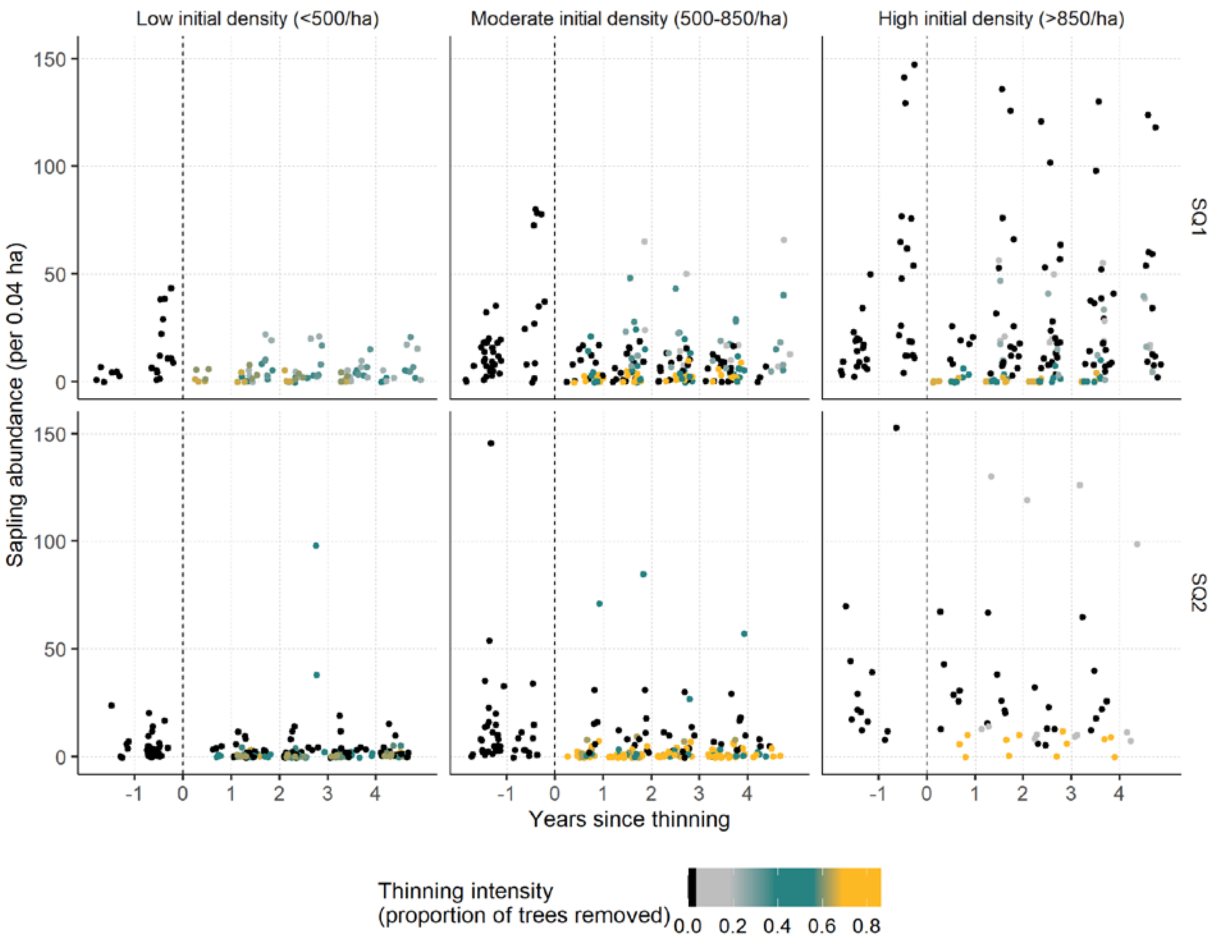

Figure 26 Data for sapling abundance in each 0.04 hectare subplot

Control plots tended to have up to 25 saplings per 0.04 hectare subplot, with a handful of plots having more than 50 (Figure 27).

On the one-third of plots that were subject to lightest intensity thinning, the number of saplings was similar to that of control plots, with few very high abundances (Figure 27).

The removal of saplings as part of the thinning operations resulted in a clear reduction in the abundance of saplings on moderate and heavily thinned plots (Figure 27). The effect has been sustained four years post-thinning.

Figure 27 Data for count of 0.04 hectare subplots with different amounts of saplings

Each bar represents a range of 5 saplings (e.g. the left-most bar in each panel represents the count of 0.04 hectare plots that had 0–5 saplings).

Model results

A model for sapling abundance was not run because saplings were included in both the initial stem density and thinning intensity data. Therefore, the response variable was not independent of the explanatory variables.

6. Results: Canopy condition

6.1 Individual tree crown extent

Key result	Thinning affected tree crown extent, but the effects varied with initial stem density, site quality and time. Most commonly, thinning increased tree crown extent and the most likely magnitude of increase four years post-thinning was 5–9% in: • moderately to heavily thinned Site Quality 1 plots that had very high initial stem density • moderately to heavily thinned Site Quality 2 plots that had very low to moderate initial stem density.

Data collection

Within each 9 hectare treatment plot, 30 trees with >10 centimetres dbh were randomly selected along a north–south transect in the centre of the plot. These 30 trees are permanently marked and are repeatedly measured for a range of parameters, including tree crown extent.

Crown extent is defined as the percentage of the potential crown that contains live foliage, including epicormic growth. The potential crown is estimated from the existing branching structure. Crown extent is sometimes referred to as 'crown vigour' in relevant literature. It was visually estimated to the nearest 5% for each of the 30 trees per plot and was analysed as a proportion.

Data summary

Prior to ecological thinning, individual tree crown extent was slightly lower and more variable on Site Quality 2 sites (an average of 74%) than Site Quality 1 sites (an average of 77%) (Figure 28).

Since thinning, tree crown extent has increased slightly, with an average tree crown extent in 2020 of 83% and 79% in Site Quality 1 and 2 plots respectively. Heavier thinning on average in Site Quality 2 also led to more variable tree crown extent (Figure 28).

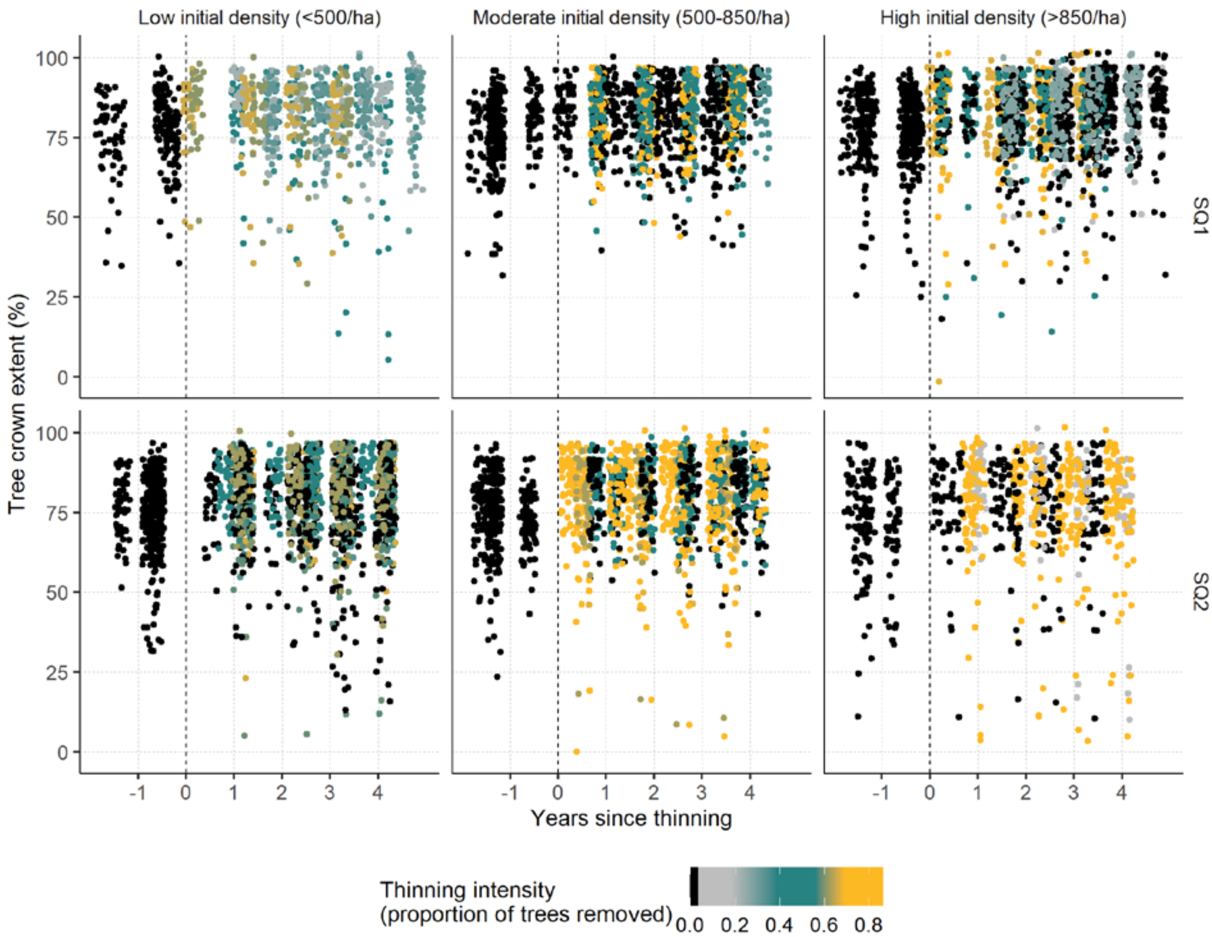

Figure 28 Data for proportion of tree crown extent for 30 trees in each 9 hectare plot

Model results

There was difficulty finding the most appropriate distribution to represent individual tree crown extent, with poor fit for binomial and Poisson distributions (see Appendix). Tree crown extent was modelled as a proportion (out of 1) using a Gaussian distribution. The model for tree crown extent included all terms listed in Table 5, except a random effect for subplot.

On control plots, individual tree crown extent was higher in Site Quality 1 than Site Quality 2 and changed over time, with a peak one year post-thinning (in 2017–18, which was also post-flood) (Figure 29). These differences were statistically significant (Table 18). Crown extent also varied with initial stem density on control plots (Table 18), with higher values on very low initial density plots in Site Quality 1 (Figure 29).

The effect of thinning on tree crown extent varied for all combinations of site quality, initial stem density and time (Figure 29) and these differences were statistically significant (Table 18).

For most combinations of site quality and initial stem density, thinning increased crown extent and the magnitude of increase continued to rise with time since thinning (Figure 29). On these plots, the increase was greatest for plots that were heavily thinned.

However, in Site Quality 1 plots with very low and moderate initial stem density, thinning initially caused an increase in tree crown extent but over time thinned plots either became indistinguishable from control plots (moderate initial density) or became substantially lower than control plots (very low initial density) (Figure 29).

Four years post-thinning, the most likely magnitude of changes in modelled individual tree crown extent was (Table 19):

- 6–9% increase for moderately to heavily thinned Site Quality 1 plots that had very high initial stem density
- 5% increase for moderate thinning in Site Quality 2 plots that had very low initial stem density
- 5–7% increase for heavily thinned Site Quality 2 plots that had very low or moderate initial stem density.

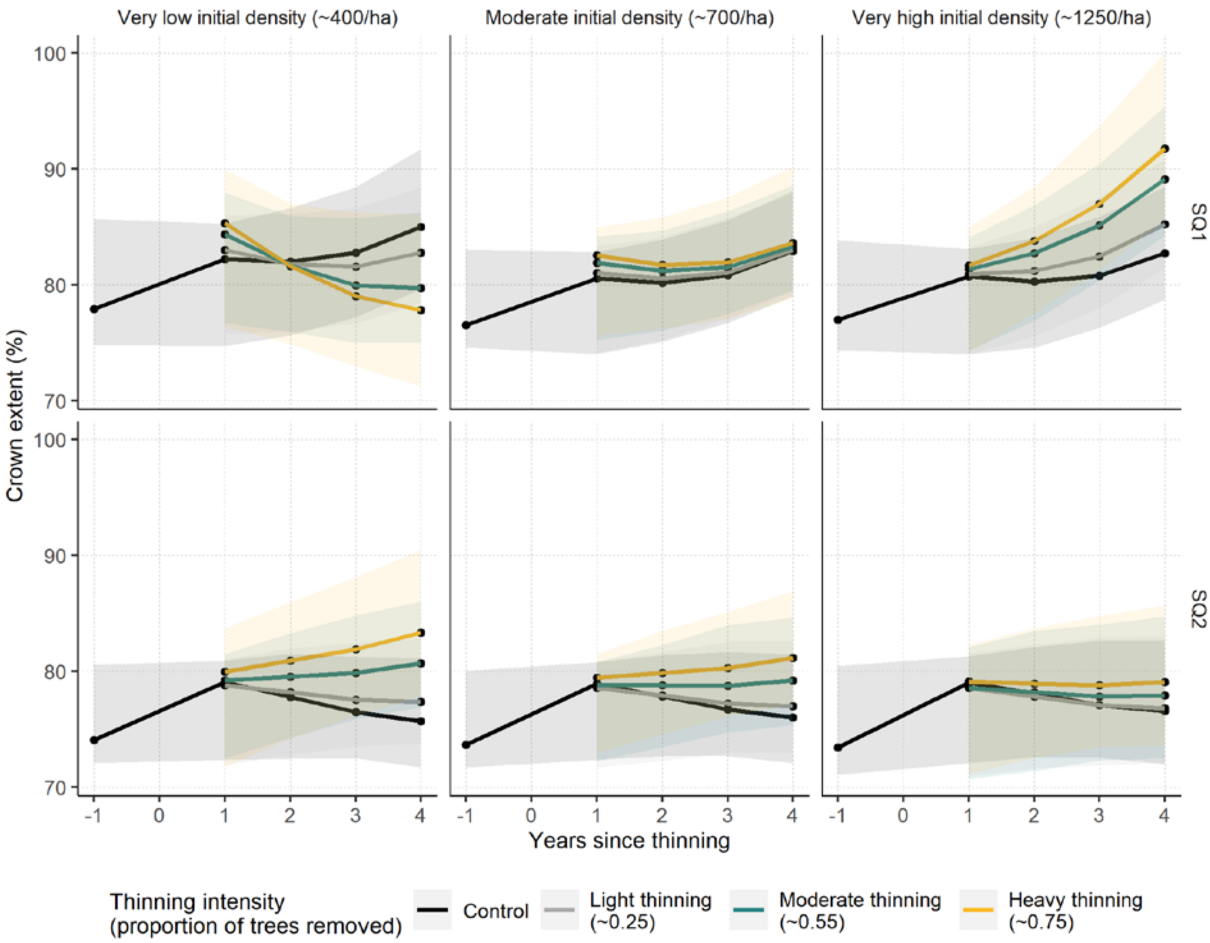

Figure 29 Modelled values and prediction intervals for proportion of tree crown extent (%)

Table 18 Statistical significance of explanatory variables on tree crown extent

	Bootstrapped likelihood ratio test significance	Description
Site quality	0.010	Tree crown extent differed by site quality
Initial stem density	0.020	Tree crown extent differed depending on initial stem density
Time since thinning	0.010	Tree crown extent changed with time since thinning
Thinning intensity	0.010	Tree crown extent was altered by thinning
Does the effect of thinning intensity vary depending on:		
• Site quality	0.020	The effect of thinning on crown extent depended on site quality
• Initial stem density	0.030	The effect of thinning on crown extent depended on initial stem density
• Time since thinning	0.010	The effect of thinning on crown extent changed over time
• Site quality **and** initial stem density **and** time since thinning	0.010	The effect of thinning on crown extent varied over all other parameters

Table 19 Estimated effect sizes for tree crown extent (per cent) four years post-thinning

<table>
<tr><th colspan="2">Site quality</th><th colspan="3">Site Quality 1</th><th colspan="3">Site Quality 2</th></tr>
<tr><th colspan="2">Thinning intensity</th><th>Low intensity</th><th>Mod intensity</th><th>High intensity</th><th>Low intensity</th><th>Mod intensity</th><th>High intensity</th></tr>
<tr><th rowspan="3">Initial stem density</th><th>Very low (400/ha)</th><td>–2.0
–6.6 to +3.4</td><td>–5.0
–10 to +1.3</td><td>–7.0
–13.7 to +1.1</td><td>+1.0
–2.2 to +6.8</td><td>+5.0
+0.9 to +10.0</td><td>+7.0
+1.9 to +14.5</td></tr>
<tr><th>Moderate (700/ha)</th><td>0.0
–3.6 to +4.8</td><td>0.0
–3.4 to +5.6</td><td>+1.0
–4.2 to +7.2</td><td>+1.0
–3.0 to +6.6</td><td>+3.0
–0.6 to +8.6</td><td>+5.0
+1.1 to +10.9</td></tr>
<tr><th>Very high (1250/ha)</th><td>+2.0
–1.5 to +7.8</td><td>+6.0
+1.3 to +12.4</td><td>+9.0
+2.7 to +17.1</td><td>0.0
–4.8 to +6.0</td><td>+1.0
–4.5 to +7.7</td><td>+2.0
–3.4 to +8.7</td></tr>
</table>

6.2 Visual estimates of live tree cover

Key result	No statistically significant effects of thinning on visually estimated live tree cover.

Data collection

Canopy cover was an on-ground estimate of the projective foliage cover of the trees covering a 0.04 hectare (20 metres x 20 metres) subplot. Canopy cover was visually estimated as a percentage by two observers independently, who then conferred to record one estimate.

Live canopy cover included the cover of all green and living projected foliage cover.

Data summary

Visual estimates of tree cover have generally declined and become less variable since monitoring began (Figure 30). The impacts of thinning have occurred against a backdrop of general decline and reduced variability on control plots that were not thinned. In 2020, average live canopy cover was slightly higher in Site Quality 1 than Site Quality 2 with average live cover of 6.9% and 5.2% respectively.

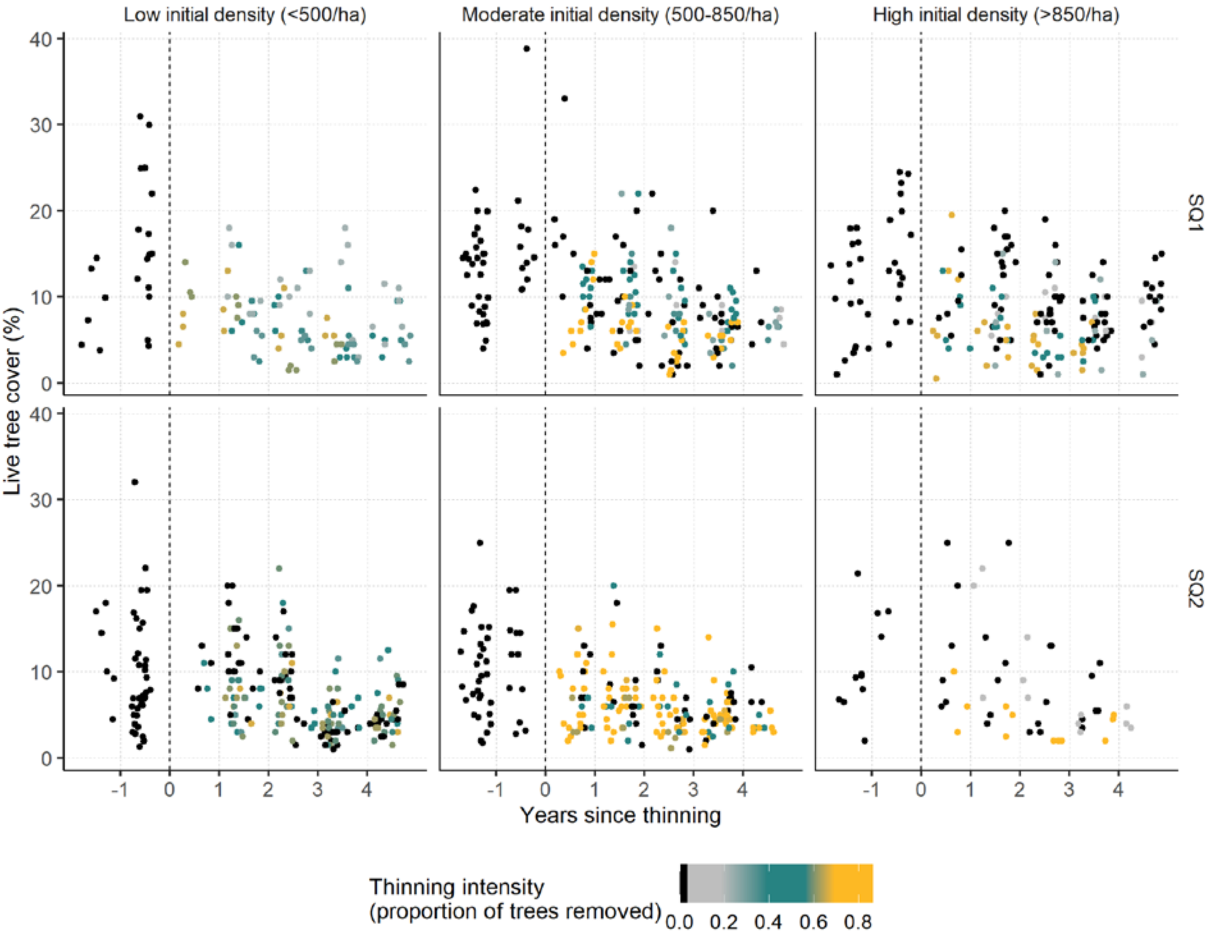

Figure 30 Data for proportion of live canopy cover in each 0.04 hectare plot

Model results

Visually estimated live canopy cover is a proportion (%), which was analysed as a log-transformed response variable with a Gaussian distribution (see Appendix). A four-way interaction between all explanatory variables was included in the model in addition to multiple two-way and three-way interactions. All random effects were also included in the model: survey year, site, 9 hectare plot and subplot. Due to high variance in the visual estimates of live canopy cover, predicted model outcomes also showed high variance.

Visual estimates of live tree cover declined between 2015 and 2019 on all plot types, but increased in the most recent survey, irrespective of thinning intensity (Figure 31). Live canopy cover was generally higher for Site Quality 1 than Site Quality 2 (Figure 31). Both site quality and change over time were statistically significant (Table 20).

Thinning reduced live canopy cover for at least the first year post-thinning (Figure 31). However, the effect was not statistically significant (Table 20).

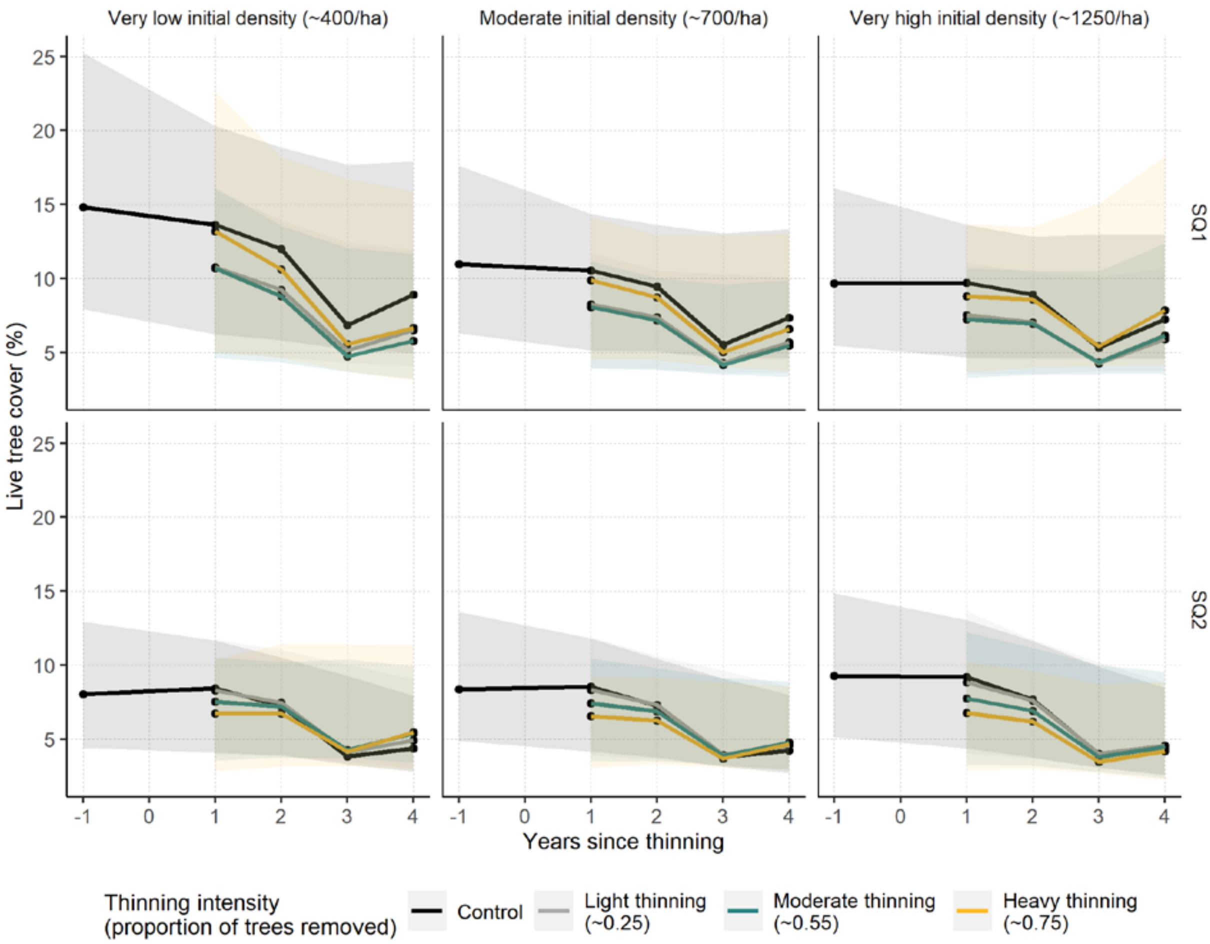

Figure 31 Modelled values and prediction intervals for proportion of visual estimates of live tree cover in each 20 metre x 20 metre plot

Table 20 Statistical significance of explanatory variables on visual estimates of live canopy cover

	Bootstrapped likelihood ratio test significance	Description
Site quality	0.010	Live canopy cover differed among site qualities
Initial stem density	0.495	Live canopy cover did not differ depending on initial stem density
Time since thinning	0.050	Live canopy cover did not change over time
Thinning intensity	0.079	Thinning did not affect live canopy cover
Does the effect of thinning intensity vary depending on:		
• Site quality	0.228	There were no significant effects of thinning
• Initial stem density	0.911	
• Time since thinning	0.119	
• Site quality **and** initial stem density **and** time since thinning	0.614	

Four years post-thinning, live canopy cover was not significantly different among thinned and non-thinned plots, but thinned plots in Site Quality 1 tended to have lower canopy cover than control plots; and thinned plots in Site Quality 2 tended to have very similar or slightly higher canopy cover than control plots (Table 21).

Table 21 Estimated effect sizes for visually estimated canopy cover (proportion) four years post-thinning

Site quality		Site Quality 1			Site Quality 2		
Thinning intensity		Low intensity	Mod intensity	High intensity	Low intensity	Mod intensity	High intensity
Initial stem density	Very low (400/ha)	–2.4 –4.8 to +3.0	–3.1 –5.7 to +2.8	–2.3 –5.8 to +7.0	+0.5 –1.3 to +4.7	+1.0 –0.9 to +5.5	+1.1 –1.4 to +7.0
	Moderate (700/ha)	–1.7 –3.7 to +2.8	–1.9 –4.0 to +2.5	–0.7 –3.6 to +5.7	+0.3 –1.4 to +4.3	+0.5 –1.3 to +4.6	+0.4 –1.3 to +4.3
	Very high (1250/ha)	–1.3 –3.5 to +3.5	–1.1 –3.7 to +5.1	+0.6 –3.1 to +11.0	+0.2 –1.8 to +4.5	+0.1 –2.0 to +5.2	–0.2 –2.1 to +4.5

6.3 Visual estimates of dead tree cover

Key result	The data suggested no effects of thinning on visually estimated dead tree cover. Statistical analyses were not conducted for this variable.

Data collection

Canopy cover is an on-ground estimate of the projective foliage cover of the trees in a stand. Canopy cover was visually estimated as a percentage in each of the three 0.04 hectare subplots on each 9 hectare plot.

Dead canopy cover is comprised of dead leaves attached to live trees. In 2015–16 observers provided precise estimates; in subsequent surveys observers' estimates of <1% were assigned a value of 0.5%.

Data summary

In all years and all thinning treatments, the most commonly recorded value of dead canopy cover was <1% (Figure 32). In 2020, only 5.5% of observations were recorded as a value other than 0.5%

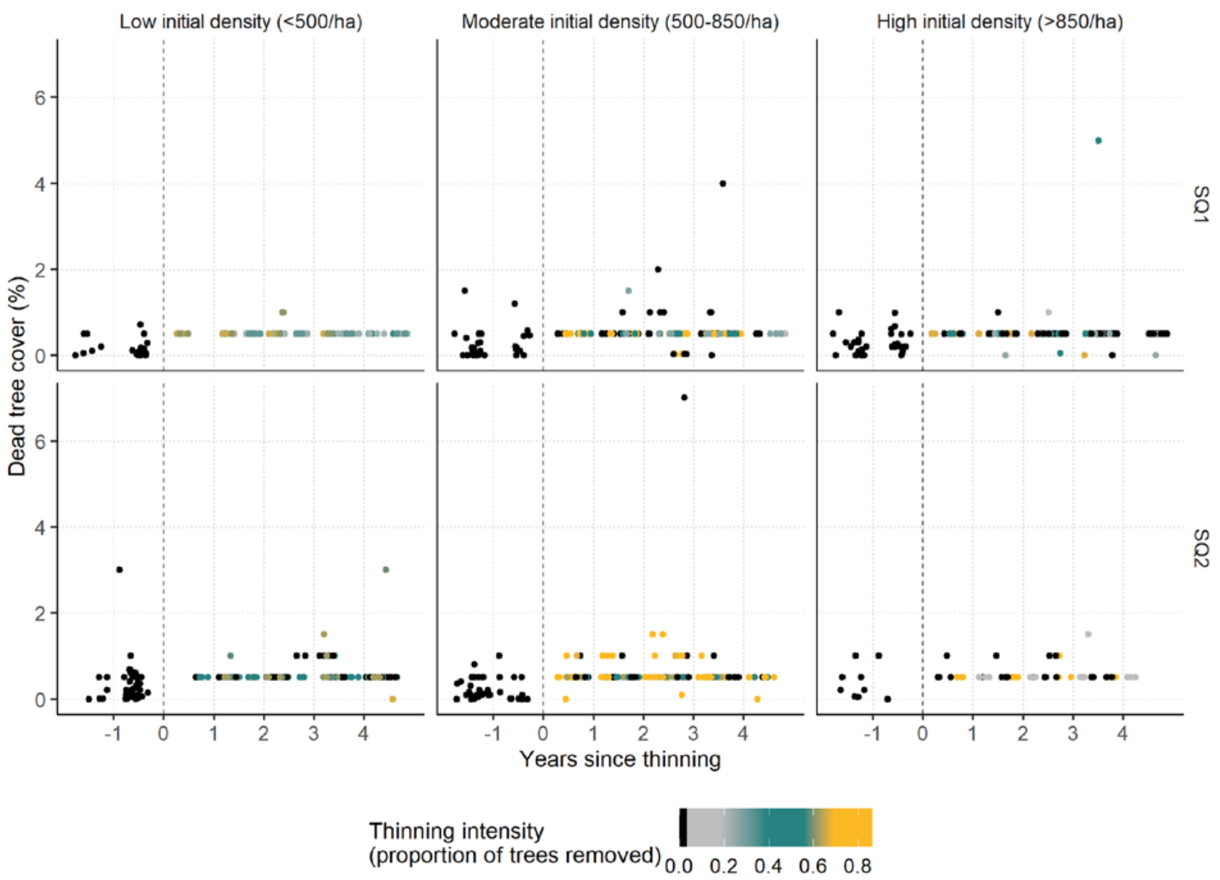

Figure 32 Data for proportion of dead canopy cover in each 0.04 hectare subplot

Model results

No model was run because there was no ecological difference among values recorded.

6.4 Remotely sensed canopy cover

Key result	Thinning reduced foliage projective cover. Over time, the magnitude of difference between thinned plots and control plots increased in Site Quality 1 but not Site Quality 2. Four years post-thinning, the most likely magnitude of reduction in foliage projective cover was: • 14–16% lower in moderately thinned Site Quality 1 plots that had moderate to very high initial stem density • 35% lower in heavily thinned Site Quality 1 plots.

Data collection

The Landsat satellite provides remotely sensed images at 30 metre resolution at 16-day intervals. Foliage projective cover (FPC) (Scarth et al. 2008) is derived from Landsat images, as a measure of canopy density that calculates the percentage of ground area covered by the vertical projection of green foliage of woody vegetation greater than 2 metres in height. FPC data were extracted from Landsat images on each cloud-free date between January 2014 and March 2021. Multiple pixels (30 metres x 30 metres) were available per 9 hectare plot for each date, from which the median FPC was calculated for each 9 hectare plot.

Data summary

Median FPC values were consistently higher on the control plots and declined with heavier thinning intensity (Figure 33). Across all site qualities and initial stem densities there was a decline in FPC with time since thinning across all thinning treatments (Figure 33), suggesting that additional environmental factors, such as hydro-climatic conditions may be driving this decline over the study period.

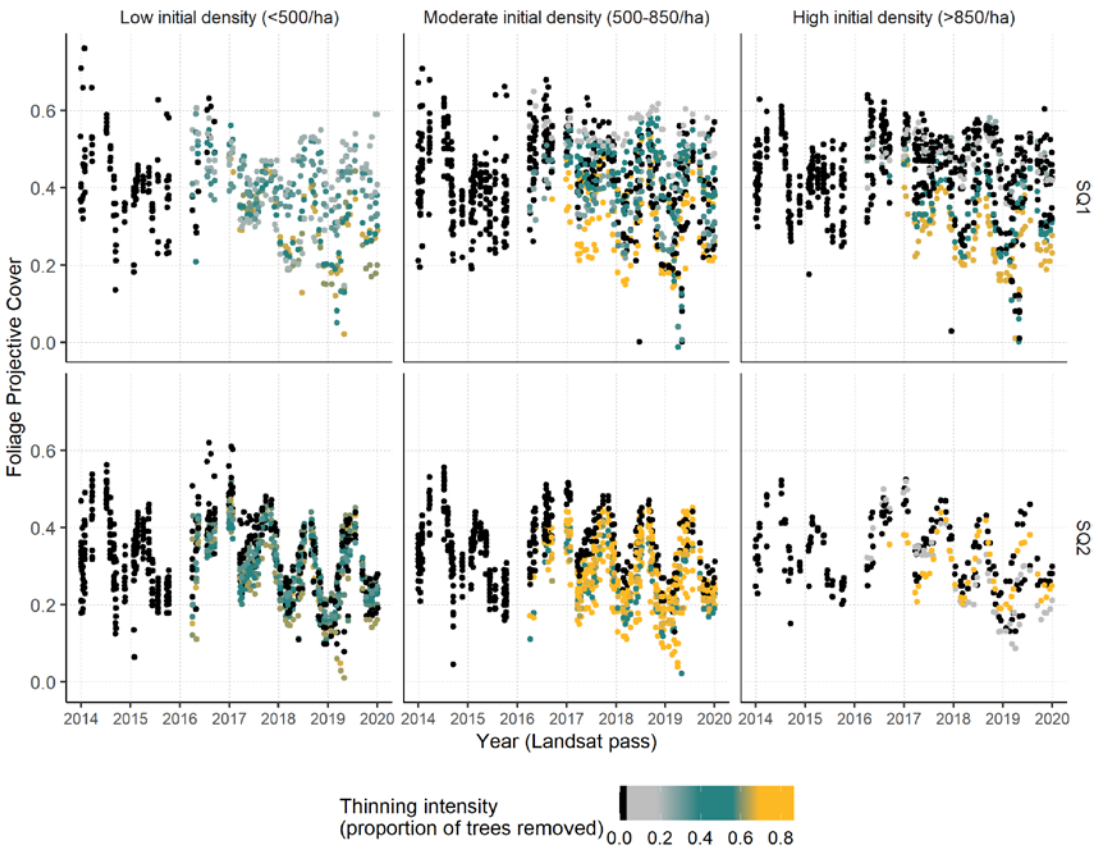

Figure 33 Data for averaged foliage projective cover in each 9 hectare plot

Model results

The model for FPC included Landsat pass instead of time since thinning, and therefore did not account for differences in thinning and survey dates among plots (see Appendix). The response variable was modelled using a Gaussian distribution. All model terms described in Table 5 were included, including a four-way interaction between the explanatory variables initial stem density, site quality, Landsat pass and thinning intensity. Random effects of site and siteplot accounted for temporal autocorrelation. Note that the modelled trends of FPC over time do not show fluctuations from year-to-year or seasonal fluctuations.

In the absence of ecological thinning, FPC was higher in Site Quality 1 than Site Quality 2 and increased with increasing initial stem density (Figure 34). FPC declined over time on all plot types. These differences in FPC among site qualities and initial stem densities, and changes over time, were all statistically significant (Table 22).

The effect of thinning on FPC was statistically significant but depended on thinning intensity, site quality and varied over time (Table 22):

- Light intensity thinning initially slightly increased FPC on both site qualities (Figure 34). On Site Quality 1 plots, the magnitude of difference declined over time. On Site Quality 2 plots, the magnitude of difference was consistent over time.
- Heavy thinning initially reduced FPC on both site qualities, with the effect much more pronounced in Site Quality 1 plots (Figure 34). Over time in Site Quality 1, the magnitude of difference between heavily thinned and control plots increased. Over time in Site Quality 2, the magnitude of difference between heavily thinned and control plots generally declined.

Four years post-thinning, the magnitude of change in FPC was most likely to be (Table 23):

- 0.05–0.07 lower in moderately thinned Site Quality 1 plots that had moderate to very high initial stem density (14–16% lower than control plots)
- 0.12–0.15 lower in heavily thinned Site Quality 1 plots (approximately 35% lower than control plots).

Table 22 Statistical significance of explanatory variables on remotely sensed foliage projective cover

	Bootstrapped likelihood ratio test significance	Description
Site quality	0.010	Foliage projective cover differed by site quality
Initial stem density	0.010	Foliage projective cover depended on initial stem density
Time	0.010	Foliage projective cover changed over time
Thinning intensity	0.010	Foliage projective cover was altered by thinning
Does the effect of thinning intensity vary depending on:		
• Site quality	0.010	The effect of thinning on foliage projective cover differed among site qualities
• Initial stem density	0.149	The effect of thinning on foliage projective cover did not differ depending on initial stem density
• Time	0.010	The effect of thinning on foliage projective cover changed over time
• Site quality **and** initial stem density **and** time	0.100	The effect of thinning on foliage projective cover did not vary for all combinations of site quality, initial stem density and time

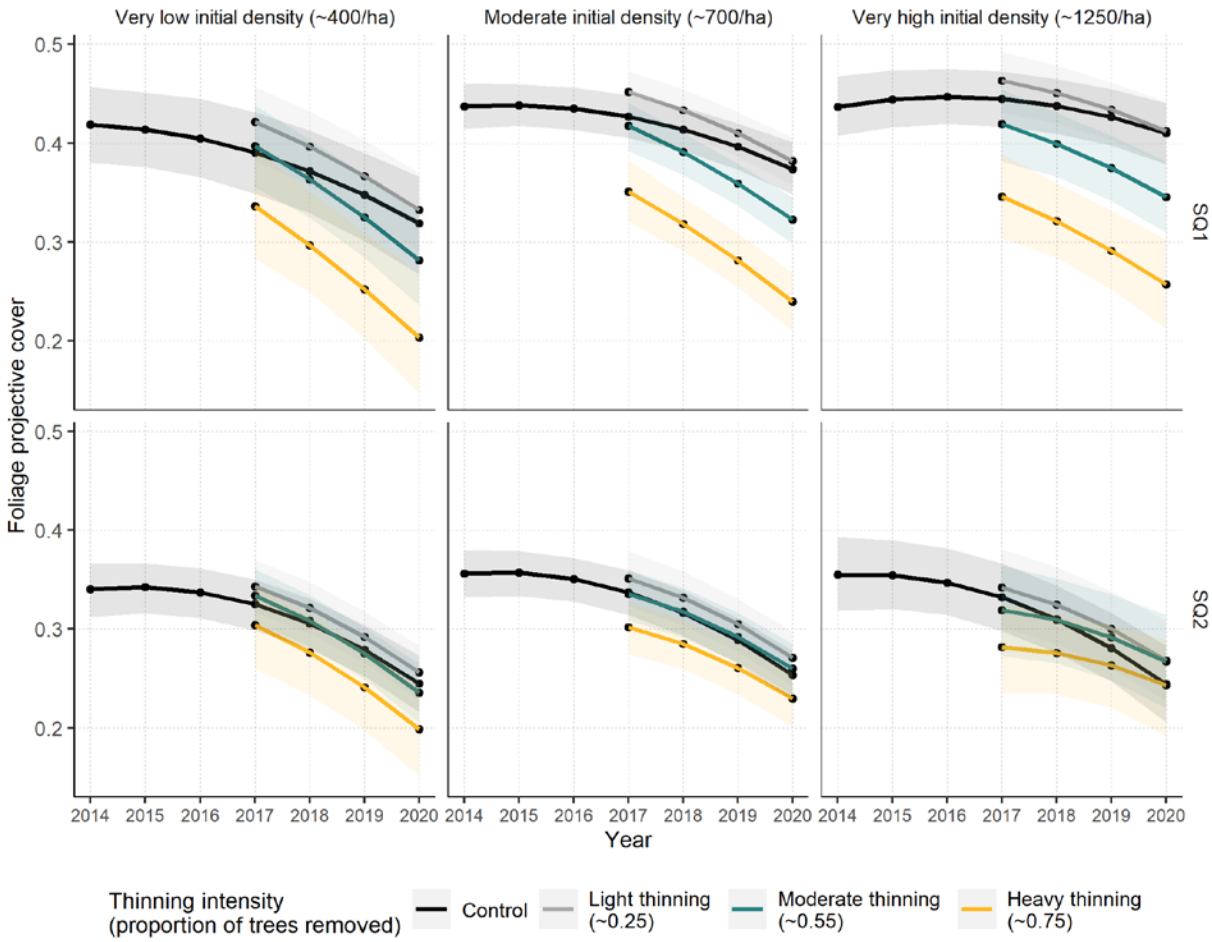

Figure 34 Modelled values and prediction intervals for remotely sensed foliage projective cover in each 9 hectare plot

Table 23 Estimated effect sizes for foliage projective cover four years post-thinning

Site quality		Site Quality 1			Site Quality 2		
Thinning intensity		Low intensity	Mod intensity	High intensity	Low intensity	Mod intensity	High intensity
Initial stem density	Very low (400/ha)	+0.01 –0.03 to +0.05	–0.04 –0.08 to +0.01	–0.12 –0.17 to –0.05	+0.01 –0.02 to +0.04	–0.01 –0.04 to +0.02	–0.05 –0.09 to 0.00
	Moderate (700/ha)	+0.01 –0.02 to +0.03	–0.05 –0.08 to –0.03	–0.13 –0.16 to –0.11	+0.02 –0.01 to +0.04	+0.01 –0.02 to +0.03	–0.02 –0.05 to 0.00
	Very high (1250/ha)	0.00 –0.03 to +0.03	–0.07 –0.10 to –0.03	–0.15 –0.20 to –0.11	+0.02 –0.02 to +0.06	+0.02 –0.02 to +0.07	0.00 –0.05 to +0.05

7. Results: Fuel hazard

Fuel hazard was assessed using the method of Hines et al. (2010). In this method, overall fuel hazard is determined from the assessment of four fuel hazard assessment components that are associated with vegetation strata from the forest floor to the canopy (Figure 35).

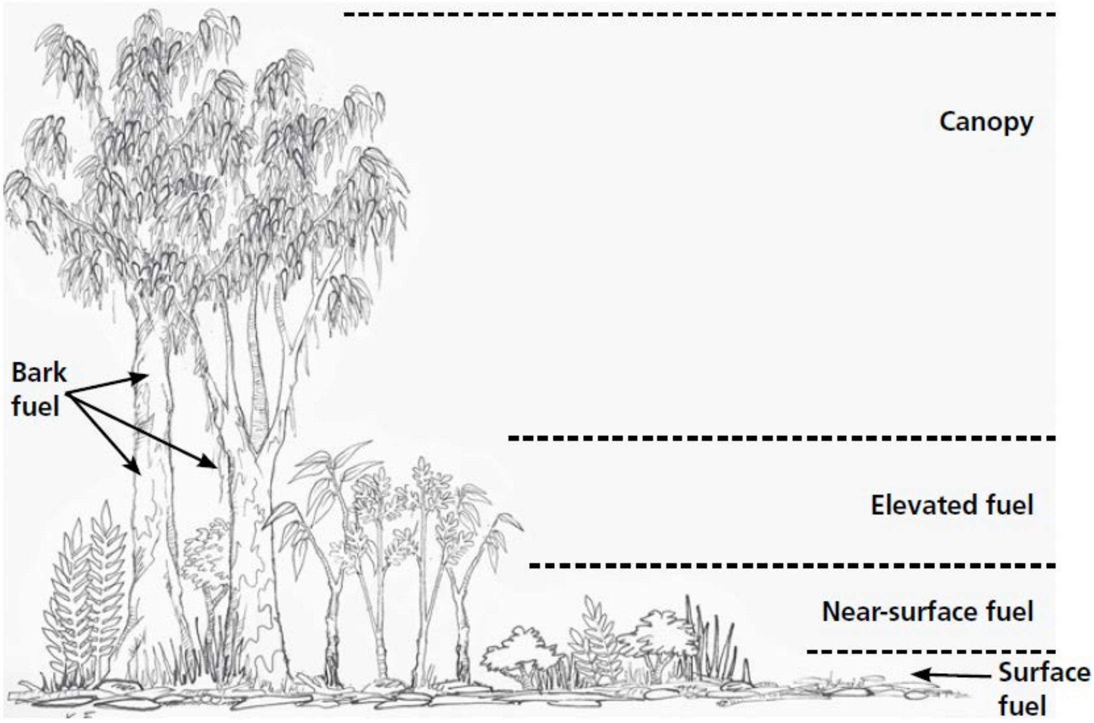

Figure 35 Fuel hazard assessment components
Source: Hines et al. 2010.

The first component is **surface fuel hazard**, which is determined using estimates of litter cover and litter depth.

The second component is **near surface fuel hazard**, which is determined using estimates of live and dead ground vegetation cover.

These two components are combined into an overall surface fuel hazard category.

The third component is **elevated fuel hazard**, which is determined using estimates of live and dead elevated vegetation cover.

The fourth component is **bark fuel hazard** (all plots were in the low to moderate category).

All four components are combined into an **overall fuel hazard category**.

Results for overall fuel hazard are presented first, and then the other four components are presented in order below. The underpinning data (litter, vegetation cover, etc.) is reported prior to the hazard assessment for each component.

The Hines et al. (2010) method specifies subjective evaluation of categories for some aspects of fuel hazard assessment; for example, distinguishing between ‘Soil surface occasionally visible through litter bed’ or ‘Litter well connected. Little bare soil’. Where possible, these subjective assessments have been replaced with objective quantitative categories, detailed below.

7.1 Overall fuel hazard

Key result	No statistically significant effects of thinning on overall fuel hazard.

Data collection

Data was collected from three 0.04 hectare subplots per 9 hectare treatment plot for all components of fuel hazard assessment in accordance with Hines et al. (2010).

Overall fuel hazard is determined from the hazard assessments of four components of fuel hazard: combined surface and near surface hazard category; the elevated fuel hazard category; and bark hazard (Table 24). Bark hazard was in the same category (low to moderate) on all plots. The analyses and results for all other components are described in following sections, below.

Overall fuel hazard is scored on a scale with five categories, from low to extreme (Table 24). For example, if the elevated fuel hazard on a plot was Medium and the combined surface and near surface fuel hazard on a plot was High, then the overall fuel hazard category was Medium.

Table 24 Overall fuel hazard assessment categories (from Hines et al. 2010)

L = Low, M = Moderate, H = High, VH = Very High, E = Extreme

1	2	3 Combined surface and near surface fuel hazard				
Bark hazard	**Elevated fuel hazard**	**L**	**M**	**H**	**VH**	**E**
Low and moderate	L	L	M	M	H	H
	M	L	M	M	H	H
	H	L	M	H	VH	VH
	VH	VH	VH	VH	VH	VH
	E	E	E	E	E	E

Data summary

The proportion of 9 hectare plots in each of the overall fuel hazard categories is shown in the bottom row of each site quality panel in Figure 36 and Figure 37.

In both site qualities all treatment types generally had very similar proportions of plots in the high and moderate categories, with slight increases in the proportion of plots in the high category over time. There were few records of low or very high fuel risk.

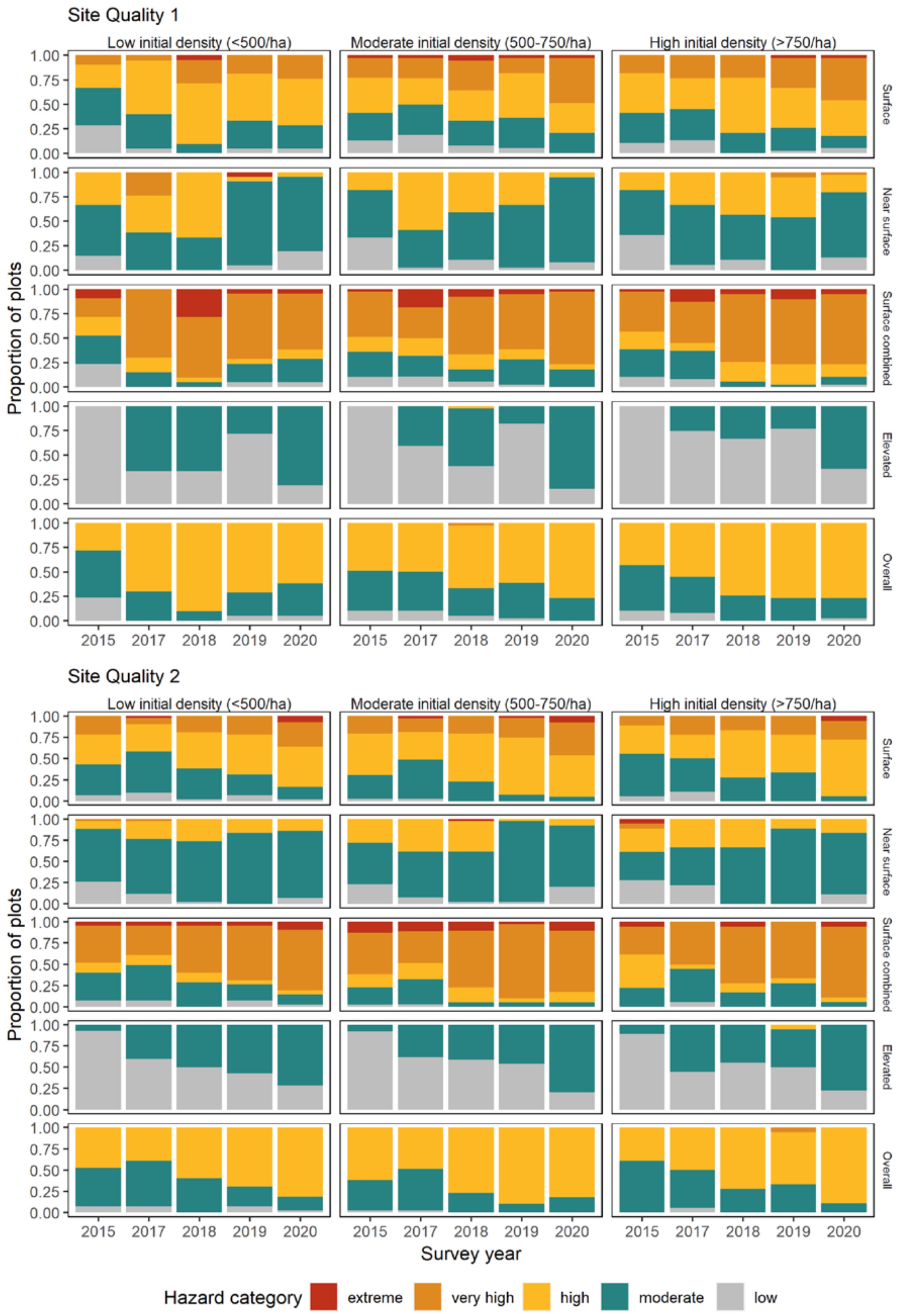

Figure 36 Proportion of 9 hectare treatment plots in each fuel hazard assessment category, by initial stem density, survey year and site quality

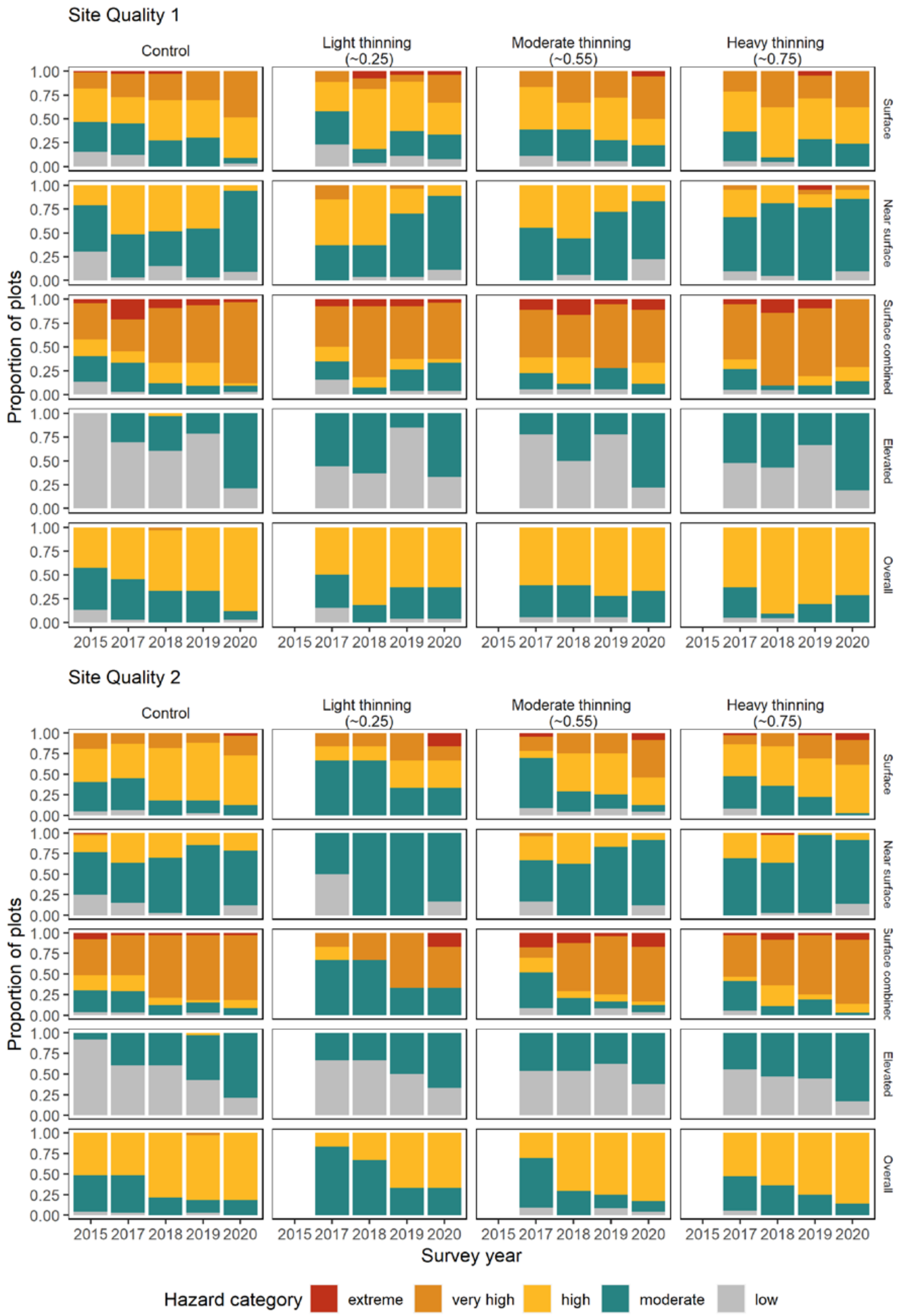

Figure 37 Proportion of 9 hectare treatment plots in each fuel hazard assessment category, by thinning intensity, survey year and site quality

Model results

A Bayesian cumulative ordinal model was run to determine whether thinning treatments affected the probability of being in any overall fuel hazard categories taking into account changes over time, initial stem density and whether any differences depended on site quality (see Appendix).

In both site qualities, the probability of being in the high hazard category increased between one and two years post-thinning (between 2017–18 and 2018–19 survey years) for all plot types (Figure 38). The proportions of plots in different categories have remained relatively stable since that time. Change over time was statistically significant (Table 25).

The effect of thinning on overall fuel hazard rating in Site Quality 1 was to slightly reduce the probability of plots in the high category (and increase the probability of being in the moderate category) (Figure 38), but this effect was not statistically significant.

The effect of light and moderate thinning on overall fuel hazard rating in Site Quality 2 was to decrease overall fuel hazard rating (Figure 38). This effect was not statistically significant (Table 25).

Table 25 Statistical significance of explanatory variables on overall fuel hazard ratings

Model term	ELPD ratio	Comment
Site quality	2.28	Overall fuel hazard rating did not differ among site qualities
Initial stem density	1.02	Overall fuel hazard rating did not depend on initial stem density
Time since thinning	5.08	Overall fuel hazard rating changed over time
Thinning intensity	1.68	Overall fuel hazard rating did not vary with thinning intensity
Does the effect of thinning intensity vary depending on:		
• Site quality	1.19	The effect of thinning on the overall fuel hazard rating did not vary by site quality
• Initial stem density	1.19	The effect of thinning on the overall fuel hazard rating did not depend on initial stem density
• Time since thinning	1.08	The effect of thinning on the overall fuel hazard rating did not vary over time
• Site quality **and** initial stem density **and** initial tree diameter	1.36	The effect of thinning on the overall fuel hazard rating did not vary across all combinations of site quality, initial stem density and time

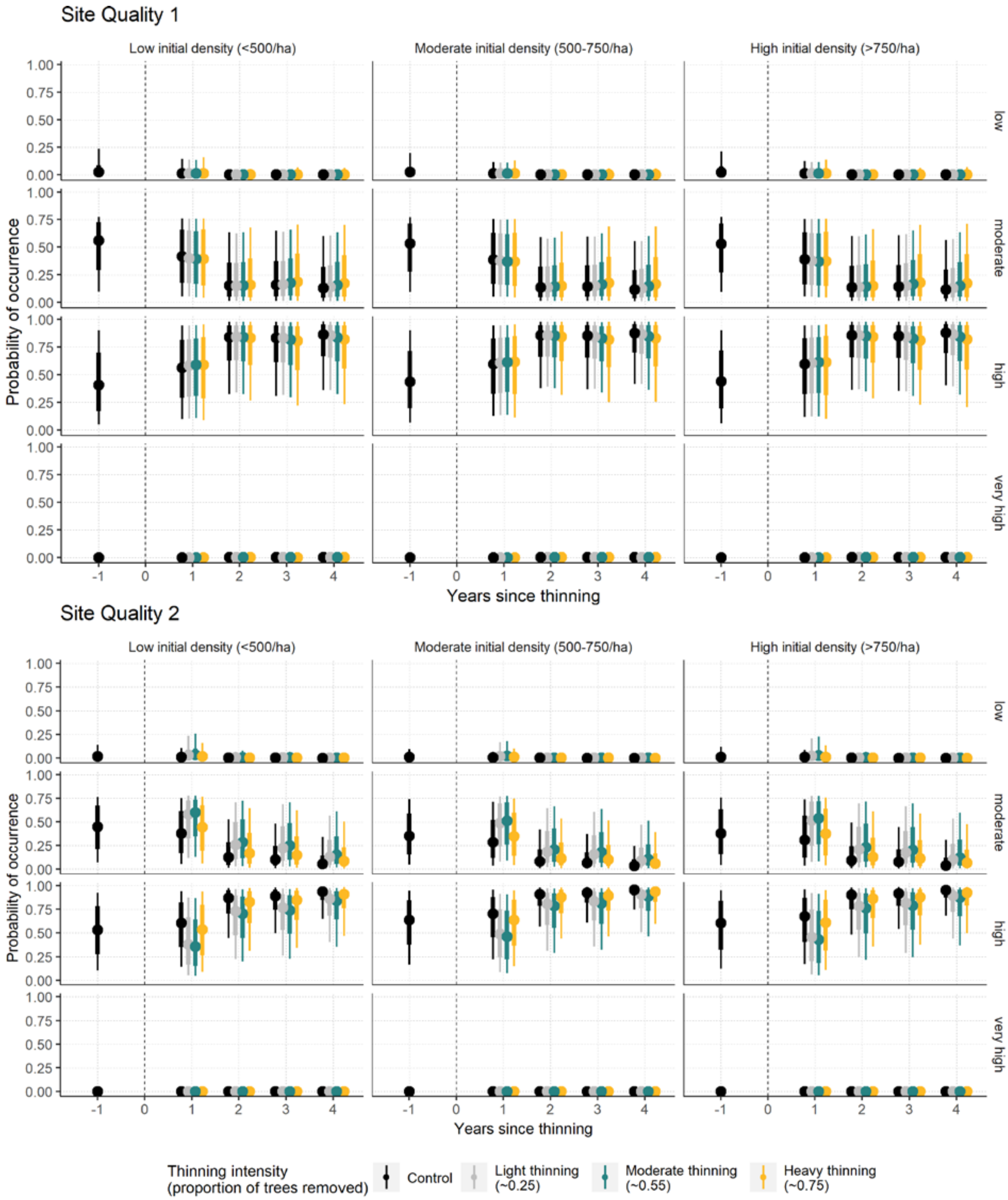

Figure 38 Modelled probability of being in each of the overall fuel hazard categories ±50% and 95% bootstrapped confidence intervals for ecological thinning treatment, survey year and site quality

7.2 Surface fuel hazard: litter depth

Key result	No statistically significant effects of thinning on litter depth.

Data collection

Litter was defined as any dead plant material that was separated from a live plant and included material <1 millimetre in diameter. Note that the definition of litter was refined between 2015 and 2018, which reduced uncertainty in observer estimates.

Litter depth was measured using the method of Hines et al. (2010). A metal ruler was inserted through the litter until it rested on the soil. A cardboard disc was held gently against the litter and used to mark the height of the litter on the ruler.

Litter depth was measured in 10 locations in each 0.04 hectare plot, giving 30 values per 9 hectare plot, which were averaged.

Data summary

Litter depth was most commonly between approximately 10 and 40 millimetres on all plot types over time (Figure 39). Occasionally, values were greater than 50 millimetres.

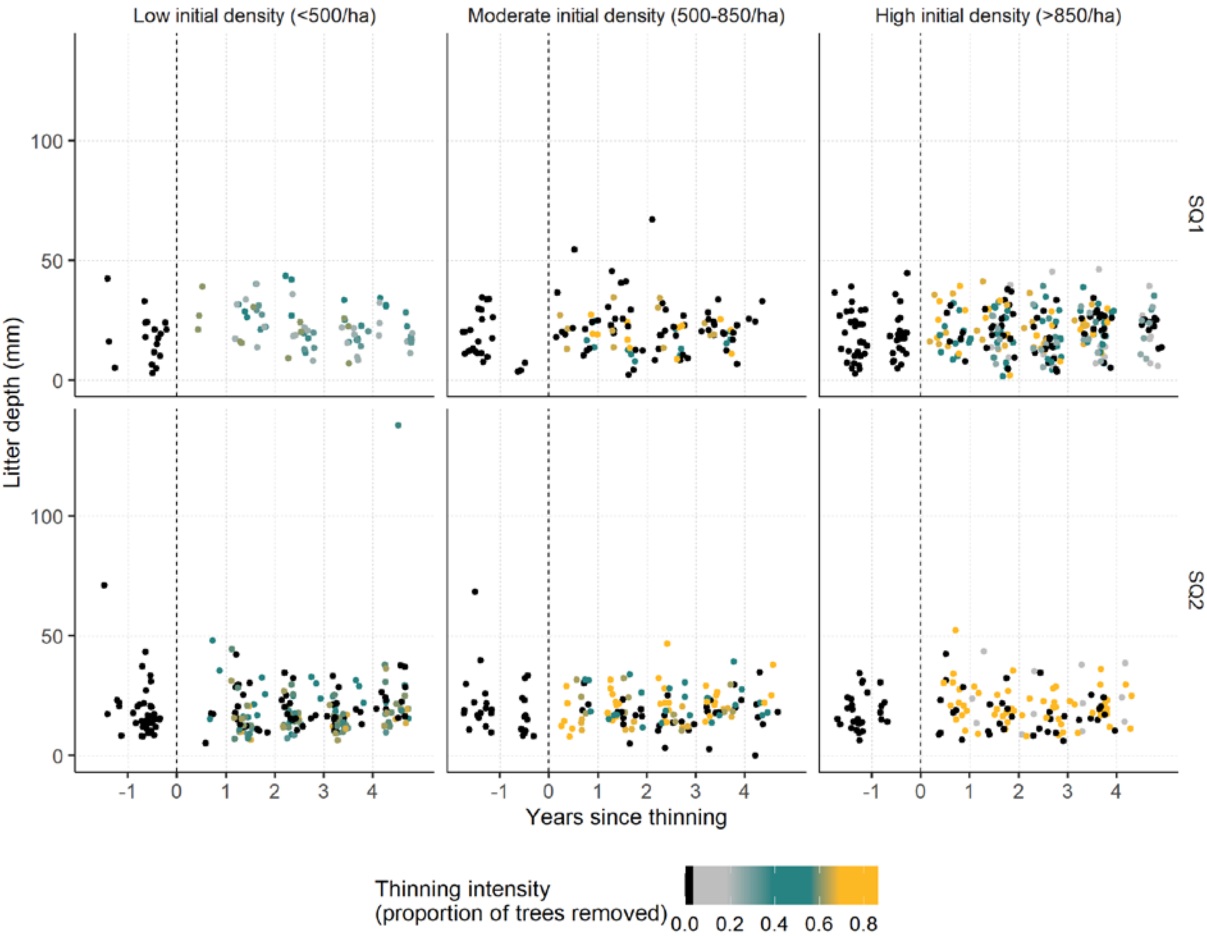

Figure 39 Data for average litter depth (millimetres) per 0.04 hectare subplot

Model results

Litter depth was modelled as a log-transformed continuous positive variable with a Gaussian distribution (see Appendix). All possible combinations of explanatory variables were included in the model, including a four-way interaction between site quality, initial stem density, time since thinning and thinning intensity.

Modelled litter depth was similar across site qualities and initial stem densities (Figure 40), and these effects were not statistically significant (Table 26). Litter depth changed slightly over time, with peaks generally occurring one and four years post-thinning (Figure 40), but these changes were not statistically significant (Table 26).

Heavy thinning temporarily increased litter depth in Site Quality 1 plots that had very low initial density and Site Quality 2 plots that had very high initial density (Figure 40). Litter depth increased on some heavily thinned plots four years post-thinning (Figure 40). However, there were no statistically significant effects of thinning on litter depth (Table 26).

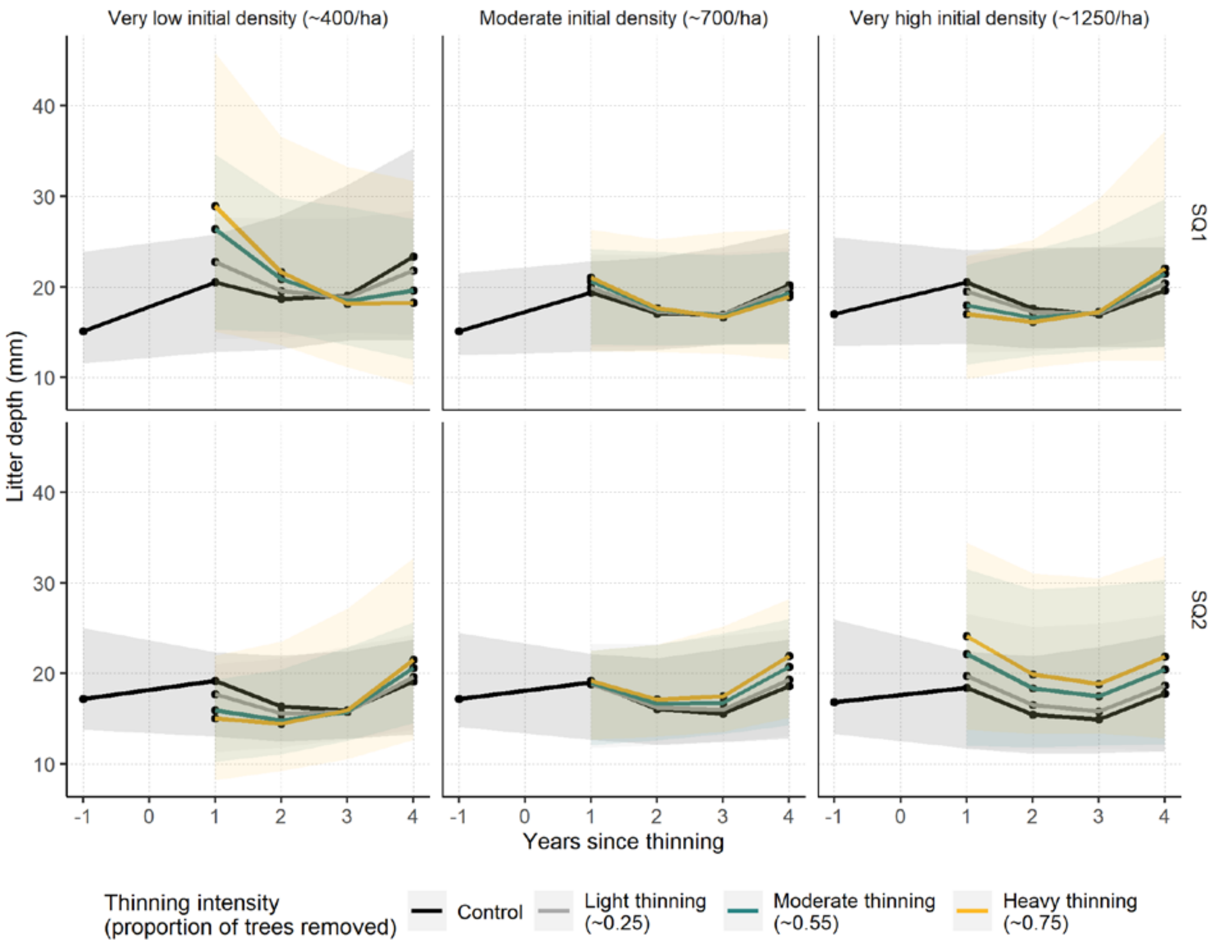

Figure 40 Modelled values and prediction intervals for average litter depth (millimetres) per 0.04 hectare subplot

Table 26 Statistical significance of explanatory variables on litter depth

	Bootstrapped likelihood ratio test significance	Description
Site quality	0.208	Litter depth was unlikely to vary by site quality
Initial stem density	0.663	Litter depth was unlikely to vary by initial stem density
Time since thinning	0.317	Litter depth was unlikely to change with time since thinning
Thinning intensity	0.584	Litter depth was unlikely to be affected by thinning intensity
Does the effect of thinning intensity vary depending on:		
• Site quality	0.267	The effect of thinning intensity on litter depth was unlikely to depend on any other predictors
• Initial stem density	0.248	
• Time since thinning	0.257	
• Site quality **and** initial stem density **and** time since thinning	0.198	

Fitted values for control plots were between 17 and 23 millimetres four years post-thinning. None of the prediction intervals for litter depth on thinned plots were outside the fitted value for control plots (Table 27).

Table 27 Estimated effect sizes for litter depth on thinned plots relative to control plots, four years post-thinning

Site quality		Site Quality 1			Site Quality 2		
Thinning intensity		Low intensity	Mod intensity	High intensity	Low intensity	Mod intensity	High intensity
Initial stem density	Very low (400/ha)	–1.5 –8.5 to +5.1	–3.7 –11.3 to +4.2	–5.1 –14.2 to +8.4	+0.5 –5.3 to +5.1	+1.5 –4.6 to +6.5	+2.4 –6.4 to +13.6
	Moderate (700/ha)	–0.3 –6.3 to +4.1	–0.9 –6.5 to +3.6	–1.3 –8.3 to +6.2	+0.7 –5.6 to +6.3	+2.1 –4.4 to +7.4	+3.3 –3.5 to +9.6
	Very high (1250/ha)	+0.8 –5.3 to +6.1	+1.8 –6.2 to +10.0	+2.5 –7.7 to +17.6	+0.9 –6.3 to +8.8	+2.7 –5.6 to +12.6	+4.1 –4.9 to +15.2

7.3 Surface fuel hazard: litter cover

Key result	No statistically significant effects of thinning on litter cover.

Data collection

Litter was defined as any dead plant material that was separated from a live plant and included material <1 millimetre in diameter. Note that the definition of litter was refined between 2015 and 2018, which reduced uncertainty in observer estimates.

Litter cover was visually estimated in three 0.04 hectare subplots in each 9 hectare treatment plot, and averaged.

Data summary

Litter cover values were most commonly between 80 and 99% on all plot types over time but values of 50% and below were also recorded (Figure 41). Mean litter cover estimates may have increased (and variability in estimates decreased) over time, particularly on moderate to very high density plots in Site Quality 2 (Figure 41, Figure 42).

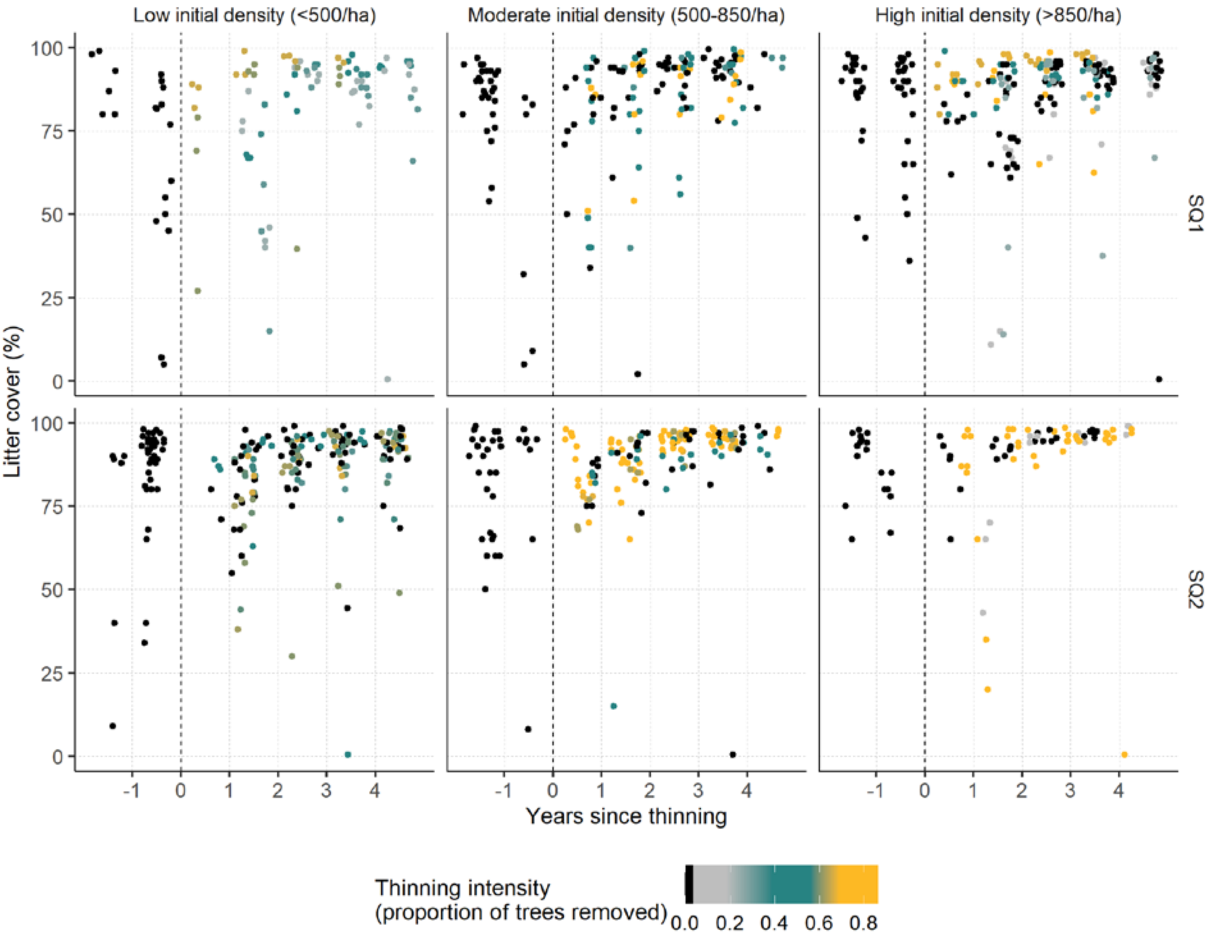

Figure 41 Data for litter cover (%) in each 0.04 hectare subplot

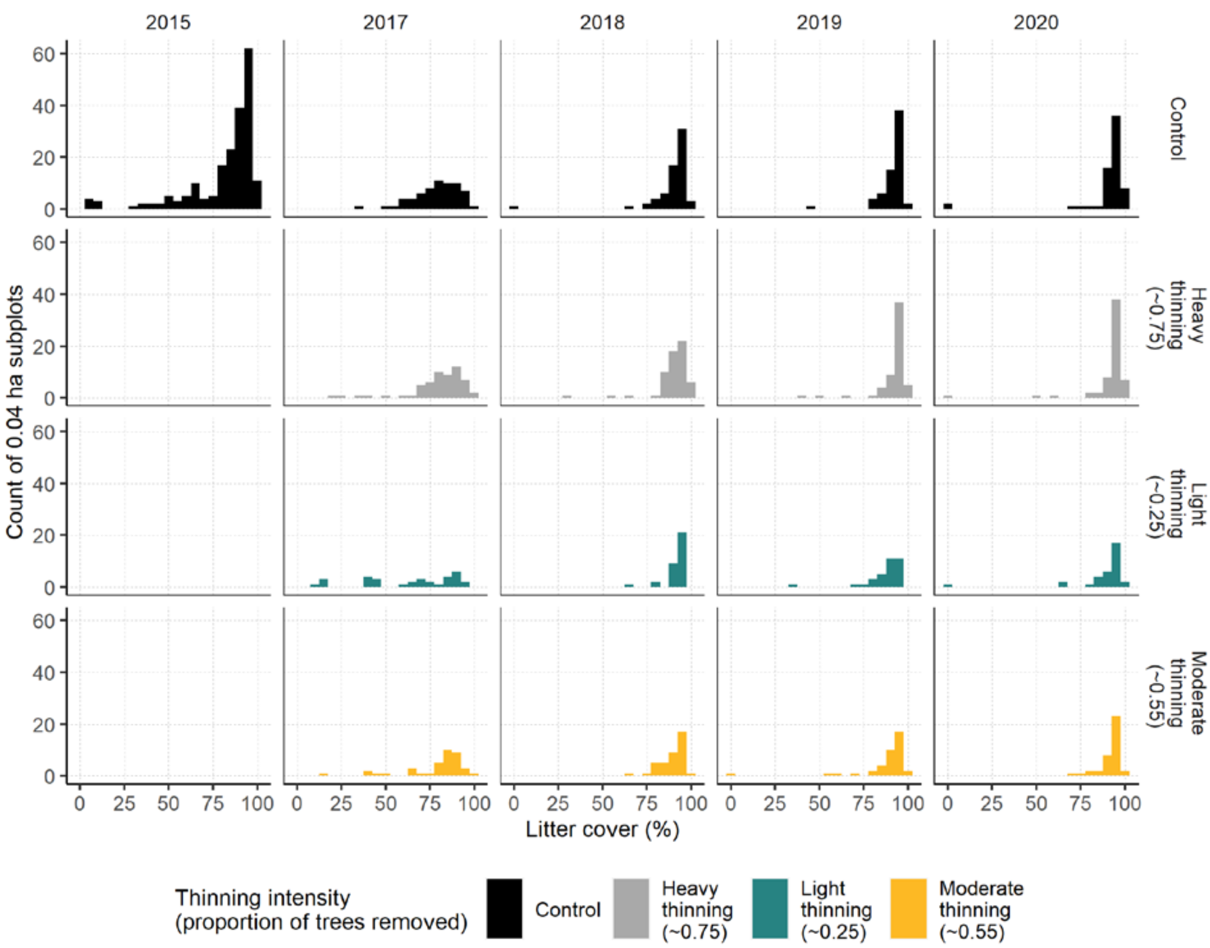

Figure 42 Data for number of 0.04 hectare subplots with different values of litter cover (%)

Model summary

Litter cover was modelled as a proportion using the beta distribution (see Appendix). The model included multiple two-way and three-way interactions between explanatory variables. Nineteen values (out of 990) that were below 25% were excluded to improve the model fit for low values. Three random effects were included: survey year, site and 9 hectare plot.

Litter cover increased over time (see comments above regarding refinement of the assessment method, which may have contributed to change over time) (Figure 43), and this change was statistically significant (Table 28). Litter cover varied by initial stem density in Site Quality 1, with the highest values modelled for very low initial density plots (Figure 43). The effect of initial stem density was statistically significant, but the effect of site quality was uncertain (Table 28).

Thinning caused a sustained decrease in litter cover on very low initial stem density plots in both site qualities; and a temporary increase on moderate and very high initial stem density plots in Site Quality 1 (Figure 43). However, none of the differences in litter cover due to thinning were statistically significant (Table 28).

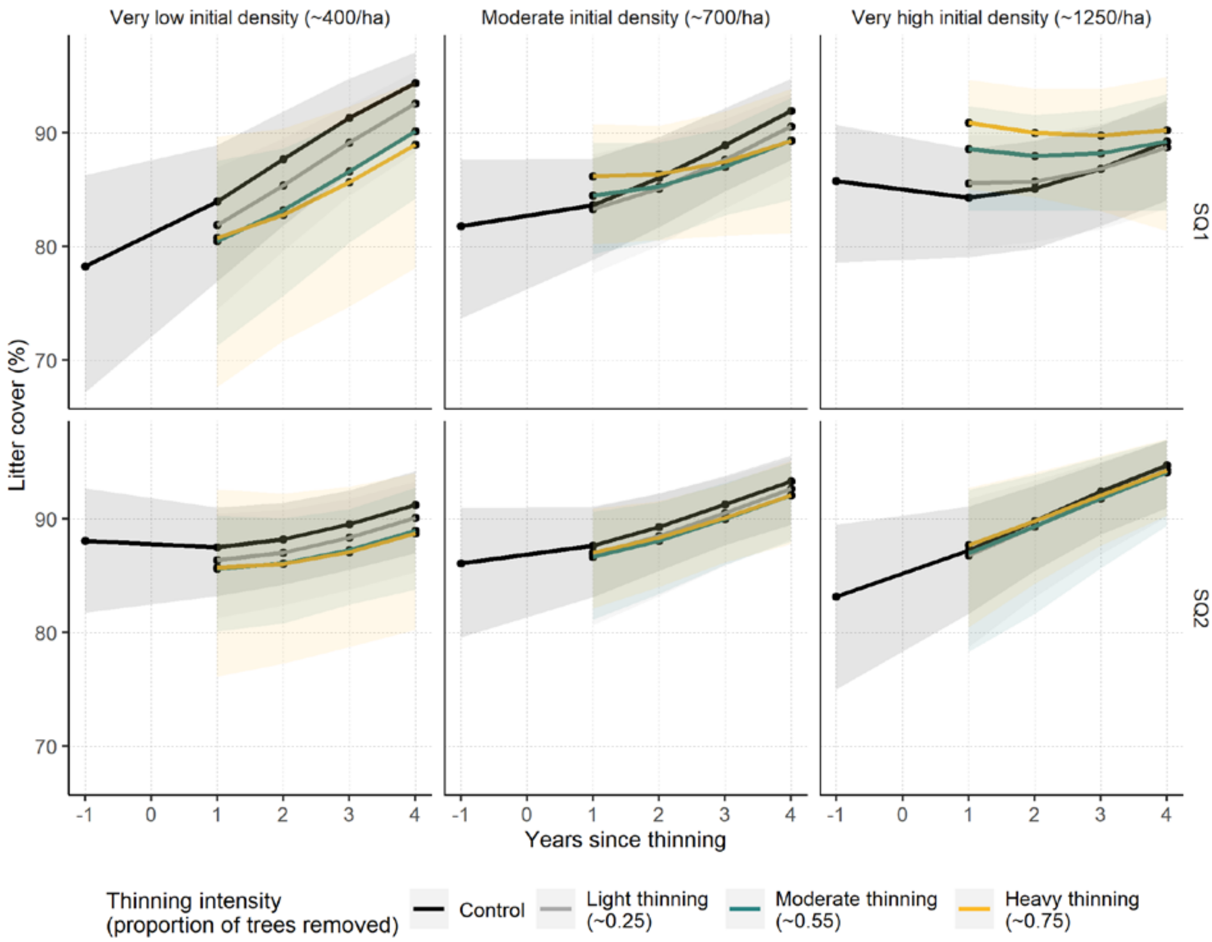

Figure 43 Modelled values and prediction intervals for litter cover (%) per 0.04 hectare subplot

Table 28 Statistical significance of explanatory variables on litter cover

	Bootstrapped likelihood ratio test significance	Description
Site quality	NA	A model without site quality as an explanatory variable could not be fitted to the data. Therefore, litter cover may differ by site quality
Initial stem density	0.011	Litter cover varied by initial stem density
Time since thinning	0.011	Litter cover changed over time
Thinning intensity	0.345	Thinning did not affect litter cover
Does the effect of thinning intensity vary depending on:		
• Site quality	0.653	Thinning did not affect litter cover
• Initial stem density	0.274	
• Time since thinning	0.128	
• Site quality **and** initial stem density **and** time since thinning	Not modelled	

Fitted values for litter cover on control plots were between 89 and 95% for all site qualities and initial stem densities four years post-thinning. Although there was no overall statistically significant effect of thinning on litter cover, moderately thinned plots with very low initial stem density in Site Quality 1 were likely to have approximately 4% lower cover four years post-thinning (Table 29).

Table 29 Estimated effect sizes for litter cover on thinned plots relative to control plots, four years post-thinning

Site quality		Site Quality 1			Site Quality 2		
Thinning intensity		Low intensity	Mod intensity	High intensity	Low intensity	Mod intensity	High intensity
Initial stem density	Very low (400/ha)	–1.8 –6.1 to +1.0	–4.2 –10.2 to –0.3	–5.4 –16.3 to +0.2	–1.1 –5.9 to +2.0	–2.2 –7.4 to +1.5	–2.5 –11.0 to +2.8
	Moderate (700/ha)	–1.4 –5.7 to +1.5	–2.6 –7.8 to +1.1	–2.6 –10.7 to +1.9	–0.7 –5.1 to +2.0	–1.2 –5.3 to +1.6	–1.2 –5.5 to +1.8
	Very high (1250/ha)	–0.5 –5.9 to +3.2	0.0 –6.1 to +4.2	+1.0 –7.9 to +5.7	–0.4 –4.5 to +2.2	–0.6 –5.3 to +2.2	–0.5 –4.4 to +2.3

7.4 Surface fuel hazard assessment

Key result	No statistically significant effects of thinning on surface fuel hazard.

Data collection

Surface fuel hazard category is determined based on litter depth and litter cover data.

Only some categories for assessing surface fuel hazard by combining litter depth and litter cover are defined by Hines et al. (2010) (grey cells in Table 30). For instance, Hines et al. (2010) define surface fuel hazard as low when litter depth is <10 millimetres and litter cover <60%; and moderate when litter depth is 10–20 millimetres and litter cover is 60–80%. However, many other categories are not defined, for example when litter depth is <10 millimetres but litter is cover >80%. Additional categories were therefore defined for all categories of litter depth and litter cover to enable objective classification of all data (white cells in Table 30).

Table 30 Surface fuel hazard assessment categories

Grey cells are defined by Hines et al. (2010), white cells are additionally defined to enable classification of all data.

Litter height (mm)	Litter cover (%)				
	<60	60–80	80–90	>90	>95
<10	L	L	M	M	M
10–20	L	M	M	H	H
20–25	M	M	H	H	VH
25–30	M	H	H	VH	VH
30–35	H	H	VH	VH	VH
35–45	H	VH	VH	VH	E
>45	VH	VH	E	E	E

Data summary

In the most recent survey year, there were fewer control plots among low and moderate categories and more among high and very high categories among both site qualities than the previous survey year (Figure 37).

For higher levels of thinning intensity and greater time since thinning, fewer plots had low and moderate surface fuel hazard ratings, and the proportion of plots with high and very high ratings increased. This trend was apparent in both site qualities and occurred irrespective of initial stem density.

Model results

A Bayesian cumulative ordinal model was run to determine whether thinning treatments affected the probability of being in any surface fuel hazard categories and accounting for changes over time, initial stem density and whether any differences depended on site quality (see Appendix).

The modelled probability of being in the high category for surface fuel hazard increased between one and two years post-thinning (that is, 2017–18 and 2018–19) (Figure 44). As noted above, this may have been partially due to refinement of the field assessment method for litter. Change over time was statistically significant (Table 31). The probability of being in the very high category increased with increasing levels of initial density, but this effect was not statistically significant.

On Site Quality 1, light and moderate thinning initially slightly increased the probability of being in the high category; and heavy thinning slightly reduced the probability of being in the high category for surface fuel hazard (Figure 44). Four years post-thinning, the probability of being in the very high category was lowest for heavily thinned plots. However, no effects of thinning were statistically significant (Table 31).

On Site Quality 2, all levels of thinning intensity initially slightly reduced the probability of being in the high surface fuel hazard category (Figure 44). These differences diminished in subsequent years. None of these effects of thinning were statistically significant (Table 31).

Table 31 Statistical significance of explanatory variables on surface fuel hazard ratings

Model term	ELPD ratio	Comment
Site quality	1.64	Surface fuel hazard rating did not differ among site qualities
Initial stem density	1.72	Surface fuel hazard rating did not depend on initial stem density
Time since thinning	5.75	Surface fuel hazard rating changed over time
Thinning intensity	1.86	Surface fuel hazard rating did not vary with thinning intensity
Does the effect of thinning intensity vary depending on:		
• Site quality	2.31	The effect of thinning on the surface fuel hazard rating did not vary by site quality
• Initial stem density	1.57	The effect of thinning on the surface fuel hazard rating did not depend on initial stem density
• Time since thinning	1.98	The effect of thinning on the surface fuel hazard rating did not vary over time
• Site quality **and** initial stem density **and** time since thinning	0.08	The effect of thinning on the surface fuel hazard rating did not vary across all combinations of site quality, initial stem density and time

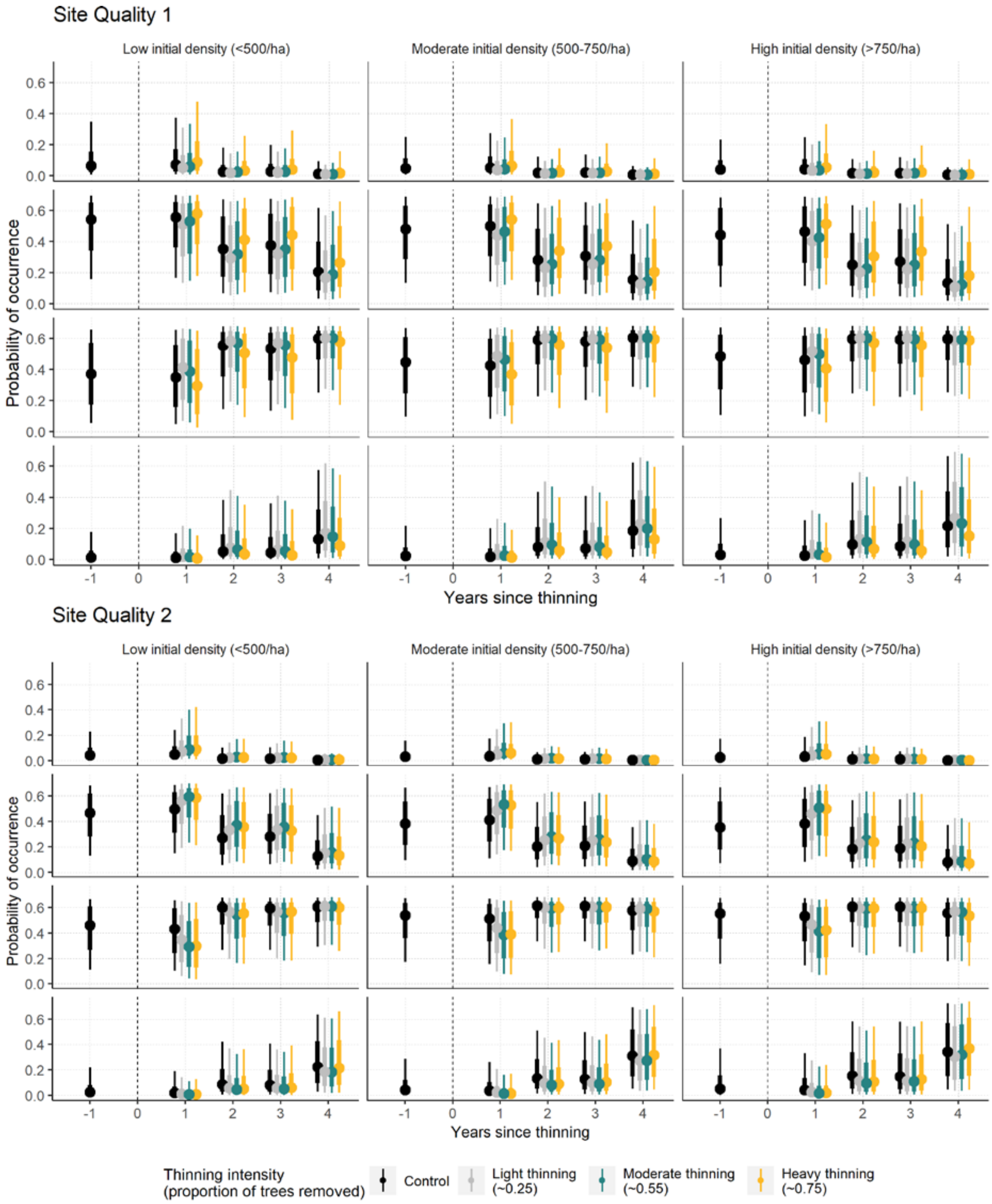

Figure 44 **Modelled probability of being in each of the surface fuel hazard categories ±50% and 95% bootstrapped confidence intervals for ecological thinning treatment, survey year and site quality**

7.5 Near surface fuel hazard: live near surface vegetation cover

Key result	Data suggested that thinning reduced live near surface vegetation cover; however, modelling and statistical analyses could not be performed on these data.

Data collection

Near surface vegetation is vegetation that is generally between 0 and 1.5 metres in height. Live and dead near surface vegetation cover were visually estimated independently by two observers who then conferred to record one estimate for each. In previous years' analyses, estimates in three 0.04 hectare subplots were averaged within each 9 hectare plot. In these analyses, all subplots were included in the model. Near surface vegetation includes all native and exotic plant cover.

Data summary

Live near surface vegetation cover tends to be between 1 and 20% cover for all plot types (Figure 45). Average near surface cover appears to have declined over time, as has variability in estimates.

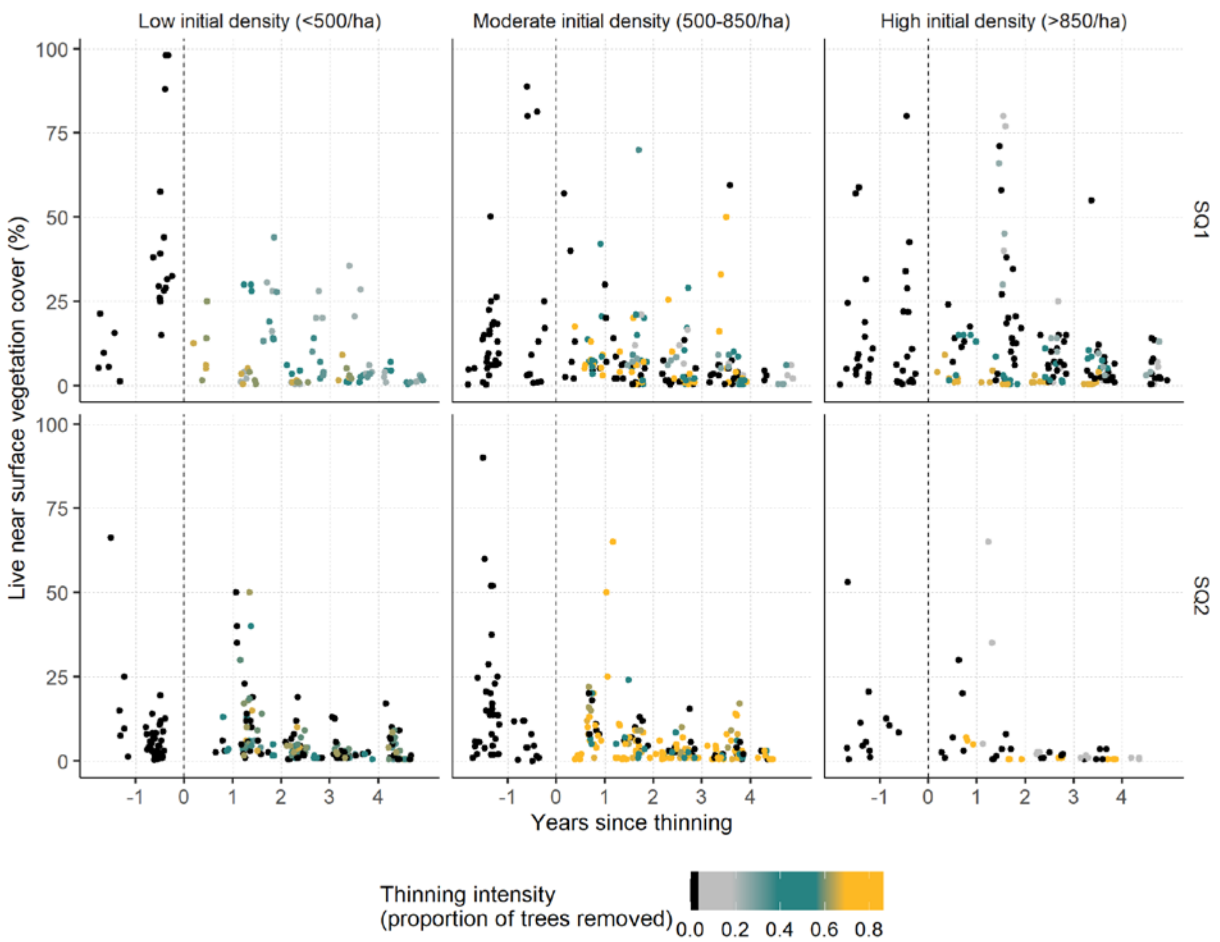

Figure 45 Data for live near surface vegetation cover (%) per 0.04 hectare subplot

Between 2018 and 2020, there were fewer records of >25% cover on all plot types including controls, which suggests change in live near surface vegetation cover occurred over time (Figure 46).

When data for all thinned plots were divided into thirds for thinning intensity, it was apparent that in 2017 moderate and heavily thinned plots had fewer records of >25% cover than control or lightly thinned plots. In the 2019 surveys, heavily thinned plots were more likely to have values closer to zero than other plot types. However, there were some higher values recorded in the 2020 surveys on heavily thinned plots. This suggests that thinning may have resulted in a temporary decrease in live near surface vegetation cover, and that the effect of thinning may have changed over time.

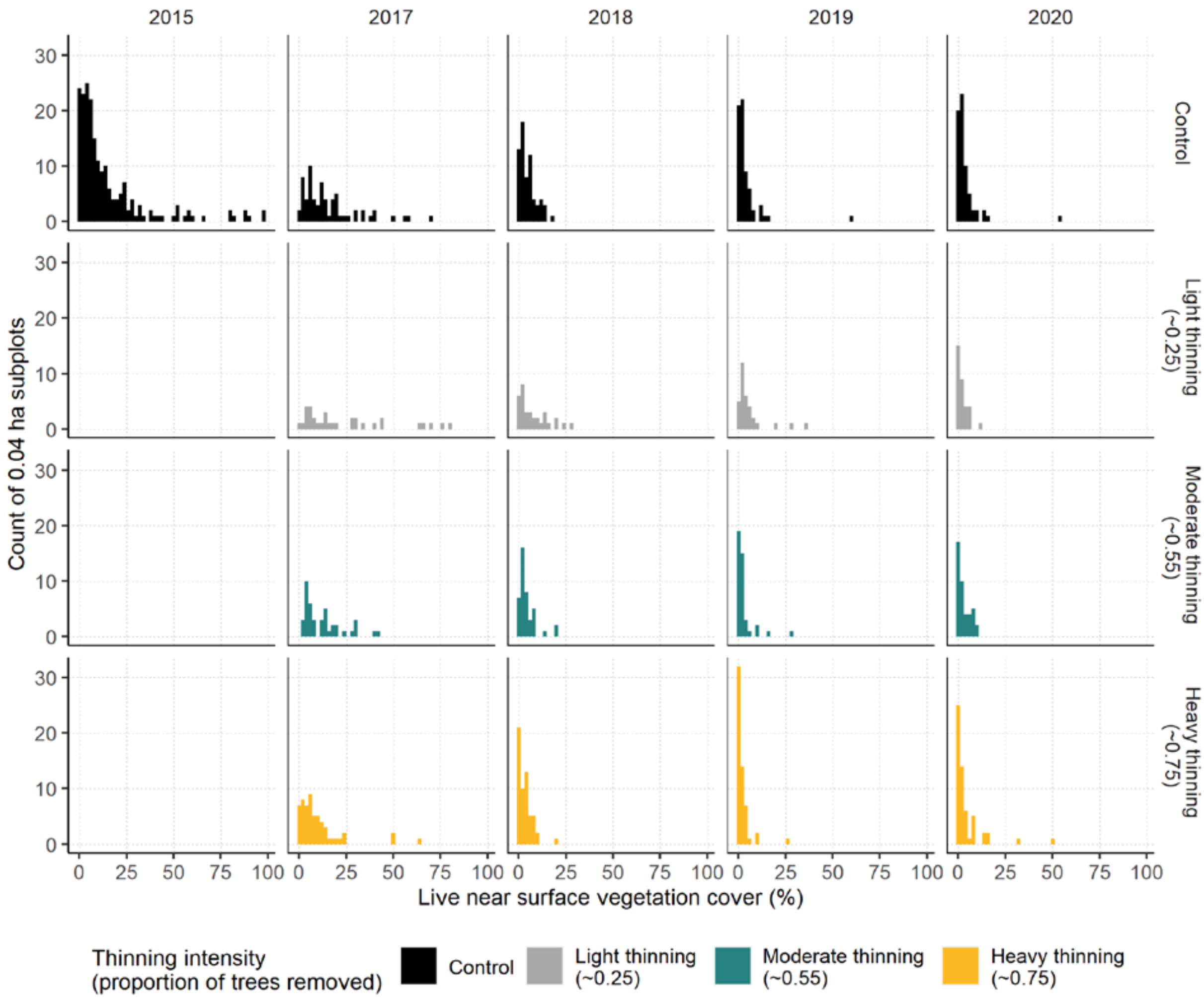

Figure 46 Data for count of subplots with different values of live near surface vegetation cover (%) per 0.04 hectare

Each bar represents a range of 2% cover.

Model results

A model was not able to be appropriately fitted to this data (see Appendix).

Plate 3 Near surface vegetation and leaf litter in river red gum forest

7.6 Near surface fuel hazard: dead near surface vegetation cover

Key result	Data suggested that thinning did not affect dead near surface vegetation cover; however, modelling and statistical analyses could not be performed on these data.

Data collection

Near surface vegetation is generally between 0 and 1 metre in height. Dead near surface vegetation is defined as dead material that is attached to a live plant. It includes both native and exotic plant material. Often, this is high when an aquatic plant is in the process of dying-off after floodwaters have receded. Dead near surface vegetation cover was visually estimated independently by two observers who then conferred to record one estimate. In previous years' analyses, estimates in three 0.04 hectare subplots were averaged within each 9 hectare plot. In these analyses, all subplots were included in the model.

Data summary

Data for dead near surface vegetation was most commonly between 1 and 10% (Figure 47). Occasionally cover was above 30%.

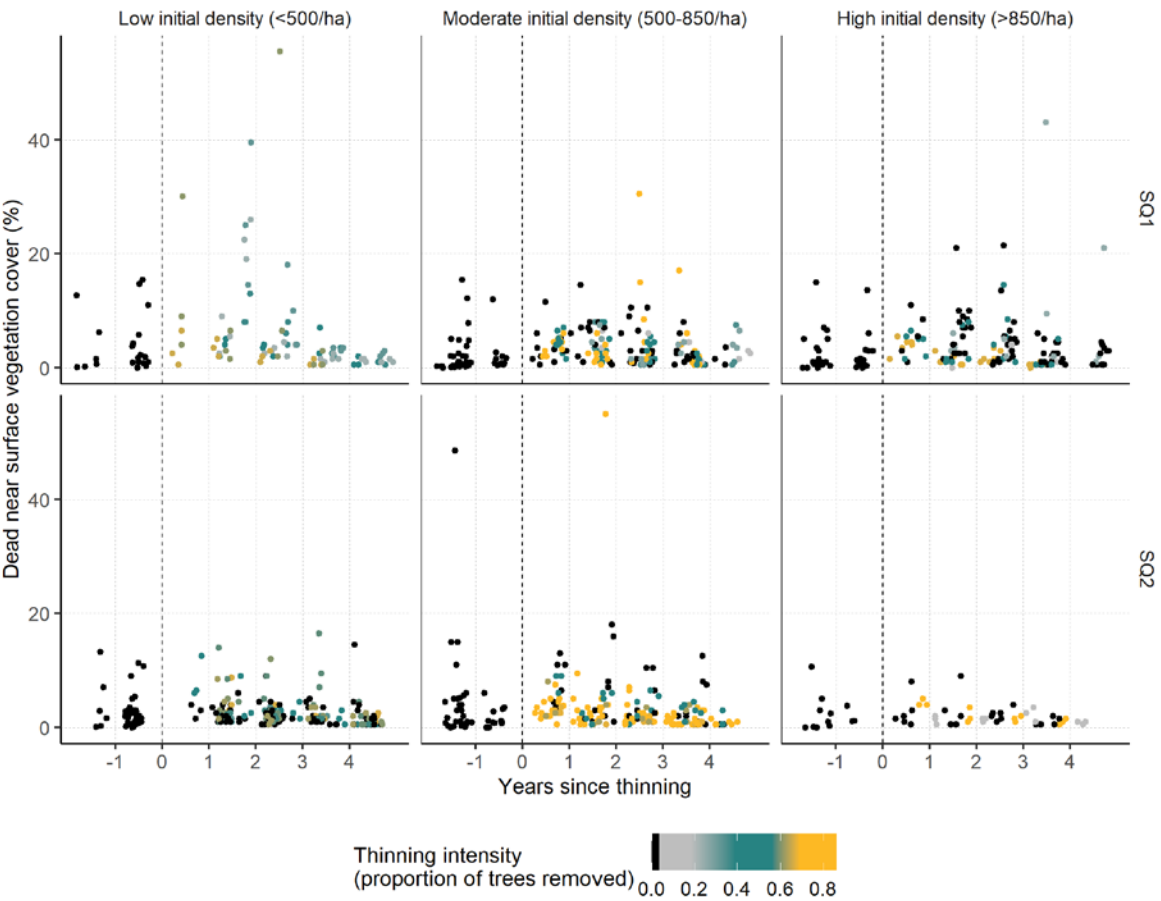

Figure 47 Data for dead near surface vegetation cover (dead vegetation attached to a live plant) (%) per 0.04 hectare subplot

Model results

It was not possible to fit an appropriate model for this variable (see Appendix).

7.7 Near surface fuel hazard assessment

Key result	Thinning affected near surface fuel hazard, but the effects differed over time: • initially, heavy thinning decreased risk in Site Quality 1 (by approximately 11%) but increased risk in Site Quality 2 (by approximately 8%) • four years post-thinning, heavy thinning reduced risk on both site qualities by 5%.

Data collection

As described for surface fuel assessment, the near surface fuel assessment categories defined by Hines et al. (2010) are incomplete. Additional categories were defined to objectively allocate all data to a near surface fuel hazard category (white cells in Table 32).

Near surface fuel assessment is based on total near surface vegetation cover (i.e. live + dead cover described in the previous two sections), and the proportion of total cover that is dead (i.e. dead cover divided by total cover).

Table 32 Near surface fuel assessment categories (adapted from Hines et al. 2010)

Grey cells are defined by Hines et al. (2010), white cells were defined by the authors to enable classification of all data.

Proportion dead cover	Total near surface plant cover (%)				
	<10	10–20	20–40	40–60	>60
<10	L	M	M	M	M
10–20	L	M	M	H	H
20–30	L	H	H	H	VH
30–50	M	H	H	VH	VH
>50	M	H	H	VH	E

Data summary

The proportion of control plots in the high category for near surface fuel hazard decreased with time (a higher proportion were in the moderate category) and this effect was strongest in Site Quality 1 (Figure 37).

In Site Quality 1, the distribution of plots among hazard categories was generally similar for thinned and control plots (Figure 37), although a small proportion of thinned plots were in very high or extreme categories.

In Site Quality 2, near surface fuel risk was reduced in plots that had light thinning, as all plots were in the low or moderate categories in all years (Figure 37). The distribution of plots among hazard categories was very similar for control, moderately and heavily thinned plots in Site Quality 2 (Figure 37).

Model results

A Bayesian ordinal categorical model was run to determine whether the probability of being in each near surface fuel hazard category depended on site quality, initial stem density, time and thinning intensity (see Appendix).

Modelled probability of being in the high near surface fuel hazard category declined over time (and the probability of being in the moderate category increased) across all plot types. The change was more pronounced in Site Quality 1 plots (Figure 48). These changes over time and differences among site qualities were not statistically significant (Table 33). There were no differences among different initial stem densities.

Thinning affected change in near surface fuel hazard ratings over time (Table 33); however, differences in the effect of thinning among site qualities and initial stem densities were not statistically significant.

Significant variation in the effect of thinning over time was due to:

- heavy thinning initially decreased near surface fuel risk in Site Quality 1 (approximately 11% relative to controls) but increased near surface fuel risk in Site Quality 2 (approximately 8% higher probability of being in the high category relative to controls)
- four years post-thinning, heavy thinning reduced near surface fuel risk on both site qualities by 5% relative to controls.

Table 33 Statistical significance of explanatory variables on near surface fuel hazard ratings

Model term	ELPD ratio	Comment
Site quality	2.63	Near surface fuel hazard rating did not differ among site qualities
Initial stem density	1.22	Near surface fuel hazard rating did not depend on initial stem density
Time since thinning	4.95	Near surface fuel hazard rating did not vary over time
Thinning intensity	1.68	Near surface fuel hazard rating did not vary with thinning intensity
Does the effect of thinning intensity vary depending on:		
• Site quality	2.12	The non-linear effect of thinning on the near surface fuel hazard rating did not vary by site quality
• Initial stem density	1.21	The effect of thinning on the near surface fuel hazard rating did not depend on initial stem density
• Time since thinning	5.04	The effect of thinning on the near surface fuel hazard rating changed over time
• Site quality **and** initial stem density **and** initial tree diameter	0.44	The effect of thinning on the near surface fuel hazard rating did not vary across all combinations of site quality, initial stem density and time

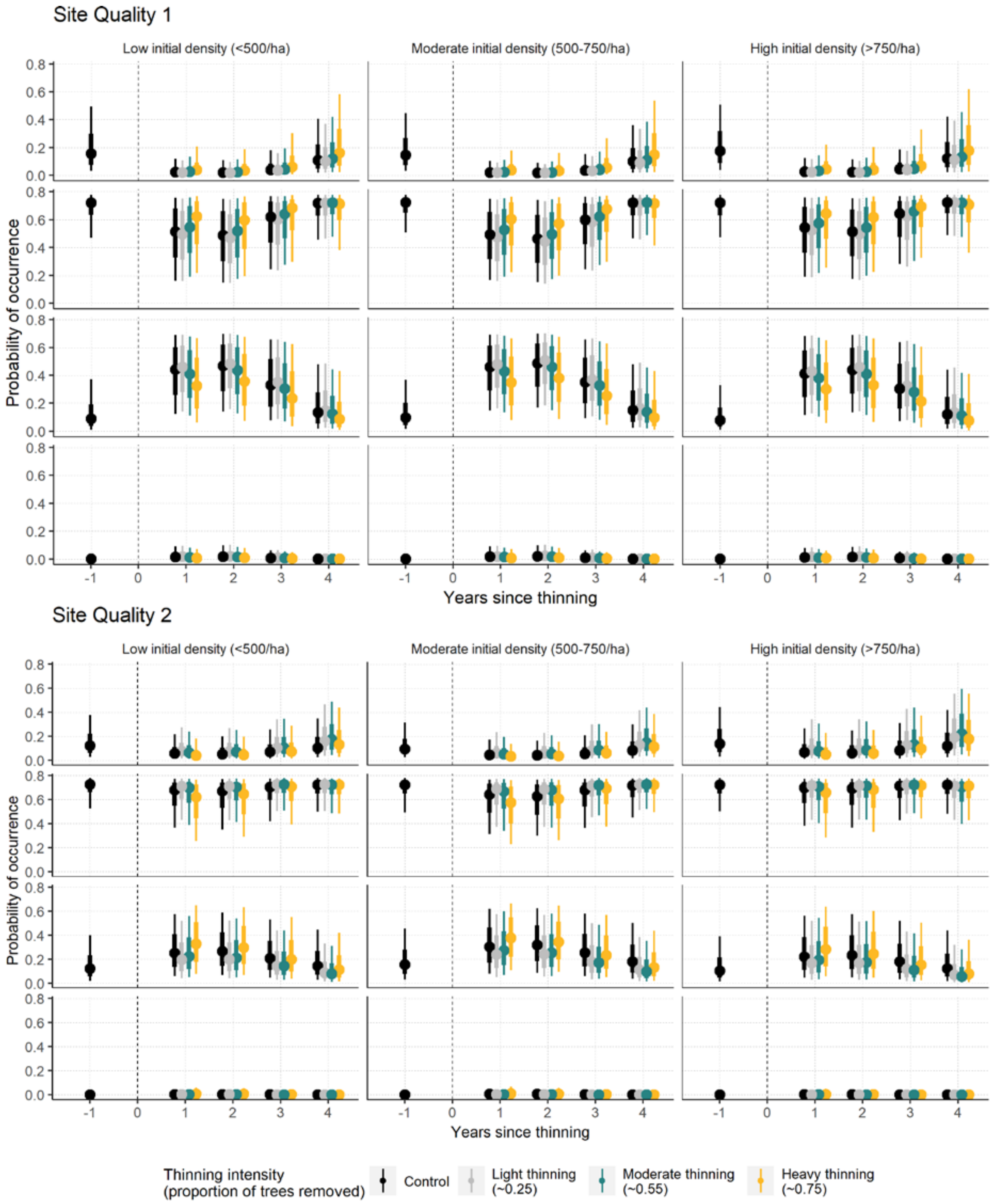

Figure 48 **Modelled probability of being in each of the near surface fuel hazard categories ±50% and 95% bootstrapped confidence intervals for ecological thinning treatment, survey year and site quality**

7.8 Combined surface and near surface fuel hazard assessment

Key result	No statistically significant effects of thinning on combined surface and near surface hazard.

Data collection

The surface and near surface fuel hazard categories are combined to determine a combined surface hazard category. All categories are defined by Hines et al. (2010) (Table 34).

Table 34 Combined surface and near surface fuel hazard assessment categories (from Hines et al. 2010)

Surface risk	Near surface risk				
	L	**M**	**H**	**VH**	**E**
L	L	L	M	H	VH
M	M	M	H	VH	E
H	H	VH	VH	VH	E
VH	VH	VH	E	E	E
E	E	E	E	E	E

Data summary

Among control plots in Site Quality 1 there was little difference in combined surface and near surface risk category proportions since last year. In Site Quality 2 there has been a slight increase in very high and extreme categories from the previous year at the expense of low and moderate categories (Figure 36, Figure 37).

The distribution of plots among combined surface and near surface risk categories was similar for thinned and control plots in Site Quality 1, however, in Site Quality 2 a greater proportion of plots that were heavily thinned were in the very high category (and fewer plots in the low and moderate categories) (Figure 37).

There were no apparent differences in the distribution of plots among combined surface and near surface risk categories among differing levels of initial stem density (Figure 36).

Model results

A Bayesian cumulative ordinal model was run to determine whether thinning treatments affected the probability of being in any combined surface and near surface fuel hazard categories (see Appendix). Our model also accounted for changes over time, initial stem density, potential differences due to site quality and their interactions.

The probability of being in the very high category for combined surface and near surface fuel hazard increased between one and two years post-thinning (between 2017–18 and 2018–19) on both site qualities and for all initial stem densities (Figure 49). None of these effects were statistically significant (Table 35).

Thinning initially increased the probability of being in the very high category in Site Quality 1; and decreased the probability of being in the very high category in Site Quality 2 (Figure 49). These differences were sustained for heavily thinned plots in Site Quality 1, but declined for other thinned plots. However, none of the effects of thinning on combined surface and near surface fuel hazard were statistically significant (Table 35).

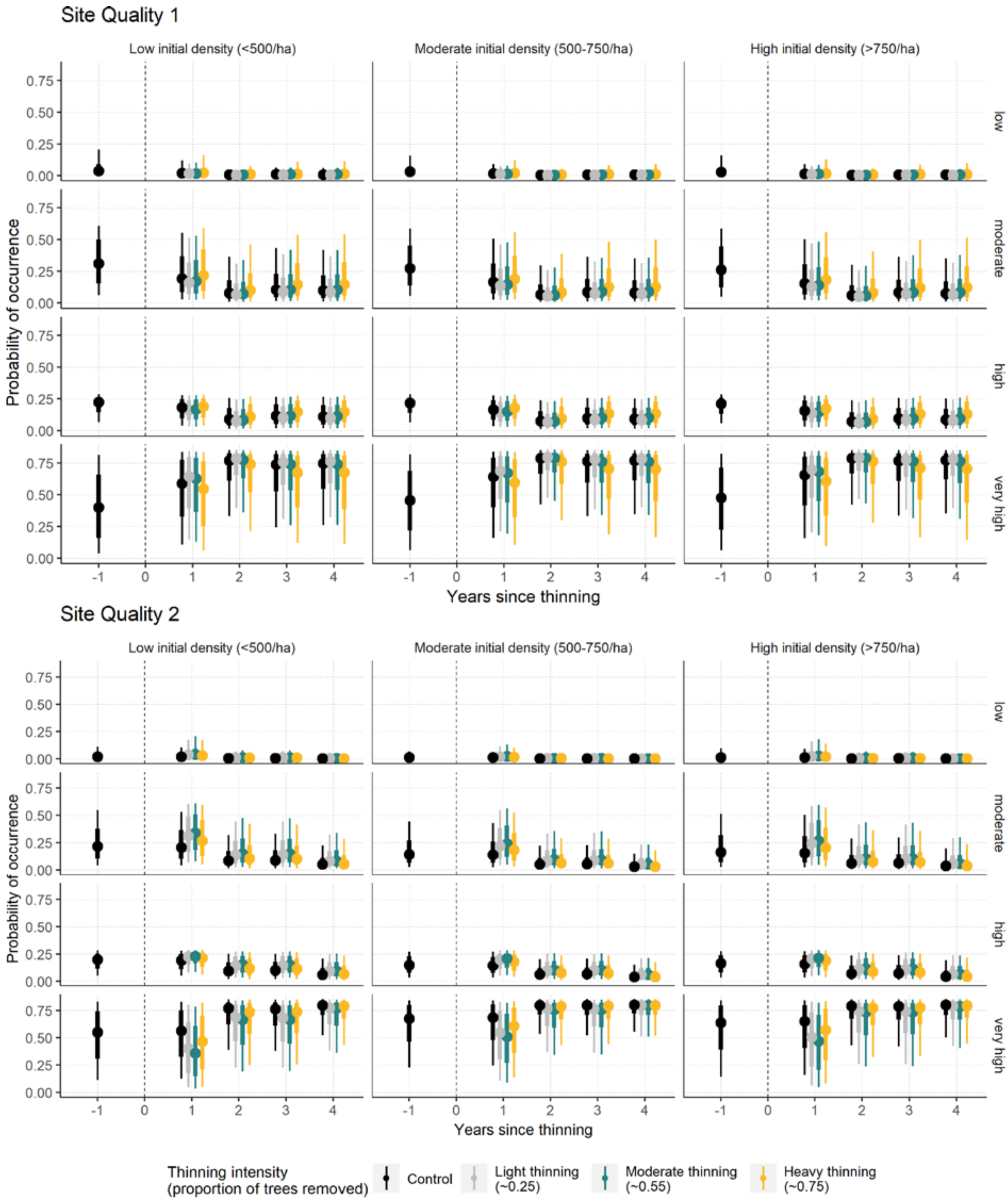

Figure 49 Modelled probability of being in each of the combined surface and near surface fuel hazard categories ±50% and 95% bootstrapped confidence intervals for ecological thinning treatment, survey year and site quality

Table 35 Statistical significance of explanatory variables on combined surface and near surface fuel hazard ratings

Model term	ELPD ratio	Comment
Site quality	2.69	Combined surface and near surface fuel hazard rating did not differ among site qualities
Initial stem density	1.58	Combined surface and near surface fuel hazard rating did not depend on initial stem density
Time since thinning	4.27	Combined surface and near surface fuel hazard rating did not vary over time
Thinning intensity	1.72	Combined surface and near surface fuel hazard rating did not vary with thinning intensity
Does the effect of thinning intensity vary depending on:		
• Site quality	2.22	The effect of thinning on the combined surface and near surface fuel hazard rating did not vary by site quality
• Initial stem density	1.56	The effect of thinning on the combined surface and near surface fuel hazard rating did not depend on initial stem density
• Time since thinning	1.84	The effect of thinning on the combined surface and near surface fuel hazard rating did not vary over time
• Site quality **and** initial stem density **and** initial tree diameter	1.69	The effect of thinning on the combined surface and near surface fuel hazard rating did not vary across all combinations of site quality, initial stem density and time

7.9 Elevated fuel hazard: live elevated vegetation cover

Key result	Data suggested that thinning did not affect live elevated vegetation cover; however, due to time constraints statistical analyses were not performed on these data.

Data collection

Live elevated vegetation cover was assessed by visual estimation in three 0.04 hectare plots within each 9 hectare plot. In river red gum forest the elevated stratum consists almost exclusively of *Eucalyptus camaldulensis* saplings and small trees.

Data summary

Estimated cover of mid-story vegetation was most commonly between 0 and 15% for Site Quality 1, and 0 and 10% for Site Quality 2 (Figure 50). Cover estimates were generally lower in the most recent survey on all plot types.

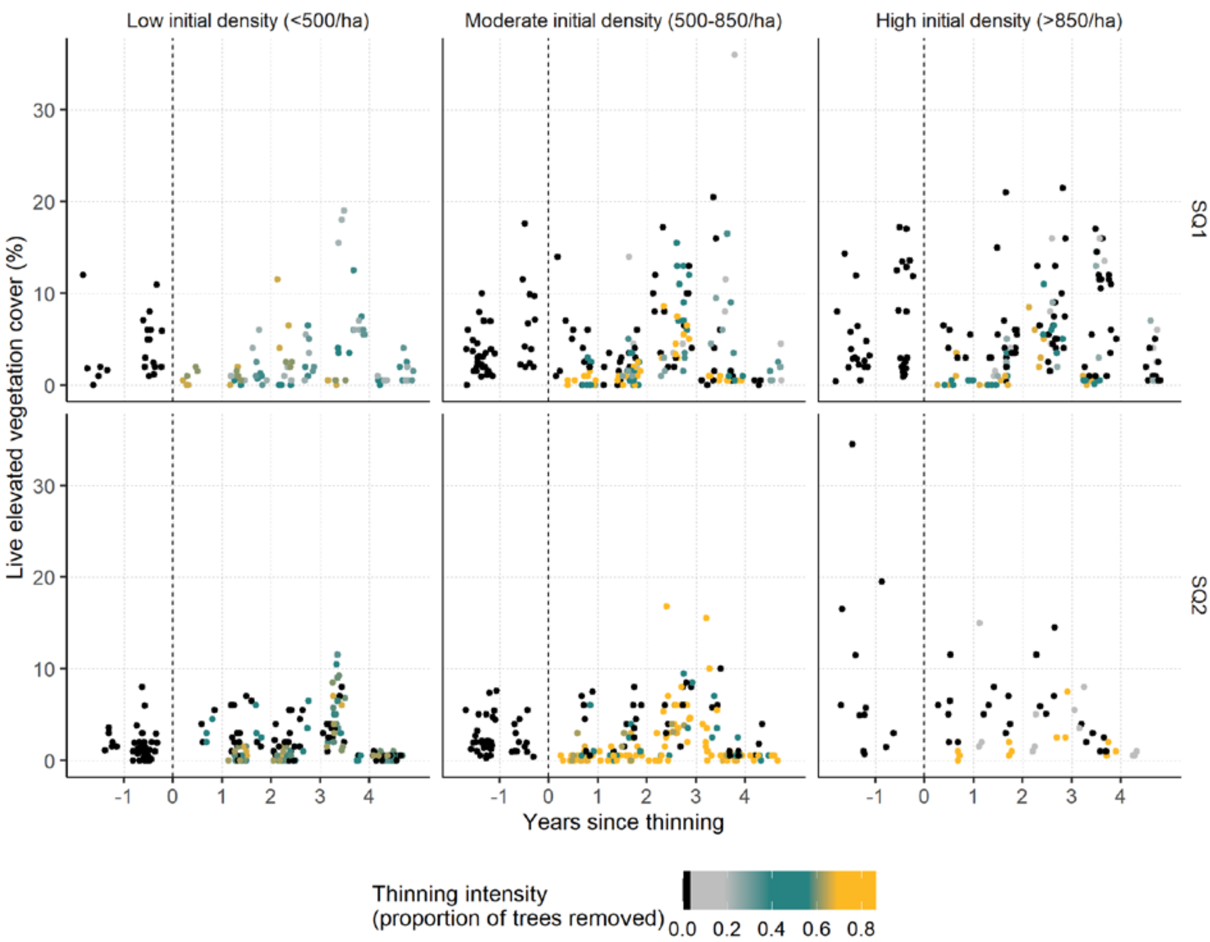

Figure 50 Data for live elevated vegetation cover (%) visually estimated per 0.04 hectare subplot

Model results

Due to time constraints, a model was not run for live elevated vegetation cover.

7.10 Elevated fuel hazard: dead elevated vegetation cover

Key result	Data suggested that thinning did not affect dead elevated vegetation cover; however, modelling and statistical analyses could not be performed on these data.

Data collection

Dead elevated vegetation cover was assessed by visual estimation in three 0.04 hectare plots within each 9 hectare plot. The elevated stratum consists almost exclusively of *Eucalyptus camaldulensis* saplings and small trees.

Data summary

Almost all estimates of dead elevated vegetation cover were less than 2% (Figure 51). There were no apparent changes over time or differences among thinning and control plots.

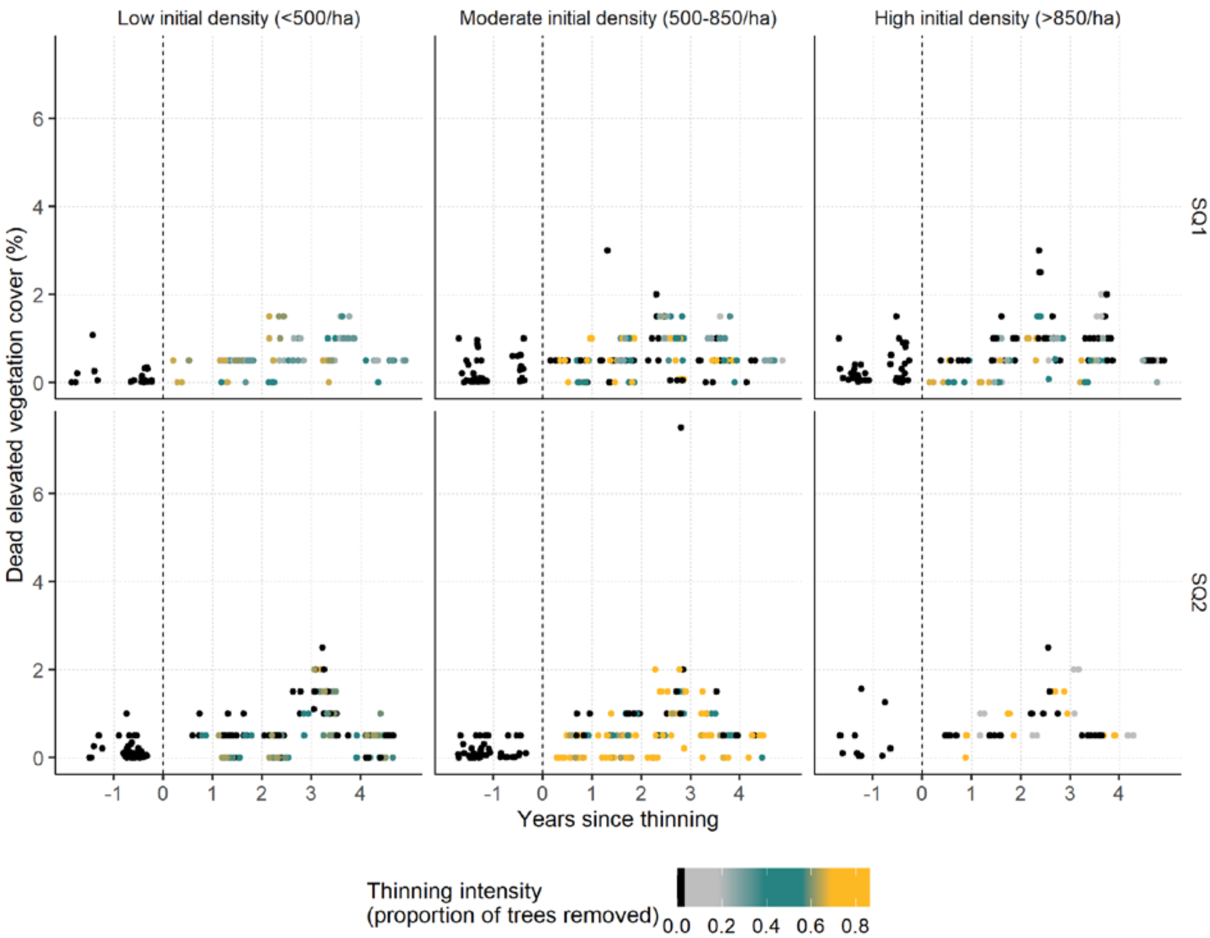

Figure 51 Data for dead elevated vegetation cover (%) visually estimated per 0.04 hectare subplot

Model results

No model was run for dead elevated vegetation.

7.11 Elevated fuel hazard assessment

Key result	No statistically significant effects of thinning on elevated fuel hazard.

Data collection

Elevated fuel assessment is based on total elevated vegetation cover (i.e. live + dead cover), and the proportion of total elevated cover that is dead (i.e. dead cover divided by total cover). Some category definitions by Hines et al. (2010) are incomplete, therefore additional categories were defined by the authors to objectively allocate all data to an elevated fuel hazard category (white cells in Table 36).

Table 36 Elevated fuel hazard assessment categories (adapted from Hines et al. 2010)

Grey cells are defined by Hines et al. (2010), white cells are additionally defined by the authors to enable classification of all data.

Proportion dead cover	Total elevated plant cover (%)		
	<5	<20	20–30
<20	L	L	M
20–30	M	M	M
30–50	M	M	H
>50	M	H	VH

Data summary

In 2020 there was a higher proportion of plots with moderate fuel hazard rating than low fuel hazard rating, when compared with all years prior. However, this increase in moderate rating occurred irrespective of thinning intensity, site quality and initial stem density (Figure 36, Figure 37).

Model results

A Bayesian cumulative ordinal model was run to determine whether thinning treatments affected the probability of being in any elevated fuel hazard categories, and accounting for changes over time, initial stem density and whether any differences depended on site quality (see Appendix).

The probability of being in the moderate elevated fuel hazard category increased in the most recent survey season (and the probability of being in the low category decreased) across all plot types and both site qualities (Figure 52). Change over time in fuel hazard category was statistically significant (Table 37).

Heavy thinning increased the probability of being in the moderate elevated fuel hazard category (and decreased the probability of being in the low category) relative to controls in both site qualities (Figure 52). Light and moderate thinning decreased the probability of being in the moderate category (and increased the probability of being in the low category) relative to controls in Site Quality 2. None of the effects of thinning on elevated fuel hazard were statistically significant (Table 37).

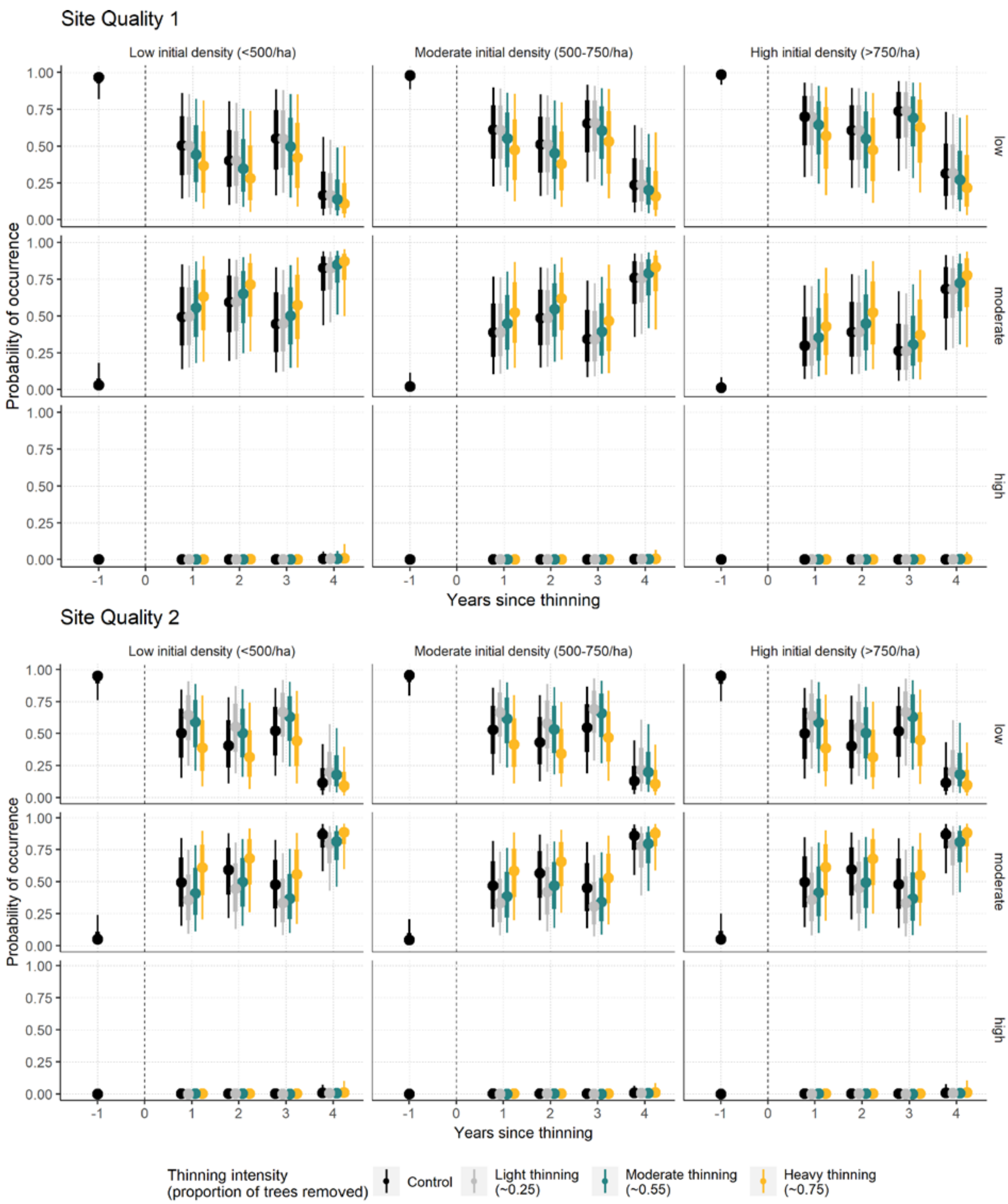

Figure 52 Modelled probability of being in each of the elevated fuel hazard assessment categories ±50% and 95% bootstrapped confidence intervals for ecological thinning treatment, survey year and site quality

Table 37 Statistical significance of explanatory variables on elevated fuel hazard ratings

Model term	ELPD ratio	Comment
Site quality	3.80	Elevated fuel hazard rating did not differ among site qualities
Initial stem density	3.70	Elevated fuel hazard rating did not depend on initial stem density
Time since thinning	7.71	Elevated fuel hazard rating varied over time
Thinning intensity	3.89	Elevated fuel hazard rating did not vary with thinning intensity
Does the effect of thinning intensity vary depending on:		
• Site quality	3.51	The effect of thinning on the elevated fuel hazard rating did not vary by site quality
• Initial stem density	3.64	The effect of thinning on the elevated fuel hazard rating did not depend on initial stem density
• Time since thinning	3.91	The effect of thinning on the elevated fuel hazard rating did not vary over time
• Site quality **and** initial stem density **and** initial tree diameter	2.95	The effect of thinning on the elevated fuel hazard rating did not vary across all combinations of site quality, initial stem density and time

8. Results: Floristics

Plate 4 Botanists in river red gum forest. Emma Gorrod/DPIE

8.1 Native plant species richness

Key result	Heavy thinning reduced native plant species richness in Site Quality 1 plots that had very high initial stem density by 4.5 species per 0.04 hectare (a 23% reduction from controls) four years after thinning. No other effects of thinning on native plant species richness were certain to be different from control plots.

Data collection

Floristic composition was surveyed in three 0.04 hectare subplots on each 9 hectare plot, with a total of 198 subplots. Floristic subplots were placed in the 9 hectare plots to sample the range of variation in understorey vegetation. Surveys involved recording all native and exotic plant species present.

Data summary

The average number of native plant species recorded per 0.04 hectare subplot was between 15 and 21, with lower average values recorded in 2018 and 2019 than the most recent survey (Table 38). Site Quality 2 plots had slightly higher averages on all years except 2015.

Table 38 Average number of native plant species recorded per 0.04 hectare subplot, by site quality and survey year

Survey year	Site Quality 1	Site Quality 2
2015	17.6	15.5
2017	18.3	20.4
2018	16.0	16.9
2019	16.0	16.0
2020	18.7	21.3

The number of native plant species was generally between 10 and 30 species per 0.04 hectare subplot, with almost all instances of more than 30 species occurring in Site Quality 2 plots (Figure 53).

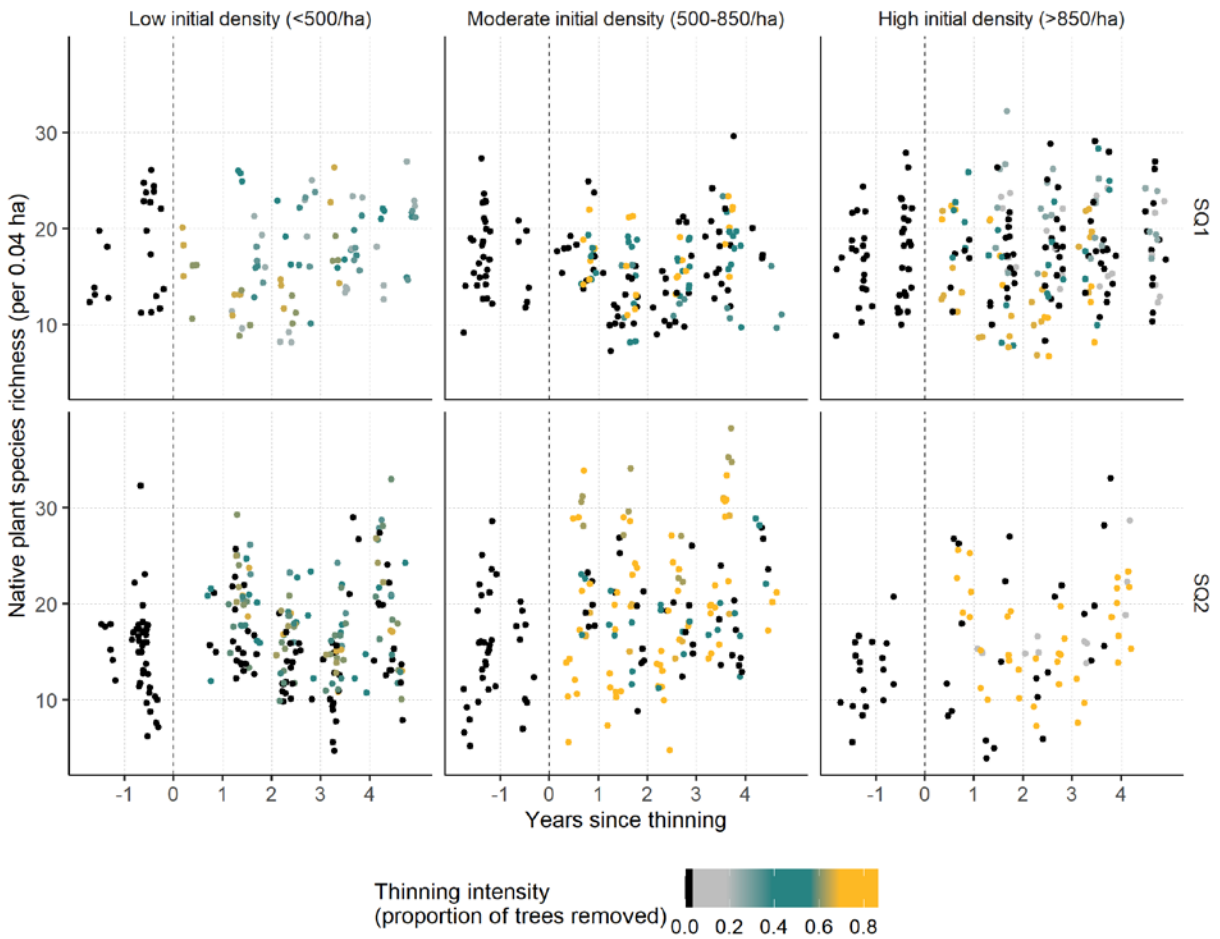

Figure 53 Data for native plant species richness per 0.04 hectare subplot

Model results

Native plant species richness per 0.04 hectare was modelled as a continuous positive variable using a Gaussian distribution, which had a superior fit to other distributions often used for count variables (see Appendix). All combinations of interactions between explanatory variables were included in this model; and there were four random effects, of survey year, site, 9 hectare plot and subplot. Prediction intervals were wide for this response variable.

Native plant species richness changed over time, with higher values generally occurring one and four years post-thinning (Figure 54). Native plant species richness was slightly lower in Site Quality 1 control plots (15–20 species) than Site Quality 2 control plots (18–21 species) four years post-thinning. Differences in native plant species richness over time and among site qualities were statistically significant, but differences among initial stem densities were not (Table 39).

The effect of thinning on native plant species richness was statistically significant, but the effects varied significantly among site qualities, initial stem densities and time since thinning (Table 39). However, the only instance where the prediction interval for thinned plots did not include the value for controls was four years after heavy thinning in Site Quality 1 plots that had very high initial stem density (Table 40). Heavy thinning in this instance reduced species richness by 4.5 species per 0.04 hectares, a 23% reduction from controls.

Other effects of thinning on native plant species richness included increases in native plant species richness in Site Quality 2 (Figure 54), but the prediction intervals for these effects were not distinct from control plots (Table 40).

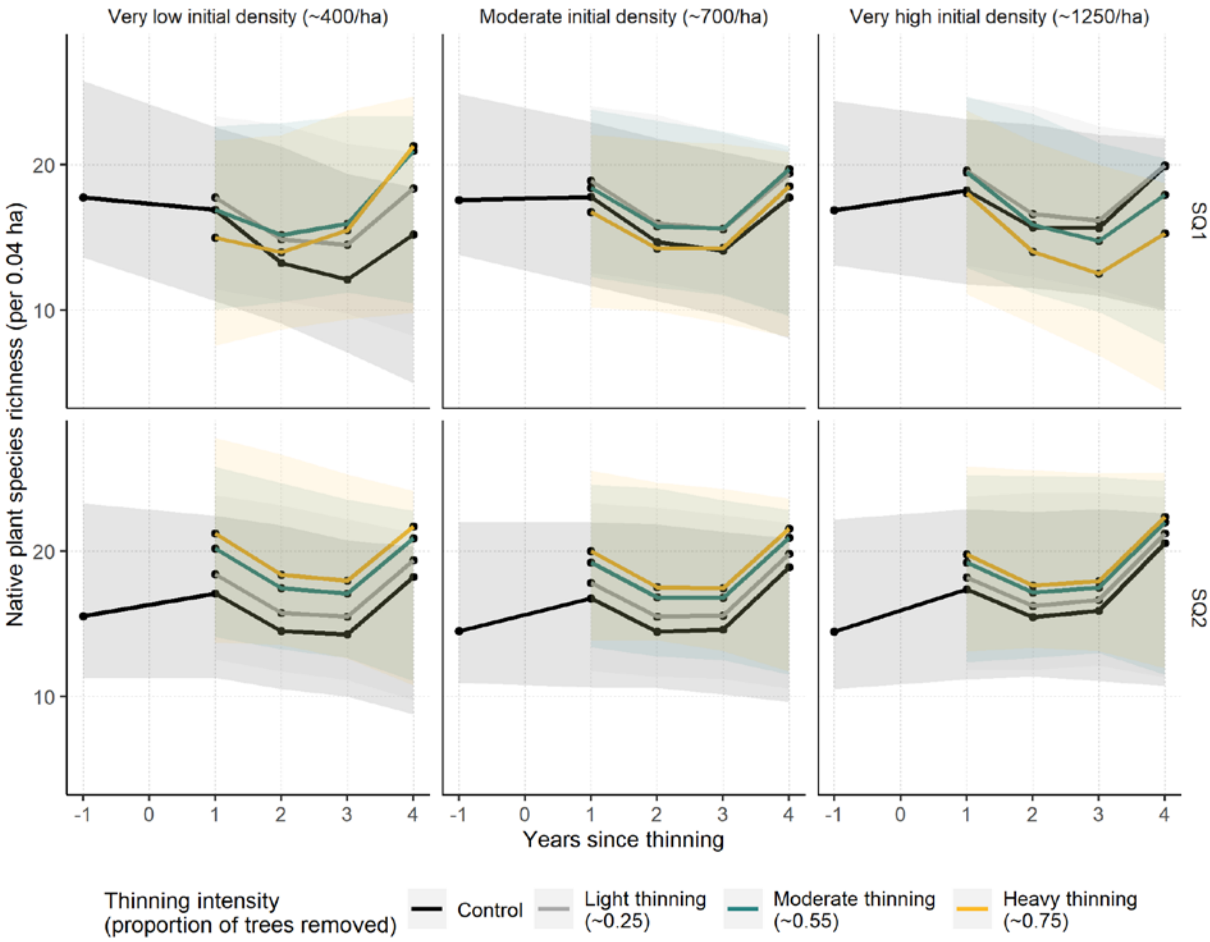

Figure 54 Modelled values and prediction intervals for native plant species richness per 0.04 hectare subplot

Table 39 Statistical significance of explanatory variables on native plant species richness

	Bootstrapped likelihood ratio test significance	Description
Site quality	0.010	Native plant species richness differed by site quality
Initial stem density	0.267	Native plant richness did not depend on initial stem density
Time since thinning	0.030	Native plant richness changed over time
Thinning intensity	0.010	Thinning intensity affected native plant species richness
Does the effect of thinning intensity vary depending on:		
• Site quality	0.040	The effect of thinning intensity on native plant richness differed among site qualities
• Initial stem density	0.149	The effect of thinning intensity on native plant richness was not affected by initial stem density
• Time since thinning	0.119	The effect of thinning intensity on native plant richness did not change over time
• Site quality **and** initial stem density **and** time since thinning	0.059	The effect of thinning was variable

Table 40 Estimated effect sizes for native plant species richness four years post-thinning

Site quality		Site Quality 1			Site Quality 2		
Thinning intensity		Low intensity	Mod intensity	High intensity	Low intensity	Mod intensity	High intensity
Initial stem density	Very low (400/ha)	+3.2 –7.0 to +5.7	+5.8 –4.7 to +8.1	+6.1 –5.4 to +9.5	+1.1 –8.4 to +3.0	+2.6 –7.2 to +4.5	+3.5 –7.4 to +5.9
	Moderate (700/ha)	+1.6 –8.1 to +3.2	+1.9 –8.2 to +3.5	+0.8 –9.6 to +3.1	+0.9 –8.4 to +3.0	+2.0 –7.4 to +4.0	+2.7 –7.2 to +4.7
	Very high (1250/ha)	+0.1 –9.8 to +2.1	–1.9 –12.2 to +0.6	–4.6 –15.5 to –1.1	+0.7 –9.2 to +3.2	+1.4 –9.0 to +4.3	+1.8 –8.6 to +4.9

8.2 Exotic plant species richness

Key result	Heavy thinning increased exotic plant species richness. The magnitude of increase that was most likely four years post-thinning was: • 4.5 species in Site Quality 1 plots that had very high initial density (70% increase relative to controls) • 4–9 species in Site Quality 2 plots that had low to moderate initial density (55–130% increase relative to controls).

Data collection

Floristic composition was surveyed in three 0.04 hectare subplots on each 9 hectare plot, with a total of 198 subplots. Floristic subplots were placed in the 9 hectare plots to sample the range of variation in understorey vegetation. Surveys involved recording all native and exotic plant species present.

Data summary

The average number of exotic plant species recorded per 0.04 hectare subplot was between 6 and 11 species in both site qualities and all survey years (Table 41). The highest average species richness values were recorded in the most recent survey.

Table 41 Average number of exotic plant species recorded per 0.04 hectare subplot, by site quality and survey year

Survey year	Site Quality 1	Site Quality 2
2015	6.3	5.5
2017	6.4	9.0
2018	6.3	6.5
2019	7.4	6.6
2020	9.6	10.8

Across all years, exotic plant species richness on 0.04 hectare subplots was between approximately 4 and 12 species (Figure 55). Values above 20 exotic species per subplot were occasionally recorded in Site Quality 2 plots. Zero exotic plant species were also occasionally recorded, more frequently in Site Quality 1 plots.

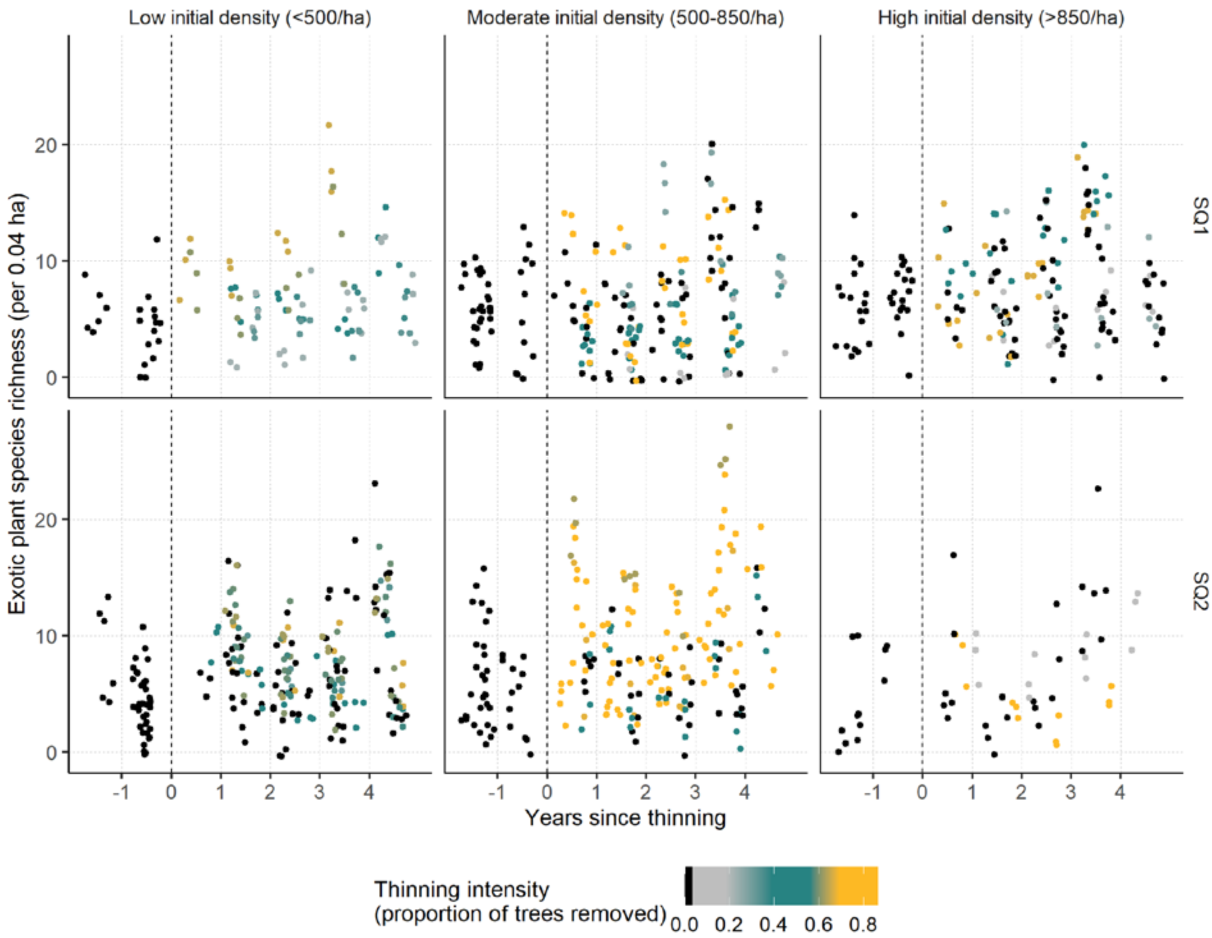

Figure 55 Data for exotic plant species richness per 0.04 hectare subplot

Model results

Exotic plant species richness was modelled as a count variable using a negative binomial distribution (see Appendix). The explanatory terms in the model included two-way and three-way interactions between initial stem density, site quality, time since thinning and thinning intensity. The random effect of survey year was not included in this model, and therefore year-to-year variation in exotic species richness was not modelled. Other random effects of site, 9 hectare plot and 0.04 hectare subplot were included.

In the absence of thinning, exotic plant species richness generally increased over time, with the exception of very high initial density plots in Site Quality 1 that were more stable (Figure 56). Differences in trends over time in exotic plant species richness among site qualities and initial stem densities were statistically significant (Table 42).

Thinning had statistically significant effects on exotic plant species richness, which differed among site qualities and changed over time (Table 42).

The effect of heavy thinning was to increase the number of exotic plant species, with the magnitude of increase substantially higher in Site Quality 2 plots (Figure 56). Moderate intensity thinning also temporarily increased exotic richness in Site Quality 2 plots that were very low stem density prior to thinning (Figure 56). Thinning did not increase exotic richness relative to control plots for other combinations of intensity and starting conditions.

The magnitude of difference between heavily thinned and control plots slightly increased over time in Site Quality 1, but decreased on some Site Quality 2 plots because exotic richness increased on control plots (Figure 56).

Four years post-thinning, the fitted value of exotic plant richness on control plots was 6–10 species per 0.04 hectare subplot in Site Quality 1; and 7–9 species per 0.04 hectare subplot in Site Quality 2.

Four years post-thinning, the magnitude of increase in exotic species richness was most likely to be (Table 43):

- 4.5 more species in heavily thinned Site Quality 1 plots that had very high initial density (70% increase relative to controls)
- 4–9 more species in heavily thinned Site Quality 2 plots that had very low and moderate initial density (55–130% increase relative to controls).

Table 42 Statistical significance of explanatory variables on exotic plant species richness

	Bootstrapped likelihood ratio test significance	Description
Site quality	0.010	Exotic plant richness differed by site quality
Initial stem density	0.020	Exotic plant richness depended on initial stem density
Time since thinning	0.011	Exotic plant richness changed over time
Thinning intensity	0.011	Thinning intensity affected exotic species richness
Does the effect of thinning intensity vary depending on:		
• Site quality	0.031	The effect of thinning on exotic plant richness differed by site quality
• Initial stem density	0.083	The effect of thinning on exotic plant richness did not vary by initial stem density
• Time since thinning	0.010	The effect of thinning on exotic plant richness changed over time
• Site quality **and** initial stem density **and** time since thinning	Not modelled	

Table 43 Estimated effect sizes for exotic plant species richness four years post-thinning

Site quality		Site Quality 1			Site Quality 2		
Thinning intensity		Low intensity	Mod intensity	High intensity	Low intensity	Mod intensity	High intensity
Initial stem density	Very low (400/ha)	–0.9 –3.7 to +3.1	–0.1 –3.3 to +4.1	+2.1 –3.0 to +9.2	–0.6 –2.3 to +1.7	+2.4 –0.1 to +5.9	+9.6 +2.9 to +19.8
	Moderate (700/ha)	–0.3 –1.9 to +1.8	+0.9 –1.1 to +3.4	+3.3 –0.1 to +7.7	–1.4 –3.0 to +1.0	–0.1 –1.9 to +2.6	+4.1 +1.2 to +7.8
	Very high (1250/ha)	0.0 –1.7 to +2.3	+1.7 –0.7 to +4.6	+4.5 +0.3 to +9.3	–2.5 –4.6 to +0.7	–2.3 –4.9 to +1.3	+0.3 –3.0 to +5.1

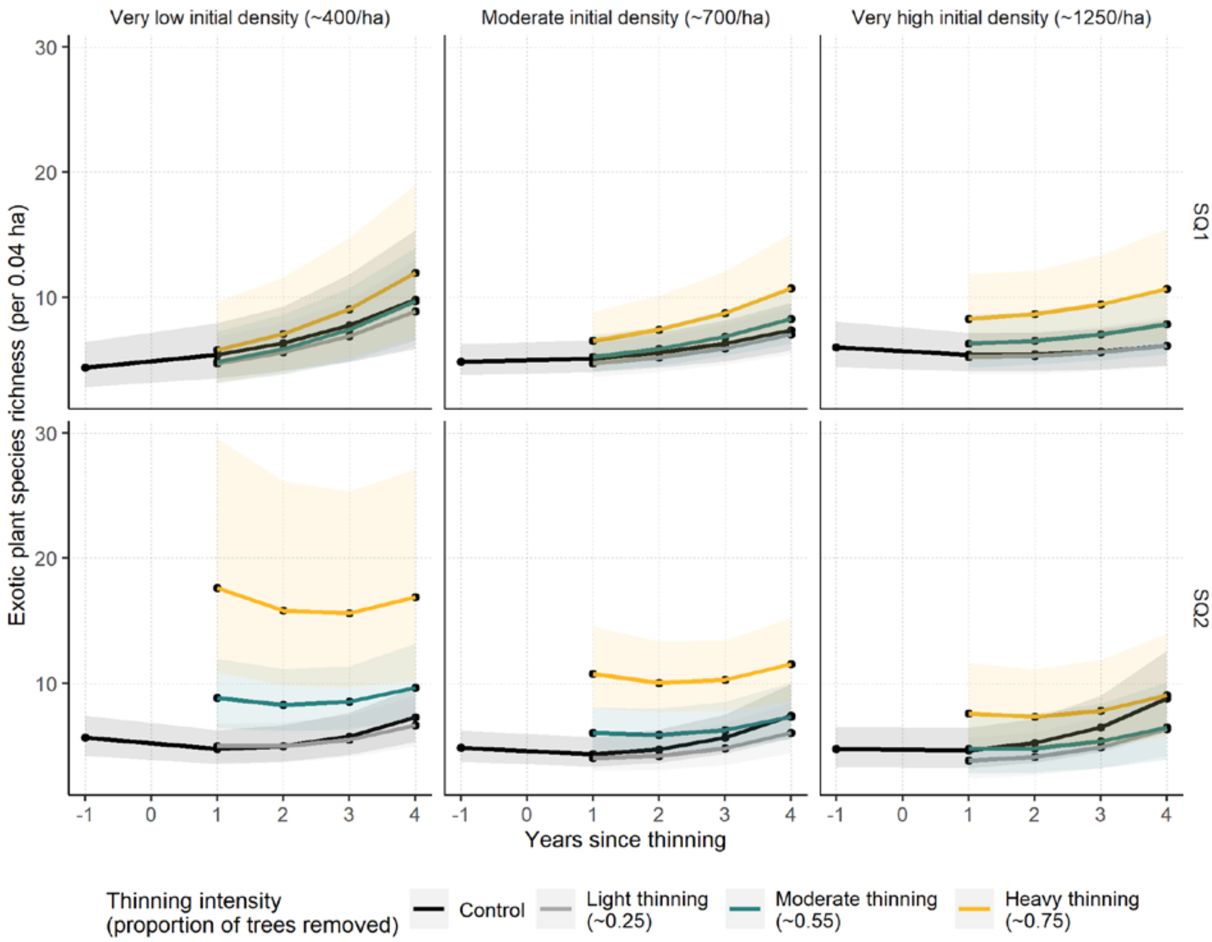

Figure 56 Modelled values and prediction intervals for exotic plant species richness per 0.04 hectare subplot

8.3 Native plant cover

Key result	Thinning may have decreased native plant cover in Site Quality 1 plots, but may have increased native plant cover in Site Quality 2 plots; however, due to time constraints, statistical analyses were not conducted for this variable.

Data collection

In 2019 and 2020 survey seasons, live native vegetation cover (not including tree cover) was visually estimated as a percentage of each 0.04 hectare plot. It had not been estimated in previous years.

Data summary

Cover estimates for native plants (%) per 0.04 hectare subplot were most often below 10%; with occasional estimates above 20% in Site Quality 1 plots (Figure 57).

On Site Quality 1 plots, native cover may increase with increasing initial stem density.

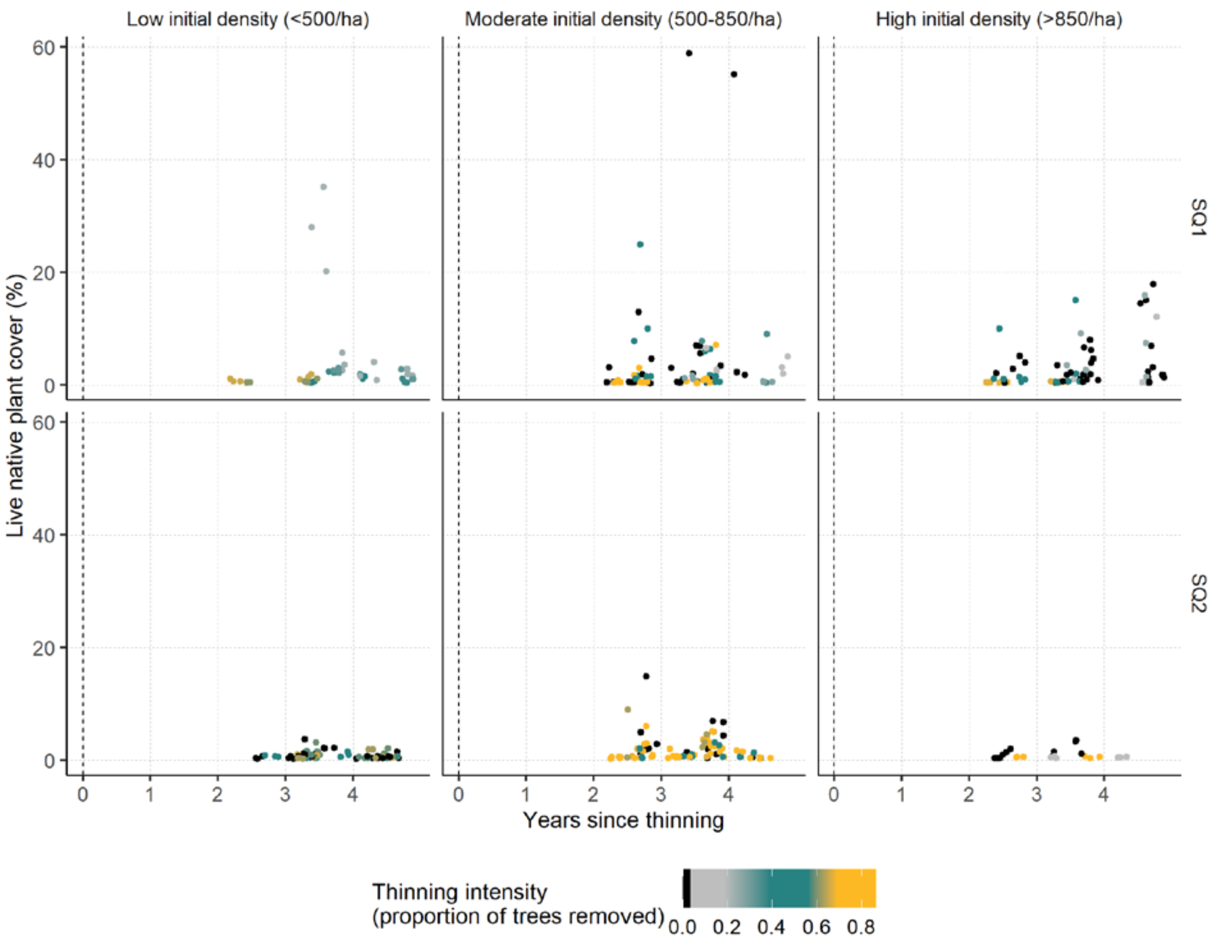

Figure 57 Data for live native plant cover (%) per 0.04 hectare subplot

Average live native plant cover was substantially lower on heavily thinned plots than control plots in Site Quality 1 in both survey years (Table 44). On Site Quality 2, all average estimates of native plant cover were very low. In 2019, heavily thinned plots had lower averages but this trend was inverted in 2020.

Table 44 Average live native plant cover (%) in the two most recent survey seasons
Values are rounded to the nearest whole percentage point.

	Thinning intensity	Average cover		Proportion of 0.04 hectare plots with >1% native cover	
		2019	2020	2019	2020
Site Quality 1	Control	5%	5%	64%	58%
	Light thinning	6%	3%	78%	52%
	Moderate thinning	4%	2%	44%	50%
	Heavy thinning	1%	1%	10%	15%
Site Quality 2	Control	2%	1%	27%	33%
	Light thinning	1%	1%	17%	0%
	Moderate thinning	1%	1%	24%	24%
	Heavy thinning	1%	2%	23%	41%

Model results

No modelling or statistical analyses were conducted for native plant cover.

8.4 Exotic plant cover

Key result	Moderate and heavy thinning may have increased live exotic plant cover in Site Quality 1 plots; however, due to time constraints, statistical analyses were not conducted for this variable.

Data collection

In 2019 and 2020 survey seasons, total live exotic vegetation cover was visually estimated as a percentage of each 0.04 hectare subplot. It had not been estimated in previous years.

Data summary

Visual estimates of live exotic plant cover (%) per 0.04 hectare subplot were most commonly close to zero on both site qualities (Figure 58). Higher values were recorded on some plots in all initial stem densities in Site Quality 1 (11 values between 20% and 65%). In Site Quality 2, plots with low initial stem density had some higher records that higher initial stem densities, but no plots had values greater than 20% in Site Quality 2.

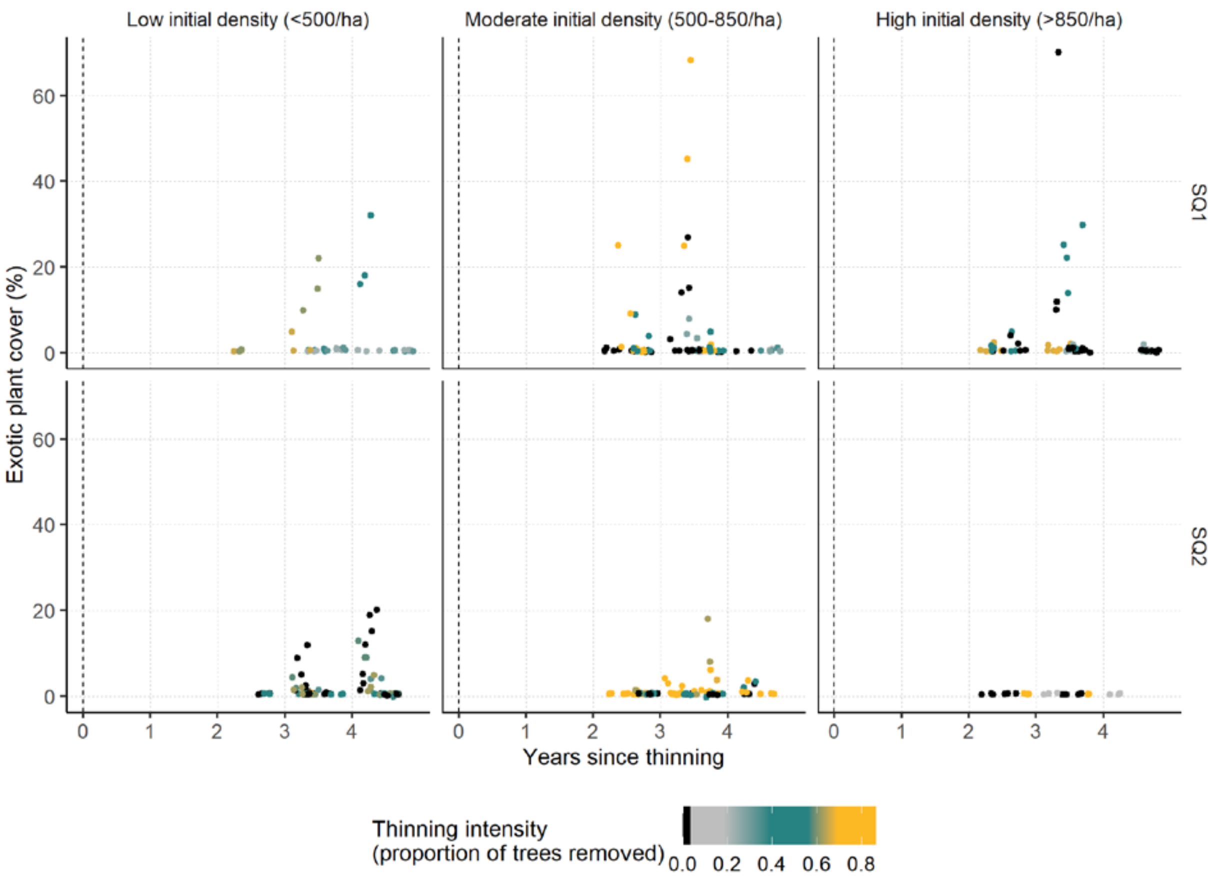

Figure 58 Data for exotic plant cover (%) per 0.04 hectare subplot

Average exotic plant cover was similar across all thinning intensities in 2019 (Table 45). In 2020, average exotic plant cover was substantially higher on moderately and heavily thinned plots in Site Quality 1 (9–10%) than control plots (5%).

Table 45 Average live exotic plant cover (%) in the two most recent survey seasons
Values are rounded to the nearest whole percentage point.

	Thinning intensity	Average cover		Proportion of 0.04 hectare plots with >1% exotic cover	
		2019	2020	2019	2020
SQ1	Control	1%	5%	9%	18%
	Light thinning	1%	1%	15%	4%
	Moderate thinning	2%	9%	22%	44%
	Heavy thinning	2%	10%	19%	50%
SQ2	Control	1%	3%	18%	24%
	Light thinning	1%	2%	17%	33%
	Moderate thinning	1%	2%	14%	29%
	Heavy thinning	1%	2%	18%	21%

Model results

No modelling or statistical analyses were conducted for exotic plant cover.

Plate 5 Paterson's curse (*Echium plantagineum*) in river red gum forest. E Gorrod/DPIE

8.5 Threatened plant species

Key result	No threatened plant species were recorded in the 2020–21 monitoring surveys.

The threatened plant species floating swamp wallaby grass (*Amphibromus fluitans*) was not recorded in 2020–21. This species is listed as vulnerable in the NSW *Biodiversity Conservation Act 2016* and Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*.

The habitat for *Amphibromus fluitans* is almost exclusively aquatic. Its occurrence tends to be temporary, associated with standing floodwaters.

9. Results: Birds

9.1 Bird species richness

Key result	No statistically significant effects of thinning on bird species richness.

Data collection

Birds were surveyed in a 2 hectare subplot within each 9 hectare treatment plot, with visual and auditory observations recorded for 20 minutes on four occasions (two pre-9am and two post-9am where possible). The unique set of bird species recorded on each plot were analysed as the species richness for that survey year.

Four observers conducted all the surveys, two of whom had conducted surveys in previous years. Each observer tended to survey all plots over a period of three or four weeks, without necessarily overlapping in dates with other observers.

Data summary

The number of bird species observed on each 2 hectare subplot was most commonly between 12 and 22 species (Figure 59). Data did not indicate there were differences between the number of birds recorded in the different site qualities.

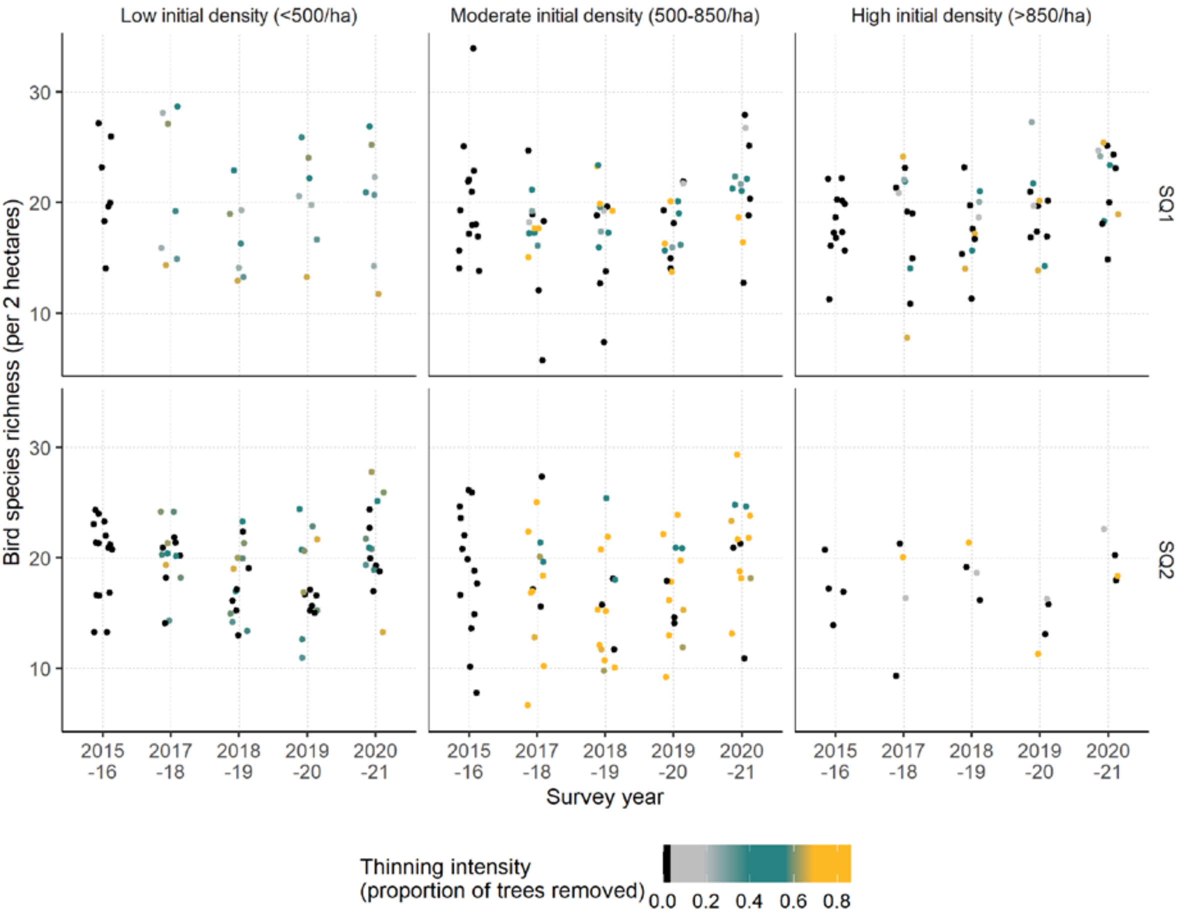

Figure 59 Data for bird species richness (number of unique species recorded in four 20-minute surveys in a 2 hectare subplot within each 9 hectare plot)

Model results

Bird species richness was analysed as a continuous positive variable, using a Gaussian distribution (see Appendix). As bird species richness was calculated from the set of unique species recorded across four occasions in each survey season, time was included in this model as a fixed factor of survey year. Years elapsed was not included, and year was not included as a random factor. All other explanatory variables were included, with all combinations of initial stem density, thinning intensity and site quality. Random effects for site and 9 hectare plot were also included.

Bird species richness changed over time, with different trends depending on initial stem density, which were statistically significant (Table 46; also see Appendix for significance of interaction between year and initial stem density). Many plots had higher richness in 2015–16 and 2020–21 than other survey years.

Thinning increased species richness in Site Quality 1 plots that had very low initial density, but this effect declined over time. Thinning decreased species richness in Site Quality 1 plots that had very high initial density. However, there were no statistically significant effects of thinning (Table 46).

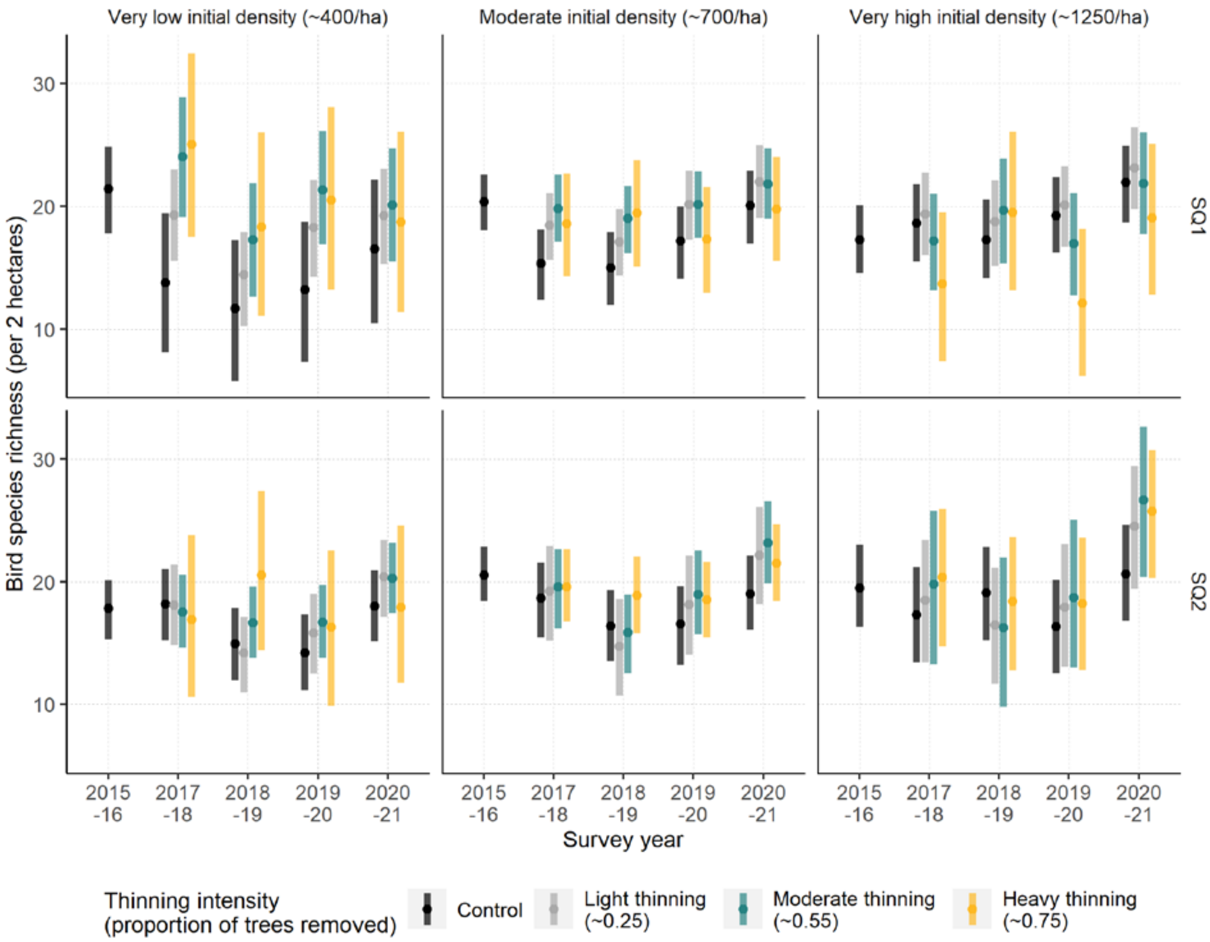

Figure 60 Modelled values and prediction intervals for bird species richness per 2 hectares from four 20-minute surveys

Table 46 Statistical significance of explanatory variables on bird species richness

	Bootstrapped likelihood ratio test significance	Description
Site quality	0.267	Bird species richness did not differ by site quality
Initial stem density	0.069	Bird species richness did not depend on initial stem density
Survey year	0.010	Bird species richness differed with survey year
Thinning intensity	0.129	Bird species richness was not affected by thinning intensity
Does the effect of thinning intensity vary depending on:		
• Site quality	0.198	Thinning intensity did not affect bird species richness
• Initial stem density	0.238	
• Time since thinning	0.475	
• Site quality **and** initial stem density **and** time since thinning	NA	Not included in this model

In 2020–21, four years post-thinning, the fitted value of bird species richness on control plots was between 17 and 22 species.

Although no statistically significant effect of thinning was identified in the model, there was one instance four years post-thinning where the range of predicted values for a thinned plot did not include the fitted value for the control plot. An additional 4 species occurred on moderately thinned Site Quality 2 plots that had moderate initial density (Table 47).

Table 47 Estimated effect sizes for bird species richness four years post-thinning

Site quality		Site Quality 1			Site Quality 2		
Thinning intensity		Low intensity	Mod intensity	High intensity	Low intensity	Mod intensity	High intensity
Initial stem density	Very low (400/ha)	+2.7 –1.3 to +6.5	+3.6 –1.1 to +8.2	+2.2 –5.2 to +9.5	+2.4 –0.9 to +5.4	+2.3 –0.6 to +5.2	–0.1 –6.2 to +6.6
	Moderate (700/ha)	+1.9 –1.0 to +4.9	+1.8 –1.1 to +4.7	–0.3 –4.6 to +3.9	+3.1 –0.9 to +7.0	+4.1 +0.8 to +7.5	+2.5 –0.6 to +5.6
	Very high (1250/ha)	+1.2 –2.2 to +4.5	–0.1 –4.2 to +4.1	–2.9 –9.2 to +3.1	+3.9 –1.2 to +8.8	+6.0 –0.3 to +12.0	+5.1 –0.4 to +10.1

9.2 Threatened bird species

Key result	Thinning is unlikely to have affected the occurrence of threatened bird species, although no tests of statistical significance were conducted. Eight threatened bird species were recorded in 2020–21, including the swift parrot, which had not been previously recorded in these surveys.

Data collection

Data collection was as described above for bird species richness.

Data summary

Ten bird species listed as vulnerable under the NSW Biodiversity Conservation Act have been recorded in two or more survey years (Table 48). Seven of these were recorded in the most recent 2020–21 surveys. In addition, swift parrots were observed in one control plot in the most recent surveys. This species had not been previously recorded in ecological thinning monitoring surveys.

Table 48 Threatened bird species recorded

Name	Habitat	Number of 9 hectare plots				
		2015	2017	2018	2019	2020
Black-chinned honeyeater	Found in drier open forests and woodlands. Large feeding territories; species locally nomadic. Forages in upper branches, trunks and canopy; feeds on insects and nectar. Nests high in the crown of a tree.	1	–	–	1	–
Brown treecreeper	Found in river red gum forest bordering wetlands. Fallen timber is important for foraging. Nests in standing dead or live trees and tree stumps.	32	42	37	38	33
Dusky woodswallow	Forest with open or sparse understorey and groundcover of grasses, sedges or fallen woody debris. Forages primarily over leaf litter and dead timber.	9	7	9	12	8
Hooded robin	Prefers lightly wooded vegetation. Requires structurally diverse habitats. Perches on low stumps and branches to forage. Nests in tree fork or crevice.	1	2	–	2	1

Name	Habitat	Number of 9 hectare plots				
		2015	2017	2018	2019	2020
Little eagle	Found in eucalypt forest and riparian woodlands. Nests in tall living trees. Soars above trees or swoops from trees to take prey from the ground, trees or bushes.	1	1	–	–	1
Painted honeyeater	Occurs in box-gum woodlands and other inland slopes vegetation. Nomadic. Specialist feeder on the fruits of mistletoes. Nests in the outer canopy of drooping tree foliage.	–	–	1	1	–
Scarlet robin	Abundant logs and fallen timber. Forages from low perches or the ground; sometimes the shrub or canopy layer. Nests are often found in a dead branch in a live tree, or a dead tree or shrub.	29	21	29	19	18
Superb parrot	Feeds on the ground and in understorey shrubs and trees. Nests in the hollows of large trees (dead or alive).	3	1	2	3	7
Swift parrot	Migrate from Tasmania to the Australian mainland where they are nomadic and mainly occur where eucalypts are profusely flowering or there are abundant lerp infestations.	–	–	–	–	1
Varied sittella	Eucalypt forests with mature smooth-barked gums with dead branches. Forages in crevices in bark, dead branches and dead trees. Nests in an upright tree fork high in the canopy.	5	4	11	11	13
White-bellied sea eagle	Large areas of open water. Breeds in mature tall open forest close to foraging habitat. Nests in large emergent eucalypts often with emergent dead branches or large dead trees nearby.	2	–	2	1	–

When the data for thinned plots were divided into thirds based on thinning intensity, the only potential effect of thinning was a temporary increase in the occurrence of brown treecreepers in heavily thinned plots in Site Quality 2 (Figure 61). This effect appears to have diminished over time.

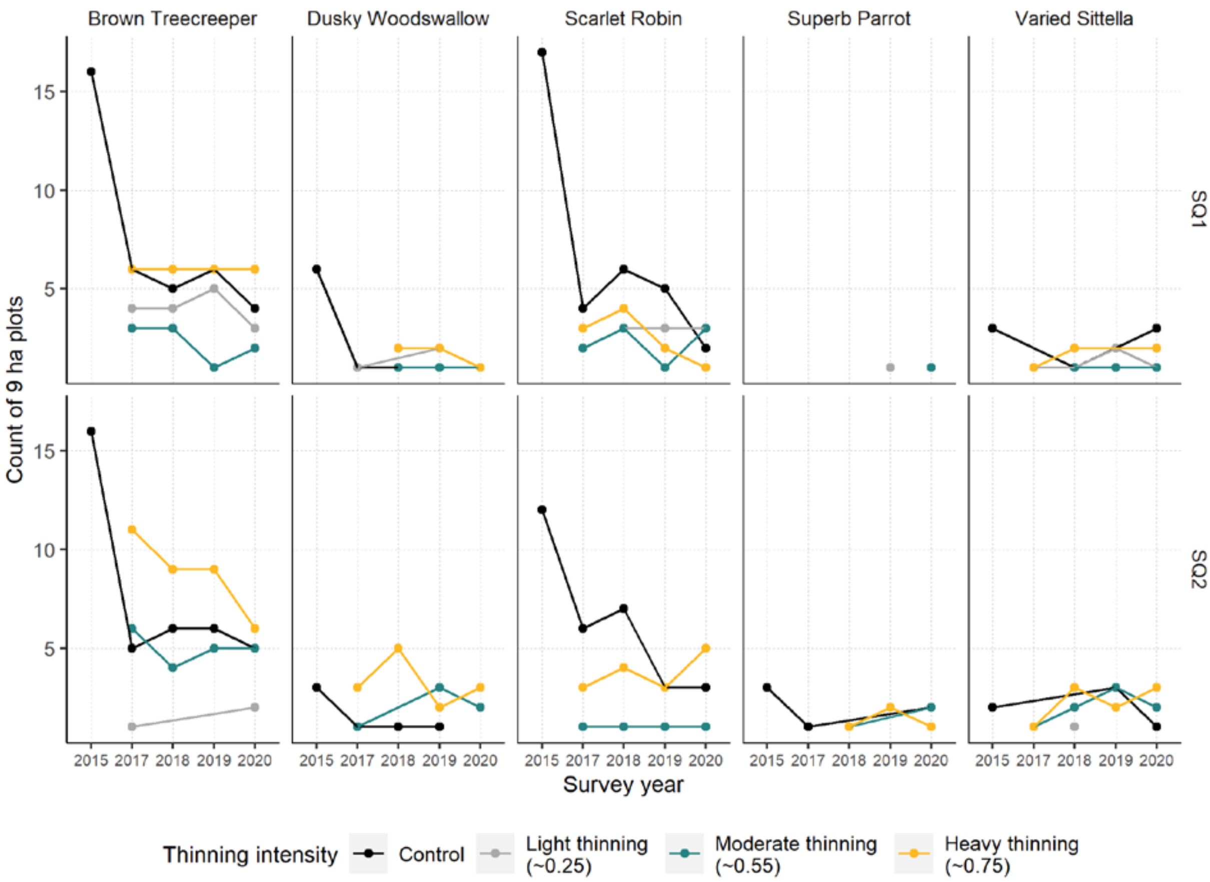

Figure 61 Number of 9 hectare plots that each threatened bird species was recorded in during each survey year

Excluding five threatened bird species that were recorded a maximum of two times in any survey.

10. References

Baur G 1984, *Notes on the silviculture of major NSW forest types, No. 5, River red gum types*, Forestry Commission of NSW, Sydney.

Bowen S, Powell M, Cox SJ, Simpson SL and Childs P 2012, *Riverina red gum reserves mapping program – Stage 1*, NSW Office of Environment and Heritage, Sydney.

Gorrod EJ, Childs P, Keith DA, Bowen S, Pennay M, O'Kelly T, Woodward R, Haywood A, Pigott JP and McCormack C 2017, Can ecological thinning deliver conservation outcomes in high-density river red gum forests? Establishing an adaptive management experiment, *Pacific Conservation Biology*, vol.23, no.3, pp.262–276.

Gorrod E, Travers S, Ellis M, Hope B, McAllister D, Val J, O'Kelly T and Curtis E 2020, *River red gum ecological thinning trial: Monitoring report 2020*, NSW National Parks and Wildlife Service, Hurstville.

Hines F, Tolhurst KG, Wilson AAG and McCarthy GJ 2010, *Overall fuel hazard assessment guide: Fire and adaptive management*, Report no. 82, 4th edition, July 2010, Victorian Department of Sustainability and Environment, Melbourne.

Murray–Darling Basin Authority, *River Murray data*, accessed 31 March 2021, riverdata.mdba.gov.au/edward-river-offtake.

OEH 2012, *Ecological thinning trial in New South Wales and Victorian River Red Gum forests: Experimental design and monitoring plan*, NSW Office of Environment and Heritage, Sydney, available at www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Parks-reserves-and-protected-areas/River-red-gums/ecological-thinning-trial-river-red-gum-forests-public-environment-report-appendices.pdf.

OEH 2014, *Public Environment Report: Ecological thinning trial in New South Wales River Red Gum Forests*, NSW Office of Environment and Heritage, Sydney, available at www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Parks-reserves-and-protected-areas/River-red-gums/ecological-thinning-trial-river-red-gum-forests-public-environment-report-140621.pdf (PDF 17MB).

OEH 2017, *River red gum pre-ecological thinning monitoring report 2017*, NSW Office of Environment and Heritage, Sydney, available at www.environment.nsw.gov.au/research-and-publications/publications-search/river-red-gum-pre-ecological-thinning-monitoring-report-2017.

OEH 2018, *River red gum ecological thinning trial monitoring report 2018*, NSW Office of Environment and Heritage, Sydney, available at www.environment.nsw.gov.au/research-and-publications/publications-search/river-red-gum-ecological-thinning-trial-monitoring-report-2018.

OEH 2019, *River red gum ecological thinning trial monitoring report 2019*, NSW Office of Environment and Heritage, Sydney, available at www.environment.nsw.gov.au/research-and-publications/publications-search/river-red-gum-ecological-thinning-trial-monitoring-report-2019.

R Core Team 2019, *R: A language and environment for statistical computing*, R Foundation for Statistical Computing, Vienna, Austria.

Scarth P, Armston J and Danaher T 2008, 'On the relationship between crown cover, foliage projective cover and leaf area index', in R Bartolo and A Edwards (eds), *Proceedings of the 14th Australasian Remote Sensing and Photogrammetry Conference*, *29 September to 3 October 2008*, *Darwin NT,* Spatial Sciences Institute, Australia.

Schonau APG and Coetzee J 1989, Initial spacing, stand density and thinning in eucalypt plantations, *Forest Ecology and Management*, vol.29, pp.245–266.