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FINAL REPORT

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Gunbower Forest Tree Assessment 2005 - 2017

A review of demographic and condition data for Red Gum, Black Box and Grey Box populations

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NORTH CENTRAL Catchment Management Authority
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This document has been prepared specifically for the North Central Catchment Management Authority and details the findings of a review of data collected by the authors as part of other studies completed for the Murray Darling Basin Authority's (MDBA) The Living Murray (TLM) program; specifically, the 'Stand Condition' and 'Wetland and Understorey Condition' monitoring programs. It should not be relied upon by other parties for any other purpose without the permission of the authors.

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EXECUTIVE SUMMARY

The floodplains of Gunbower Forest are characterised by extensive Red Gum and Box forests and woodlands. Since 2005, on-ground surveys of these vegetation types have occurred at a (largely) annual sampling interval. The surveys have yielded demographic data that describe the health and structure of each forest type, and their constituent canopy species. A review and analysis of this data, collected as part of the TLM Stand Condition Assessment Program (2010 – 2017) and Sentinel Wetland and Understorey Vegetation Condition Monitoring Program (2005 – 2017), was completed in August 2017. The purpose of the review was to describe the structure and growth of sampled populations from 2005 to 2017.

The core components of the study were descriptive and statistical analyses of each dataset, and collation of available data from other studies specific to the Murray-Darling Basin floodplains. The latter, to provide context for interpreting the demographic data collected at Gunbower Forest. The principal themes explored were temporal change in tree density, basal area, population structure, recruitment, and tree growth. The relationship between tree growth and flood frequency was also examined. The study focused on Red Gum (*Eucalyptus camaldulensis*) and Black Box (*E. largiflorens*) populations; however, where data permitted, Grey Box (*E. microcarpa*) populations were also investigated. Both quantitative site-based measures such as basal area, and tree-scale measures including crown extent were derived. Total tree density, and size-class frequency distributions, were also employed as descriptors of stand and population structure.

The review yielded evidence to suggest that Red Gums, Black Box and Grey Box trees were recruiting and growing, and in the case of the former two species, were likely to comprise sustainable population structures. In both Red Gum and Black Box populations, it was found that growth rates were effected by crown condition (i.e. trees with a *healthy* crown at the beginning of the monitoring period grew faster than those with a *poor* crown). For Red Gums, flood frequencies of more than two years in an 8-year period, were also found to promote growth (i.e. trees in this flood class grew faster than those at non-flooded sites, and faster than those at sites that were flooded at a lower frequency).

Notably, in 2017, less than half of the sampled trees supported healthy canopies. This alone, suggests that interventive management remains warranted, and that the forests and woodlands of Gunbower Forest are likely to require more water for continued growth and population maintenance. Extant tree density was also found to differ markedly from natural tree density prior to European settlement, and was substantially higher than that estimated for similar floodplain forests at this time. Saliently, however, there was considerable inter-site variability in all the derived metrics, and, some of the observed patterns may be a consequence of sample size. Larger plots, and sampling all forest types at the same intensity may reveal different trends, and yield different levels of inter-site variability.

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1.0 INTRODUCTION

1.1 Project Context

In the context of the Murray-Darling Basin, the relationship between the growth and health of floodplain trees, and flood frequency and duration, has been subject to extensive study (see for example, Bacon *et al*.1993; George *et al*. 2005; Jensen, 2006; and Doody *et al.* 2014). Synopses of the water requirements of individual floodplain species are provided by Johns *et al.* (2009), Rogers (2011), and Roberts and Marston (2011). Saliently, the appropriate application of such knowledge is perceived as fundamental to successful interventive forest management in a changing climate (George *et al*. 2005). Parameters such as stand structure are of similar importance. Johns *et al.* (2009 p. 6), report that "differences in tree density between sites will affect the frequency of flooding required to maintain growth and health." While Taylor *et al.* (2016, p. 122), assert that an understanding of tree and stand structure is "essential to effective vegetation management and habitat conservation."

Various metrics have been employed to describe the structure and condition of stands and trees across the basin. Several authors have evaluated the effectiveness of these, with the utility of quantitative site-based measures such as basal area, and tree-scale measures including crown extent, espoused by Cunningham *et al.* (2007). George (2004) has also adopted basal area, coupled with total tree density, and size-class frequency distributions, as descriptors of stand and population structure. Additionally, the latter were used to make inference regarding on-going population viability.

1.2 Project Objectives

The floodplains of Gunbower Forest are characterised by extensive Red Gum and Box forests and woodlands. Since 2005, on-ground surveys of these vegetation types have occurred at a (largely) annual sampling interval. The surveys have yielded demographic data that describe the health and structure of each forest type, and their constituent canopy species. To date, the extraction of information from these surveys has been limited to the computation of crown health indices, where these were used to report on Icon Site ecological objectives (see Bennetts *et al.* 2017). From 2010, predictive modelling of stand condition at the floodplain scale, using the stand condition assessment tool developed by Cunningham *et al*. (2011), has also been completed (MDBA, 2016). The modelling utilises metrics including live basal area, mean crown extent and plant area index to inform stand condition, and is validated by ground survey.

The purpose of the current study was to review and analyse existing tree data, and subsequently to describe the structure and growth of sampled populations from 2005 to 2017. A secondary component of the study was to, where appropriate, compare the resulting findings with those of other similar forests. The study expands on works previously completed by Fire, Flood and Flora (Bennetts *et al.* 2017; Bennetts and Jolly, 2017). The core themes explored were temporal change in tree density, basal area, population structure, recruitment, and tree growth. The relationship between tree growth and flood frequency was also examined. The review focused on Red Gum (*Eucalyptus camaldulensis*) and Black Box (*E. largiflorens*) populations; however, where data permitted, Grey Box (*E. microcarpa*) populations were also investigated. Saliently, no new data were collected during the study; data collected as part of *TLM Stand Condition Assessments* (2010 – 2017) and *Sentinel Wetland and Understorey Vegetation Condition Monitoring Program* (2005 – 2017) were solely used to inform changes in tree demography and condition from 2005 to 2017.

Figure 1 Red Gum forest and woodlands of Gunbower Forest: Riverine Grassy Woodland, April 2012 (top); Sedgy Riverine Forest, April 2013 (bottom left); flooded Riverine Swampy Woodland, April 2012 (bottom right)

Figure 2 Black and Grey Box woodlands of Gunbower Forest: Riverine Chenopod Woodland with *Eucalyptus largiflorens* canopy near Black Swamp, April 2014 (top); Riverine Chenopod Woodland with *E. largiflorens* canopy at understorey site 111A, March 2017 (middle); and Plains Woodland with a *E. microcarpa* canopy, at understorey site 134A, March 2017 (bottom)

2.0 METHODS

2.1 Study Area

Gunbower Forest (35° 39' S to 36° 00' S, 144° 08' E to 144° 30' E) is a large (19,450 ha) narrow forest located on the River Murray floodplain in northern Victoria, between the townships of Koondrook and Torrumbarry. Mean annual precipitation for the region is 373.8 mm (Kerang Station 80023 - 1880 to 2017), with mean minimum and maximum annual temperatures of 9.4 of 22.9 ºC, respectively.

Twenty-five permanent 0.25 ha plots (50 m x 50 m) were established in 2009 by Monash University as part of the *TLM Stand Condition Assessment Program* (Souter *et al.* 2012). The sites were stratified to capture the diversity of forest types and landscape positions in the forest. They sample River Red Gum Forest, River Red Gum Woodland, and Black Box Woodland, and landscape positions ranging from riverside to floodway channels, floodplain and gilgai.

Eighty permanent 0.01 ha plots (10 m x 10 m) were established in 2005 by Brett Lane and Associates as part of the *Sentinel Wetland and Understorey Vegetation Condition Monitoring Program*, with a further 30 sites added by Australian Ecosystems in 2008 (Crome, 2004b). The sites were stratified in a random pattern (based on location), and by water regime class. They sample Red Gum forest with flood dependent and flood tolerant understorey, and Black Box and Grey Box woodlands, and were designed to monitor the condition of understorey vegetation and eucalypt health.

The monitoring sites from both programs have been subject to inundation to varying extents, depths and durations over the past decade; where floodwaters were of both natural and artificial origin (see Bennetts *et al.* 2017).

2.2 Data Acquisition and Analysis

Data collected as part of the *TLM Stand Condition Assessment Program* (2010 – 2017) and *Sentinel Wetland and Understorey Vegetation Condition Monitoring Program* (2005 – 2017) were reviewed. For the latter, the review was limited to the tree components of the understorey program, and only autumnal records were considered.

In summary, the datasets comprised the following variables for the respective monitoring periods. For each stand condition site: a live/dead assessment and a measurement of the DBH of all trees with DBH > 10cm; and, a crown extent value for the 30 permanently marked trees within the plot. For the understorey sites, individuals within each plot were classified according to the following age/size classes: seedling <0.25 m in height; sapling 0.25 m – 3 m in height; sapling/pole >3 m in height and <10 cm DBH; tree >3 m in height and >10 cm DBH. For each site, there was: a count of the number of seedlings; an estimation of the height of each sapling; DBH measurements and crown condition assessments for all saplings >3 m in height and for all trees; and crown condition assessments for the 20 permanently marked trees, where upon occasion the latter fell outside the bounds of the defined plot.

Interrogation of the datasets yielded the metrics itemised in Table 1 for each forest type, tree species and sample year (as applicable). Definitions for these metrics are provided in Section 3.0 and 4.0.

For each site, the flood frequency was also tallied (i.e. the total number of years that a site was flooded in the specified monitoring period), and differences in response to this variable were explored. Flood frequency was grouped into three intervals: not flooded; flooded 1 – 2 years; and flooded > 2 years. Note, that flood frequency is *observed* frequency, and was garnered from evidence of flooding that was recorded during field assessments; it does not take into account flood depth, duration or seasonality, nor distinguish between the source of flooding (i.e. natural or artificial).

Tests were completed to determine the statistical significance of several of the observed trends. A one-way ANOVA was conducted to compare the effect of sampling year on the total basal area of all sampled trees (Appendix 2). The differences in growth rates between species (t-test), and the effect of flood frequency and initial crown condition on growth rates (one-way ANOVA and post hoc comparisons using the Tukey HSD test), were also examined (Appendix 4).

Table 1 List of metrics derived from TLM Stand Condition Assessment and Sentinel Wetland and Understorey Vegetation Condition Monitoirng Programs

Theme and Metric	Stand Condition Dataset (n = 25 sites)	Understorey Dataset (n = 110 sites)
Tree Density		
Number of live and dead trees	all trees > 10 cm DBH per 0.25 ha plot	-
Density of trees per hectare	all trees > 10 cm DBH per 0.25 ha plot	-
Basal Area		
Total live and dead basal area per site (m^2 ha^{-1})	all trees > 10 cm DBH per 0.25 ha plot	-
Proportion of live basal area per site (%)	all trees > 10 cm DBH per 0.25 ha plot	-
Population Structure		
Total number of individuals by age class	-	all individuals per 0.01 ha plot
Proportion of sites where each age class was present (%)	-	all individuals per 0.01 ha plot
Height class frequency distributions (15 cm increments)	-	all saplings per 0.01 ha plot
Size class frequency distributions (10 cm increments)	all trees > 10 cm DBH per 0.25 ha plot	all saplings and trees per 0.01 ha plot
Size class frequency distributions by stand density	all trees > 10 cm DBH per 0.25 ha plot	-
Total number of Large Old Trees	all trees > 10 cm DBH per 0.25 ha plot; classified by EVC benchmark	-
Tree Growth		
Mean (quadratic) DBH per site (cm)	all trees > 10 cm DBH per 0.25 ha plot	-
Annual incremental change in DBH(OB) (cm yr^{-1})	permanently marked trees (n = 30) within each plot from the crown condition survey	permanently marked trees (n = 20) within^ each plot from the crown condition survey
Total change in DBH(OB) for monitored period (cm 9 yr^{-1})	permanently marked trees (n = 30) within each plot from the crown condition survey	permanently marked trees (n = 20) within^ each plot from the crown condition survey
Mean crown extent per site (%)	permanently marked trees (n = 30) within each plot from the crown condition survey	-
Proportion of trees in each crown extent/condition class	permanently marked trees (n = 30) within each plot from the crown condition survey	permanently marked trees (n = 20) within^ each plot from the crown condition survey

^where fewer than 20 trees fell within the bounds of a plot, then the crown condition survey was supplemented with those trees nearest the plot

A representative set of results from the exploratory analyses are provided in Appendices 1 – 4, with a subset of these presented in the main document. In some instances, counts (of the number of individuals) are presented rather than the proportion of sites in each category/class. This is due to the low number of monitoring sites in some forest types. Here, while the presentation of proportions would normalise differences in sample size between the forest types, for those less intensively sampled types, it may suggest a more robust population than was sampled.

2.3 Limitations of Available Data

Notably, as a consequence of using archival data, the selection of analyses and reporting measures was governed by the variables stipulated in the survey methodologies for each program; namely Crome (2004a; 2004b) and Souter *et al.* (2012). Further, the different variables measured as part of each monitoring program necessitated that different metrics be explored using each dataset, and while some variables were measured as part of both programs, different techniques/measurement scales were routinely adopted (for example to assess crown extent/condition).

Pertinently, plot size, as well as the number of sites sampled differed markedly between the programs, and both were limiting factors with regard to making broader inference regarding forest health for Gunbower Forest. For some measures, these disparities, as well as site position within the landscape, resulted in a lack of correlation between trends identified in the two datasets. Such differences, and fundamentally, the different age/size classes sampled by each program, also prohibited the pooling of all data and tabulation of metrics on a larger aggregated dataset. Overall, however, there were sufficient replicates in the stand and understorey datasets to calculate site and tree based metrics for Red Gum and Black Box forest and woodlands. Conversely, the paucity of Grey Box trees contained in the sampled plots hindered robust derivation of some metrics. Further, as this forest type was not sampled as part of the stand condition program, it was not possible to tabulate site based metrics such as total basal area.

Other analytical limitations pertained to the unequal number of sites in each (observed) flood class, and the absence of empirical data on this explanatory variable at the site level, including the scarcity of quantitative data on source, duration, depth, and interval between flooding. Furthermore, as there were no control and impact/treatment sites, it was only possible to make *inference* regarding the effect of flooding rather than determine *causality*.

Notably, a third set of monitoring sites were established in Gunbower Forest in 2009 as part of the *TLM Tree Condition Assessment Program.* These data were, however, excluded from the review, as sampling was not completed at the same interval as for the other programs, and was last undertaken in 2014, and thus cannot inform current structure or condition.

3.0 LITERATURE REVIEW

3.1 Structure of Literature Review

A summary of empirical research on Red Gum, Black Box and Grey Box tree demographics is presented in the section that follows. The referenced studies are specific to the Murray-Darling Basin (MDB) floodplains, and were grouped into the themes: tree density; basal area; population structure; and tree growth. The purpose of reviewing these largely comparable studies, was to provide context for interpreting the demographic data collected at Gunbower Forest from 2005 to 2017 (see Section 4.0).

For additional information on these eucalypts, their ecology, water regime requirements and history, refer to the following:

Di Stefano J (2002) River red gum (Eucalyptus camaldulensis): a review of ecosystem processes, seedling regeneration and silvicultural practice. *Australian Forestry* **65** (1) 14 – 22.

Frood D and Papas P (2016) A guide to water regime, salinity ranges and bioregional conservation status of Victorian wetland Ecological Vegetation Classes, Arthur Rylah Institute for Environmental Research, Technical Report Series No. 266, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Roberts J and Marston F (2011) Water regime for wetland and floodplain plants: a source book for the Murray–Darling Basin, National Water Commission, Canberra.

Rogers K (2011) Vegetation. In Floodplain wetland biota in the Murray-Darling Basin: Water and Habitat Requirements (Eds Rogers K and Ralph TJ) pp 17-82, CSIRO Publishing, Victoria.

VEAC (2006) River Red Gum Forests Investigation Discussion Paper, Victorian Environmental Assessment Council, Melbourne.

Other seminal studies include that by Johns *et al.* (2009), who provide a synopsis of watering requirements fundamental to tree growth and health, and discuss the implications management intervention; namely flow management including environmental watering. Notably, the majority of published literature pertains to Red Gums, and scant information was available for Black and Grey Box trees, especially in a floodplain context.

3.2 Tree Density

The number, age and arrangement of trees distinguish woodland from forest and intact ecosystems from degraded ecosystems. Tree density, a count of trees and/or coppiced stems per hectare, is one means of quantifying the number and arrangement of trees.

Gunbower Forest

In 1874 Gunbower Forest was mapped with a range of tree densities from open to dense. Included were descriptions such as "Red Gum forest, very dense, abounding with swamps, reed beds and small lagoons" (north-west end), "Red Gum Forest … timber in dense and open belts alternatively" (low, swampy areas east of Little Reedy Lagoon) and "Red Gum, tolerably open with fair grazing" (towards Nursery Bend) (Moorhouse, 1874). Black Box was typically described as "very dense and scrubby Box Forest" and Grey Box, simply, as "Box Forest" (Figure 1).

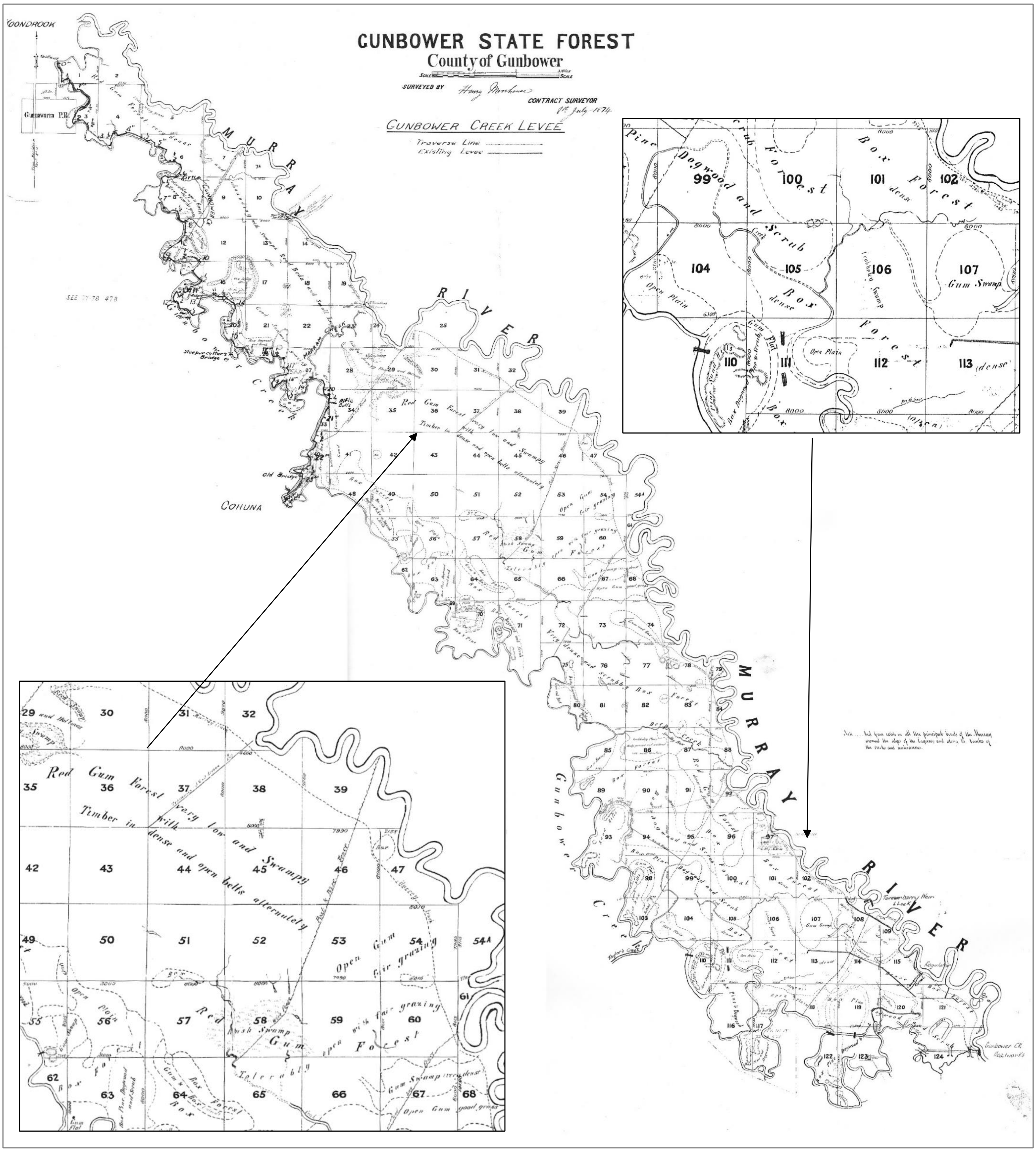


Figure 3 Survey map of Gunbower State Forest July 1874 (source: Moorhouse, 1874)

Subsequent flooding and timber harvesting are reported to have promoted dense regeneration of Red Gum (Perrin as cited in Russel and McGowan n.d.). Ringbarking large and difficult to harvest trees was common practice in Gunbower Forest in the late 1800s and 1900s. The aim was to remove trees with large 'zones of influence' and encourage new regeneration (Di Stefano, 2001). Forest management practices now require, within the Mid Murray Management Zone (including Gunbower Forest) the retention of 20 trees 50 - 100 cm in DBH in every 10 ha, along with all trees over 100 cm DBH (DEPI, 2014).

Murray-Darling Basin

Red Gums, Black Box and Grey Box in the MDB grow at a range of densities from thickets to well-spaced woodlands (Table 2). The lowest tree densities reported were 1 tree ha^{-1} (agricultural landscape) and 8 trees ha^{-1} (site with severe dieback). The highest tree densities reported were 8000 trees ha^{-1} (plantation) and 756 trees ha^{-1} (Victorian floodplains). Cunningham *et al*. (2010) reported high density stands (e.g. >800 trees ha^{-1}) were relatively uncommon in their assessment of 176 Victorian floodplain sites. Furthermore, a study of tree stumps remaining from the late 1800s in Millewa Forest by McGregor *et al.* (2016), indicates pre-European Red Gum floodplain tree densities were as low as 17 trees ha^{-1}.

Table 2 Published number of tree/stems per ha for Red Gum, Black Box and Grey Box species in the Murray-Darling Basin

Location	Stem/Trees per ha	Comments	Source
River Red Gum			
Floodplain forest River Murray Millewa Forest, NSW	17	Historical stem number - determined by stumps or stags likely to have been cut during the late 1800s.	McGregor *et al.* (2016)
	147	2016 stem number (note, likely to be higher than tree density). Stem density has increased 9-fold.	
Floodplain River Murray Banrock Station South Australia	25.1	Stems > 10 cm DBH Mature trees were found to be more widespread than younger stages (pole, saplings and seedlings).	George *et. al.* (2005)
	44.4	Stems < 10 cm Pole trees were concentrated where water accumulates from river flows or run-off from surrounding cliff faces and irrigation areas.	
Floodplains River Murray Ovens River Goulburn River Victoria	16 - 756	Surveys of 176 sites suggests high-density stands (e.g. >800 trees ha^{-1}) are rare along the Victorian Murray River probably due to long-term logging practices and the scarcity of the flooding events necessary to establish dense stands.	Cunningham *et al.* (2010)
Riparian and floodplain woodlands Lower Namoi River Northern NSW	8 - 22	Tree number in floodplain sites with tree dieback classed as severe.	Smith and Renton (2017)
	15 - 464	Tree number in riparian and floodplain sites with tree dieback classed as intermediate to healthy	
	120 - 216	Tree number in riparian sites with tree dieback classed as intermediate to healthy	
Floodplain Murray River Barmah-Millewa Forest	732	After 42 years, the median DBH was 22.0 cm.	Horner *et. al.* (2010)
	470 - 732	The number of trees was thinning to 7 trees ha^{-1}. After 42 years, the median DBH was 48.4cm.	
Black Swamp, River Murray Barmah-Millewa Forest	8000	Planted density (highest). After 42 years, the mean DBH was 9.2 (± 0.7) cm. Drought post 1996 resulted in dramatic decrease in live trees.	Horner *et. al.* (2009)
	600	Lowest tree planting density. After 42 years, the mean DBH was 25.1 (± 1.5) cm. Drought post 1996 resulted in little change to density.	
Mixed Species			
Plains or Riparian vegetation Central NSW	1 – 277 (mean: 35 ± 39)	10 eucalypt species (94% of trees were: *Eucalyptus camaldulensis*, *E. melliodora* (yellow box), *E. microcarpa* (grey box) and *E. populnea* subsp. *bimbil* (poplar box), however the sample also included *E. largiflorens*)	Taylor *et al.* (2016)
Black Box			
Floodplain River Murray Banrock Station South Australia	14.0	Stems > 10 cm	George *et. al.* (2005)
	4.2	Stems < 10 cm	

One study into the Red Gum regeneration in Barmah-Millewa Forests found evidence of high density stands limiting growth in girth. Here, Horner *et al.* (2010) report that sites planted with 4000 trees ha^{-1} were after 42 years (2007) dominated by trees less than 30 cm in DBH, whereas sites that were thinned to 270 trees ha^{-1} were, after the same time period, dominated by trees over 30 cm in DBH (Figure 4). Furthermore, greater mortality was observed in the higher density stands (Horner *et al.* 2009).

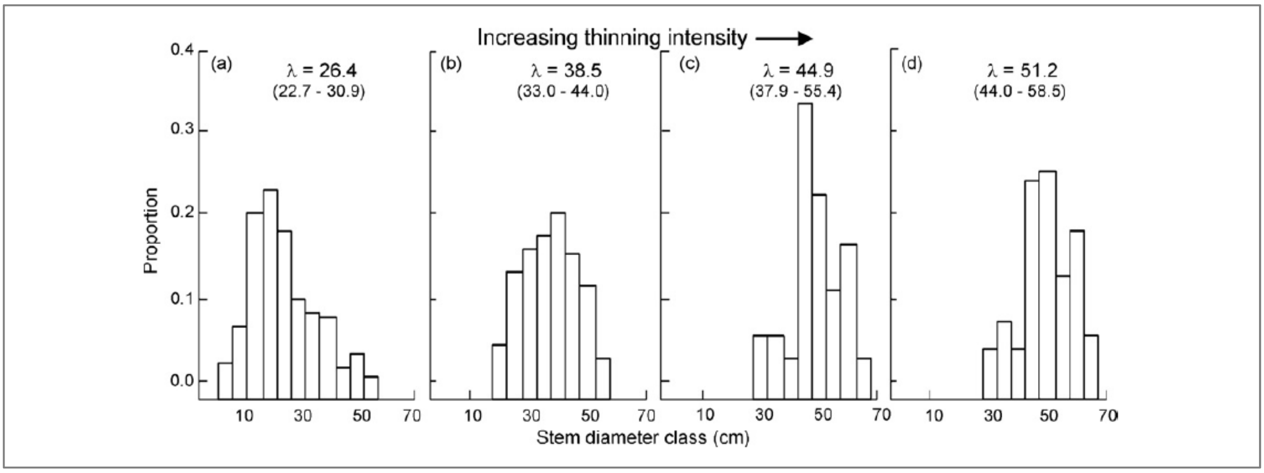


Figure 4 Stand size distribution in 2007 for 4000(a), 750 (b), 560 (c) and 270 trees ha^{-1} (d) treatments. Proportions are treatment means. Estimates of Weibull scale (λ) are included with 95% credible intervals in parentheses (source: Horner *et al.* 2010)

3.3 Basal Area

Basal area (BA) is a common forest management term that refers to the area that trees occupy at a given site. In other words, it is a cross-section of the forest or woodland at 1.3 m (DBH). It is a site based measure employed to summarise stem frequency and diameter information, and provides a useful measure of competition (Brack, 1999). Cunningham *et al*. (2017 p. 693) also assert BA “takes into account the greater importance of larger trees to nutrient cycling”, and hence BA can be applied as a measure of ecosystem productivity. Notably, sites with a few large sized trees can have a similar BA to sites with many small trees.

Gunbower Forest

Two 0.4 ha permanent growth plots were established near Threader (P2) and Wee Wee Rup (P3) tracks in Gunbower Forest in 1959. Plot treatment details include thinning in 1929 and 1956, followed by periodic harvesting which resulted in a mosaic of original trees, coppiced trees, and natural regeneration (VicForest, 2008).

BA (under bark) was measured in the P2 growth plot in 1979 at 25.8 m^2 ha^{-1} and in 1982 at 27.3 m^2 ha^{-1} (VicForest, 2008). This indicates 2% annual growth in BA over the three years, on which the following was reported: “The low growth rate during the last period has been attributed to a lack of forest flooding and associated water stress. This will have an impact on the sustainable harvest levels” (VicForest, 2008).

Koondrook-Perricoota Forest

Thirty-five 0.4 ha permanent growth plots were established in Koondrook-Perricoota Forest by the Forestry Corporation of NSW. When measured in 2015, BA (over bark) at these Red Gum sites ranged from 8.5 m^2 ha^{-1} to 53.2 m^2 ha^{-1} (Forestry Corporation of NSW, 2017).

Murray-Darling Basin

The BA of Victorian floodplains varied from 3 to 110 metres^2 ha^{-1} (Cunningham *et al*. 2010, Table 3). McGregor *et al.* (2016) estimate the BA of floodplain sites in Millewa Forest would, in the late 1800s, have been 13 m^2 ha^{-1}. The BA for the same Millewa sites in 2006 was 18% higher (e.g. 15.3 m^2 ha^{-1}, McGregor *et al.* 2016).

Table 3 Published basal area values for Red Gum, Black Box and Grey Box vegetation in the Murray-Darling Basin

Location	Basal Area (m^2) per ha	Comments	Source
River Red Gum			
Floodplain forest River Murray Millewa Forest NSW	13.0	Historical estimate - calculated from size and density of stumps or stags likely to have been cut during the late 1800s.	McGregor *et al.* (2016)
	15.3	2016 data, the culmination of lots of small trees.	
Floodplains River Murray Ovens River Goulburn River Victoria	3 - 110	Based on surveys of 176 sites, which included open forests and woodlands inundated at a range of frequencies. Stand condition improved with basal area.	Cunningham *et al.* (2010)
Mixed Species			
Plains or Riparian vegetation Central NSW	4.43 – 21.43	*Eucalyptus camaldulensis, E. melliodora* (yellow box*), E. populnea* (poplar box) and *E. largiflorens* (black box)	Taylor *et al.* (2014)

3.4 Population Structure

Gunbower Forest

The extant tree population in Gunbower Forest is the product of over 150 years of timber harvesting interacting with flooding. Reports from district foresters in 1878 suggested that only limited untouched forest remained on Gunbower Island (Kennedy, 1878) and that the river front, in particular, had been 'worked' for an average of 2 miles from the bank (Wallis, 1878). Dense regeneration was however observed after flooding, and by 1890, Gunbower Forest was described as having 'degenerated into a whipstick scrub' dominated by saplings (Perrin as cited in Russell and McGowan n.d.). Most trees in the central Murray region are thought to have germinated in response to flooding between the late 1800s and early 1900s (OEH and Parks Victoria, 2009).

The tree diameter distribution for the permanent growth plot (P2) near Threader Track, indicates the majority of trees were, in both 1979 and 1982, less than 25 cm in diameter (VicForest, 2008, Figure 5). It is likely some such stems were coppice regrowth following harvesting rather than regeneration.

Date	Plot	0-12	12-24	24-36	36-48	48-60	60-72	72-84	84-96	96-108	108-120
12/1979	2	111	68	4	5	15	8	3			
7/1982	2	105	69	8	4	14	9	4			

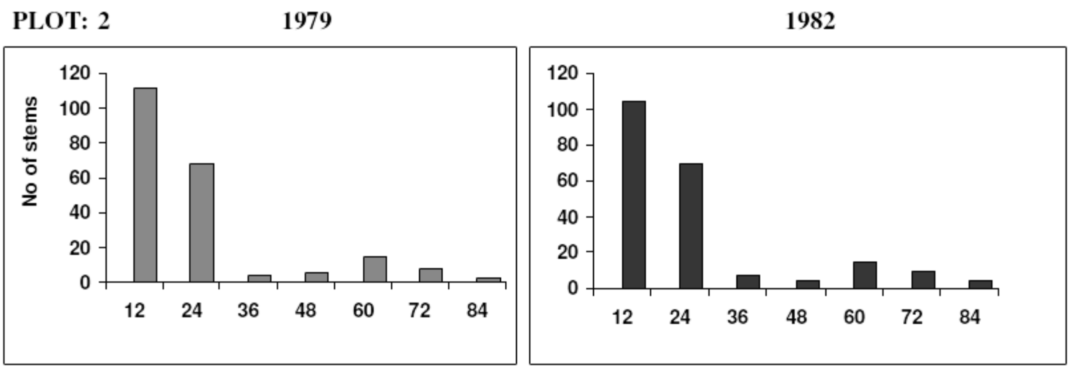


Figure 5 Size class frequency distribution for permanent growth plot (P2) near Threader Track (source: VicForest, 2008)

TLM Stand condition sites

Tree population structure is often reported as the number of individuals in given size classes. It generally holds true that the larger the trees' girth, the older it is, although there are exceptions to such rules. For example, Black Box saplings, believed to have germinated on the Chowilla floodplain remained approximately 150 cm high and only 2 cm in DBH for more than 50 years (George, 2004). Further to the above, the tree populations in Gunbower Forest include the ringbarked 'ghosts' from the past.

The TLM stand condition data for Barmah-Millewa indicates that a range of trees in each DBH size class were recorded in each tree density category (Figure 6). Numerically, the distribution plots were skewed towards more smaller trees and less larger trees (OEH and Parks Victoria, 2009). That is to say, the data presents as an inverse 'j-shaped distribution', which reflects the large number of small trees required to maintain a population with large mature trees. Such a frequency distribution is typical of an uneven-aged stand (Brack, 1999). A similar *skewed* tree distribution was reported from a survey of 176 Victorian floodplain sites by Cunningham *et al.* (2010).

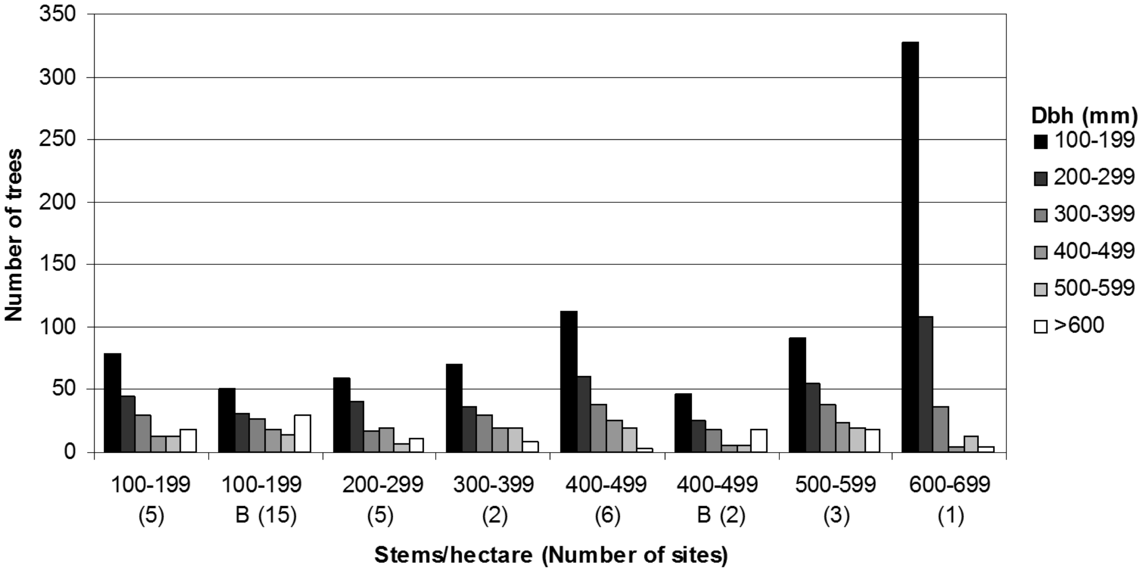


Figure 6 Distribution of trees across DBH classes, for stands mapped as different stem densities (stems per hectare, based on 50 0.25 ha sites), in Barmah (indicated by a B on the x axis) and Millewa Forests (source: OEH and Parks Victoria, 2009)

At Barmah-Millewa, there were more than three times the number of small trees (e.g. < 20 cm DBH) at the TLM site with 600 - 699 stems ha^{-1}, than reported for the lower density stands (Figure 6). The highest number of large trees was recorded in stands with between 100 and 199 stems ha^{-1}.

River Murray Floodplains, Banrock Station, South Australia

George *et al.* (2005) found the distribution of Red Gum age classes on the Banrock Station floodplain corresponded with specific water regimes. For example, while mature trees were widespread, pole trees (e.g. tall with small diameters) were concentrated where water from the river and local run-off accumulated; saplings bordered less-frequently inundated areas; and seedlings clumped along the river and floodplain margins (George *et al.* 2005).

When plotted, the Red Gum size class distribution resembled an inverse j-shaped distribution (Figure 7). George (2004) suggests the deviation of the Black Box population from the j-shaped distribution is indicative of episodic flooding, but that in this case, does not necessarily reflect a viable population.

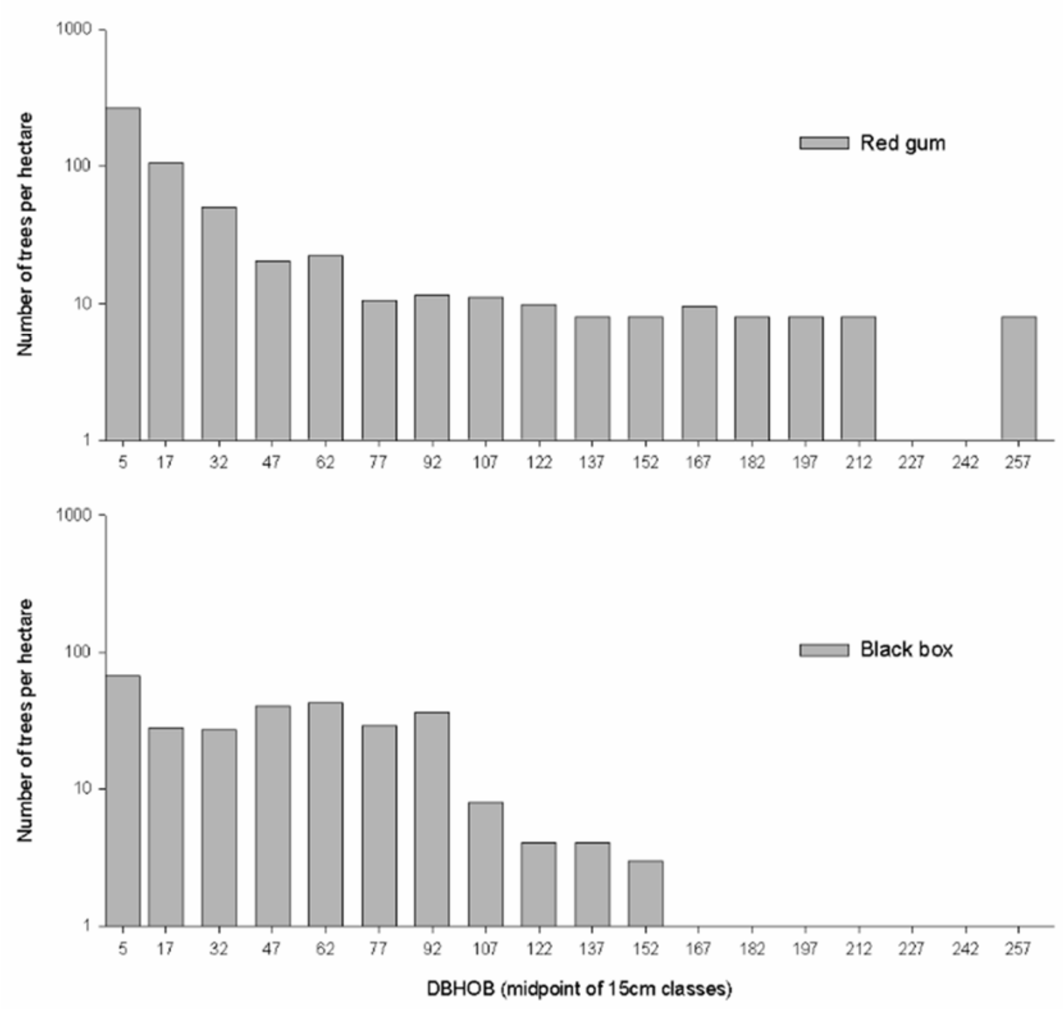


Figure 7 Distribution of DBHOB of River Red Gum and Black Box at Banrock Station (source: George, 2004, p. 46)

3.5 Tree Growth

Tree growth, such as increase in girth, provides a measure of a plant's persistence through past climatic conditions and alludes to its competitive ability and capacity to be adaptive to future climates (Rawal *et al.* 2014). Taylor *et al.* (2016) found growth in Red Gum and Grey Box trees (amongst eight other eucalypt species) changed from height-oriented to width-orientated once the trees reached around 15 cm DBH.

Gunbower Forest

Data provided by VicForest (2008) for the two permanent growth plots established in Gunbower Forest indicates that growth in diameter ranged from annual increments of 0.24 cm year^{-1} (1950 to 1969), up to 0.27 cm year^{-1} (1969 to 1998), and down to 0.17 cm year^{-1} (1998 to 2005).

Koondrook-Perricoota Forest

Growth rates derived from data provided by the Forestry Corporation of NSW (2017) for the permanent growth plots established in Koondrook-Perricoota Forest indicate that average growth in diameter for the subset of trees (n = 685) measured in both 2002 and 2015 was 0.16 cm yr^{-1}, with total growth over the monitored period of 2.14 ± 2.60 cm 13 yr^{-1} (mean ± standard deviation). For a second population of trees (n = 535) sampled in both 2003 and 2015, growth was 0.24 cm yr^{-1}, with total growth over the monitored period of 2.84 ± 3.00 cm 12 yr^{-1}.

Murray-Darling Basin

The lowest recorded diameter growth rate was 0.05 cm year^{-1} in Red Gums that were on average 37.5 m from a waterway (Stone and Bacon, 1994) (Table 4). The highest diameter growth rate was 6 cm year^{-1} in widely-spaced, healthy, riparian Red Gums during a La Nina weather pattern (Smith and Renton, 2017). The latter appears to be an unprecedented high rate of growth, given the other reported rates are all below 3 cm year^{-1} (Table 4).

Table 4 Published growth rates (mean ± standard deviation) for Red Gum and Grey Box species in the Murray-Darling Basin

Location	DBH(OB) Increment	Comments	Source
River Red Gum			
Riparian Macquarie and Bogan Rivers NSW	0.48 cm yr^{-1} (2.4 ± 2.2 cm 5 yr^{-1})	Mean growth rate from 227 trees. Red Gums increased in diameter faster than Grey Box.	Taylor *et al.* (2014)
Riparian and floodplain woodlands Lower Namoi River Northern NSW	<3 cm yr^{-1} (most trees) 6 cm yr^{-1} (max.)	Nine sites. Tree growth rate declined significantly with tree size (DBH), site density and dieback severity.	Smith and Renton (2017)
	0.2 cm yr^{-1} 2.5 cm yr^{-1}	Minimum and maximum rates reported for the various sites in the Murray Darling Basin.	Jacobs (1955), Colloff (2014), Taylor *et al*. (2014) as reported in Smith and Renton (2017)
Floodplain forest Gulpa Island River Murray NSW	0.59 yr^{-1} (1.18 ± 0.73 cm 2 yr^{-1})	Growth (DBHOB increment 1990-92) of trees growing in waterways. Trees within intermittently flooded waterways grew significantly faster than those 37.5m away from the waterway.	Stone and Bacon (1994)
	0.42 cm yr^{-1} (0.83 ± 0.49 cm 2 yr^{-1})	Growth (DBHOB increment 1990-92) of trees 7.5m from a waterway.	
	0.05 cm yr^{-1} (0.1 ± 0.15 cm 2 yr^{-1})	Growth (DBHOB increment 1990-92) of trees 37.5m from a waterway.	
Floodplains River Murray Victoria	0.76 cm yr^{-1}	Average diameter increment of better class trees prior to river regulation.	Jacob (1955) as reported in VEAC (2006)
	0.25 cm yr^{-1}	Average diameter increment post 1983, recorded across a wide range of tree diameters.	DNRE (2002) and Dexter and Poynter (2005) as reported in VEAC (2006)
Riparian and plains Macquarie River NSW	0.64 cm yr^{-1} (3.2 ± 2.8 cm 5 yr^{-1})	2008 – 2015 Mean of 60 trees sites subject to permanent water supply and surrounded by irrigated agriculture.	Ellis *et al.* (2017)
Riparian and plains Bogan River NSW	0.46 cm yr^{-1} (2.3 ± 2.3 cm 5 yr^{-1})	2008 – 2015 Mean of 587 trees at sites subject to ephemeral inundation and surrounded by dryland agriculture.	
Grey Box			
Riparian and plains landscapes of the Macquarie and Bogan Rivers NSW	0.24 cm yr^{-1} (1.2 ± 1.6 cm 5 yr^{-1})	24 semi-arid sites (21 plains and 3 riparian), 468 trees measured.	Taylor *et al*. (2014)

4.0 RESULTS

4.1 Structure of Results

A summary of the metrics derived from the *TLM Stand Condition Assessment* and *Sentinel Wetland and Understorey Vegetation Condition Monitoring Programs* is presented in the section that follows. Akin to the structure of the literature review, the results are grouped into the themes: tree density; basal area; population structure; and tree growth. For site-based measures such as tree density and basal area, results are reported for all sites on aggregate (i.e. the entire sampled population), by individual site, and then grouped by forest type. For other themes, such as tree growth, results are reported for each tree species, and then by forest type. The purpose of the latter is to ascertain whether observed trends were consistent for each forest type, or whether they differed between types.

Notably, given that neither dataset provided for investigation of all themes, it was necessary to alternate between presentation of results from each of the two datasets. While the stand dataset is primarily used to report on tree density and basal area, the understorey dataset is the principal source of data on age classes and population structure. Further, although all sample years were the subject to exploratory analysis, 2010 and 2017 are routinely used to profile the trajectory of sampled populations.

4.2 Tree Density

The total density of trees > 10 cm DBH (i.e. independent of forest type and canopy species), increased from 251 to 297 trees ha^{-1} across the stand condition sites (n = 25) sampled from 2010 to 2017 (Table 5). Many of the sampled trees were multi-stemmed, where this is the result of timber harvesting.

At the site level, both density, and the magnitude of change over the monitored period, were highly variable. Tree density per site ranged from 112 to 552 trees ha^{-1} across the sampled years (28 to 138 trees per plot), and increased from 2010 to 2017 at 20 of the 25 sites sampled (Appendix 1). However, in addition to *actual* increases in tree density, *observer error* may account for some of the recorded change (different contractors were employed in 2010 and 2012, and thus the location of plot boundaries may have differed between sample years). Tabulation of change from 2012 to 2017 (when the same contractors were employed) yielded increased densities at 17 of the 20 sites (range -4 to 36 trees ha^{-1}).

In 2017, as in all sampled years, Red Gum Forest and Red Gum Woodland supported a higher total density of trees (311 and 312 trees ha^{-1}, respectively) than Black Box Woodland (238 trees ha^{-1}) (Table 5). While there were modest increases in overall tree density for all forest types; inter-site variability within each population was high. For example, in 2017 the density of trees at Black Box Woodland sites ranged from 124 to 396 trees ha^{-1} (31 to 99 trees per plot).

Table 5 Density of trees (> 10 cm DBH) per hectare recorded across the 0.25 ha stand condition sites (n = 25) sampled in Gunbower Forest 2010 – 2017

^ Note: 11 of the 16 Red Gum Forest sites were sampled in 2012 due to flooding impeding access

Forest Type	*n*	2010	2012 ^	2013	2014	2016	2017
River Red Gum Forest	16	257	251	295	297	309	311
River Red Gum Woodland	4	261	293	308	312	313	312
Black Box Woodland	5	226	232	226	228	244	238
All	**25**	**251**	**255**	**283**	**285**	**297**	**297**

Similarly, there was high inter-site variation in the number (and proportion) of live trees for each forest type across all sampled years. This was particularly so for Red Gum Forest and Woodland, as evident in Figure 8 (note, the height of the boxes and associated whiskers). There was negligible difference in the overall proportion of live Red Gum trees from 2010 to 2017 (81% to 83%), however there was a notable increase in the proportion of live Black Box trees recorded from 2010 to 2012 (82% to 88%) (Appendix 1).

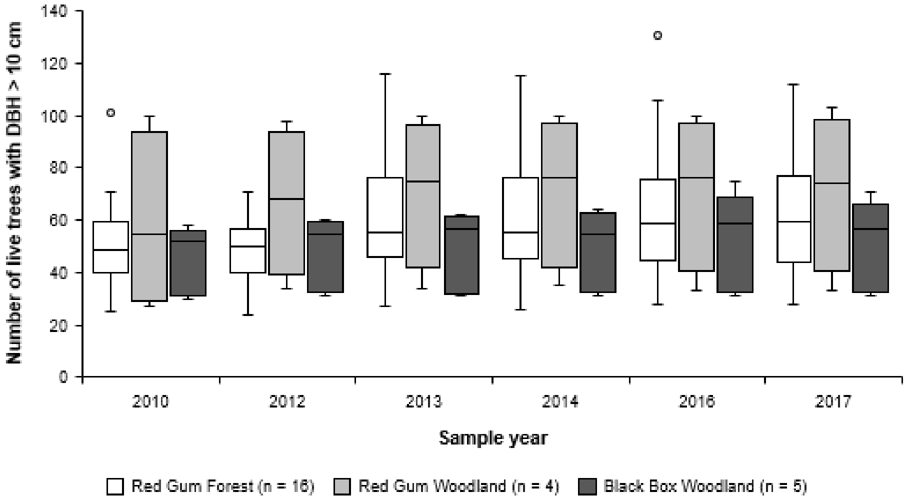


Figure 8 Number of live trees with DBH > 10 cm, grouped by forest type, for stand condition sites (n = 25) sampled in Gunbower Forest 2010 – 2017

Synopsis of Findings:	
	• Tree density varied markedly between sites; however Red Gum Forest and Woodland sites were denser than Black Box Woodland in all years
	• There were modest increases in tree density at the majority of the sites sampled from 2010 to 2017
	• The proportion of lives trees varied greatly between sites, and between forest types
	• The proportion of live Black Box trees increased from 2010 to 2012, however changed little from 2012 to 2017

Note, the tree density of Grey Box Woodlands was not calculated as this forest type was not sampled as part of the stand condition program.

4.3 Basal Area

Total BA (for standing trees, both live and dead) ranged from 10 to 66 m^2 ha^{-1} at the stand condition sites sampled from 2010 to 2017 (Appendix 2). At the site level, the magnitude of change in BA over this temporal period was variable (range -0.75 to 19.45 m^2 ha^{-1} per site); however, an increase was recorded at 24 of the 25 sites sampled. Across all samples (n = 25), there was an average increase of 5.27 ± 5.08 m^2 ha^{-1} (mean ± standard deviation) from 2010 to 2017. One-way ANOVA (all sites (all years); F statistic (5, 139) = 0.518, p = 0.762), nonetheless, indicated that the difference in BA between sample years (n = 6) was *not* statistically significant at the $p < 0.5$ level; that is, sample year did not significantly affect basal area.

Table 6 Total basal area (mean ± standard deviation) (m^2 ha^{-1}), grouped by forest type, for stand condition sites (n = 25) sampled in Gunbower Forest 2010 – 2017

Basal area was derived from the DBH of all trees > 10 cm DBH contained within each 0.25 ha plot

Forest Type	*n*	2010	2012	2013	2014	2016	2017
River Red Gum Forest	16	28.47 ± 12.44	29.42 ± 11.09	32.26 ± 14.34	32.61 ± 14.93	33.67 ± 14.19	34.03 ± 14.33
River Red Gum Woodland	4	28.03 ± 12.55	35.72 ± 20.13	34.13 ± 15.58	34.17 ± 15.56	36.77 ± 19.94	36.99 ± 20.66
Black Box Woodland	5	17.74 ± 5.13	19.60 ± 4.82	18.49 ± 5.31	18.66 ± 5.24	20.01 ± 4.95	19.11 ± 4.70

In 2017, as in all sampled years, the mean and median BA of Red Gum Forests and Woodlands was higher than for Black Box Woodlands (Table 6, Figure 9). Mean BA increased for all forest types over the monitored period, although examination of individual samples revealed substantial variation between sites within each forest type (Figure 9); markedly so for Red Gum Woodland. This variation reflects difference in size structure at the sites.

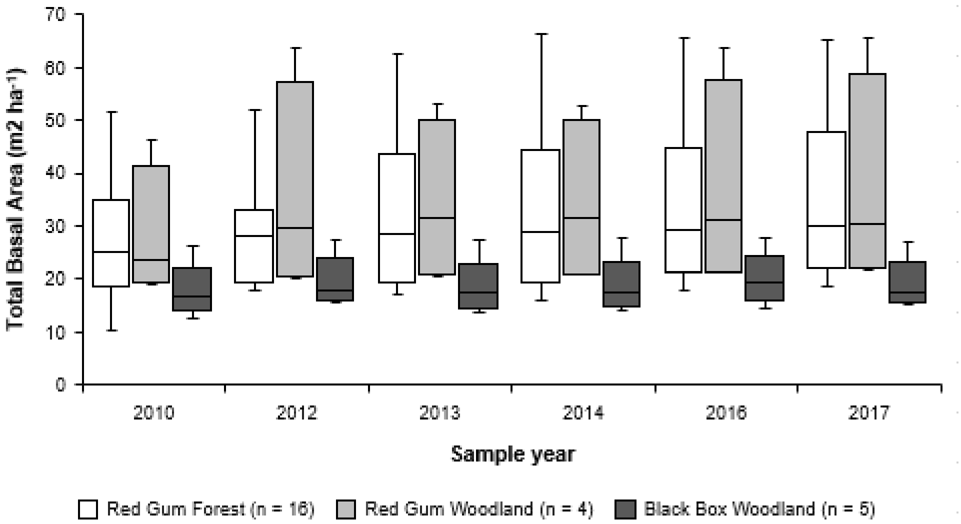


Figure 9 Basal area (m² ha⁻¹), grouped by forest type, for stand condition sites (n = 25) sampled in Gunbower Forest 2010 – 2017

Congruent with total BA, inter-site variability in Live BA was high within and between forest types (Appendix 2). Overall, there was an increase in the proportion of sites in *good* condition from 2010 to 2017 (Table 7); where, as per Cunningham *et al.* 2016, a site was deemed in *good* condition when it supported greater than 80% live BA. Notably, despite measured increases from 2010 to 2012, and from 2012 to 2013, the total proportion of sites in *good* condition did not change between 2013 and 2017.

For Black Box Woodlands, the proportion of sites in *good* condition increased from 2010 to 2017 (Table 7), with three of the five sites comprising 100% live BA across all years of the monitoring period (Appendix 2). For Red Gum Forest, there were both increases and declines across this period, whereas the proportion of Red Gum Woodland sites in *good* condition remained constant.

Table 7 Proportion of sites in *good* condition based on proportion of live basal area (i.e. where the proportion of Live Basal Area is 80% or higher) across all stand condition sites (n = 25) sampled in Gunbower Forest 2010 - 2017

Forest Type	*n*	2010	2012	2013	2014	2016	2017
River Red Gum Forest	16	50.00	54.55	62.50	62.50	56.25	56.25
River Red Gum Woodland	4	75.00	75.00	75.00	75.00	75.00	75.00
Black Box Woodland	5	60.00	60.00	60.00	60.00	80.00	80.00
Total	**25**	**56.00**	**48.00**	**64.00**	**64.00**	**64.00**	**64.00**

Note, the basal area of Grey Box Woodlands was not calculated as this forest type was not sampled as part of the stand condition program. Further, given the available data, it was not possible to calculate this metric for the understorey program.

Synopsis of Findings:	• **Basal Area varied markedly between sites and forest types** • **An increase in Basal Area was recorded at the majority of sites from 2010 to 2017** • **Live Basal Area also varied markedly between sites and forest types** • **There was an increase in the proportion of sites in good condition (i.e. > 80% live basal area) from 2010 to 2017**

4.4 Population Structure and Recruitment

Number of Individuals by Age Class

Red Gum, Black Box and Grey Box seedlings, saplings, poles, and mature trees were observed at the suite of understorey sites (n = 110) in all sample years from 2005 to 2017 (Figure 10). The number of individuals per age class varied between sample years, and by forest type. Not all sites supported all age classes (see Appendix 3 for the proportion of sites in each year).

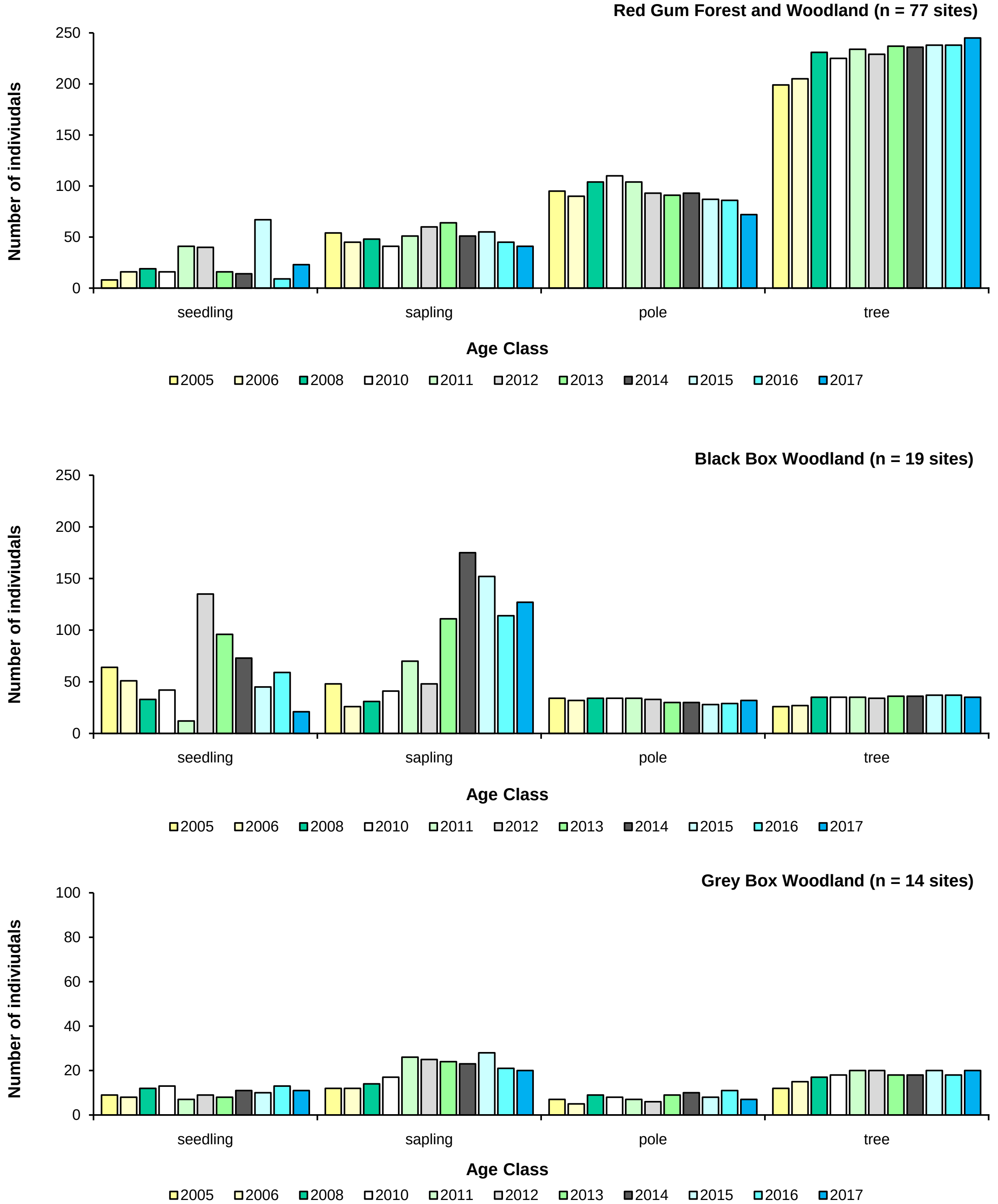


Figure 10 Total number of individuals by age class and forest type for all 0.01 ha understorey sites (n = 110) sampled in Gunbower Forest 2005 – 2017

Age classes: seedlings (<0.25 m in height); saplings (>0.25 m and < 3 m in height); poles (> 3 m in height and <10 cm DBH) and trees (> 3 m in height and >10 cm DBH). Note: only 80 sites were sampled in 2005 and 2006.

In all sample years, there were more pole and mature Red Gums than there were seedlings and saplings (Figure 10). Conversely, the Black Box population comprised a higher proportion of seedlings and saplings than pole and mature trees. The composition of Grey Box individuals was less skewed, with comparable numbers of saplings and trees. Additionally, while the number of pole and mature Black and Grey Box trees was relatively constant over time, the composition of the Red Gum population was more mixed. For example, from 2005 to 2017 there was a noticeable decline in the number of pole trees, and a small increase in the number of mature trees.

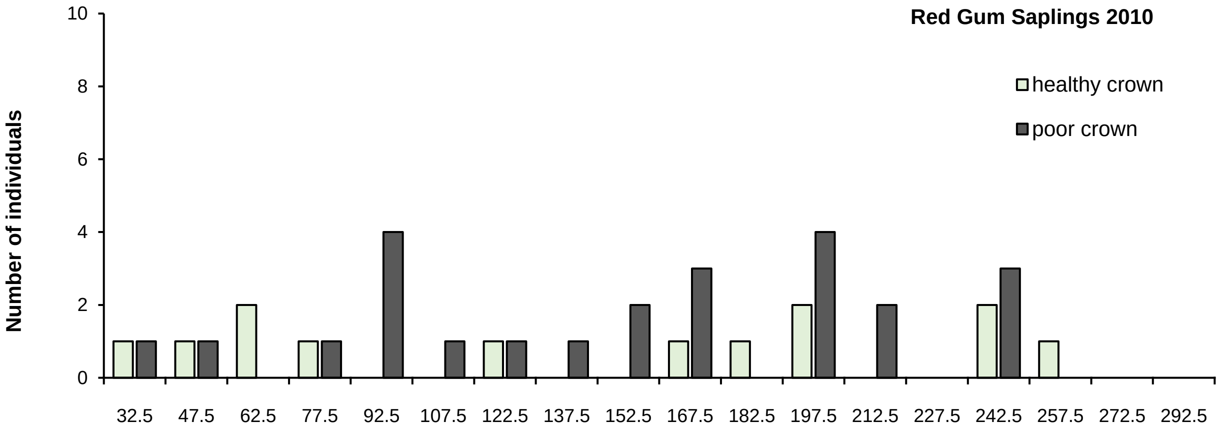
Figure 11 Black Box recruitment, Gunbower Forest, April 2013

Eucalypt seedlings were recorded in each vegetation type and in each sample year, however, total abundance varied temporally (Figure 10). Black Box seedlings peaked in numbers between 2011 and 2014 (see Figure 11 for an example of Black Box recruitment), as did Red Gum seedlings in 2011 and 2012, and more noticeably in 2015. Change in the number of Grey Box seedlings over the monitoring period was less pronounced.

Sapling numbers also varied over time and by species (Figure 10). Notably, while the total abundance of Red Gum saplings was relatively consistent (ranging between 41 and 64 individuals per year), the abundance of box saplings was highly variable; more so for Black Box (41 individuals in 2008, compared with 175 in 2014). The large increase in Black Box saplings in 2013, once again, followed a period of high rainfall and widespread flooding. A similar increase was observed in the Grey Box species, yet to a lesser extent.

Height and Size-class Frequency Distributions for Saplings and Trees

The frequency of saplings recorded at the understorey sites, when categorised by height, revealed a disparate distribution of size classes from 2005 to 2017 (Appendix 3). The pattern was more marked for Red Gum and Grey Box saplings, with gaps in the height classes represented. However, classification of the 2010 and 2017 populations by height class and crown health, revealed an increase in the proportion of *healthy* saplings (i.e. with > 50% original canopy intact) (Figure 12 and Figure 13). In 2017, the majority of height classes were dominated by healthy saplings. This was noticeably so for saplings less than one metre.



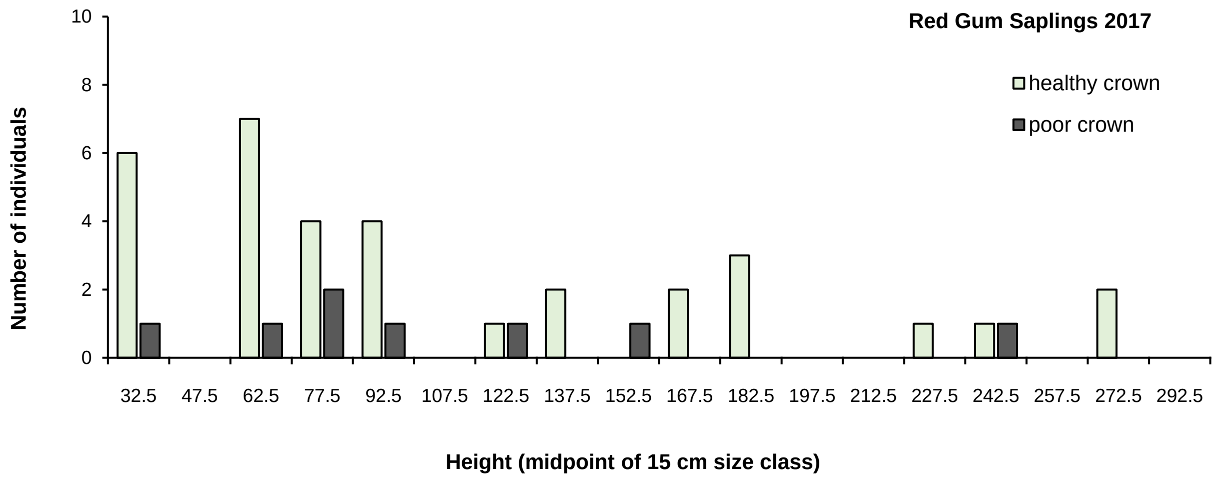


Figure 12 Number of saplings in each height size class (15 cm increments) based on canopy health classification, across all Red Gum understorey sites (n = 77) sampled in Gunbower Forest 2010 and 2017

Crown health was determined by visual inspection. Saplings with a ‘healthy crown’ were those assigned a crown condition index score of 4 or 5 (i.e. with >50% of original canopy intact). Saplings with a ‘poor crown’ were assigned a score of 1 – 3 (i.e. had < 50% of original canopy intact. Dead saplings are not displayed.

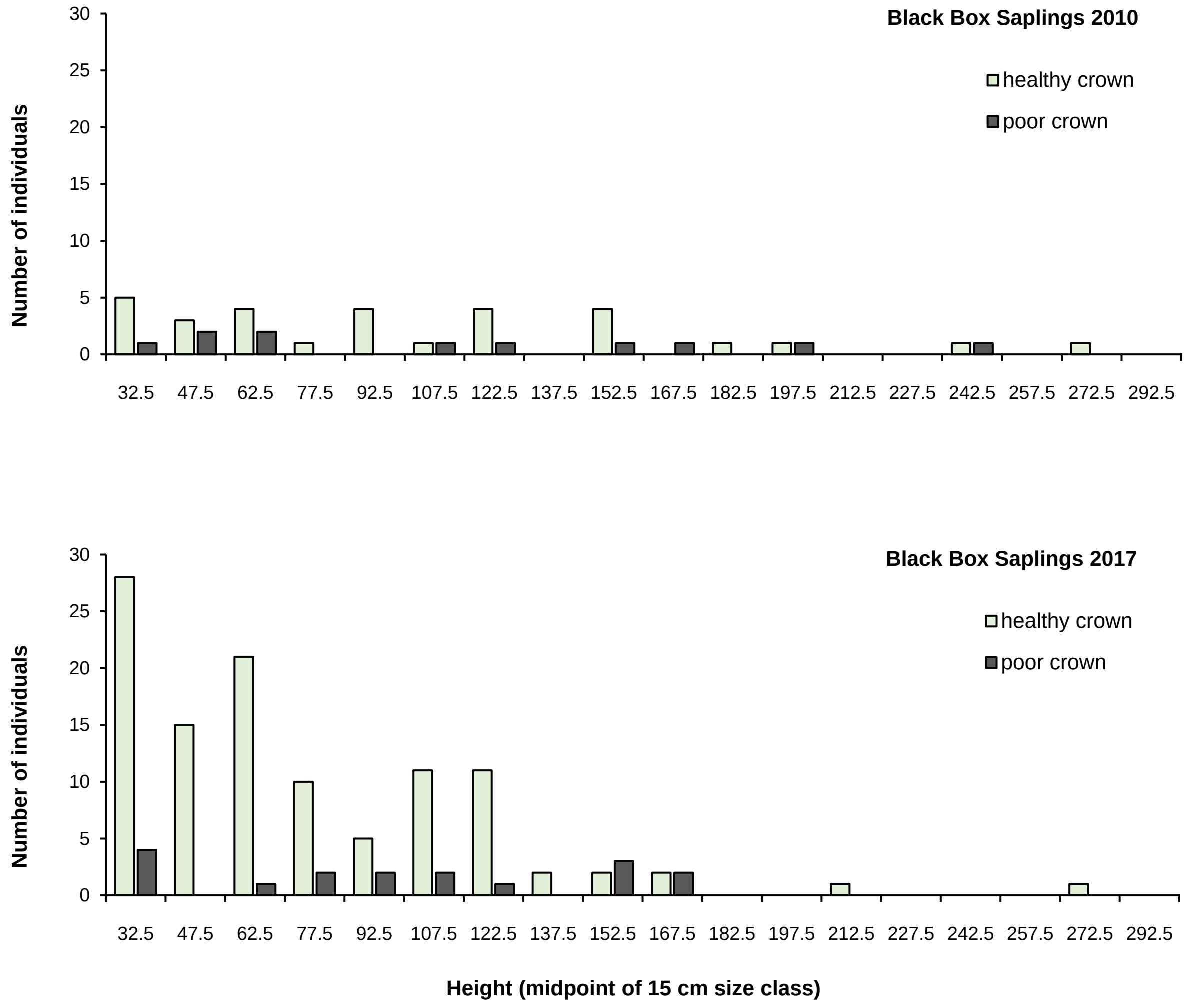


Figure 13 Number of saplings in each height size class (15 cm increments) based on canopy health classification, across all Black Box understorey sites (n = 19) sampled in Gunbower Forest 2010 and 2017

Crown health was determined by visual inspection. Saplings with a ‘healthy crown’ were those assigned a crown condition index score of 4 or 5 (i.e. with >50% of original canopy intact). Saplings with a ‘poor crown’ were assigned a score of 1 – 3 (i.e. had < 50% of original canopy intact. Dead saplings are not displayed.

Comparably, the frequency of mature trees (> 10 cm DBH) recorded at the stand condition and understorey sites, revealed a more-continuous distribution of size-classes from 2010 to 2017 (Appendix 3). Notably, at all sites in all sample years, there were higher numbers of trees in the smaller size classes; i.e. between 10 and 40 cm DBH. In principal, the sampled populations of both Red Gum and Black Box trees approximated an inverse J-shaped distribution, where there were progressively fewer trees with each increment in size class (see for example Figure 14 and Figure 15). There were however insufficient samples of Grey Box trees for comparison.

Akin to the pattern observed for saplings, classification of the 2010 and 2017 populations by size class and crown health, revealed an increase in the proportion of *healthy* trees (i.e. with > 50% original canopy intact) per size class (Appendix 3). Further, in 2017 the majority of size classes were dominated by healthy trees. That said, the overall proportion of healthy trees remained low for Red Gum trees, and at some sites, incidences of tree mortality were observed across the monitoring period (largely from 2008 to 2010). The latter are consistent with the results of the separate crown condition survey at understorey sites, which shows a decline in healthy trees from 2008 to 2010, followed by an increasing proportion of Red Gums with > 50% original canopy from 2010 to 2017 (Appendix 3; Bennetts *et al.* 2017). Examination of data from the crown extent survey at the stand condition sites supports these trends, and additionally reveals a high level of variability in crown health between sites (Appendix 3).

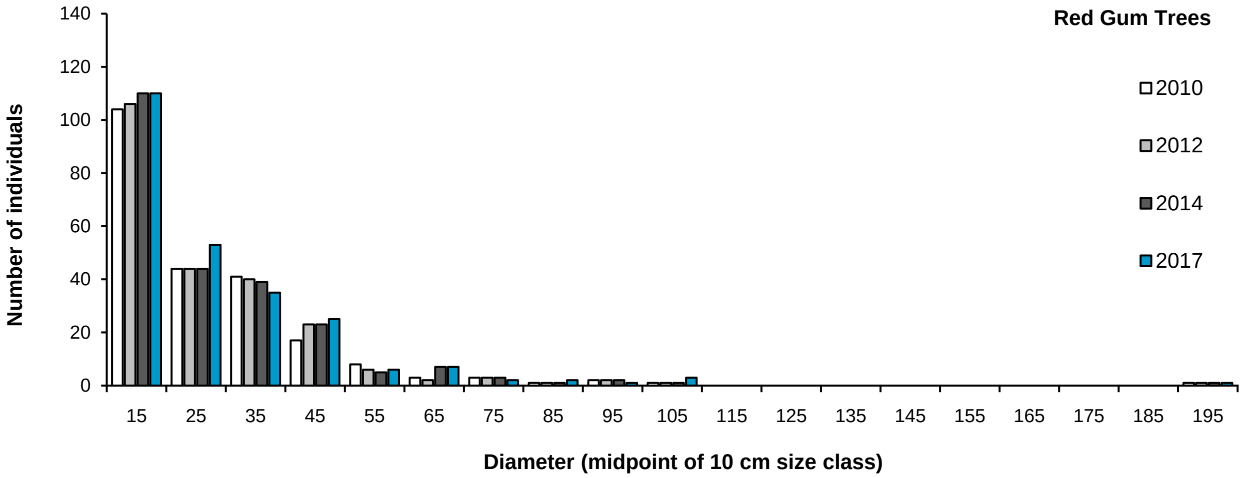


Figure 14 Number of Red Gum trees (> 10 cm DBH) in each size class (10 cm increments) across all Red Gum Forest understorey sites (n = 77), sampled in Gunbower Forest 2010 - 2017

The number of individuals is limited to trees > 10 cm DBH that fall within the bounds of each 0.01 ha plot. Note: only a subset of the sample years from the monitoring period are shown to enable visual differentiation between sample years. An equivalent size-class distribution is presented for Black Box trees in Appendix 3.

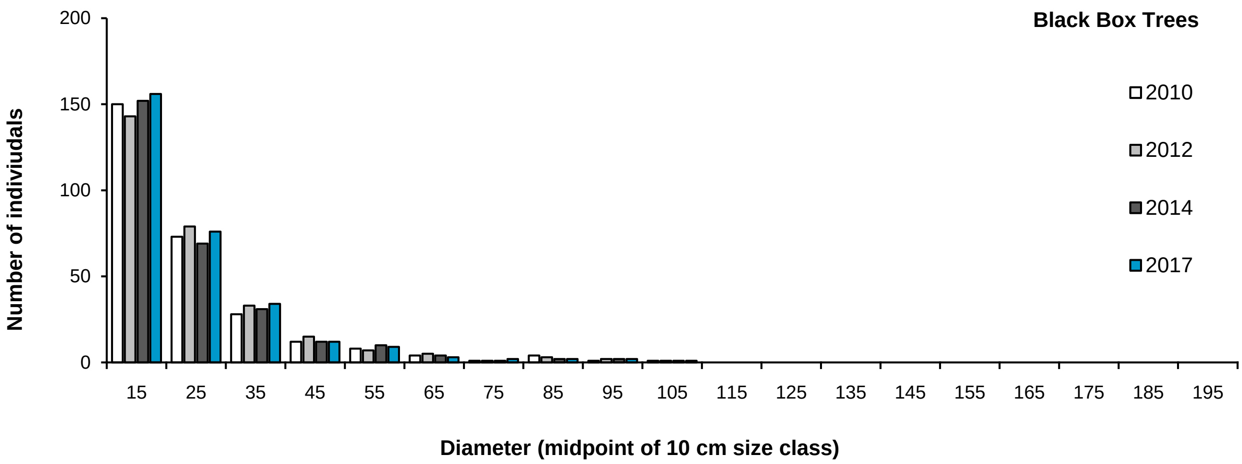


Figure 15 Number of Black Box trees (> 10 cm DBH) in each size class (10 cm increments) across all Black Box Woodland stand condition sites (n = 5), sampled in Gunbower Forest 2010 - 2017

The number of individuals is limited to trees > 10 cm DBH that fall within the bounds of each 0.25 ha plot. Note: only a subset of the sample years from the monitoring period are shown to enable visual differentiation between sample years. An equivalent size-class distribution is presented for Red Gum Forest and Woodland in Appendix 3.

Variation in Population Structure and Crown Condition by Site

Inspection of population structure and crown condition at the site-level reveals a high degree of variability between sites within each forest type. A summary of temporal change in the age composition of trees, and the trajectory of crown health, is presented in Figure 16 to Figure 21 for an illustrative subset of the Red Gum and Black Box understorey sites. Here, the tally of individuals per age class is limited to specimens falling within the bounds of each 0.01 ha plot. The results for crown health are informed by the survey of 20 permanently marked trees within or proximate to each plot. Note: site 31A did not contain any trees (irrespective of age class) within the bounds of the plot. Photographic examples of the variability of Grey Box Woodland are provided in Figure 22.

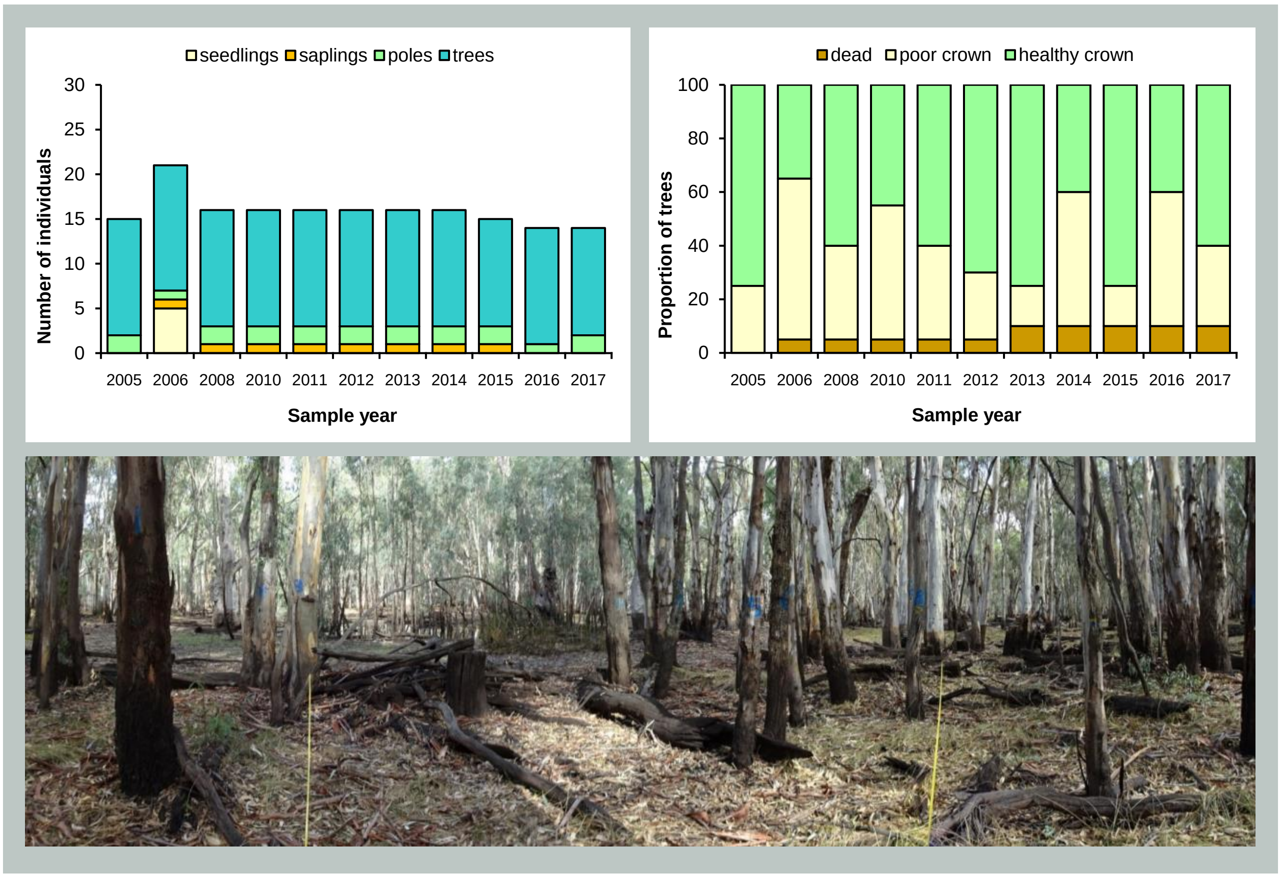


Figure 16 Red Gum Forest at Understorey Site 10A, March 2017

This site supports Riverine Swamp Forest, and occurs in low lying country near Little Gunbower Complex. It has been flooded in 6 of the 11 sample years.

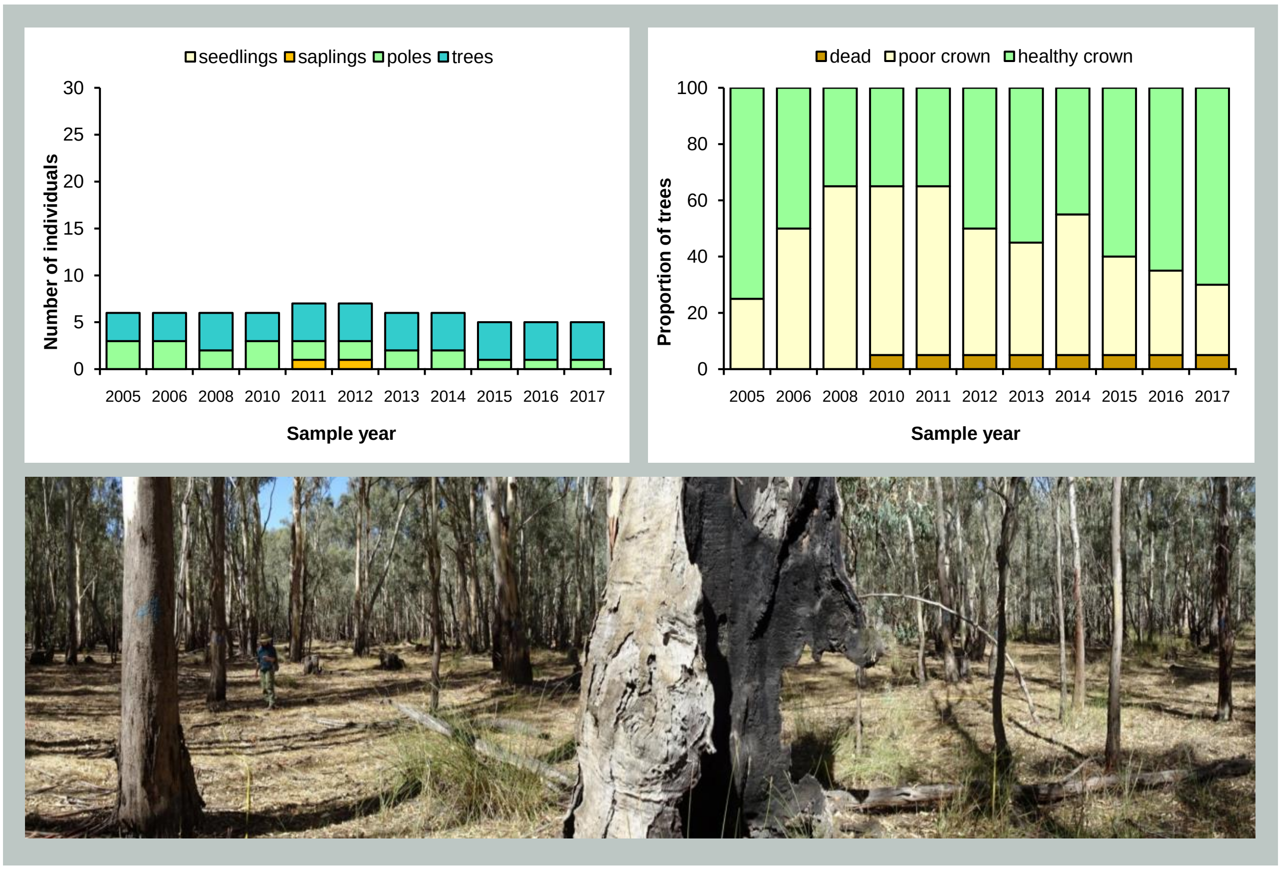


Figure 17 Red Gum Forest at Understorey Site 21A, March 2017

This site supports Sedgy Riverine Forest, and lies in a bend on Yarran Creek. It is regularly flooded. It has been flooded in 5 of the 11 sample years.

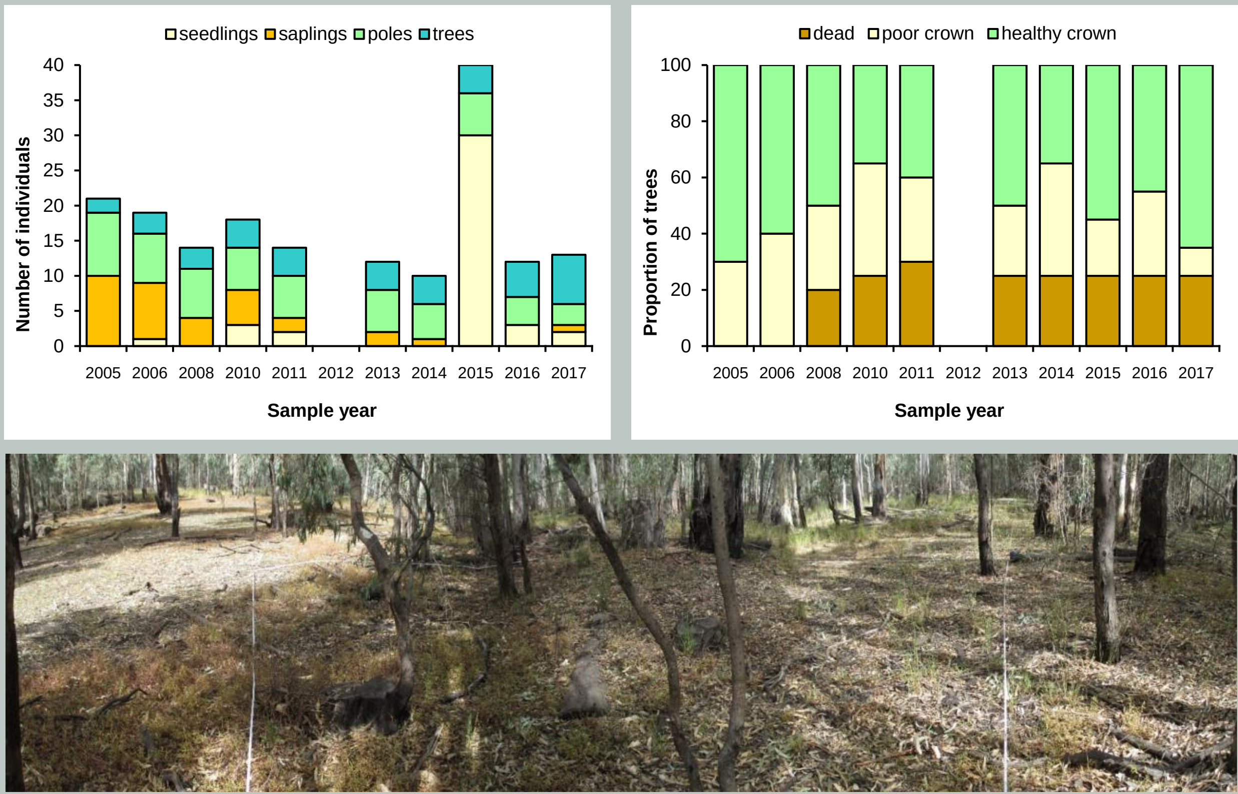


Figure 18 Red Gum Forest at Understorey Site 39A, March 2017

This site occurs mid-floodplain, near a shallow flood runner. It supports Grassy Riverine Forest. It has been flooded in 5 of the 11 sample years.

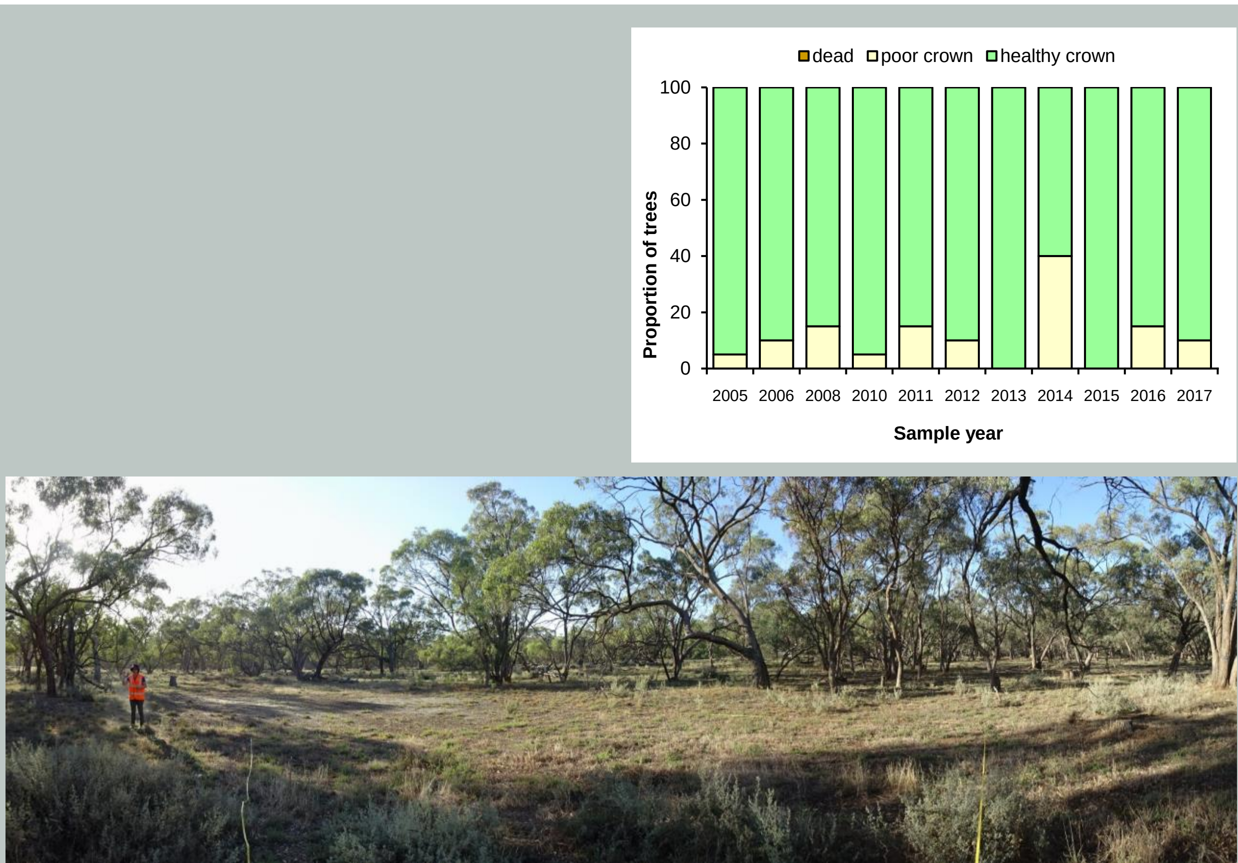


Figure 19 Black Box Woodland at Understorey Site 31A, March 2017

This site supports Riverine Chenopod Woodland. It lies near Horse-shoe Lagoon, and is rarely flooded.

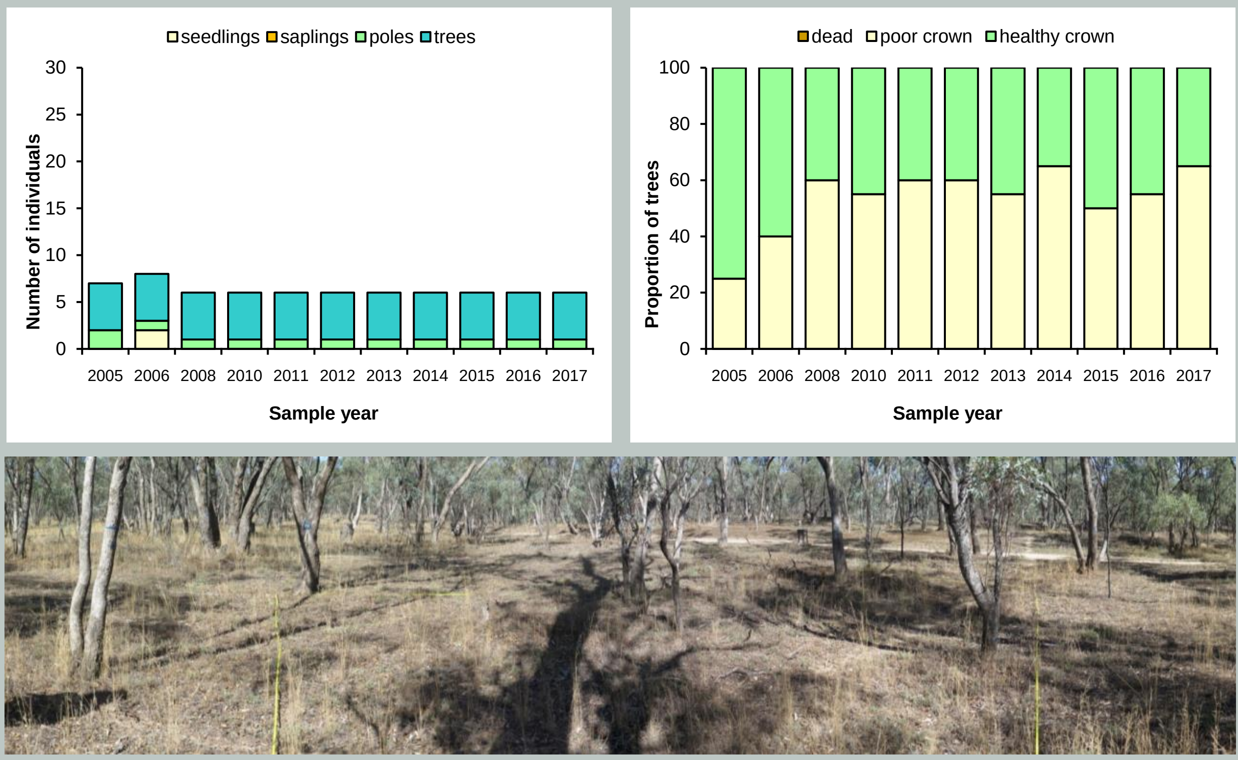


Figure 20 Black Box Woodland at Understorey Site 94A, March 2017

This dry site supports Riverine Swampy Woodland with Black Box.

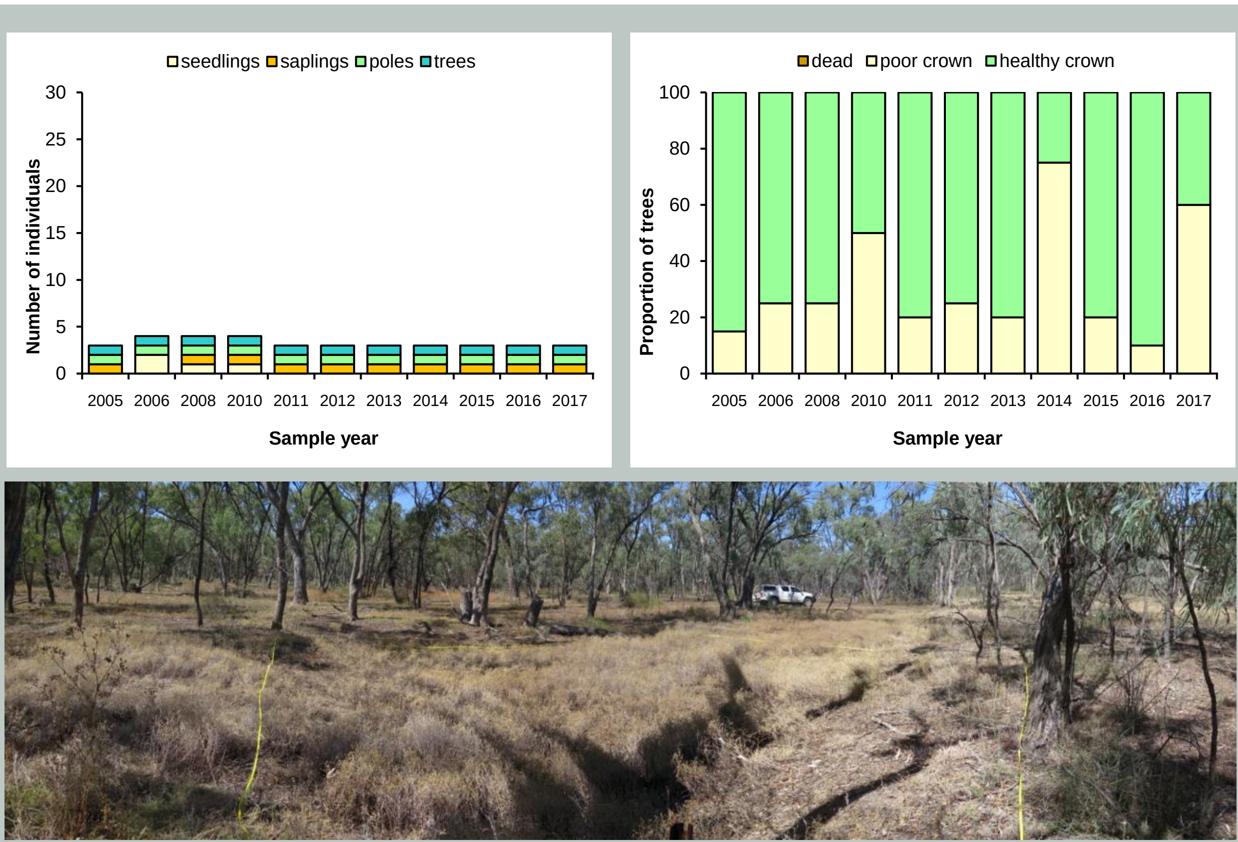


Figure 21 Black Box Woodland at Understorey Site 96A, March 2017

This site occurs in a rain-filled depression of Riverine Chenopod Woodland near Emu Hole Creek. It has been flooded in 1 of the 11 sample years.

Figure 22 Variation in the quality of Grey Box Woodlands at Gunbower Forest: poor quality Grey Box at Spur Island, June 2009 (top); Understorey Site 86, March 2017 (middle); and Understorey Site 134, March 2017

When surveyed in autumn 2017, 95% of the trees in the crown survey at Site 86 were deemed healthy. Comparably, only 60% of the trees at Site 134 were assessed as healthy. For Site 134, this represents a decline in condition from 2008 when all assessed trees were healthy (see Bennetts *et al.* 2017).

Variation in Population Structure with Tree Density

Inspection of population structure for the stand condition sites (n = 25) sampled in 2017 also reveals variation in the size-class frequency distributions with tree density (Figure 23). A greater number of small trees (< 20 cm DBH) were recorded at the higher density stands (> 200 trees ha^{-1}) than at the lower density stands (100 – 199 trees ha^{-1}). The proportion of small trees relative to other size-classes also increased with tree density; while at low density stands only 27% of the sampled population comprised trees < 20 cm DBH, at high density stands (for example 500 -599 trees ha^{-1}), 67% of trees were <20 cm DBH. The highest number of large trees (DBH > 60 cm) were recorded at the low density stands with between 100 and 199 trees ha^{-1}.

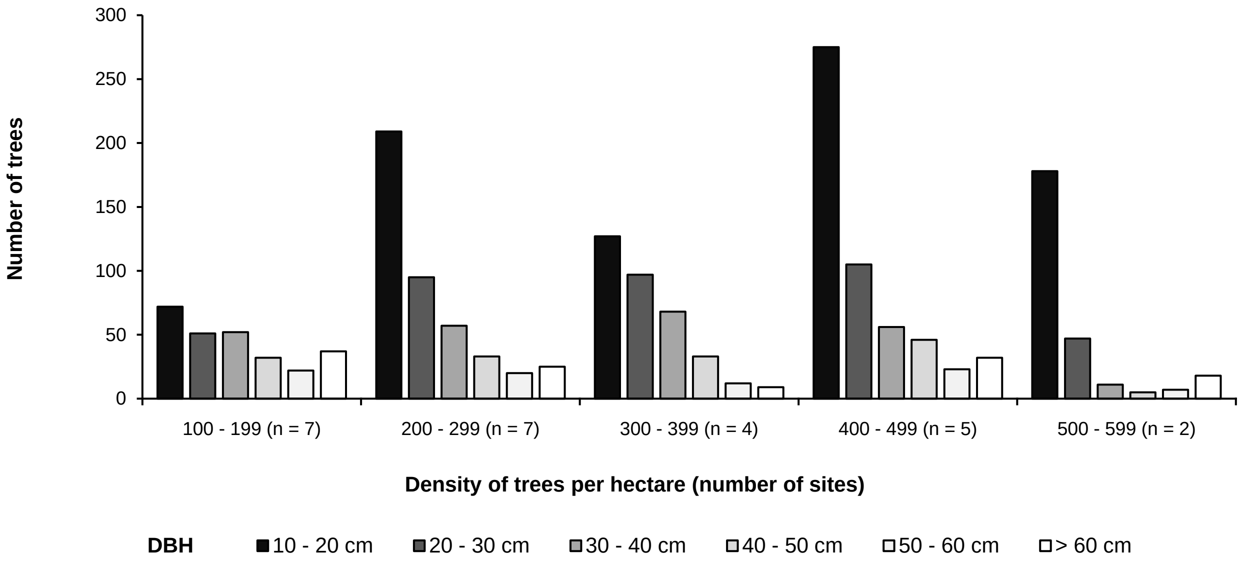


Figure 23 Distribution of Red Gum and Black Box trees (> 10 cm DBH) in each DBH size class (10 cm increments), by stand density, across all stand condition sites (n = 25), sampled in Gunbower Forest in 2017

Figure 24 Hemispherical photographs of Stand Condition Site S102-GRF (left) and S104-GRF (right), March 2017

When sampled in 2017, the density of trees at S102-GRF was 180 tree ha^{-1}. 30% of the trees at this site were < 20 cm DBH, while 18% were > 60 cm DBH. The density of trees at S104-GRF was 552 tree ha^{-1}. 69% of the trees at this site were < 20 cm DBH, while < 2 % were > 60 cm DBH.

Large Old Trees

A small number of large Red Gum (i.e. > 80 cm DBH) and Black Box (i.e. > 40 cm DBH) trees were recorded at both the stand and understorey monitoring sites (see for example Figure 14 and Figure 15). Photographic examples of these trees are provided in Figure 25 and Figure 26). The largest live Red Gum (DBH 205 cm) was recorded at S106-GRF in 2010. For Black Box, the largest live specimen was recorded at site S124-GBB in 2013 (DBH 103.20 cm) (Appendix 3).

When assigned to size classes using the relevant Ecological Vegetation Class benchmark, a modest increase in the number of trees at stand condition sites that met or exceeded the criteria for Large Old Trees (LOTs) was evident from 2010 to 2017 (Table 8). There were also approximately three times the number of benchmark Black Box trees than Red Gums. Of those surveyed in 2017, 73% of the LOTs were alive.

Table 8 Total number of Large Old Red Gum and Black Box trees recorded at the 0.25 ha stand condition sites (n = 25) sampled in Gunbower Forest 2010 and 2017

Forest Type and EVC	*n*	DBH	2010		2017	
			Live	Dead	Live	Dead
Red Gum Forest						
Sedgy Riverine Forest	5	≥ 80 cm	15	5	14	5
Grassy Riverine Forest and Riverine Swamp Forest	11	≥ 90 cm	3	9	3	11
River Red Gum Woodland						
Riverine Grassy Woodland and Floodplain Riparian Woodland	4	≥ 80 cm	5	2	8	3
Black Box Woodland						
Riverine Chenopod Woodland	5	≥ 40 cm	29	2	30	1
All			**52**	**18**	**55**	**20**

In 2017, survey of the 108 *bench trees* that mark the understorey sites found 59% were dead. These typically distinctive trees are > 100 cm DBH, and are habitat trees as classified by DSE Forestry (i.e. they are non-commercial trees that will not be harvested and are retained for habitat purposes (Crome, 2004b)). Just under half of the dead bench trees (27/64) appear to have been ringbarked, most likely between the late 1800s and the 1980s.

Synopsis of Findings:

- **All age classes were recorded at the suite of understorey sites in all sample years from 2005 to 2017**
- **Population structure varied markedly between sites and forest types and with time**
- **There was an increase in the proportion of healthy saplings from 2010 to 2017, and in 2017 the majority of height-classes were dominated by healthy saplings**
- **Mature Red Gum and Black Box trees had a continuous distribution of size classes, and this approximated an inverse J-shaped distribution, where there were progressively fewer trees with each increment in size class**
- **For Red Gums, the overall proportion of healthy trees remained low despite increases in population health**
- **Population structure varied between stands of different tree density**
- **The monitoring sites continue to support a small number of Large Old Trees**

Figure 25 Large Old Trees (LOTs) of Gunbower Forest: live *Eucalyptus camaldulensis* on Chettle Creek, March 2014 (top left); numerous live *E. camaldulensis* near understorey site 68, March 2014 (top right); live and fallen *E. camaldulensis,* March 2013 (bottom left); and dead *E. camaldulensis*, March 2014 (bottom right)

Figure 26 Large Old Trees of Gunbower Forest: *Eucalyptus largiflorens,* July 2014 (top left); *E. microcarpa,* August 2014 (top right); and *E. largiflorens*, April 2014 (bottom)

4.5 Tree Growth

Average Size of Trees per Site

The mean size of trees ranged from 19.55 to 72.35 cm DBH at the stand condition sites sampled from 2010 to 2017 (Appendix 4). Despite high inter-site variability within each of the forest types sampled, there was negligible difference in this metric across the sample years. For example, the mean size of trees in Red Gum Forest in 2010 was 37.99 ± 11.70 cm (mean ± standard deviation), compared with 37.89 ± 11.25 cm in 2017. In 2017, as in all sample years, the mean DBH of Red Gum Woodland sites was higher than for Red Gum Forest sites (Figure 27). While the range of recorded values was greater at non-flooded sites, there was little difference in the mean DBH of sites that were flooded vs. those that were not-flooded (Appendix 4).

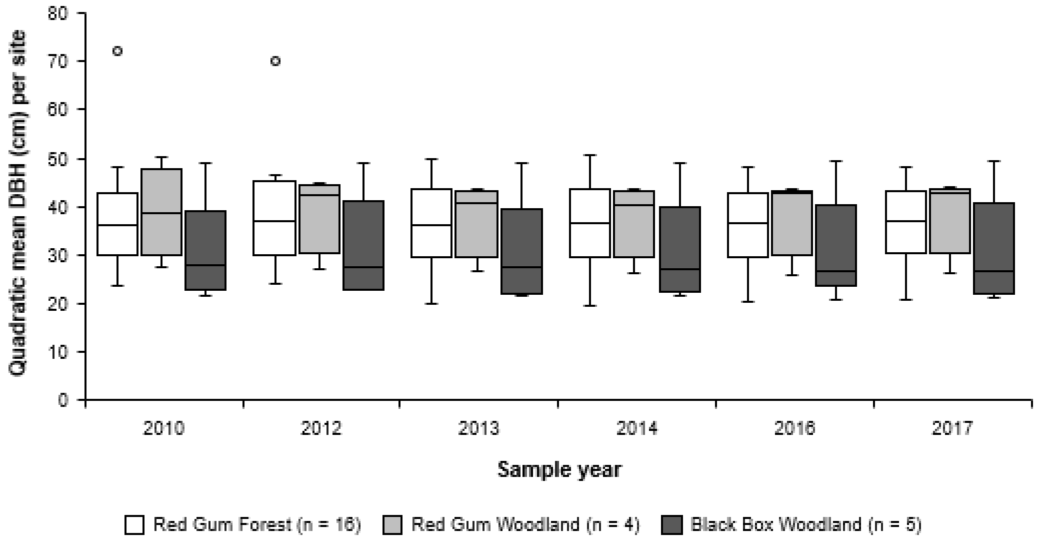


Figure 27 Mean DBH (cm) per site, grouped by forest type, for stand condition sites (n = 25) sampled in Gunbower Forest 2010 - 2017

The quadratic mean = the square root (of the summed DBH of all stems within the plot) / by the number of trees within the plot. The sample is limited to all trees with DBH > 10 cm contained within each 0.25 ha plot. This measure was adopted as it gives greater weight to large trees than arithmetic mean (Brack, 1999).

Figure 28 Flooded Black Box Woodland, Gunbower Forest, March 2012

Growth Rates for Individual Trees

The mean annual growth rates (i.e. measured change in DBH(OB)) for the Red Gum and Black Box populations sampled at the stand condition sites were 0.44 and 0.15 cm yr^{-1} respectively, with total growth over the monitored period of 3.10 ± 3.06 (mean ± standard deviation) and 1.04 ± 1.57 cm 7 yr^{-1} (Table 9). Analysis confirmed that the difference in growth rates between the two species *was* statistically significant (t- test; Red Gums (n = 584), Black Box (n = 149); t statistic (461.85) = -11.365, p < 2.2e-16); that is, Red Gums grew faster than Black Box. Growth rates derived for Red Gums from the smaller understorey dataset were comparably lower over the period from 2008 to 2017; 2.10 ± 2.83 cm 9 yr^{-1} (Appendix 4).

Notably, growth rates varied between sites, and for the stand condition sites, the mean change in DBH per site ranged from 0.36 to 7.23 cm 7 yr^{-1}. Inter-site variation was also high within each forest type (Figure 29), however, differed little between forest types. That is, for Red Gum Forest and Red Gum Woodland, there was negligible difference in mean growth rates (Table 9). Analysis confirmed this pattern; i.e. the observed difference was not statistically significant (Appendix 4).

Table 9 Annual (mean) and total change (mean ± standard deviation) in DBH(OB) (cm) from 2010 – 2017 for Red Gum and Box trees across all stand condition sites

Comparison of the DBH measurements for the trunk/largest stem of the 30 permanently marked trees at each stand condition site from 2010 and 2017 yielded the rate of growth for each tree over the 8-year monitoring period; total growth was divided by the number of sample years less 1 (n – 1) to derive annual growth increments.

	n	Annual DBH(OB) Increment (cm)	Total Change in DBH(OB) (cm)
Canopy Species			
River Red Gum	584	0.44 cm yr^{-1}	3.10 ± 3.06 cm 7 yr^{-1}
Black Box	149	0.15 cm yr^{-1}	1.04 ± 1.57 cm 7 yr^{-1}
Forest Type			
River Red Gum Forest	466	0.45 cm yr^{-1}	3.13 ± 3.10 cm 7 yr^{-1}
River Red Gum Woodland	119	0.43 cm yr^{-1}	2.98 ± 2.91 cm 7 yr^{-1}
Black Box Woodland	148	0.15 cm yr^{-1}	1.04 ± 1.58 cm 7 yr^{-1}

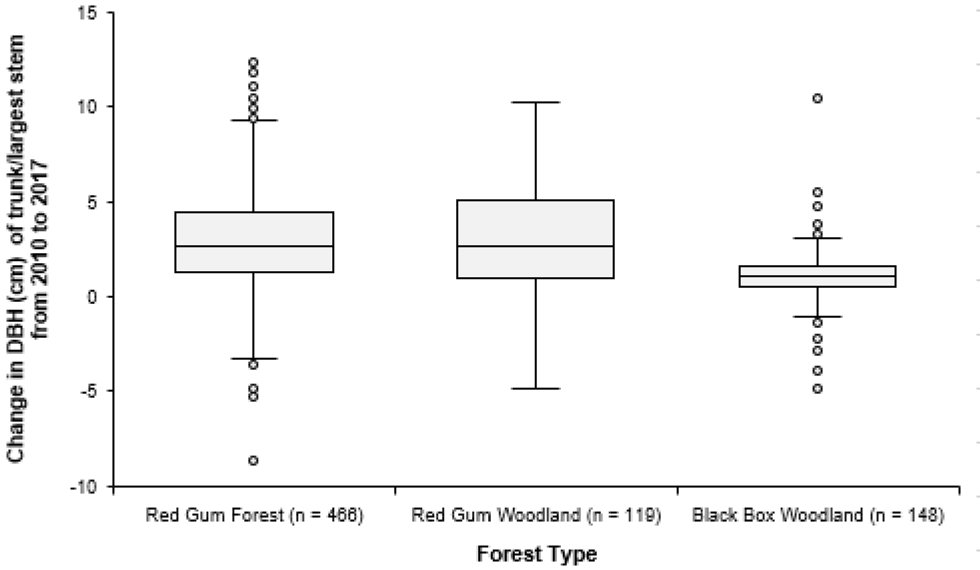


Figure 29 Total change in DBH(OB) (cm) from 2010 to 2017 for Red Gum and Black Box trees, categorised by forest type, across all stand condition sites (n = 25) sampled in Gunbower Forest

Comparison of the DBH measurements for the trunk/largest stem of the 30 permanently marked trees at each stand condition site from 2010 and 2017 yielded the rate of growth for each tree over the 8-year monitoring period. The initial dataset comprised 750 replicates; however, potentially anomalous records were inspected and removed prior to calculation of changes in DBH. Records were deemed anomalous where annual change was > 15 cm; these records generally correlated with a change in survey tree at some stage of the monitoring period.

Variables Influencing Tree Growth

Categorisation of the sampled trees by *crown extent in 2010* revealed higher mean growth rates for Red Gum and Black Box trees that comprised a *healthy* crown (i.e. ≥ 60% assessable crown) upon initial assessment in 2010 (Table 10). Analysis confirmed that these differences were statistically significant at the p < 0.5 level for both populations (one-way ANOVA; all Red Gums (crown condition); F statistic (2, 581) = 95.26, p <2e-16) (one-way ANOVA; all Black Box (crown condition); F statistic (2, 143) = 12.42, p = 1.06e-05); that is, growth was affected by initial crown condition, and trees with a *healthy* crown grew more from 2010 to 2017 than trees with a *poor* crown.

Table 10 Total change (mean ± standard deviation) in DBH(OB) (cm) from 2010 to 2017 for Red Gum and Box trees across all stand condition sites, categorised by crown health in 2010

A healthy crown was defined as a crown extent score of 4 or 5 (i.e. ≥ 60% assessable crown; a full or declined crown); and a poor crown as a crown extent score of 1, 2 or 3 (i.e. < 60% assessable crown)

Crown Extent	*n*	River Red Gum	*n*	Black Box
Healthy crown	338	4.15 ± 2.69 cm 7 yr^{-1}	101	1.30 ± 1.02 cm 7 yr^{-1}
Poor crown	182	2.47 ± 2.88 cm 7 yr^{-1}	41	0.40 ± 1.66 cm 7 yr^{-1}
No crown (i.e. dead)	64	-0.66 ± 1.68 cm 7 yr^{-1}	4	-1.05 ± 2.71 cm 7 yr^{-1}

Categorisation of the sampled trees by the *observed flood frequency* at each site over the 8-year monitoring period also revealed substantial variation in growth rates for the Red Gum population (Appendix 4). The mean growth of Red Gum trees was, nevertheless, highest at sites that were flooded more than two years in the 8-year period; 3.58 ± 0.18 cm (mean ± standard error) (Figure 30). For Black Box trees, mean growth at those sites *flooded one or two years* in the eight-year period was higher (1.44 ± 0.40 cm) than for *non-flooded* sites (0.95 ± 0.13 cm); however, there were fewer replicates (n = 30 trees) in this group than the non-flooded group (n = 119 trees).

For Red Gums, analysis confirmed the statistical significance of these trends at the p < 0.5 level (one-way ANOVA; all Red Gums (flood frequency); F statistic (2, 581) = 10.69, p = 2.77e-05); i.e. growth rates were effected by flood frequency. Further testing (post hoc comparisons using the Tukey HSD test) indicated that flooding needed to be more frequent than two years out of eight to be associated with a significant difference in Red Gum growth rates. That is, mean growth rates did not differ significantly between sites that were not flooded and those that were flooded one or two out of eight years. Comparably, for Black Box, the recorded flood frequencies did not have a significant effect on the growth rates of trees (t-test; flood frequency (not-flooded (n = 119), flooded 1 – 2 years (n = 30); t statistic (34.977) = -1.1744, p = 0.2482).

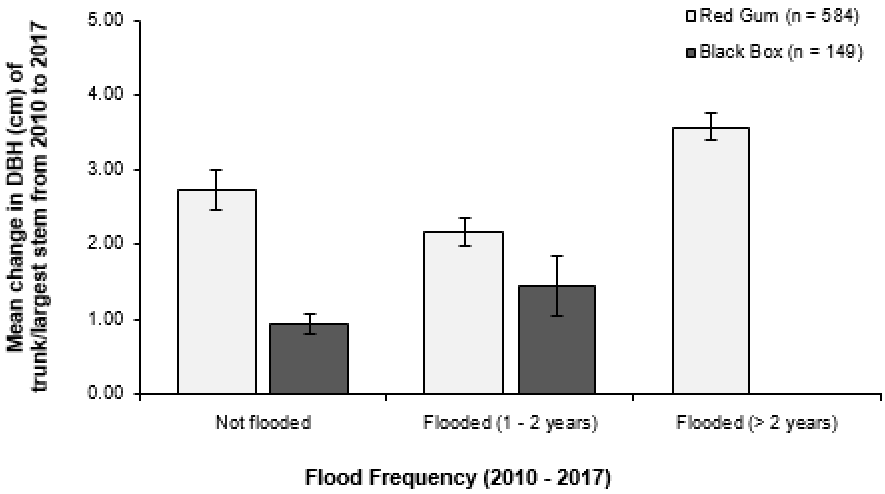


Figure 30 Mean change in DBH(OB) (cm) ± standard error from 2010 to 2017 for Red Gum and Black Box trees across all stand condition sites (n = 25) Gunbower Forest, categorised by observed flood frequency over the preceding 8-year period (2010 - 2017)

The influence of flood frequency on crown health was also explored. Examining the subset of Red Gum trees with a healthy crown in 2017 (which was 66.5% or 392 of the 589 trees sampled), revealed that a higher proportion of these (60.2%) occurred at sites that were flooded more than two years in the 8-year period (Appendix 4). Conversely, for Black Box trees a higher proportion of the sampled trees with a healthy crown (76.8%) occurred at the non-flooded sites. Notably, these trends may be an artefact of sample size; as, for Red Gums the sampled population comprised a greater number of trees at flooded sites than non-flooded sites, and vice versa for Black Box.

Note, the growth rate of Grey Box trees was not calculated as this species was not sampled as part of the stand condition program. Further, given the available data, it was not possible to calculate this metric for the understorey program.

Synopsis of Findings:

- **The average size of trees differed between sites, however not between sample years**
- **The growth rates for individual trees varied by species, however for Red Gums, not between forest types**
- **For Red Gums, flood frequencies (of >2 years out of 8 years) and canopy condition upon initial assessment influenced growth rates**
- **For Black Box, canopy condition upon initial assessment influenced growth rates**

Figure 31 River Red Gum Forest, post flood, Gunbower Forest, January 2017

5.0 DISCUSSION

5.1 Context for Interpreting Forest Structure and Condition

It has been suggested that long-lived species, such as Red Gum trees, modulate their physical environment and its resources, and can therefore be thought as ‘ecosystem engineers’ (Colloff and Baldwin, 2010). In accordance with this assertion, Colloff and Baldwin (2010) propose that data which measures the ecophysiological performance of tree species (e.g. age structure, recruitment and condition) may prove useful surrogates for the assessment of *ecosystem resilience*. The current study compiled data for these and other metrics using measurements from over 3,300 Red Gum, Black Box and Grey Box trees sampled between 2005 and 2017 at permanent stand condition and understorey monitoring sites in Gunbower Forest. Published research on the structure and growth of these species in the Murray Darling Basin was also reviewed to provide context for the results.

Saliently, when interpreting floodplain ecosystems, it is important to acknowledge the influence of spatially and temporally varying hydrological conditions which create considerable inter-site variability. At times, this variability can mask or enhance overall population trends, and thus can make the identification of condition and growth trajectories difficult. This task may also be hindered by spatio-temporal variance in anthropogenic intervention. For example, it is important to recognise the influence of changes to Aboriginal land management practices, river regulation, past and present timber harvesting, recreational activities, and the introduction of exotic animals, on extant population structure and health (Di Stefano, 2002). Essentially, as described by Brack (1999), extant stand structure is a product of the growth habit of individual species, ecological conditions, and the history of disturbance and management.

Figure 32 Timber harvesting near Understorey Site 20A, Gunbower Forest, March 2014

5.2 Tree Density

While there was considerable inter-site variability, the average density of Red Gum trees at the permanent Gunbower Forest monitoring plots in 2017 (311 – 312 trees ha^{-1}) was approximately half of the maximum tree density reported for natural Victorian floodplains (756 trees ha^{-1}, Cunningham *et. al.* 2010). It was however, more than 18 times the estimated pre-European tree density of comparable floodplain forest in Millewa (e.g. 17 trees ha^{-1}, McGregor *et al.* 2016). Further to the above, tree density appears to have increased, albeit modestly, at the stand condition sites between 2010 and 2017, and despite observations of natural thinning in Red Gum vegetation (Bennetts and Jolly, 2013); the majority (e.g. > 80 %) of Red Gums within the monitoring plots were alive when surveyed in 2017. Notably, the comparable density of Red Gum Forest and Woodland may reflect the more open nature of forest at some monitoring sites.

The density of Black Box trees at the monitoring sites in 2017 was lower than that for Red Gums (e.g. on average 238 trees ha^{1}). Yet, given the similar harvesting history, it is likely that the current densities are also well above the natural tree density prior to European settlement. Notably, there was limited evidence of natural thinning of this drought-tolerant species in Gunbower. Further, while there was insufficient data to validate this trend, it likely that tree density in Grey Box woodlands followed a similar pattern.

Gauging from the descriptions of Gunbower Forest in the late 1800s (see section 3.2, Figure 3), it is possible that the tree densities recorded in 2017 are within the natural range that existed prior to European settlement. However, it is likely that dense stands were interspersed with lower density stands, and were less common than observed today. The dramatic increase in tree density is most likely the result of flooding interacting with timber harvesting, as witnessed during early European settlement in the area (Perrin as cited in Russell and McGowan n.d.).

In a management context, the relationship between tree density and optimal flood frequency warrants consideration. In summary, high density stands are reported to require more water than low density stands to maintain tree health (Johns *et al.* 2009; Paul *et al.* 2003). High tree densities are also thought to limit tree growth (Horner *et al*. 2009). Consequently, a long-term ecological thinning project has been initiated in Millewa Forest to investigate whether reducing the number of trees per unit area will improve the health of the remaining floodplain trees (see OEH and Parks Victoria, 2009).

5.3 Basal Area

Patterns in BA were similar to that described for tree density; in that, there was marked variation between sites and forest types, and there was a modest increase in this measure from 2010 to 2017. Congruent with results reported by George (2004), the BA contributed by Red Gum Forest and Woodland sites was routinely higher than for Black Box Woodland sites, despite comparable tree densities at some sites.

While still within the range of BA values published for Red Gum floodplains, the average BA for Red Gum forests and woodlands in Gunbower (34 – 37 m^2 ha^{-1}), was however, around a third of the maximum recorded along the Murray River (110 m^2 ha^{-1}, Cunningham *et al*. 2010). The average BA for Red Gum forest was also 25% greater than that calculated for the comparable permanent inventory plot P2 in 1982. While the latter is based on 'under-bark' DBH values, and the former is calculated using over-bark measurements of DBH, this is still likely to represent an increase in BA (and hence productivity) for Red Gum Forests over the past 35 years.

5.4 Population Structure and Recruitment

Individuals within each age category (seedlings, saplings, pole trees and mature trees) were recorded for Red Gum, Black Box and Grey Box species at the understorey sites in all sample years from 2005 to 2017. This suggests repeated recruitment has occurred and conditions have been sufficient for the recruits to progress through the age categories over time. The age composition of populations varied markedly for each trees species however, and also between sites. The latter possibly indicative that some sites support more viable populations than other sites.

Relatively, there were more than double the number of Black Box seedlings and saplings per hectare compared to Grey Box, and up to ten times the number of Black Box seedlings and saplings per hectare than Red Gums. This could indicate that conditions over the past few decades promoted Black Box more so than Red Gum recruitment. That said, recruitment in floodplain trees is linked to the flood regime, with large numbers of seedlings emerging after appropriately seasoned inundation (CSIRO, 2004). And, given that box trees generally occur higher on the floodplain and are less likely to have been flooded than the low lying Red Gums, the larger numbers of Black Box recruits is therefore more likely to reflect the ability of this species to persist in the saplings size class during sub-optimal conditions. This latter explanation is consistent with observations made by George (2004) in Chowilla, South Australia. Alternatively, the difference in the number of recruits could be an artefact of timber harvesting, which ceased in box vegetation in the late 1900s (E. Monroe *pers. comm.* 2013), however continues to date, in Red Gum vegetation.

Saliently, while large recruitment cohorts are important for sustaining species' populations, regeneration is only successful when the recruits reach maturity and reproduce (George *et al.* 2005). George (2004) surmises that the viability of a stand of trees depends on successful recruitment supplementing the population at a rate that compensates for mortality within each age class. Progressive thinning of the seedlings, saplings and trees generally results in an inverse j-shaped size-class distribution, where there are large numbers of smaller (presumably younger) trees and fewer larger (presumably older) trees. This population structure is commonly considered sufficient to sustain long-lived species. Both the Red Gum and Black Box tree populations (comprising individuals > 3 m that are > 10cm DBH) sampled at Gunbower Forest approximate this size-class distribution. Having said that, distributions that include peaks in different size-class are not uncommon in episodic recruiting ecosystems such as floodplain populations, and are still considered sustainable (George, 2004).

In addition to a continuous progression through size and height classes, the health of individuals in each class will also determine a population's long-term viability, as well as its ability to respond to management intervention. As stated by George *et al.* (2005, p. 8) in reference to water delivery, "if poor trees die or fail to successfully reproduce, the proportion of trees available for continued population response to environmental flows is limited." For the understorey monitoring sites at Gunbower Forest, the transition from sapling and tree classes dominated by individuals in poor health in 2010, to classes dominated by healthy individuals in 2017, is a positive progression.

Notwithstanding the above, size-class distributions may be influenced by sampling patterns and high variability between sites. Rubin *et al.* (2006) recommend that areas of at least one hectare should be sampled to accurately account for population structure in temperate forest, and thus the 0.01 ha plots used to describe population structure at Gunbower Forest, may be insufficient. Given this, caution should be adopted when making inference about the overall health of floodplain trees, particularly with regards to size-class trends evident in the understorey dataset. Height and size-class frequency distributions were limited to individuals within the bounds of each plot (DBH measurements were not taken for trees in the concurrent crown condition survey), and many plots did not support saplings or trees.

5.5 Tree Growth

Red Gum and Black Box trees grew in diameter at the stand condition sites between 2010 and 2017, and at the understorey sites between 2005 and 2017. Rates of growth differed between species, and in relation to flood frequency and the health of trees upon initial assessment.

The recorded growth rate for Red Gums between 2010 and 2017 (0.44 cm yr^{-1}) falls in the upper range of those published for the Murray-Darling Basin. Growth as low as 0.05 cm $year^{-1}$ has been recorded at Barmah (Stone and Bacon, 1994), and the estimated post-1983 rate across Victorian Red Gum floodplain was 0.25 cm $year^{-1}$ (VEAC, 2006). Further, the growth rates recorded at permanent inventory plots in the forest between 1950 and 2005 were 0.27 cm $year^{-1}$ or less (VicForest, 2008). Similar outcomes were recorded for Black Box species, except that average growth rates (0.15 cm yr^{-1}) were considerably lower than for the Red Gums. As with many of the metrics analysed there was insufficient data to report on the growth of Grey Box species.

Provenance may explain some of the differences in growth between Gunbower Forest and other similar locations, as was found in a Red Gum seed lot trial undertaken by Bush *et al.* (2013). Tree condition is also likely to influence growth, as trees that supported healthy canopies at the beginning of monitoring period grew faster than those with poor canopies. Ellis *et al.* (2017) also recorded faster growth rates in trees with healthy canopies compared to those dominated by epicormic growth. It is therefore likely that the trees in Gunbower would potentially grow faster if they supported more canopy than detected in condition monitoring. For example, only 52% of Red Gums, 59% of Black Box and 77% of Grey Box trees that were part of the crown survey, supported *healthy* canopies in 2017 (Bennetts *et al.* 2017).

It is also likely that above average rainfall and widespread flooding in 2010 and 2012 promoted growth, as annual diameter increments were higher in Red Gums that were flooded more than twice over the eight-year period. Smith and Renton (2017) also recorded Red Gums growing as fast as 6 m year^{-1} during the same period that was governed by La Nina. With the decline in rainfall recorded over recent times it is conceivable that growth rates in Gunbower Forest have declined. The Natural Resources Commission (2009) suggest that Red Gum growth rates post-2003 were half of those recorded between 1970 and 2002. Notably, in the current study, there were an unequal number of replicates in each flood frequency class, so again observed trends may be an artefact of sample size.

Growth is not only important for sustaining tree species and floodplain forests, but also for the fauna species that depend on them. Taylor *et al.* (2014) suggest that given the growth rates they recorded (e.g. 0.2 – 0.5 cm year^{-1}), it would take one to two centuries for a healthy Grey Box individual to gain sufficient size to support a large habitat hollow.

6.0 CONCLUSION AND RECOMMENDATIONS

In summary, a review of existing tree data for Gunbower Forest yielded evidence to suggest that Red Gums, Black Box and Grey Box trees were recruiting and growing, and in the case of the former two species, were likely to comprise sustainable population structures. In both Red Gum and Black Box populations, it was found that growth rates were effected by crown condition (i.e. trees with a *healthy* crown at the beginning of the monitoring period grew faster than those with a *poor* crown). For Red Gums, flood frequencies of more than two years in an 8-year period, were also found to promote growth (i.e. trees in this flood class grew faster than those at non-flooded sites, and faster than those at sites that were flooded at a lower frequency).

There was, however, considerable inter-site variability in all the derived metrics, and in 2017, less than half of the sampled trees supported healthy canopies. This alone, suggests that interventive management remains warranted, and that the forests and woodlands of Gunbower Forest are likely to require more water for continued growth and population maintenance. Extant tree density was also found to differ markedly from natural tree density prior to European settlement, and was substantially higher than that estimated for similar floodplain forests at this time. With regard to this, further examination of the relationship between stand density and growth may be prudent, and similarly, the relationship between tree density and optimal flood frequency. The purpose of such investigations would be to ascertain whether extant tree density was limiting tree growth and/or condition. A possible scenario may see a partnership with VicForest to survey thinned (harvested) Red Gums to assess the differences in tree density at these sites vs. elsewhere in the forest.

Notably, in the current study, the paucity of available data for Grey Box woodland, meant there were insufficient replicates for valid tabulation of several of the metrics, including tree growth. Further, some of the observed patterns for Red Gum and Box populations may be a consequence of sample size; larger plots, and sampling all forest types at the same intensity may reveal different trends, and yield different levels of inter-site variability. Additionally, as *observed* flood frequency, does not consider the depth, duration, seasonality, or the interval between each flooding event, and given the different number of replicates in each flood class, caution should be adopted when inference is made from these trends. The longevity of pattern emergence in forest data should be a further consideration. Fundamentally, if further exploration of the relationship between tree growth and flood frequency is of management interest, then it is recommended that Black Box and Grey Box sample sizes be increased, particularly given the under underrepresentation of these taxa in published data.

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