Are extreme wet periods the key to successful floodplain tree recruitment in the Queensland Murray–Darling Basin?

Floodplain tree recruitment post 2020-2022 La Niña

Queensland Government

Prepared by: Queensland Herbarium, Department of Environment, Science and Innovation (DESI)

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"We would like to acknowledge Aboriginal peoples of the Queensland Murray–Darling Basin as the First Nations peoples of the country on which this work took place. We recognise their enduring connection to land, water, sky Country and community. We pay our respects to them, their cultures, and to their Elders past and present."

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Cover photo: Weir-CB*, Recruitment of coolibah in a fenced paddock with low grazing taken in the Border Rivers catchment in Sept 2023.*

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Summary

Floodplain ecosystems are water dependent for their health and sustainability. In Australia's Murray–Darling Basin, water is a limited commodity and water use must be carefully planned to meet environmental and anthropogenic needs. However, there are many knowledge gaps regarding the water requirements of floodplain ecosystems, and this impacts the ability to manage for, and report on, objectives of the Murray–Darling Basin Plan and Queensland water plans. Determination of these water requirements is complex and tantamount to determining a water balance and thresholds for key environmental services in a healthy functional ecosystem. This quandary is best understood by studying ecological analogues or natural processes.

Sustainable and healthy populations of floodplain tree species are dependent on successful recruitment of seedlings and their development into mature adults. Species demographic data for river red gum, coolibah and black box in the Queensland Murray–Darling Basin (QMDB) have suggested that variable rainfall within the basin over time has resulted in spatially patchy recruitment, and under representation of young trees (<10cm diameter size cohorts). A rare triple La Niña climatic event between 2020 and 2022 has provided an opportunity to observe and examine rejuvenation of floodplains associated with sustained rainfall and repeated floods over a period of three years.

In this study we asked the question, "Are extreme wet periods key to successful floodplain tree recruitment in the Queensland Murray–Darling Basin?" Field assessments were conducted in the Border Rivers and Moonie; Condamine and Balonne; and Warrego, Bulloo, Paroo and Nebine water plan areas, sampling 103 sites. Recruitment of river red gum, coolibah and black box was recorded within their mapped regional ecosystems throughout the QMDB and, although spatially variable, it indicated that the triple La Niña was successful in providing rainfall, river flows and conditions that supported germination of seedlings and their development into saplings and young adults. This resulted in a greatly improved demographic structure of the floodplain species.

Abundant grass cover and flourishing vegetation was observed throughout the basin during the La Niña rainfall. However, the basin experienced a dry winter in 2023, and at the time of the field sampling in July to September 2023, recruits were observed to be vulnerable to high grazing pressure from native, stocked, and feral animals at several sites. In the summer months of 2023/2024, heavy rainfall resumed throughout the basin suggesting that there may have been subsequent recovery and further development of the observed recruits. Our observations suggest that unique conditions and past rainfall events at basin scale have been responsible for mass establishment of the evenly sized tree cohorts evident in the basin.

Given these findings, it is recommended that:

1. Follow-up field monitoring be undertaken in 2024/2025 and subsequent years to document the survival and development of the observed recruits.
2. An assessment of groundwater availability is undertaken at recruitment sites to determine the potential for further development of recruits under El Niño and neutral ENSO conditions.
3. Work is undertaken to develop capacity to age trees and thus determine likely recruitment date and associated weather conditions at the time of tree recruitment. It is anticipated that the radiocarbon dating methodology being tested in Minjerribah (North Stradbroke Island) and the ongoing work on the development of an epigenetic clock for river red gum, if successful, will provide a useful tool.
4. Detailed study to document environmental assets (for example abundance of recruits) along selected river channels that are likely to benefit from environmental flows be conducted to help inform the potential of utilizing this option to support tree health.
5. Future risk assessment be conducted to determine the risk to floodplain tree population stability into the future under various climate change scenarios.

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INTRODUCTION

Floodplain ecosystems are dependent on water for their health and sustainability. However, the watering requirements of floodplain trees, specifically the links between flow regimes and floodplain vegetation health, is a major knowledge gap. This is impacting our ability to manage these ecosystems through water planning in the Queensland Murray–Darling areas and to report on them under the Murray–Darling Basin Plan (MDBA 2012). Due to the current lack of understanding of watering requirements from flow, as opposed to other water sources (e.g. groundwater, rainfall), floodplain vegetation is not currently included as an ecological asset in any of the Queensland Murray–Darling Basin (QMDB) water plans, nor the corresponding long-term watering plans, despite it being an important part of the ecosystem of the region.

Research into water availability and use by floodplain vegetation on the Lower Balonne floodplain showed no direct links with the flow regime and adult tree condition (DSITI and DNRM 2017); and while flooding may at times provide a water source to these species, the lack of an established "critical link" to flow brands it an unsuitable indicator for ecological risk modelling for QMDB water planning. Research found rainfall was the major driver of coolibah (*Eucalyptus coolabah*) condition, and river red gum (*Eucalyptus camuldulensis*) maintained condition by accessing channel or shallow alluvial groundwater in bank storage and palaeochannels through meander bends.

Opportunities to better understand watering requirements for recruitment of floodplain trees in the QMDB have been hampered by periods of extended drought from the 1990s to 2011, 2012–2015 and from 2017 to January 2020 (BOM 2020). However, the reproductive phenology of coolibah and river red gum has been monitored in the Condamine-Balonne catchment in the QMDB, with a view to better understand the role of rainfall and river flow in maintaining these populations (Kerr *et al.* 2022, In press). This study found that the timing of bud production, flowering, fruiting and seed production was largely consistent across the catchment and similar to results published for the southern region of the basin (George 2004; Jensen 2008; Casanova 2015). Higher bud density, and therefore flower and fruit density, was associated with rainfall, flooding, and warming temperatures. While seed production was not measured, the data suggests a seed- fall maxima that coincides with late summer/autumn flooding. These floods are likely to provide conditions that support seed germination and seedling establishment, suggesting a role for flooding and river flows in tree recruitment (Kerr *et al.* 2022).

Previous population demographics assessment of river red gum, coolibah and black box (*Eucalyptus largiflorens*) found significantly fewer juvenile trees than expected in the QMDB (Capon and Prior 2012; Ngugi *et al.* 2022); meaning the long-term viability of these populations is potentially threatened, with numbers declining as the old trees die off. This finding is consistent with several reports and anecdotal evidence that there has been little recruitment for over two decades (George *et al.* 2005; Woods *et al.* 2012). However, given the very long lifespan of these species, little is known about the required frequency of successful recruitment opportunities to achieve sustainable populations, including under our changing climate.

Localised and dense germination of floodplain tree seedlings was observed in the QMDB following widespread significant rainfall and drought-breaking flows in 2020 (Ngugi *et al.* 2022), suggesting that extreme weather events may be key to successful tree recruitment events. Since then, three back-to-back La Niña events (2020–2022) have led to consistently wet conditions and multiple flood events. These rainfall events provide a unique opportunity to investigate whether they support floodplain tree recruitment and reassess the viability of populations in the QMDB; When paired with tree ageing models (currently under development), will help us understand the frequency of recruitment events required to maintain sustainable floodplain tree populations, and the timing of flow and other conditions that contribute to recruitment opportunities.

Both native and exotic animals (including cattle, sheep, goats and pigs), have the potential to significantly impact the recruitment of floodplain tree species (Stefano 2002; Dorrough and Moxham 2005). Impacts from animals, primarily consumption/herbivory and trampling, have direct and negative impacts on the survival of germinating seedlings, and the development of seedlings into saplings, and saplings into established trees with a canopy beyond the reach of grazing animals (approximately two metres or higher)(Li *et al.* 2003; Reid *et al.* 2011).

The objectives of this project are to:

- Assess recruitment and survival of seedlings and saplings in the QMDB.
- Re-run the species population analysis for coolibah (*E. coolabah*), river red gum (*E. camaldulensis*) and black box (*E. largiflorens*) if sufficient data are available to determine if recent recruitment/lack of recruitment has affected population viability.
- Identify the drivers of, and threats to, floodplain tree recruitment.

METHODS

Selection of field sampling sites

The selection of recruitment assessment sites was undertaken in three stages to ensure good spatial coverage of the major QMDB floodplains. Firstly, the geographic location of all sites used for vegetation condition and tree demographic assessments in 2017–2020 in the QMDB was mapped (Ngugi *et al.* 2022). Secondly, the geographic locations of these sites and regional ecosystem maps were used to show spatial distribution, presence of sampling gaps and identify potential location of additional sites to be located along major floodplains within the basin (Figure 1). Finally, the additional sites were included and pre-selected based on accessibility (generally on public land for ease of access now and into the future); target species distribution and representation; and basin-wide spatial coverage.

Recruitment assessment sites were located either at the edge of waterways or on the adjacent floodplains and, to ensure representative coverage, were distributed across the major waterways of the QMDB water plan areas**.** These included the: Paroo and Warrego Rivers, Nebine and Mungallala Creeks (*Water Plan (Warrego, Paroo, Bulloo and Nebine)* (RDMW 2022)); the Condamine, Balonne, Maranoa, Culgoa, Bokhara, and Narran Rivers (*Water Plan (Condamine and Balonne)*(Lobegeiger and Prior 2022a)); and the Moonie, Weir, Dumaresq and Macintyre Rivers (*Water Plan (Border Rivers and Moonie)* (Lobegeiger and Prior 2022b)).

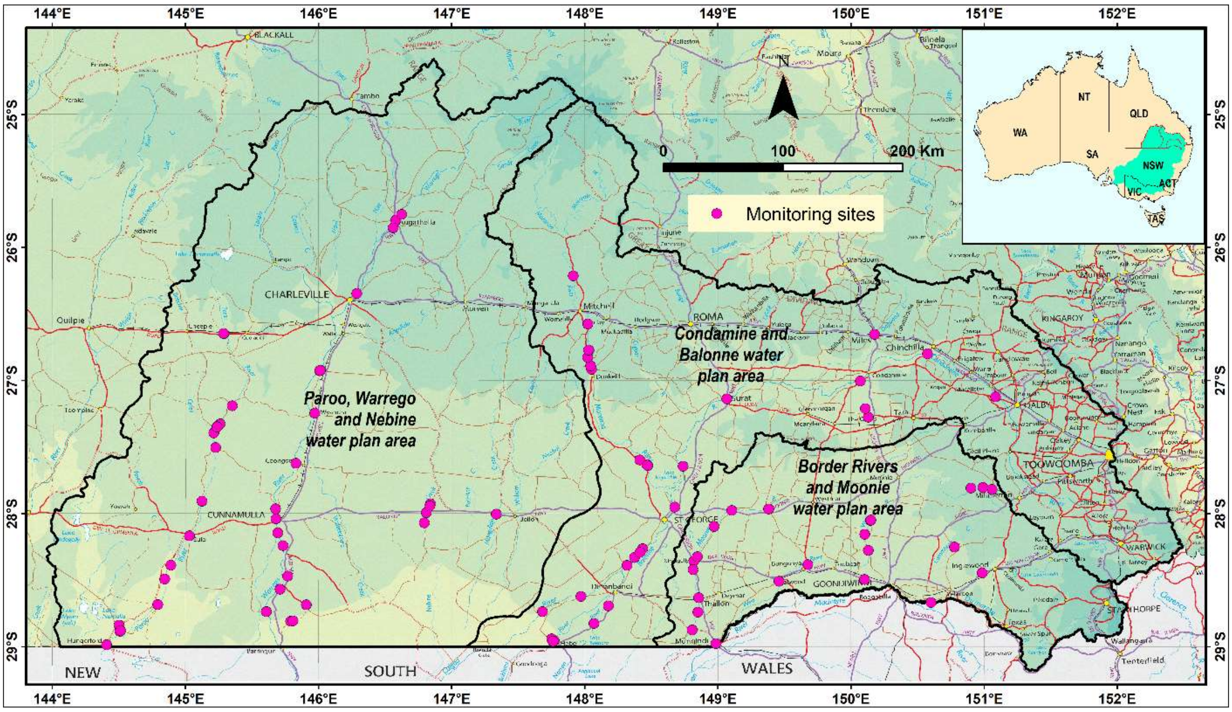

Figure 1. Location of all sites monitored in 2023.

Field assessments were undertaken using the detailed species condition assessment methodology field protocol (Cunningham *et al.* 2018) (Appendix 1). Due to the linear nature of riparian vegetation stands (<50m width), and to capture the diversity of riverine vegetation at each site, 25m x 100m (0.25ha) transects were mapped out at each site, parallel to the river channel. However, in some cases where recruitment was localised to a water pond or a microenvironment, such as a creek edge or channel, a smaller plot size was used as necessary. The smallest plot size used was 50m x 5m. In each plot, all seedlings (<0.3m tall), saplings (0.3–0m tall) and young trees (>2m tall and <10cm DBH) were recorded. In cases where the density of the recruits was very high, such as at the Callandoon site near Goondiwindi, ten 1m x 1m quadrats spaced at 10m intervals along the measuring tape were used to estimate the number of recruits in a plot.

Since seedling recruitment and survival is influenced by grazing pressure from animals. This includes native animals mainly kangaroos and both non-native stocked animals (cows, sheep) as well as non-native feral animals (pigs, goats, and escaped and now feral cattle and horses). Recruitment can also be influenced by the condition of the ground cover, the status of the ground cover along each 100m x 25m transect was sampled using a total of ten 1m x 1m quadrats to estimate the potential influence of this layer on seedling recruitment. Relative ground cover percentage was estimated for vegetation, plant litter, bare-ground, rocks and stones and coarse woody debris (fallen dead trees or branches on the ground >10cm diameter) and expressed as a percentage of the total area in each quadrat ($1m^2$).

Site Information

Additional site attributes that may influence recruitment of floodplain species were collected at each site. Assessed site attributes and their response categories are listed in Table 1.

Table 1. Site attributes that may influence recruitment of floodplain species and assessed response categories.

Assessed site attributes	Response categories
Seedling/sapling recruits	- Scattered - Clumped - Banded
Recruitment	- Seedling (0.3m tall), - Sapling (0.3-2.0m tall) - Young trees (>2m tall and <10cm diameter).
Land system	- River/creek: permanent / ephemeral - Wetland: permanent / ephemeral - Floodplain
Stand type	- Forest - Woodland - Open woodland - Scattered trees - Creek channel
Weeds	- High (25 – 100% veg cover) - Medium (≥5 – 25% veg cover) - Low (<5% of vegetation cover - Absent
Grazing pressure	- Exotic: high / medium / low / absent - Native: high / medium / low / absent
Inundation	- Present - Absent - Unknown (within last 12 months)
Inundation depth	- High - Medium - Low - Absent
Pig disturbance	- Present - Absent
Fire	- Present - Absent - NA (within last 5 years)
Timber extraction	- Present - Absent
Soil Moisture	- Waterlogged - Damp - Dry
Other disturbances	- Vehicle tracks - Camping - Any others?
Lignum	- Present - Absent

Rainfall and hydrology data

Rainfall is a critical factor in the recruitment of floodplain trees, therefore, understanding the pattern and amount of rainfall over the period preceding and during the La Niña would provide insights into the conditions and rainfall patterns that are likely to result in successful recruitment events. Rainfall data for at least two sites within each plan area for the period between 2010 and 2023 were obtained from the SILO database of Australian climate data, which is hosted by Queensland's Department of Environment, Science and Innovation (DESI). Climate data interpolation is based on daily weather records from the Australian Bureau of Meteorology (BOM) . The year 2010 was selected as the start date for the rainfall data as it marked the most recent La Niña event.

Hydrological conditions were characterised for the study region using daily stream discharge data from the Queensland Government surface water gauging station network, accessible via the Water Monitoring Information Portal (WMIP) (RDMW 2024). Field sampling sites were associated with relevant gauging stations by intersecting site locations with Floodplain Assessment Reaches (FARs), which are spatial units delineating the river channel and floodplain areas where the hydrological conditions are represented by flows at a gauge (DSITIA 2013; DES 2018a; b; c). To identify the effect of wet La Niña conditions on riverine flow conditions, bankfull flow volume thresholds for each gauge were applied to the daily flow time series to produce summaries of the frequency and duration of overbank flooding events (Appendix 2).

Drought conditions were estimated using a evapotranspiration deficit index (Svoboda and Fuchs 2016; Zhang *et al.* 2023). The index was used to estimate climatic water balance and characterize the severity and impacts of drought conditions by integrating rainfall, temperature, soil moisture, and evaporation rates to provide a comprehensive understanding of the drought situation and each monitoring site. The following formula is used to calculate the Drought Index:

$$DI=(P-E)/(P+E)$$

Variables:

- DI is the Drought Index
- P is the total precipitation received from the first of January 2020 to the field sampling date in 2023 (mm)
- E is the total of daily Morton's areal actual evapotranspiration (mm) over the same period as the total precipitation (mm)

Daily rainfall and Morton's areal actual evapotranspiration were obtained from SILO climate database (DESI 2024). The Drought Index (DI) can range from -1 to 1. DI = 1 occurs when there is no evapotranspiration (E = 0), indicating extremely wet conditions. DI = -1 occurs when there is no precipitation (P = 0), indicating extremely dry conditions and DI = 0 occurs when the total precipitation equals the total evapotranspiration (P = E), indicating neutral conditions. Hence values between -1 and 1 represent varying degrees of drought or wetness, with negative values indicating drier conditions and positive values indicating wetter conditions.

Data analysis

All recruitment data collected at each plot were converted (standardised) to per hectare. To interrogate the association between observed recruitment density and site factors in Table 1, multivariate regression analysis method was used. All the categorical variables were included in the analysis by creating proxy variables to represent these categories numerically and allowed us to incorporate categorical information as the indicator variables into multivariate regression models. For example, for pig damage with two categories (present or absent), a value of 1 was assigned if "present" and a value of 0 assigned if "absent". For variables with several categories such as grazing pressure from exotic animals (four categories: high, medium, low and absent), sub-variables were created e.g. Exotic_high, Exotic_medium, Exotic_low and Exotic_absent. The sub-category that was observed in a plot was assigned a value of 1, and the remaining sub-categories not observed in a plot assigned a value of 0 (zero). Hence it was possible to elucidate the relationship between the observed recruitment and the intensity (or absence) of grazing pressure in the dataset.

Multivariant regression analysis was also used to elucidate the association between quantity of recruits and drought index, and hydrological variables (the number of rainfall events that exceeded the bankfull threshold of the river gauges, total days the threshold was exceeded and the number of days since the last flood) at the sampling sites. The statistical data analyses were undertaken using Analysis ToolPak which is an add-in application for Microsoft Excel (Halpern *et al.* 2018). Significant associations between observed recruitment density and ground cover site covariates (proportions of vegetation, bare ground, rock/stones and plant litter) were identified using stepwise multivariate linear regression methods. Fitted models were compared using the coefficient of determination (r^2) and the p - value ($p = 0.05$).

RESULTS

Recorded floodplain tree recruitment

A total of 103 sites were visited and assessed for presence of floodplain tree recruits. While the recruits varied in height, those observed within the same sampling site were generally the same size or cohort suggesting that they germinated following one event. Recruitment was observed in 34% of the visited sites (Table 2), and the sites were distributed across the water plan areas as shown in Figure 2. The estimated density of recruits ranged from 4 to 3,372 stems per hectare, but the highest density of recruitments was equivalent to 298,180 saplings per ha of river red gum. These were observed growing along a 10m wide x 120m long band within a fenced site adjacent Callandoon Lake near Goondiwindi. Recruitment was observed in over 47% of the sites visited in the Warrego, Paroo, Nebine water plan area (Table 2).

Table 2. Number of sites visited in each water plan area and the proportion of the sites in which recruitment was recorded.

Water plan area	Number of sites	Number of sites with recruits	Proportion of sites with recruit (%)
Border Rivers and Moonie	25	5	20
Condamine and Balonne	33	9	27
Warrego, Paroo, Nebine	45	21	47
Total	103	35	34

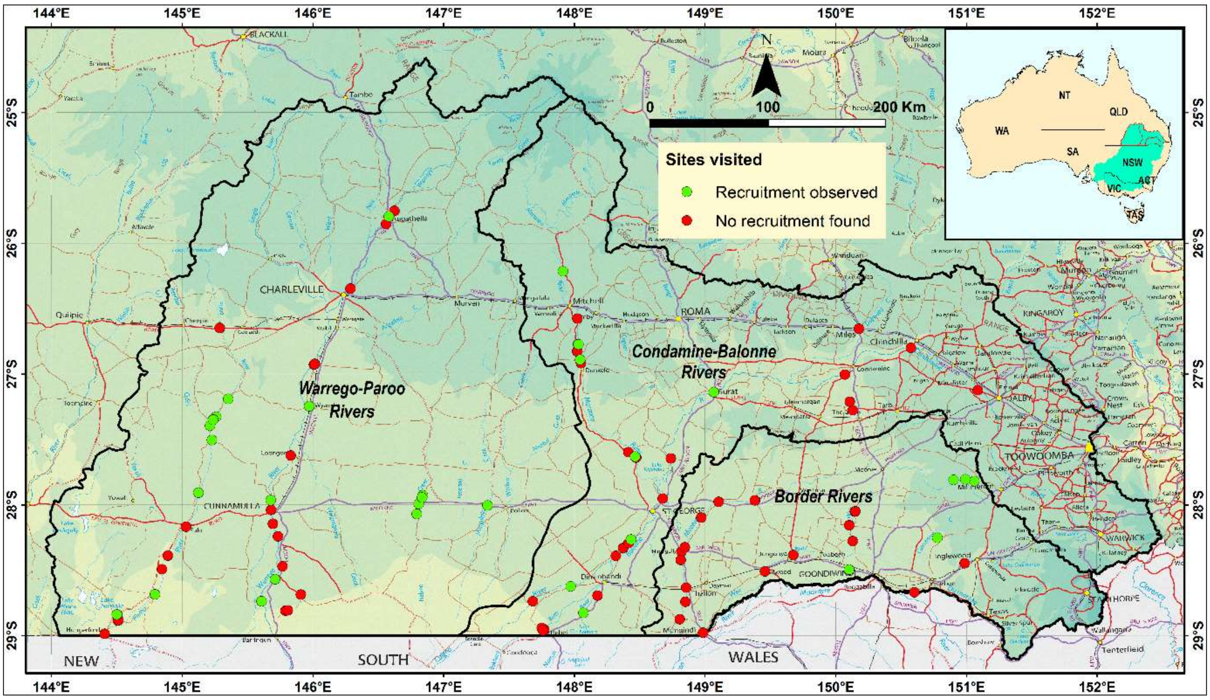

Figure 2. Locations of observed recruitment events on sites sampled in 2023, showing the 67 sites where recruitment was not observed (red) and 36 sites in which some recruitment was recorded (green marker).

Non-native flora (weed) cover

Non-native plant species (weeds) were common in grazing areas in the visited catchments. The number of sites and the category of weed condition in each catchment, and the proportion of sites with weeds are presented in Table 3. Weeds were observed in over 77 % of all the sites visited across the basin. The highest proportion of sites with weeds and high weed dominance was in the Border Rivers and Moonie catchment followed by Condamine-Balonne (Table 3). The dominant non-native species were green panic grass (*Megathyrsus maximus* var. *pubiglumis*)(

Figure 3) and buffel grass (*Cenchrus ciliaris*) (Figure 4) both common in adjacent grazing land. During the field assessment, most of the sampled sites were not grazed and were covered by high grass cover, which was competing with saplings for light and resources.

Table 3. Proportion of sites in the QMDB where non-native flora (weeds) was recorded, displaying the intensity of presence in four categories: high (25–100% cover), medium (5–25% cover), low (<5% cover) and absent.

Water plan area	High	Medium	Low	Absent	Percent of sites with weeds (%)
Border Rivers and Moonie	3	2	19	1	96
Condamine and Balonne	0	1	28	2	94
Warrego, Paroo and Nebine	1	3	22	21	55
Total	4	6	69	24	77

Figure 3. Ground cover dominated by green panic grass (*Megathyrsus maximus var. pubiglumis*) at site 283 in the Border Rivers catchment.

Figure 4. Ground cover dominated by buffel grass (*Cenchrus ciliaris*) at site MUL9-2 in the Warrego River catchment.

Grazing pressure from exotic and native animals

Evidence of native and stocked animal grazing was distinguished based on exclusion fencing, and other signs such as footprints, tracks, and scats to indicate what was eating the recruits. Because of accessibility requirements, most assessment sites were generally on public land such as waterways and road reserves. In the Border Rivers and Moonie; and the Condamine and Balonne water plan areas, over 80% of the sampled sites showed evidence of grazing by exotic animals, with 40% of the sites recorded as having medium to high grazing pressure (Table 4). In the Warrego, Paroo and Nabine water plan areas, the proportion of sites that were grazed by exotic animals was 72%. Within the Paroo catchment, several of the sampled sites were within Currawinya National Park, where stocked animals were excluded. The impact of grazing pressure from stocked and non-stocked non-native animals was evident at various sites in the Condamine–Balonne and Border Rivers (Figures 5, 6, 7 and 8), and contributed to the loss and death of seedling and saplings.

Table 4. Grazing pressure from exotic animals showing the number of grazed sites in each water plan area (total number of sampled sites) in which grazing was recorded and the proportion of sites in which grazing was recorded.

Water plan area	Number of sites	High	Medium	Low	Absent	Grazed (%)
Border Rivers and Moonie	25	4	6	13	2	92
Condamine-Balonne	31	3	12	10	6	81
Warrego, Paroo, Nebine	47	2	14	18	13	72
Total		9	32	41	21	80

Figure 5. Recruitment of coolibah present on fenced and unfenced site but heavily grazed by livestock along a stock route at the Weir_CB site within the Weir River catchment (Border Rivers) (12 Sept 2023).

Figure 6. Thriving coolibah recruitment within a fenced paddock in September 2023 (adjacent Figure 5) with low grazing pressure at Weir _CB site within the Weir River catchment (Border Rivers).

Figure 7. River red gum recruitment site (DD17) in September 2023. In 2020, this was a flourishing recruitment site adjacent to a wetland along the Balonne River (Condamine-Balonne).

In 2023, the wetland had dried, and the recruits were dying because of high grazing pressure from exotic animals and dry condition.

Grazing from native animals was evident as distinguished by scants, sightings and tracks at 97% of the sites in the QMDB (Table 5). Grazing pressure was variable but mainly of low intensity and targeted to the lush green saplings. This may be because much of the ground level vegetation was drying up quickly at the time of the monitoring due to hot and dry weather in the weeks prior to sampling.

Table 5. Categorical grazing pressure from native animals in each water plan area from sites where grazing was recorded, and the proportion of sites in which grazing was recorded.

Catchment	Number of sites	High	Medium	Low	Absent	% grazed
Border Rivers and Moonie	25	1	11	12	1	96
Condamine and Balonne	31	1	8	21	1	97
Warrego, Paroo and Nebine	47	0	7	39	1	98
Total	103	2	26	72	3	97

Figure 8. Recruitment of coolibah grazed by native animals within a road reserve at Callandoon Lake, near Goondiwindi (Border Rivers); the site is fenced off from the adjacent stocked paddock.

Association between recruitment and site variables

Multivariate regression analysis revealed no significant association between the recorded quantity of recruits at a site and the observed tree species (Table 6). This was mainly because the tree species have their own habitat niche and recruited in large numbers under favourable conditions. The presence of a permanent water body (i.e. permanent creek) was not significantly associated with the number of recruits ($p = 0.08$. Ephemeral creek and floodplain land systems were significantly associated with quantity of recruits ($p < 0.01$). Most river red gum recruits were observed along the banks of ephemeral waterways, while coolibah were mainly on the floodplains further from the waterways. This reflects the dominant landscape distribution of these two species.

Drought index for the sites ranged from -0.267 to -0.022. They were much higher compared to that of the driest year in a decade at WP 11 (Paroo catchment) (Figure 36) in 2018 of -0.401, -0.502 at Moonie in 2019 (Figure 16) and -0.587 recorded at site 251 in the Condamine-Balonne catchment at Surat in 2018 (Figure 21). The density of observed recruits was significantly associated with the flood attributes ($p < 0.05$) but not with the drought index ($p = 0.084$) as shown in Table 7. Although only 53 of the sites had a corresponding gauging station, the result suggests that the observed recruitment of floodplain species was associated with flooding events. However, flood mapping for the flood events recorded during the study period were not available to enable precise determination of flooding history at each site.

The association between quantity of recruits and grazing pressure was also investigated using multivariate regression analysis (Table 8). The quantity of recruits was significantly associated with absent, low and medium levels of native animal grazing pressure ($p < 0.01$) but was not significantly associated with medium or high grazing pressure from exotic animals. All the sites assessed by the study are on crown land and included road reserves, waterway channels and conservation parks. Consequently, majority of sampled sites were rarely grazed by domestic animals, the grass cover was very high and native animal impact was minimal in the context of the overgrown grass cover. Because of the large quantity of grass on the landscape, the impact of native animal grazing on recruits was localised to few sites and minimal on majority of sites.

Table 6. Association between quantity of recruits and site variables including species (RRG = river red gum, EC = Eucalyptus coolabah, BB = black box and mixed stands of the floodplain species), forest type, land system and soil texture. Asterisks denote significant levels *p <0.05; ** p<0.01; ***p<0.001.

Attributes	Coefficient	Standard error	t-statistic	*P*-value
Intercept	1434.029	697.202	2.057	0.043*
RRG	430.278	422.694	1.018	0.311
EC	268.195	422.678	0.635	0.527
RRG+EC	143.387	446.196	0.321	0.749
RRG+EC+BB	-47.824	802.668	-0.060	0.953
BB	-64.550	521.785	-0.124	0.903
Permanent_creek	-1255.720	706.565	-1.777	0.079
Ephemeral	-1745.190	508.703	-3.431	0.001**
Floodplain	-1564.990	528.314	-2.962	0.006**
Woodland	361.703	220.752	1.639	0.105
Clay	6.172	234.980	0.026	0.979
Loam	-125.888	258.101	-0.488	0.627
Sandy	48.504	366.935	0.132	0.895
R-squared	0.189			
Adjusted R-squared	0.060			
Observations	103			

The association between ground cover and the quantity of recruits observed at each site was also investigated (Table 9). The attributes considered were the relative proportions of vegetation cover, bare ground cover, litter cover and rock cover in a 1m x 1 m quadrat. None of the attributes were significantly associated with quantity of recruits recorded.

Table 7. Association between the quantity of recruits and hydrological variables, including: drought index; river bankfull exceedance events (number of rainfall events exceeding bankfull threshold (2020-2023)); total days of exceedance (number of days bankfull threshold was exceeded (2020-2023)); and days since the last flood (days between last flood and sampling). Asterisks denote significant values i.e. *p <0.05; ** p<0.01; ***p<0.001.

Attributes		**Coefficients**	**Standard error**	**t -statistic**	***P*-value**
Intercept		-930.963	660.454	-1.410	0.166
Drought index		-3897.62	2207.010	-1.766	0.084
Bankfull exceedance events		195.390	81.650	2.393	0.021*
Total days of exceedance		-19.745	8.122	-2.431	0.019*
Days since last flood		0.198	0.094	2.107	0.041*
R Square	0.573				
Adjusted R Square	0.359				
Observations	54				

Table 8. Association between quantity of recruits and site variables including grazing pressure from exotic and native animals, and soil type. Asterisks denote significant values i.e.*p <0.05; ** p<0.01; ***p<0.001.

Attributes	**Coefficients**	**Standard error**	**t-statistic**	***P*-value**
Intercept	2162.654	558.857	3.870	0.000***
Grazing exotic - medium	308.039	210.309	1.465	0.146
Grazing exotic - high	84.584	322.069	0.263	0.793
Grazing native - absent	-2048.710	633.934	-3.232	0.002***
Grazing native - low	-1791.300	497.949	-3.597	0.001***
Grazing native - medium	-2076.230	515.473	-4.028	0.000***
R Square	0.189			
Adjusted R Square	0.057			
Observations	103			

Table 9. Summary results of stepwise multiple regression analyses of the effects of ground layer attributes on the observed quantity of recruits. Asterisks denote significant values i.e. *p<0.05; ** p<0.01; ***p<0.001).

Attribute	Coefficients	Standard Error	t Stat	*P*-value
Intercept	-13194.800	92642.400	-0.142	0.888
Vegetation cover %	132.465	926.426	0.143	0.887
Bare ground cover %	135.144	926.290	0.146	0.885
Litter cover %	146.314	925.669	0.158	0.875
Rock cover %	135.113	926.569	0.146	0.885
Non-natives cover %	17.670	19.286	0.916	0.366

R Square	0.069
Adjusted R Square	-0.064
Observations	41

Floodplain recruitment assessments

Border Rivers and Moonie Water Plan area

All sites assessed within the Border Rivers and Moonie Water Plan area are shown in Figure 9, with site details presented in Table 10. Recruitment was recorded on five sites. Over the study period (2020–2023), this plan area experienced the greatest amount of riverine flooding of all the QMDB water plan areas. There was an average of eight overbank flood events (ranging from one to 21) across the nine hydrological gauging stations assessed, providing an average inundation duration of 63 days (range 1–180) (Appendix 2).

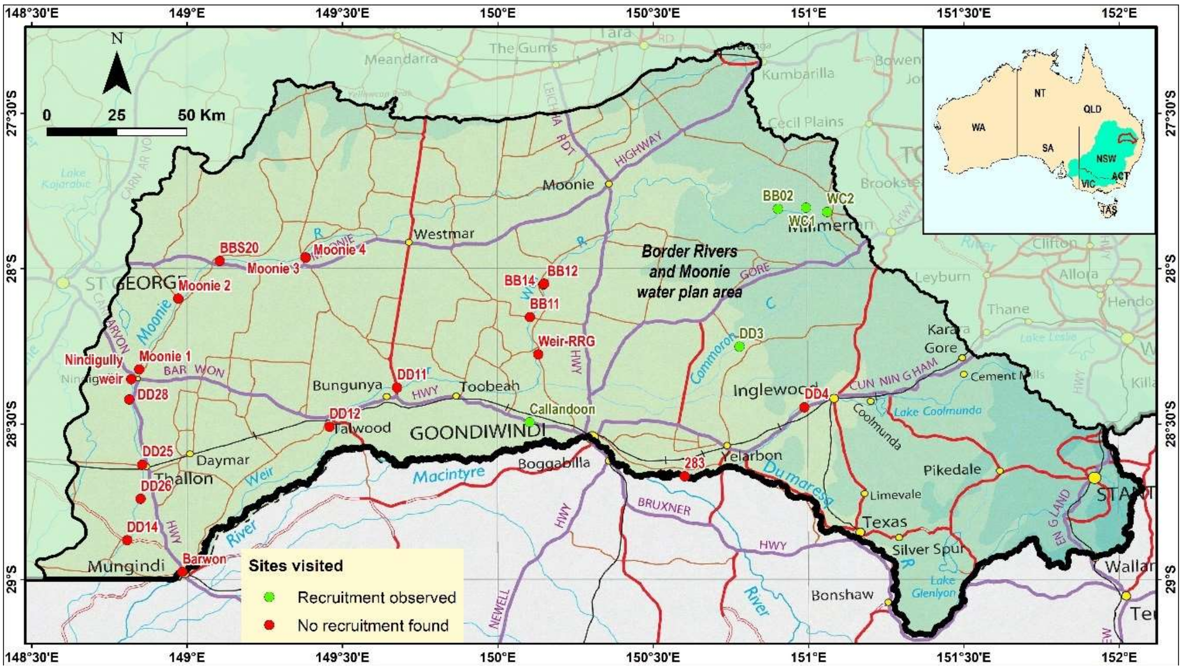

Figure 9. The geographic locations of sampled sites in the Border Rivers and Moonie Water plan area, showing sites where recruitment was recorded (green marker) and sites at which recruitment was not observed (red marker).

The rainfall data for Callandoon Lake, near Goondiwindi between 2010 to 2023 is presented in Figure 10. The rainfall chart shows the long-term average of total rainfall, with 2019 as the driest year in the last decade. It also shows that though 2020 received drought breaking rainfall, and germination of river red gum seedlings was recorded in the Weir creek, the total annual rainfall was below average. There were two prominent rainfall peaks recorded at the location and these have been accompanied by flooding events, the 2010-2011 (two year La Niña) and the 2020-2022 (three year La Niña) (Figure 11). Periods of very low river flow were recorded between 2018-2020.

The dense recruitment recorded at Callandoon, near Goondiwindi in 2023 was adjacent to a small lake (Figure 12).

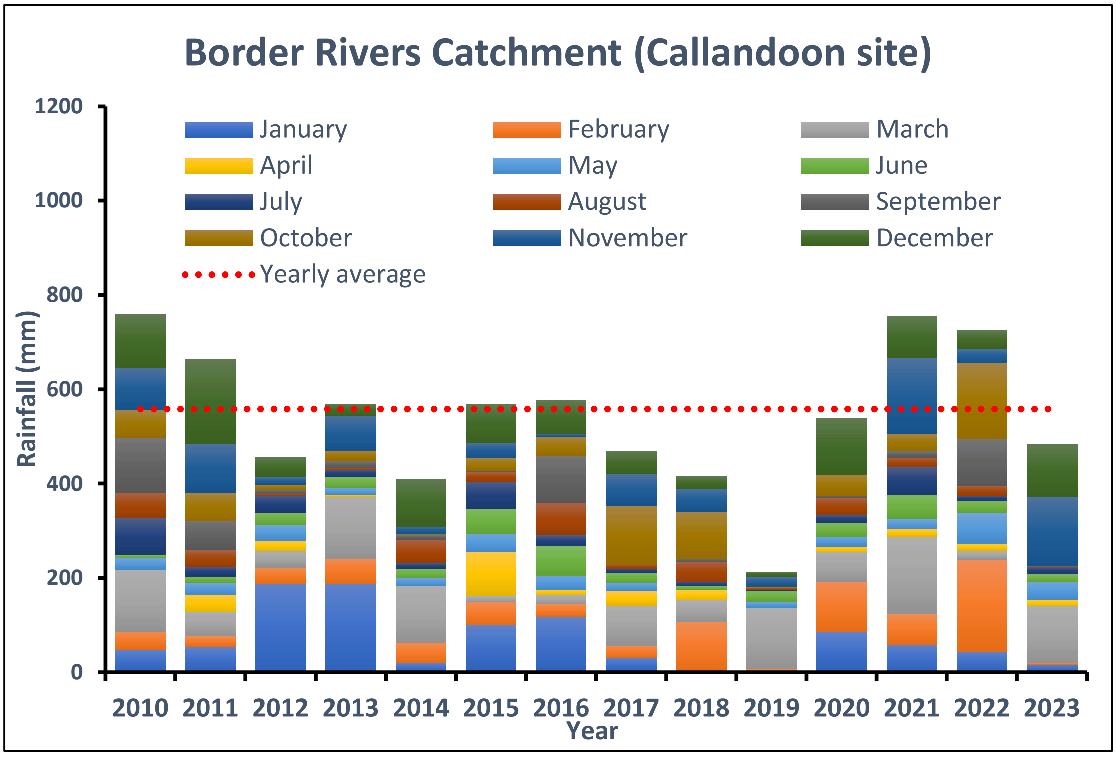

Figure 10. Monthly rainfall total recorded at Callandoon near Goondiwindi in the Border Rivers catchment between 2010 and 2023, showing the amount of rainfall recorded each month. The long-term average of total annual rainfall (558 mm) is shown by a red dotted line.

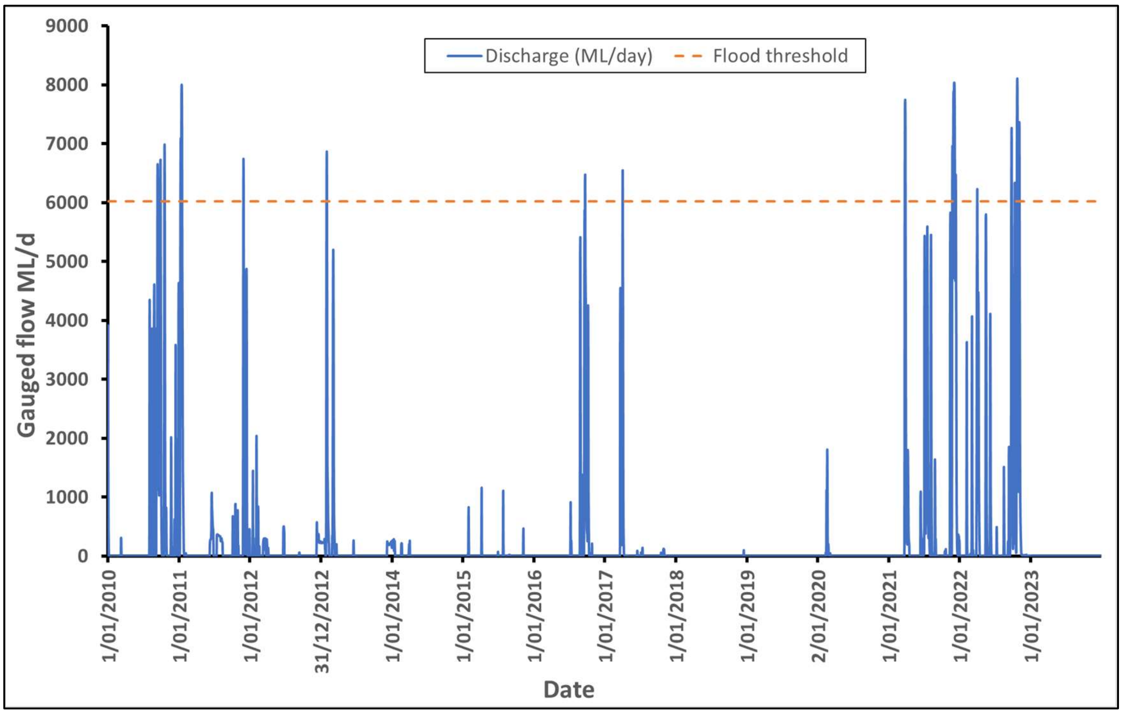

Figure 11. Daily flow data recorded at the Callandoon Creek at Carana Weir gauging station (416203A). Bankfull flow threshold, indicating which flow events were associated with overbank flooding, is represented by the orange dashed line.

The river red gum recruitment at the Callandoon site was enclosed by a fence and was in the form of a long band, likely indicating the water level as flood waters receded (Figure 12). Other river red gum recruitment sites were recorded in the eastern part of the Border Rivers and Moonie WPA, mainly along the edge of the channels of ephemeral creeks in the Western Creek State Forest (Figures 13 and 14).

No recruitment was recorded at the sampled sites along the Moonie River (Figure 9, Figure 15). While it was not clear why this was the case, it was noted that the rainfall records from site Moonie 4 which is, west of Finton (Figure 9), indicated only two years of above average rainfall in 2021 and 2022 (Figure 16). The two-year rainfall peak received relatively less rainfall than that recorded in the 2010-2011 La Niña (Figure 16). While there was a series of flood events in 2022, these were small compared to the very large flood peak in 2010, inundating much less area of floodplain habitat (Figure 17). It is therefore likely that there was germination of seedlings, but they did not successfully get established (Figure 18).

Figure 12. Dense recruitment of river red gum, recorded in September 2023 adjacent to the Callandoon Lake (near Goondiwindi) on the Weir River floodplain (Border Rivers).

Figure 13. Recruitment of river red gums recorded along the banks of the Weir River (Border Rivers) at Site WC2 in the Western Creek State Forest in September 2023.

Table 10. Recruitment status within the Border Rivers and Moonie water plan area. The species are coolibah (EC, Eucalyptus coolabah), river red gum (RRG, Eucalyptus camaldulensis) and black box (BB, Eucalyptus largiflorens). Counts of seedling (0.3m tall), sapling (0.3-2.0m tall) and young trees (>2m and <10cm diameter). WDL = woodland, OWDL = open woodland and CRCH = creek channel.

Water plan area	**SiteID**	**Latitude**	**Longitude**	**Target Species**	**Seedling per ha**	**Sapling per ha**	**Young trees per ha**	**Grazing Pressure Exotic**	**Grazing Pressure Native**	**Stand Type**	**Soil Type**	**Lignum**
Border Rivers and Moonie	Weir-CB	-27.276	150.131	EC	0	0	0	High	Medium	OWDL	Clay	Present
Border Rivers and Moonie	211	-27.210	150.108	EC	0	0	0	Low	Low	WDL	Clay	Absent
Border Rivers and Moonie	DD12	-28.508	149.459	EC	0	0	0	Medium	Medium	WDL	Clay	Present
Border Rivers and Moonie	Callandoon	-28.494	150.103	RRG	0	298180	0	Low	High	OWDL	Clay	Absent
Border Rivers and Moonie	DD25	-28.631	148.856	EC	0	0	0	Medium	Low	WDL	Clay	Absent
Border Rivers and Moonie	BB2	-27.808	150.902	RRG	32	12	0	Medium	Low	CRCH	Sandy	Absent
Border Rivers and Moonie	WC1	-27.804	150.992	RRG	84	12	0	Low	Low	CRCH	Sandy	Absent
Border Rivers and Moonie	WC2	-27.817	151.060	RRG	4	84	0	Low	Low	CRCH	Sandy	Absent
Border Rivers and Moonie	DD3	-28.251	150.778	RRG	108	92	0	Medium	Low	CRCH	Sandy	Absent
Border Rivers and Moonie	Weir-RRG	-28.276	150.131	RRG	0	0	0	Low	Low	Forest	Silty	Absent
Border Rivers and Moonie	283	-28.668	150.602	RRG	0	0	0	Low	Medium	Forest	Loam	Absent
Border Rivers and Moonie	DD4	-28.446	150.987	RRG	0	0	0	Absent	Low	Forest	Loam	Absent
Border Rivers and Moonie	BB12	-28.048	150.149	RRG	0	0	0	Low	Medium	OWDL	Loam	Absent
Border Rivers and Moonie	BB14	-28.051	150.147	RRG	0	0	0	Low	Low	Forest	Loam	Absent
Border Rivers and Moonie	Nindigully	-28.356	148.820	RRG	0	0	0	Absent	Absent	OWDL	Clay	Absent
Border Rivers and Moonie	Barwon	-28.976	148.985	RRG	0	0	0	Low	Low	Forest	Clay	Absent
Border Rivers and Moonie	Moonie 4	-27.964	149.382	RRG	0	0	0	High	Medium	Forest	Clay	Absent
Border Rivers and Moonie	DD26	-28.741	148.851	RRG/BB/EC	0	0	0	High	Medium	WDL	Clay	Absent
Border Rivers and Moonie	BB11	-28.155	150.104	RRG/EC	0	0	0	Low	Low	Forest	Loam	Absent
Border Rivers and Moonie	DD11	-28.382	149.676	RRG/EC	0	0	0	Medium	Low	WDL	Clay	Present
Border Rivers and Moonie	DD28	-28.420	148.814	RRG/EC	0	0	0	High	Medium	WDL	Clay	Absent
Border Rivers and Moonie	Moonie 3	-27.964	149.381	RRG/EC	0	0	0	Low	Medium	WDL	Clay	Absent
Border Rivers and Moonie	BBS20	-27.975	149.105	RRG/EC	0	0	0	Low	Medium	WDL	Clay	Absent
Border Rivers and Moonie	Moonie 1	-28.324	148.846	RRG/EC	0	0	0	Medium	Medium	Forest	Clay	Absent
Border Rivers and Moonie	Moonie 2	-28.097	148.972	RRG/EC	0	0	0	Low	Medium	Forest	Clay	Absent

2020 2023

Figure 14. Recruitment of river red gum recorded at Western Creek State Forest (Site DD2) along the Weir River (Border Rivers) in October 2020 (left). These recruits were mostly washed away by subsequent flood between 2020 and 2023. Few seedlings and saplings were recorded at the site on 11 September 2023 (right).

Figure 15. Site Moonie 4 with no recruitment observed along the Moonie River in the Border and Moonie Rivers plan area (15 September 2023).

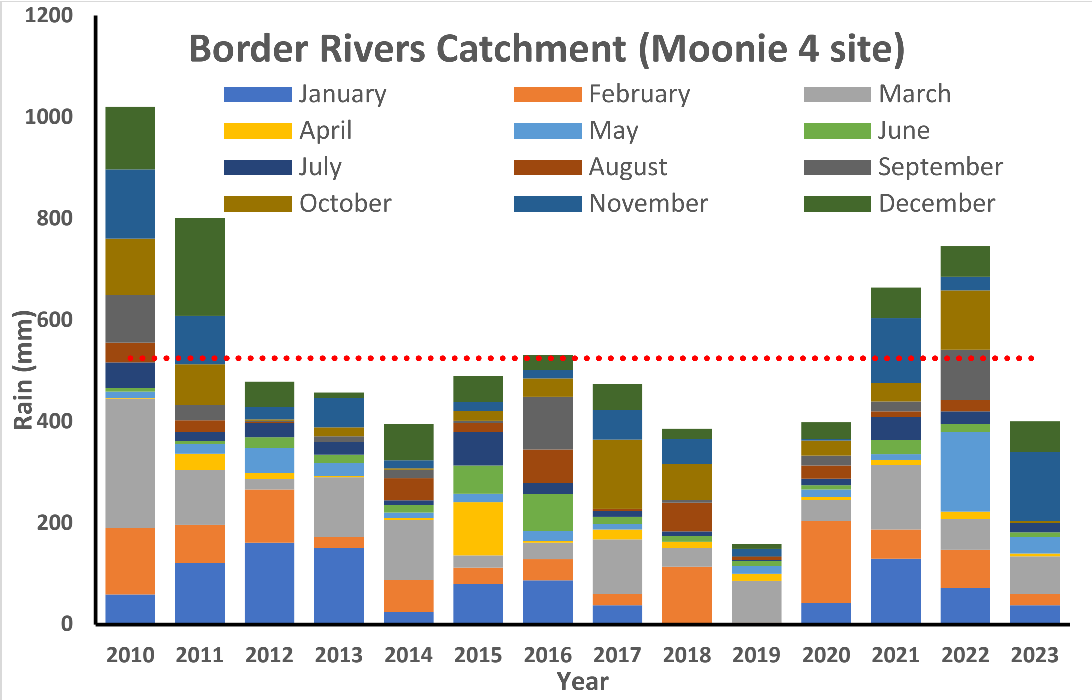

Figure 16. Monthly rainfall total recorded at Site Moonie 4 (west of Flinton) along the Moonie River between 2010 and 2023, showing the amount of rainfall recorded each month. The long-term average of total annual rainfall (525 mm) is shown by a red dotted line.

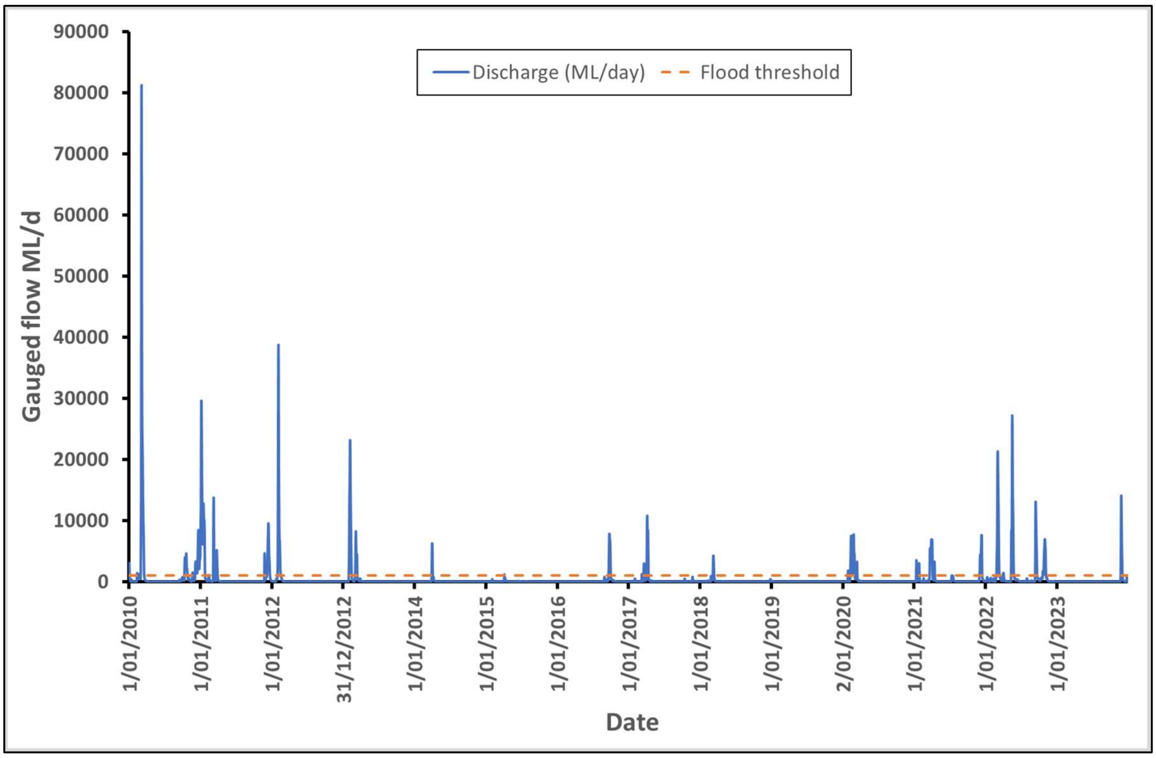

Figure 17. Daily flow data recorded at the Moonie River at Nindigully gauging station (417201B). Bankfull flow threshold, indicating which flow events were associated with overbank flooding, is represented by the orange dashed line.

Figure 18. Site DD14 along the Moonie River where no recruitment was observed in September 2023.

Condamine and Balonne water plan area

All the sites assessed within the Condamine and Balonne water plan area are shown in Figure 19 and the details at each location are presented in Table 11. Recruitment was recorded on 10 sites and included river red gum and coolibah seedlings and saplings. Over the study period (2020–2023), the Condamine and Balonne WPA experienced an average of four overbank flood events (range 0-10) across the 13 hydrological gauging stations assessed, providing an average inundation duration of 50 days (range 0–134) (Appendix 2).

No recruitment was observed along the Condamine River in the visited sites east of Surat as shown in Figure 20 in red, but these monitoring sites were dominated by either mature river red gum or coolibah tree communities and had been established for long-term monitoring of floodplain stand condition. For example, no recruitment was observed at site BB06 (Figure 20). The rainfall amount received at Surat between 2010 to 2023 (Figure 21) shows that 2019 was the driest year in the last decade and the rainfall received in 2020-2022 was relatively less than that received in the 2010-2012 La Niña as shown in Figure 21. A series of small flood peaks occurred during 2022, resulting in an extended period of floodplain inundation, however the spatial extent of inundation was small compared to the very large flood events that occurred in 2010 (Figure 22).

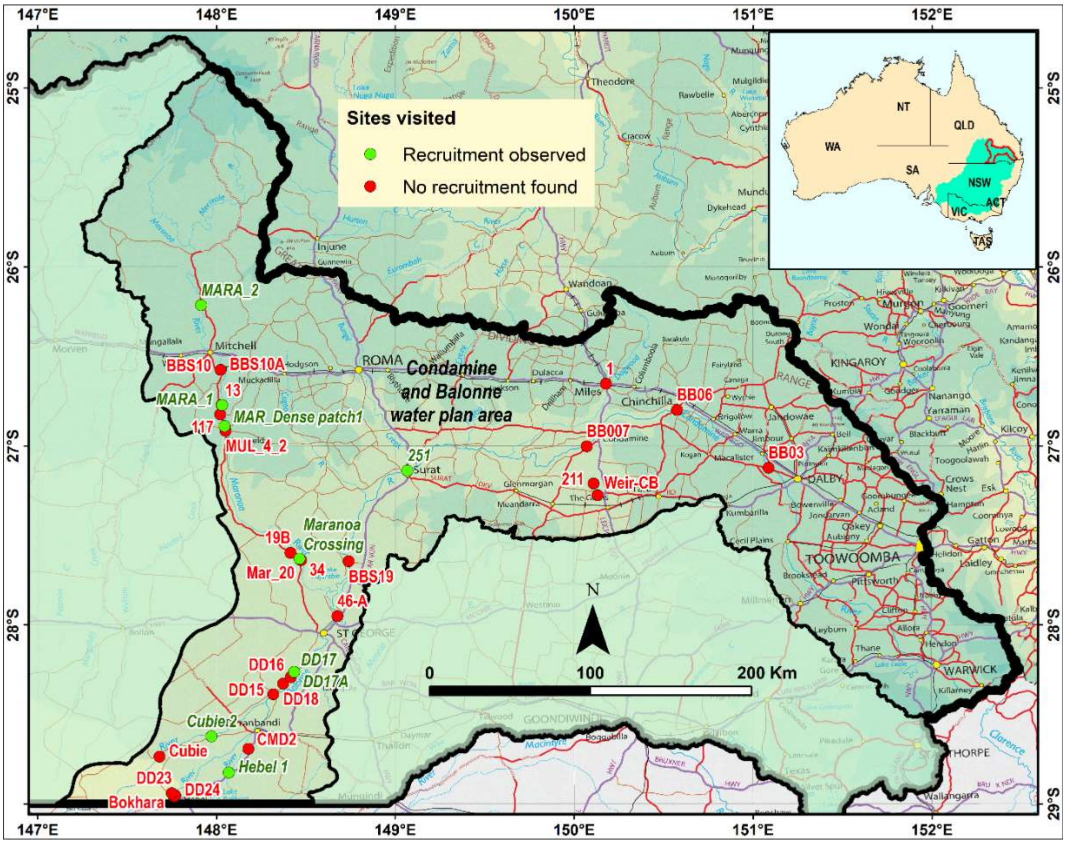

Figure 19. The geographic locations of sampled sites in the Condamine and Balonne water plan area, showing the sites where some recruitment was recorded (green marker) and site in which recruitment was not observed (red marker).

Figure 20. Site BB06 along the Condamine River where no recruitment was observed, though the site had been flooded, indicated by the visual flood height on the trees observed on 31 July 2023.

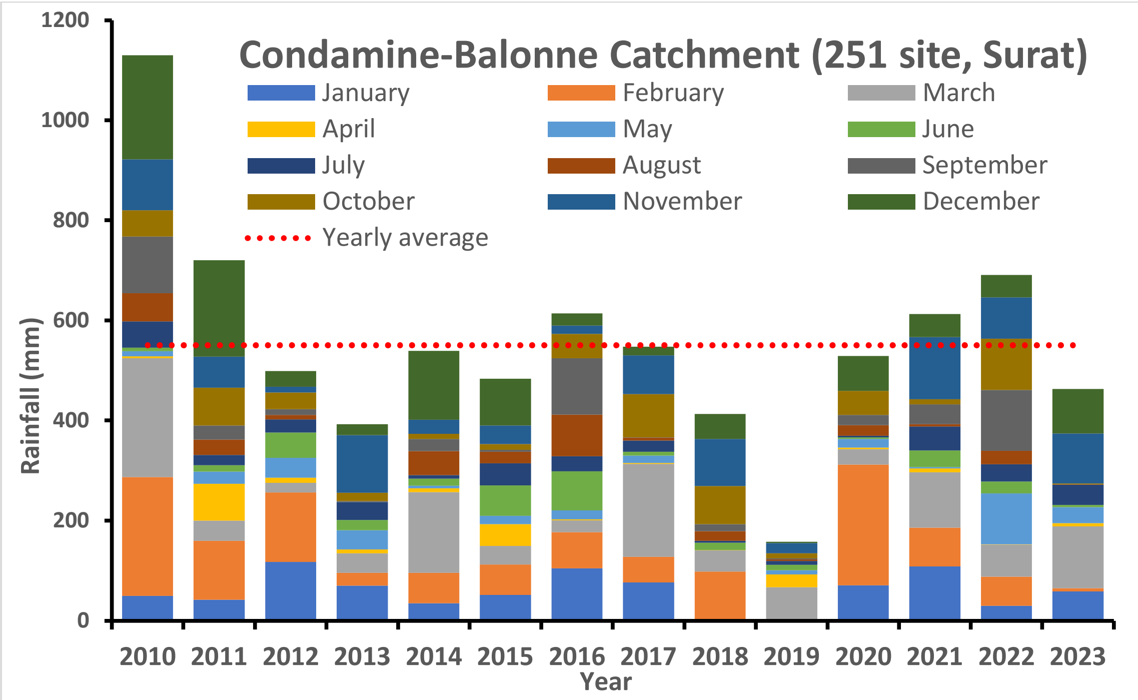

Figure 21. Monthly rainfall total recorded at Site 251 (Surat) along the Condamine River in the Condamine-Balonne plan area between 2010 and 2023 showing the amount of rainfall recorded each month. The long-term average of total annual rainfall (550 mm) is shown by a red dotted line.

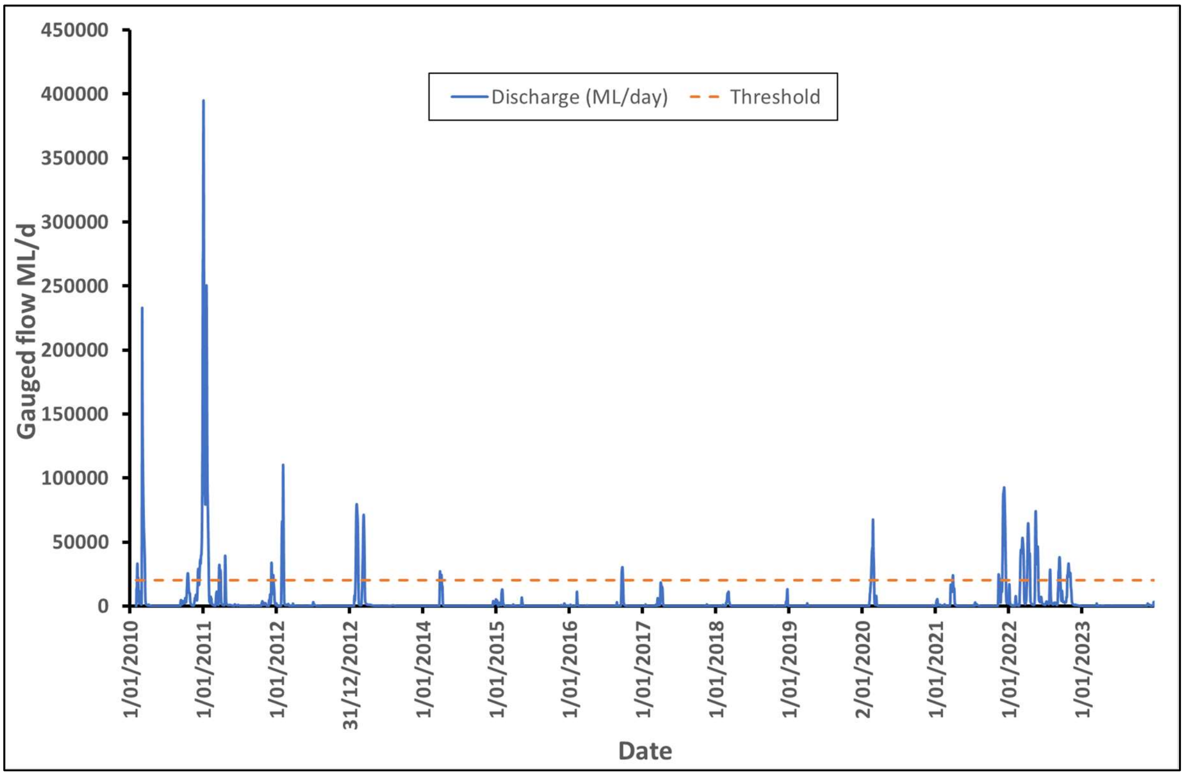

Figure 22. Daily flow data recorded at the Balonne River at Surat gauging station (422220A). Bankfull flow threshold, indicating which flow events were associated with overbank flooding, is represented by the orange dashed line.

Table 11. Sites sampled within the Condamine and Balonne Water Plan area showing observed recruitment status of floodplain tree species. The species are EC (*Eucalyptus coolabah*) and RRG (*Eucalyptus camaldulensis*). Counts of seedling (0.3 m tall), sapling (0.3-2.0m tall) and young trees (>2m and < 10cm diameter at breast height). WDL = woodland and OWDL = open woodland.

Catchment	**SiteID**	**Latitude**	**Longitude**	**Target Tree Species**	**Seedling per ha**	**Sapling per ha**	**Young trees per ha**	**Grazing Pressure Exotic**	**Grazing Pressure Native**	**Stand Type**	**Soil Type**	**Lignum**
Condamine and Balonne	1	-26.653	150.177	RRG	0	0	0	Absent	Absent	Forest	Clay	Absent
Condamine and Balonne	13	-26.771	148.029	RRG	0	0	0	Medium	Medium	WDL	Loam	Absent
Condamine and Balonne	34	-27.638	148.473	EC	0	0	0	Medium	Medium	WDL	Loam	Absent
Condamine and Balonne	117	-26.824	148.022	RRG	0	0	0	Medium	Medium	WDL	Sandy	Absent
Condamine and Balonne	251	-27.138	149.068	EC	8	0	0	Low	Low	WDL	Clay	Present
Condamine and Balonne	19B	-27.597	148.415	RRG/EC	0	0	0	Low	Low	OWDL	Loam	Absent
Condamine and Balonne	46-A	-27.951	148.677	RRG	0	0	0	Medium	Low	OWDL	Loam	Absent
Condamine and Balonne	BB007	-27.002	150.071	EC	0	0	0	Low	Low	WDL	Clay	Absent
Condamine and Balonne	BB03	-27.122	151.087	RRG	0	0	0	Low	Low	Forest	Clay	Absent
Condamine and Balonne	BB06	-26.799	150.575	RRG	0	0	0	Absent	Low	Forest	Clay	Absent
Condamine and Balonne	BBS10	-26.575	148.023	RRG	0	0	0	Absent	High	WDL	Loam	Absent
Condamine and Balonne	BBS10A	-26.575	148.023	RRG	28	0	36	Absent	Medium	WDL	Sandy	Absent
Condamine and Balonne	BBS19	-27.644	148.739	RRG/EC	0	0	0	Low	Low	WDL	Silty	Absent
Condamine and Balonne	BBS6	-25.750	146.625	RRG	0	0	0	Low	Medium	WDL	Loam	Absent
Condamine and Balonne	Bokhara	-28.957	147.761	EC	0	0	0	High	Medium	OWDL	Clay	Present
Condamine and Balonne	CMD2	-28.692	148.179	EC	0	0	0	Low	Low	OWDL	Silty	Present
Condamine and Balonne	Cubie	-28.735	147.683	EC	0	0	0	Low	Low	OWDL	Clay	Absent
Condamine and Balonne	Cubie 2	-28.622	147.973	EC	0	624	0	Low	Low	OWDL	Clay	Present
Condamine and Balonne	DD14	-28.873	148.807	EC	0	0	0	Medium	Low	WDL	Clay	Absent
Condamine and Balonne	DD15	-28.388	148.318	RRG	0	0	0	Low	Low	Forest	Clay	Absent
Condamine and Balonne	DD16	-28.292	148.416	RRG/EC	0	0	0	Medium	Low	WDL	Clay	Present
Condamine and Balonne	DD17	-28.263	148.434	RRG/EC	0	1160	0	High	Low	WDL	Clay	Absent
Condamine and Balonne	DD17A	-28.263	148.435	RRG	0	940	12	Medium	Low	Forest	Clay	Absent
Condamine and Balonne	DD18	-28.328	148.374	RRG/EC	0	0	0	Medium	Medium	WDL	Loam	Present

Catchment	SiteID	Latitude	Longitude	Target Tree Species	Seedling per ha	Sapling per ha	Young trees per ha	Grazing Pressure Exotic	Grazing Pressure Native	Stand Type	Soil Type	Lignum
Condamine and Balonne	DD23	-28.940	147.751	EC	0	0	0	High	Medium	OWDL	Clay	Present
Condamine and Balonne	DD24	-28.953	147.771	EC	0	0	0	Medium	Low	OWDL	Clay	Present
Condamine and Balonne	Hebel 1	-28.825	148.070	EC	0	672	1332	Absent	Low	OWDL	Clay	Present
Condamine and Balonne	MARA 20	-27.638	148.474	EC	0	0	0	Low	Low	Forest	Silty	Absent
Condamine and Balonne	Mara_ Cross	-27.630	148.465	RRG/EC	0	176	0	Absent	Low	WDL	Loam	Absent
Condamine and Balonne	MARA_1	-26.772	148.032	RRG	1876	1496	0	Medium	Low	WDL	Sandy	Absent
Condamine and Balonne	MARA_2	-26.214	147.914	RRG	136	160	0	Low	Low	WDL	Sandy	Absent
Condamine and Balonne	MARA_patch1	-26.890	148.045	RRG	0	0	2000	Medium	Low	WDL	Loam	Absent
Condamine and Balonne	MUL_4_2	-26.915	148.051	RRG	0	0	0	Medium	Medium	WDL	Loam	Absent

The Condamine and Balonne plan area is an expansive catchment. The rainfall received in the different parts of the catchment is also variable and may have had impact on the state of recruitment of floodplain tree species. The rainfall recorded in the Maranoa River catchment north of Mitchell at site MARA_2 suggests that more rainfall was received in the catchment in the 2010-2012 La Niña relative to 2020-2022 La Niña as shown in Figure 23. Only small flows, not exceeding the flood inundation threshold, were observed at the Mitchell gauging station in 2020-2022, suggesting vegetation recruits from this period were supported by rainfall (Figure 24).

Recruitment was observed at several locations along the Maranoa River. For example, some recruitment was observed along dry riverbanks adjacent the main channel of the river but none within the channel (see Figure 25). Due to the dry weather condition at the time of the assessment, the grass along the riverbanks was highly grazed and saplings were also being browsed. Dense recruitment of river red gum was observed on several sites within the Maranoa River catchment that seemed to have had water pooling during wet weather. The recruitment patch shown in Figure 26 was at the edge of a river red gum stand in a heavily cattle grazed paddock that was fenced off from a stock route. Recruitment, though spatially patchy, was observed on the Culgoa floodplain, such as this patch of coolibah trees (Figure 27) observed adjacent to a mature coolibah tree.

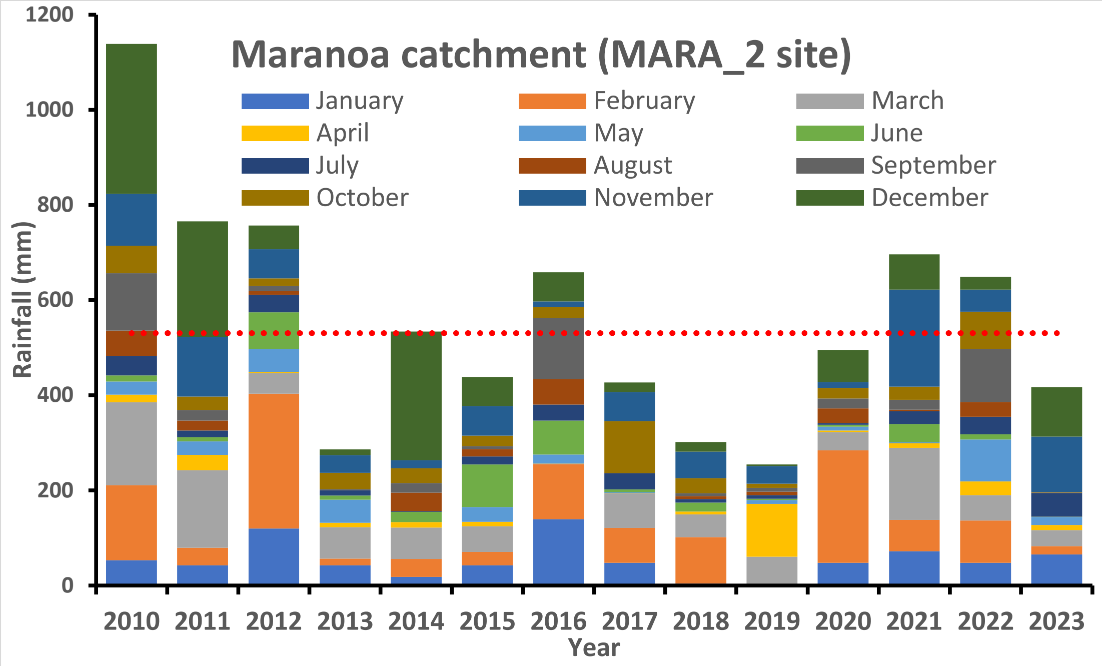

Figure 23. Monthly rainfall total recorded at site MARA_2 along the Maranoa River, north of Mitchell in the Condamine and Balonne catchment between 2010 and 2023, showing the amount of rainfall recorded each month. The long-term average of total annual rainfall (531 mm) is shown by a red dotted line.

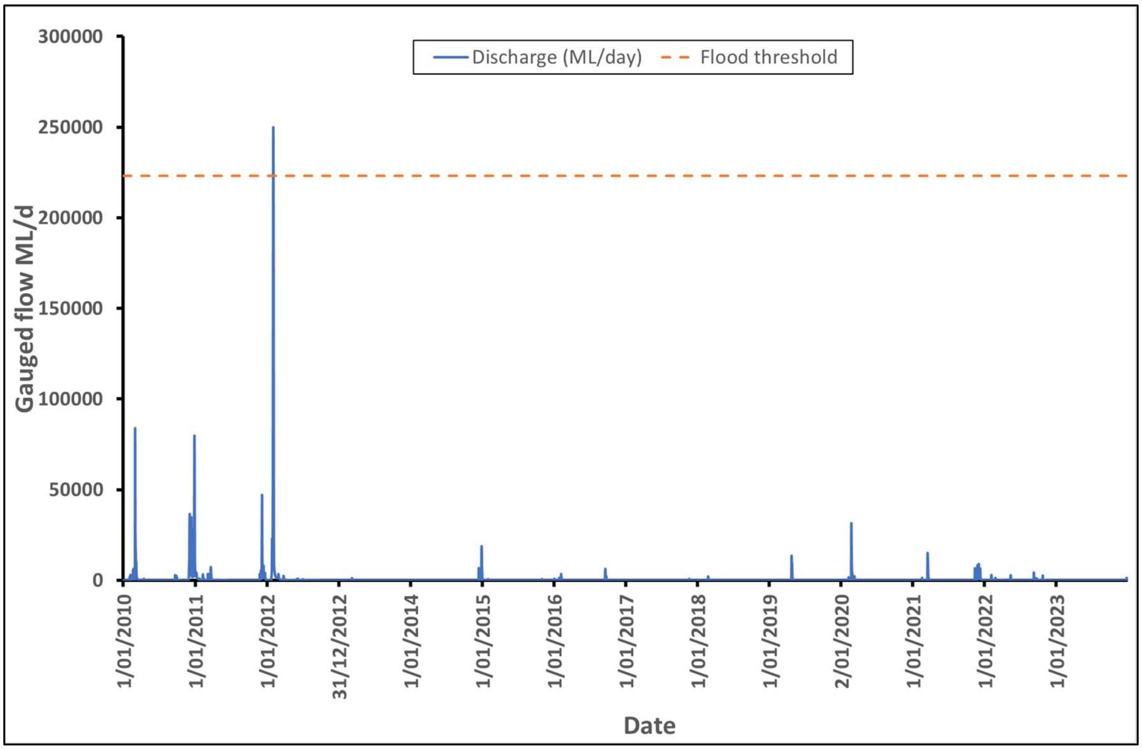

Figure 24. Daily flow data recorded at the Maranoa River at Mitchell gauging station (422401D). Bankfull flow threshold, indicating which flow events were associated with overbank flooding, is represented by the orange dashed line.

MARA_1 BBS10A

Figure 25. Young river red gum recruits observed on the banks of the Maranoa River at site MARA_1 (left) and recruitment inside the river channel at site BBS10A (right), both sites are located south of Mitchell and measured on the 1st of August 2023.

Figure 26. A dense recruitment patch of river red gum observed at site MARA_Patch 1, south of Mitchell and adjacent to the Maranoa River, recorded on 1st of August 2023.

Figure 27. A recruitment patch of coolibah observed at site Hebel1 in September 2023, along Dirranbandi Hebel Road in the Culgoa floodplains (Condamine–Balonne).

Warrego, Paroo, Bulloo and Nebine water plan area

All the sites assessed within the floodplains of the Warrego River, Paroo River and Nebine Creek are shown in Figure 28 and the detailed locations presented in Table 12. In the Warrego catchment, recruitment was recorded on seven of the 21 sites and included river red gum and coolibah seedlings and saplings. This water plan area experienced the least riverine flooding of all the QMDB water plan areas during the study period. There was an average of three overbank flood events (range 1–7) across the five hydrological gauging stations assessed, providing an average inundation duration of 15 days (range 2–43) (Appendix 2).

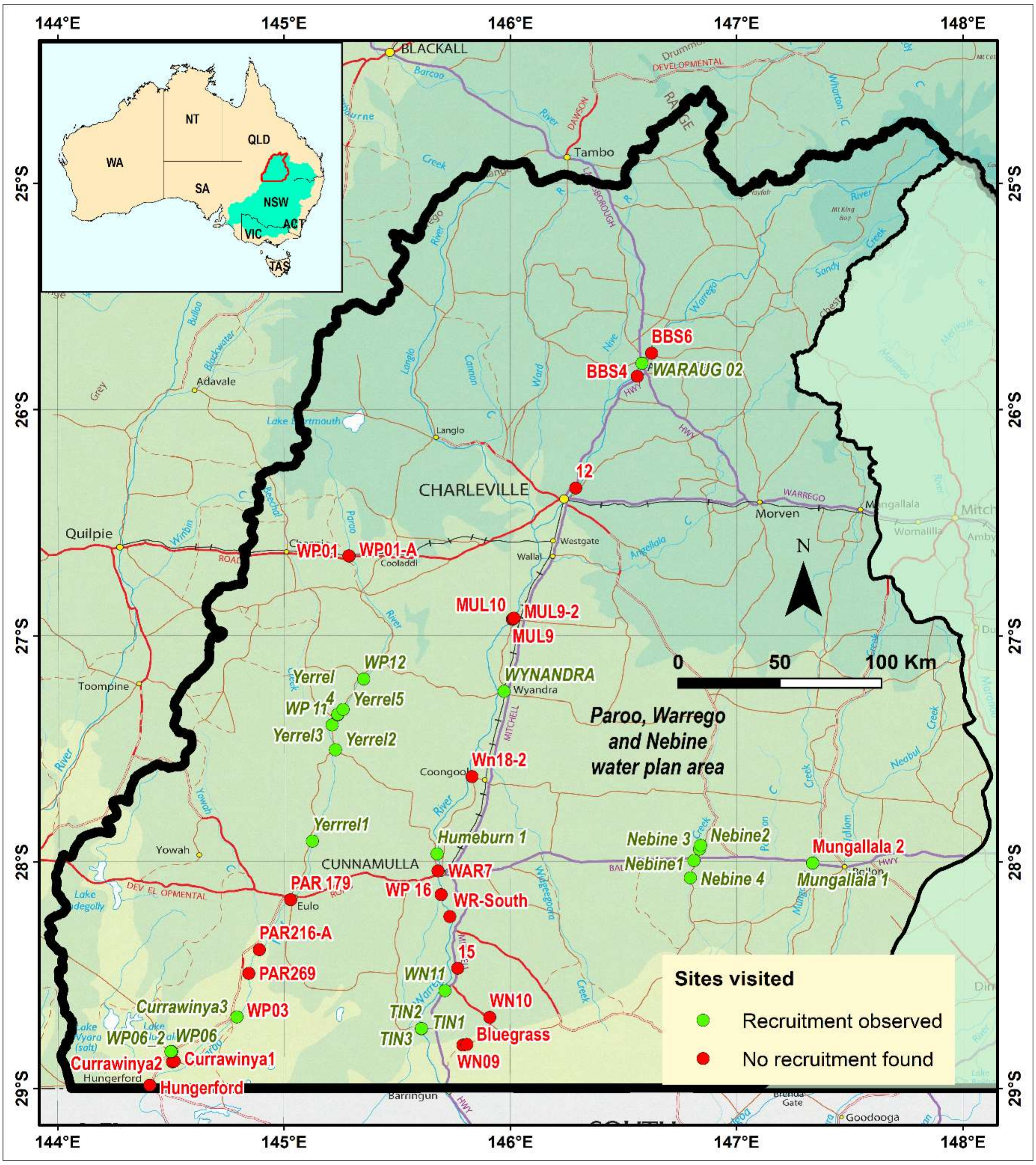

Figure 28. The geographic locations of sampled sites in the Paroo, Warrego and Nebine catchments, showing the sites where some recruitment was recorded (green marker) and sites in which recruitment was not observed (red marker).

Recruitment of river red gum and coolibah were also observed in the floodplains of Nebine and Mungallala creeks (Figure 29 and 30).

Figure 29. River red gum saplings observed at site Nebine CK1 in August 2023 near the Nebine Creek crossing, on the Balonne Highway (Cunnamulla to St George) in the Nebine floodplains.

Figure 30. Coolibah saplings observed at site Mungallala1 in August 2023 near the Mungallala Creek crossing, on the Balonne Highway (Cunnamulla to St George) in the Mungallala floodplains (Nebine catchment).

Table 12. Sites sampled within the Warrego and Nebine catchments showing observed recruitment status of floodplain tree species (EC = Eucalyptus coolabah, RRG = Eucalyptus camaldulensis). Counts of seedlings (0.3m tall), saplings (0.3–2.0m tall), and young trees (>2.0m and <10cm diameter). WDL = woodland and OWDL = open woodland and CRCH = creek channel.

Catchment	SiteID	Latitude	Longitude	Species	Seedling per ha	Sapling per ha	Young trees per ha	Grazing exotic	Grazing native	Stand Type	Soil Type	Lignum
Warrego	12	-26.346	146.288	EC	0	0	0	Absent	Low	WDL	Loam	Absent
Warrego	15	-28.469	145.769	EC	0	0	0	Medium	Low	CRCH	Clay	Present
Warrego	Augath_2	-25.794	146.582	RRG	0	0	180	Absent	Low	OWDL	Loam	Absent
Warrego	BBS4	-25.852	146.561	EC	0	0	0	Low	Medium	WDL	Silty	Absent
Warrego	Bluegrass	-28.805	145.809	EC	0	0	0	Medium	Low	OWDL	Sandy	Absent
Warrego	MUL10	-26.924	146.013	EC	0	0	0	Absent	Low	OWDL	Clay	Absent
Warrego	MUL9	-26.926	146.009	RRG	0	0	0	Absent	Low	WDL	Loam	Absent
Warrego	MUL9-2	-26.921	146.015	EC	0	0	0	Absent	Low	OWDL	Clay	Absent
Warrego	TIN1	-28.736	145.608	RRG	0	340	20	Medium	Low	WDL	Loam	Present
Warrego	TIN2	-28.735	145.608	RRG	588	160	12	Medium	Low	WDL	Clay	Present
Warrego	TIN3	-28.735	145.608	RRG	1120	2040	0	Medium	Low	WDL	Clay	Present
Warrego	WAR7	-28.039	145.681	EC	0	0	0	Low	Low	WDL	Loam	Absent
Warrego	WN09	-28.808	145.791	EC	0	0	0	Medium	Low	OWDL	Clay	Present
Warrego	WN10	-28.685	145.909	EC	0	0	0	Low	Low	OWDL	Clay	Absent
Warrego	WN11	-28.568	145.712	EC	0	0	0	Medium	Low	CRCH	Clay	Present
Warrego	Wn18-2	-27.622	145.832	RRG	0	0	0	Low	Low	WDL	Silty	Absent
Warrego	WP 16	-28.143	145.695	RRG	0	0	0	High	Low	Forest	Loam	Absent
Warrego	WP01	-26.646	145.287	EC	0	0	0	Low	Low	WDL	Clay	Absent
Warrego	WP01-A	-26.647	145.289	EC	0	500	0	Low	Low	OWDL	Silty	Absent
Warrego	WR-South	-28.240	145.733	RRG/EC	0	0	0	Medium	Medium	WDL	Clay	Absent
Warrego	Wynandra	-27.245	145.973	EC	0	172	0	Absent	Low	OWDL	Clay	Absent
Nebine	Munga_1	-28.004	147.336	EC	0	0	760	Medium	Low	OWDL	Loam	Absent
Nebine	Munga_2	-28.003	147.336	EC	0	0	0	Medium	Medium	WDL	Loam	Absent
Nebine	Nebine 3	-27.942	146.836	RRG	0	0	832	Medium	Medium	WDL	Loam	Absent

Catchment	**SiteID**	**Latitude**	**Longitude**	**Species**	**Seedling per ha**	**Sapling per ha**	**Young trees per ha**	**Grazing exotic**	**Grazing native**	**Stand Type**	**Soil Type**	**Lignum**
Nebine	Nebine 4	-28.069	146.795	RRG/EC	0	168	144	Low	Medium	OWDL	Loam	Absent
Nebine	Nebine1	-27.993	146.811	RRG/EC	0	0	1348	Low	Low	WDL	Clay	Absent
Nebine	Nebine2	-27.925	146.841	EC	0	0	644	Low	Medium	OWDL	Clay	Present

The rainfall data for Augathella between 2010 to 2023 (Figure 31) shows that the two consecutive years 2021 and 2022, had above average rainfall, but less rainfall than was received in the 2010–2012 floods (Figure 31 and Figure 32). Also, while there have been years with above average rainfall at the location, these have been followed by low rainfall. This suggests that recruits germinating after these rain events were unlikely to survive without access to below-ground water resources.

Floodplain tree recruitment within the Warrego catchment was spatially patchy and no recruitment was recorded in most of the previously monitored sites as shown in red in Figure 28. Few river red gum recruits were observed along the banks of Warrego River channel at Augathella, north of Charleville (Figure 33). Those that occurred were crowded by dense, tall grass but there was no sign of any cattle grazing. Some recruits were observed at Wyandra (Figure 34), but these appeared to have arisen from lignotubers rather than seed. Young saplings were also recorded to the south of Cunnamulla (Figure 35), but they were vulnerable to cattle grazing.

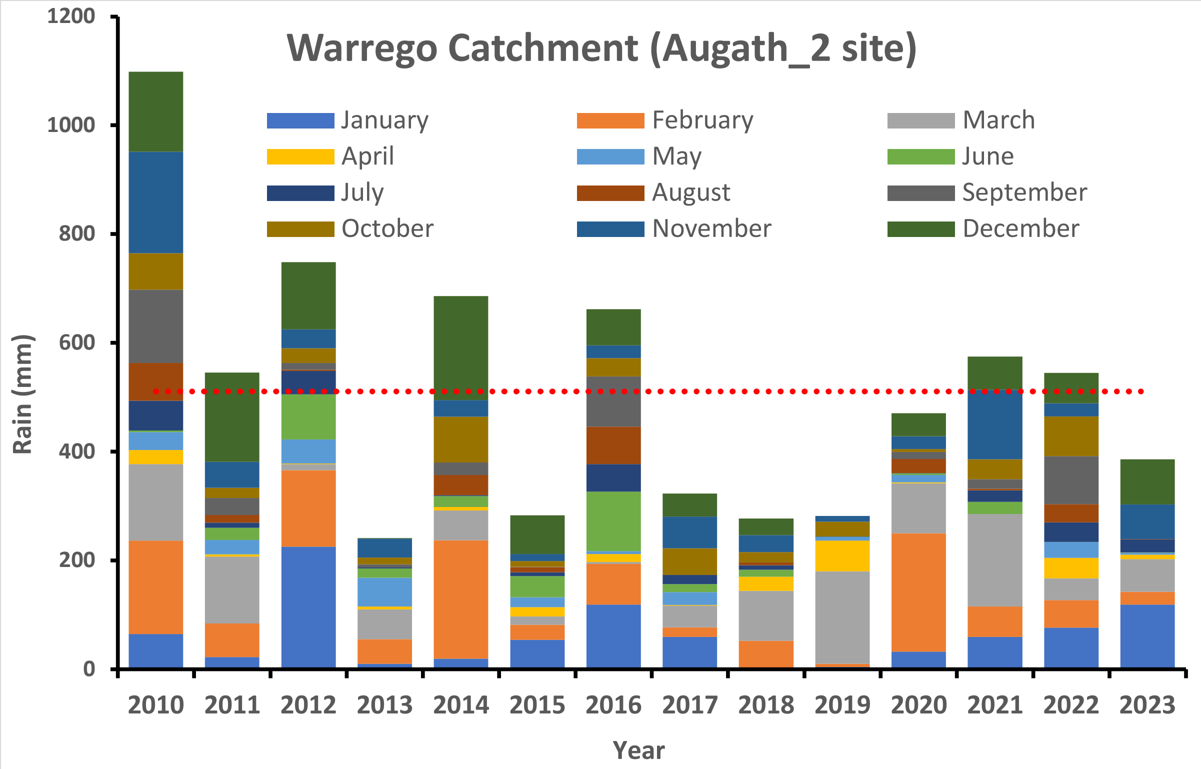

Figure 31. Monthly rainfall total recorded at WAR_AUG_2 south of the Warrego River crossing at Augathella, north of Charleville (Warrego catchment) between 2010 and 2023, showing the amount of rainfall recorded each month. The long-term average of total annual rainfall (511mm) is shown by a red dotted line.

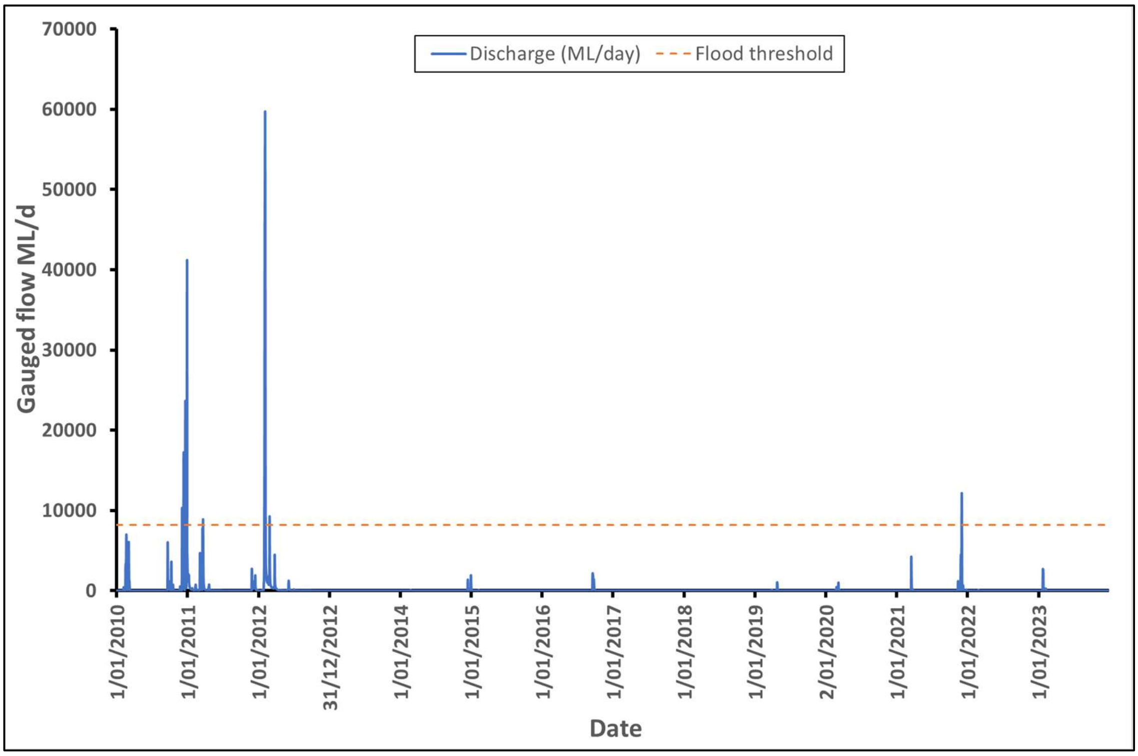

Figure 32. Daily flow data recorded for the Warrego River at Augathella (gauging station 423204A). Bankfull flow threshold, indicating which flow events were associated with overbank flooding, is represented by the orange dashed line.

Figure 33. River red gum recruits observed on the banks of the Warrego River at Augathella (site WAR_AUG2), north of Charleville in August, 2023.

Figure 34. Coolibah recruits observed on the Warrego River floodplains at Wyandra, north of Cunnamulla in August, 2023.

Figure 35. Young coolibah recruits observed on the Warrego River floodplains (site Tin2), south of Cunnamulla, looking vulnerable to grazing pressure in August 2023.

Paroo catchment

All the of sites assessed within the Paroo catchment are shown in Figure 28, with detailed locations presented in Table 13. Recruitment was recorded at 10 of the 17 sites and included river red gum, coolibah and black box seedlings and saplings.

Table 13. Sites sampled within the Paroo catchment showing observed recruitment status of floodplain tree s (*Eucalyptus coolabah*), RRG (*Eucalyptus camaldulensis*) and BB (*Eucalyptus largiflorens*). Counts of seedli tall) and young trees (>2m and <10cm diameter at breast height). WDL = woodland, OWDL = open woodlan

Catchment	SiteID	Latitude	Longitude	Target tree species	Seedlings per ha	Saplings per ha	Young trees per ha	Grazing pressure exotic
Paroo	Currawinya1	-28.879	144.514	BB	0	0	0	Absent
Paroo	Currawinya2	-28.882	144.508	BB	0	0	0	Absent
Paroo	Currawinya3	-28.683	144.792	EC	0	1792	0	Absent
Paroo	Hungerford	-28.985	144.408	BB	0	0	0	Absent
Paroo	PAR 179	-28.166	145.030	EC	0	0	0	Low
Paroo	PAR216-A	-28.386	144.891	EC	0	0	0	Low
Paroo	PAR269	-28.491	144.845	RRG/EC	0	0	0	Low
Paroo	WP 11	-27.349	145.238	EC	0	20	4	Low
Paroo	WP03	-28.683	144.792	EC	0	0	0	Absent
Paroo	WP06	-28.837	144.501	BB	0	4	0	Absent
Paroo	WP06_2	-28.837	144.504	BB	0	52	0	Absent
Paroo	WP12	-27.190	145.353	RRG/EC	0	28	0	Medium
Paroo	Yerrel4	-27.346	145.238	EC	0	0	112	Low
Paroo	Yerrel2	-27.503	145.228	RRG	0	84	0	Low
Paroo	Yerrel3	-27.393	145.213	EC	272	0	80	Medium
Paroo	Yerrel5	-27.325	145.262	EC	0	0	52	High
Paroo	Yerrel1	-27.906	145.126	EC	80	2060	4	Low

The data for rainfall received at site WP11, north of Eulo on the Paroo River floodplain, between 2010 and 2023 (Figure 36), shows that 2018 was the driest year in the last decade and the rainfall received in 2020–2022 was relatively less than that received in the 2010-2012 La Niña event (Figure 36). Regular, annual flooding from 2019 to 2023 may have helped to support recruitment success (Figure 37). However, relatively widespread coolibah recruitment was observed on the floodplains within the Paroo catchment, north of Eulo along Yerrel Road (Figures 38 and 39) and south of Eulo towards Hungerford (Figure 40). The saplings were of variable sizes, but the tallest recruits were approximately 4 m in height.

Recruitment of black box (*E. largiflorens*) was recorded at site WP06_2 on the Paroo floodplains south of Eulo. However, recruitment in that part of the catchment was spatially patchy and no recruitment was recorded in the long-term vegetation condition monitoring sites as shown in Figure 41.

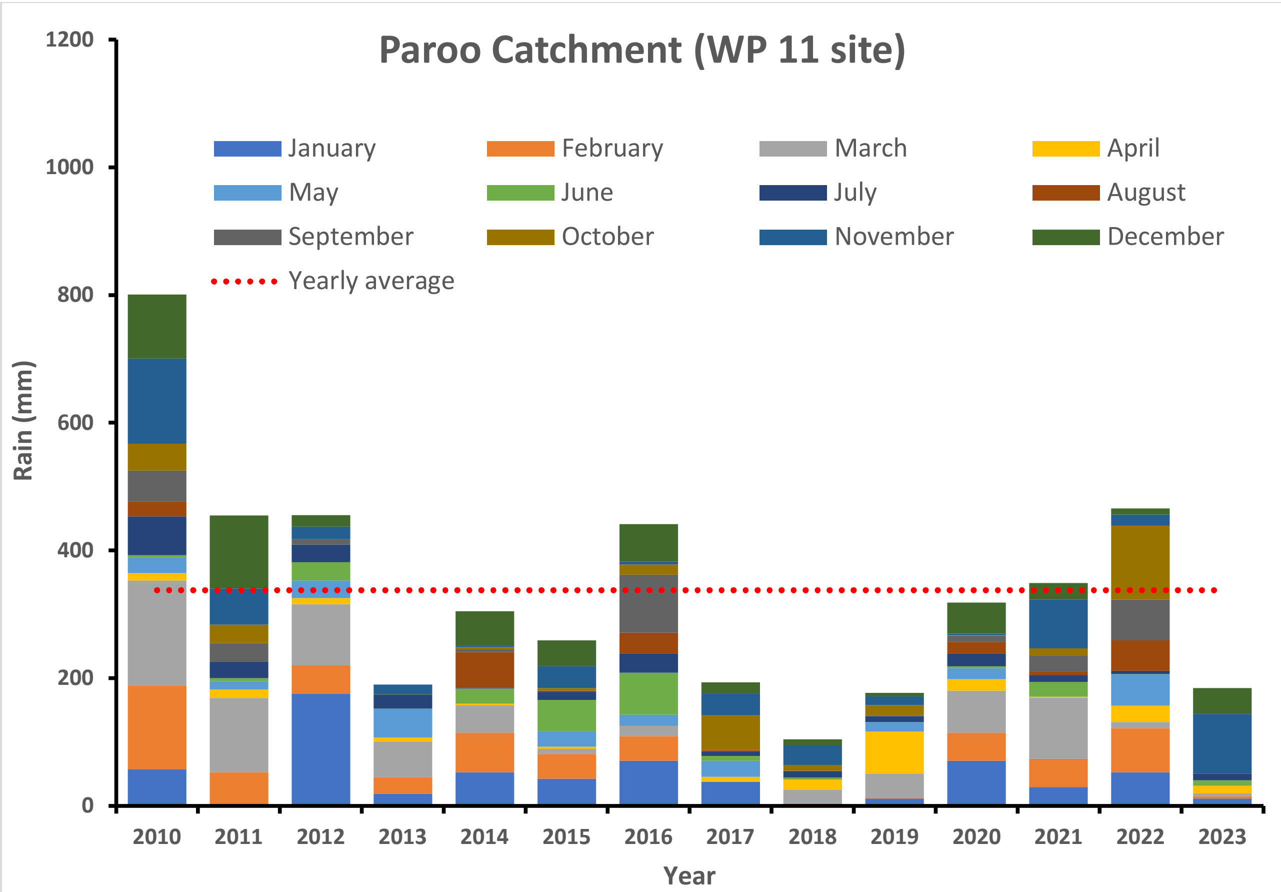

Figure 36. Monthly rainfall total recorded at site WP 11, north of Eulo on the Paroo River floodplain between 2010 and 2023, showing the amount of rainfall recorded each month. The long-term average of total annual rainfall (338mm) is shown by a red dotted line.

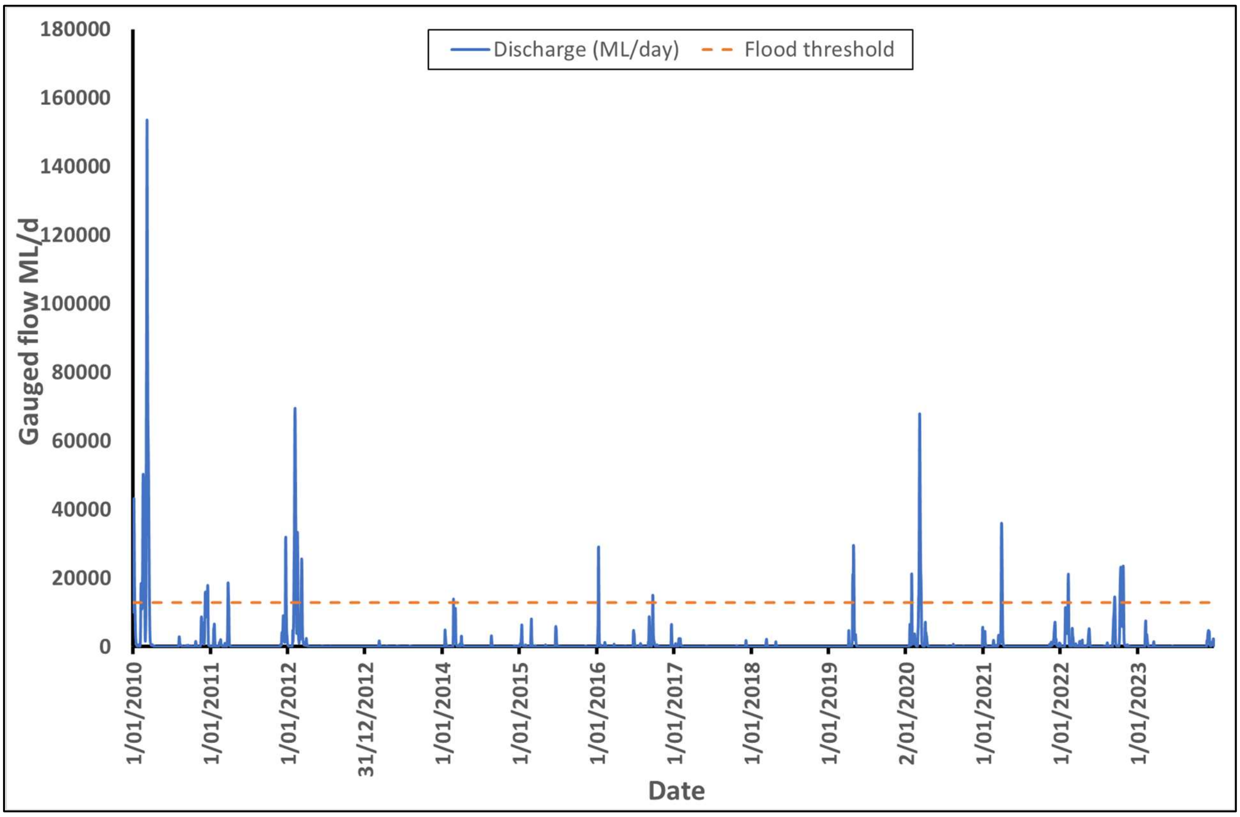

Figure 37. Daily flow data recorded at the Paroo River at Caiwarro (gauging station 424201A). Bankfull flow threshold, indicating which flow events were associated with overbank flooding, is represented by the orange dashed line.

Figure 38. Extensive coolibah recruitment observed on the floodplains of Paroo River along Yerrel Road north of Eulo at site Yerrel1 in August, 2023.

Figure 39. Coolibah recruitment observed on the floodplains of Paroo River along Yerrel Road north of Eulo at site Yerrel3 in August, 2023.

Figure 40. Coolibah recruitment observed on the floodplains of the Paroo River, south of Eulo towards Hungerford at site Currawinya3 in August, 2023.

Figure 41. No recruitment was observed at this previously monitored coolibah site (WP03) on the floodplains of the Paroo River, south of Eulo towards Hungerford. This image shows heavy grass cover with minimal grazing on the

Species Demographic Condition

The demographic structure of river red gum and coolibah within the QMDB, based on data collected between 2017 and 2020, is presented in Figure 42 (Ngugi *et al.* 2022). Murray–Darling This figure shows a low abundance of trees in the <10cm diameter class in river red gum and coolibah relative to the reverse J-curve. Field assessment data collected in 2023 after the 2020–2023 La Niña event showed moderate recruitment in the <10cm diameter class for both species (Figure 43). Demographic structure of black box was not included because of limited data. The species is not widely distributed in Queensland as the southern parts of the QMDB forms the northern extent of its geographical distribution. Hence the dataset was relatively small (Table 13). Using data from young trees (those with height >2m and DBH <10cm) the demographic structure curves for the river red gum and coolibah were re-constructed and showed an improved fit to the reverse J-curve, indicating a more stable population structure if the recruits continue to thrive (Figure 43). However, the stem sizes of the recruits were skewed towards <3cm at DBH on a 0–10cm scale. When the recruitment data were assorted into demographic sizes (Figure 44), saplings had the highest density, indicating a likelihood to progress to young trees under favourable growth conditions.

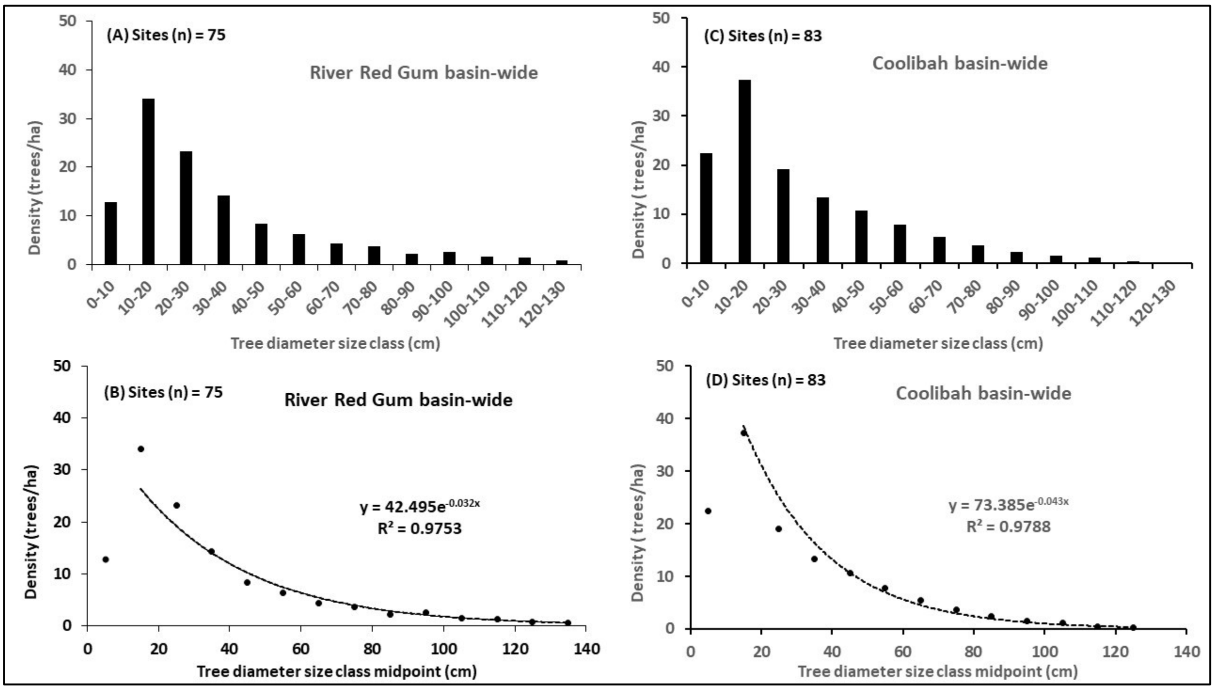

Figure 42. The 2017-2020 tree demographic structure showing tree size class structure for live trees and reverse J-curves fitted to trees size class midpoints for river red gum (A and B), and coolibah (C and D) at Queensland Murray–Darling basin-wide scale.

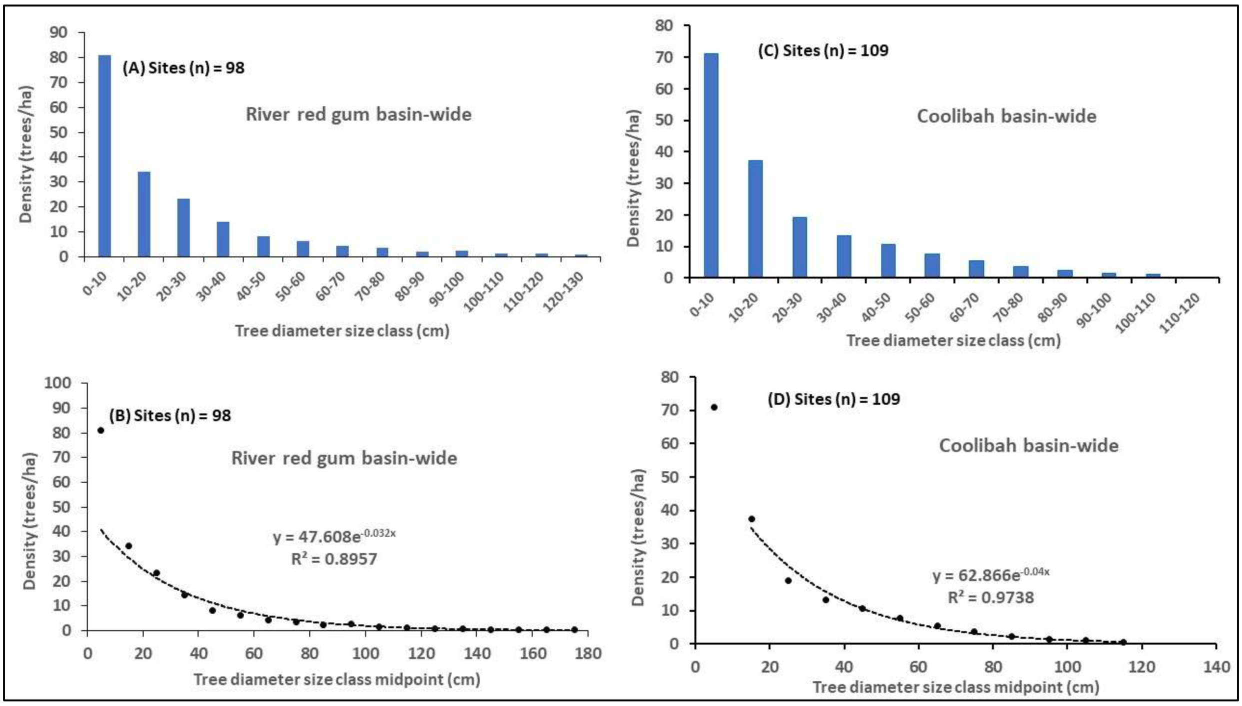

Figure 43. The 2023 tree demographic structure showing tree size class structure for live trees and reverse J-curves fitted to trees size class midpoints for river red gum (A and B), and coolibah (C and D) at Queensland Murray–Darling basin-wide scale.

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Figure 44. Size distribution of river red gum and coolibah recruits observed in 2023 within the QMDB.

DISCUSSION

This study reports on a Queensland-wide Murray–Darling basin (QMDB) field assessment that was conducted from July to September 2023 to examine the status of tree recruitment following a triple La Niña weather event from 2020–2022. The field assessment aimed to answer the question: "Are extreme wet periods key to successful floodplain tree recruitment in the QMDB?"

Recruitment data for river red gum, coolibah and black box indicated that the triple La Niña was successful in providing rainfall, flooding and other conditions that supported germination of seedlings and early establishment of saplings. There was no difference in the effects of the triple La Niña between the species. However, recruitment was spatially variable across the QMDB. Recruits were least common under mature tree stands, indicating greater success on sites that were exposed to full sun.

Conditions required for successful establishment and survival of recruits in the QMDB are complex at the site scale and over time. In the last decade, successful recruitment of floodplain tree species was rare despite recorded heavy rainfalls in various years and locations (Ngugi *et al.* 2022). In 2020, after drought breaking rain and onset of a La Niña event, mass germination of floodplain tree seedlings was observed across the basin (Ngugi *et al.* 2022). However, after only a short period of high temperatures and lack of follow-up rainfall, the soils dried out and seedling mortality followed. The survival rate of saplings also diminished considerably. These observations suggest that favourable growth conditions (rainfall, suitable temperatures, and low grazing pressure) must persist for a sufficient period after germination to foster early plant development and the progression from seedling to sturdy young adult. Beyond rainfall dependence in the initial growth stages, young trees must develop drought tolerance mechanisms such as extensive root systems to access groundwater if they are to survive the low rainfall periods (Balcombe *et al.* 2021).

Rainfall data presented here shows that even during the triple La Niña, rainfall amount and distribution were variable across the QMDB. This was also reflected in variable hydrology across the study area and may partly explain why the recruitment was spatially patchy. However, the triple La Niña was also associated with abundant grass cover growth that provided fodder for the herbivores for a longer period, and this grass provided an alternative to browsing tree saplings. During the dry winter months, the dense drying grass provided ground cover which has been found to enhance the survival of coolibah seedling by shading the soil and reducing evaporation (Good *et al.* 2014). Lower grazing pressure and higher rainfall provided an opportunity for saplings to grow and exceed the browsing height of most animals, but the fast growth of grass also resulted in intense competition that prevented some of the young recruits from growing to heights that reduced their risk of being grazed. Field observations of wallowing, tracks and scats suggest that feral animals (goats and pigs) and kangaroos were the main grazers on public lands, while on private land, cattle, sheep and goats were the main grazers.

The dispersal of seeds on floodwaters (hydrochory) was a major factor associated with successful germination and establishment of seedlings. This was evident from the multiple sites where high-density germination had taken place. Flood maps for the QMDB over the study period were not available, however, data from 53 of the sampled sites that had a corresponding riverflow gauging station, that indicated the frequency of bankfull exceedance (flood), suggests that the observed recruitment of floodplain species was associated with flooding events. As the flood receded, seeds were deposited on moist substrates (soil and sand) in bands along the banks of either a water channel or edge of a water body, or randomly scattered in the channel or on the floodplain flats. This suggests that floodplain areas inundated with low energy water favour germination, while areas experiencing high energy floodwaters become stripped of young recruits (Figure 14 and Figure 29).

After germination, sustained rainfall rather than flooding provided the necessary moisture for the rapid growth of saplings. The critical role of sustained moisture in this study is consistent with that identified by Kerr *et al*. (2022). For example, we observed river red gum seedlings establishing on an in-channel sand bar in the Maranoa River, where no major flood had occurred recently but there had been a significant rainfall event (Figure 25). These trees had survived and anchored themselves, contributing to the further deposition of sand on these sand bars and diverting low energy water flows around them. However, it is unlikely that these trees will survive a major flood event in this location.

Previous population demographic analysis of floodplain species in the QMDB reported low recruitment and possible early evidence of a decline in the sustainability of the populations according to the Law of de Liocourt (Manion and Griffin 2001; Cale *et al.* 2014). The revised demographic structure for river red gum and coolibah based on post La Niña event, approximates a reverse J-curve with high numbers of trees in the <10cm diameter size class. However, the demographic results for seedling and sapling must be used with great caution because the tree size distribution of the recorded recruits was highly skewed toward very young trees with diameter sizes mainly <2cm. Notwithstanding, it is reasonable to say that the recent recruitment associated with three years of sustained rainfall has shifted the demographics from a risky state depauperate of juvenile trees to a more sustainable distribution for both species. However, recruitment success and improved population stability is dependent on the continued survival of recruits to become young trees, and their capacity to withstand periods of low rainfall and high temperatures.

This study found that consecutive years or an extended period of wet conditions such as a triple La Niña event was associated with recruitment of floodplain trees at basin wide scale, but occurrence was spatially patchy. A similar field assessment of recruitment across the basin after the 2010–2012 La Niña event recorded spatially patchy and very low recruitment (0–10 saplings) except at few locations where mass recruitment was recorded (Capon and Prior 2012). The results from the 2010–2012 suggest that the La Niña events and conditions then were different from the 2020–2022 event. The 2010–2012 La Niña was a double-dip event occurring in two consecutive summers while the 2020–2022 event was triple-dip La Niña event occurring in three consecutive summers (Gillet and Taschetto 2022). Triple-dip events are rare and have only happened twice since 1950 (in 1973–1976 and 1998–2001) (Gillet and Taschetto 2022).

Given the rarity of the triple-dip events, it is unlikely that they are the only conditions associated with floodplain species recruitments in the basin. As shown in the demographic structure of floodplain species reported in Ngugi *et al.* (2022), some quantity of young trees in the <10cm diameter class was present, but that quantity was below that projected by the reverse J-curve suggesting a declining population. The results suggests that other La Niña events may result in small, localised recruitment events such as those reported in Capon and Prior (2012), while a triple La Niña event provides an opportunity for a recruitment 'reset" at basin-wide scale as characterised by mass recruitment of evenly sized tree cohorts evident in the demographic structure for various diameter size classes (Figure 12 and 26).

The capacity to age the evenly sized tree cohorts within the spread of diameter classes may provide the needed insight on when the saplings may have recruited and link the timing to the corresponding historical rainfall events. Such understanding would inform our expectations on the occurrence frequency of tree recruitments at regional scale and likely impacts of climate change. The ongoing work on the development of an epigenetic clock for river red gum (Janice Kerr 2024, Department of Regional Development, Manufacturing and Water, personal communication) using the DNA methodology that was successfully applied for fish species in the Murray–Darling Basin (Fallon *et al.* 2019; Mayne *et al.* 2021) may provide a tool to further explore the timing of recruitment from current population and associated conditions at the time of their recruitment in the past.

The survival of saplings after the La Niña events is critical for the sustainability of the floodplain tree species. The observed recruits in this study have developed under three consecutive years of favourable wet conditions, suggesting reliance on continued rainfall, river flows and flooding. Their future survival after the La Niña will therefore depend on their capacity to adapt to low moisture conditions, and the availability and accessibility of groundwater resources to supplement moisture requirements during periods of low rainfall. Doody *et al*. (2014) found that bank-full flows were important to maintain the condition of river red gum trees along the River Murray, because these flows encouraged lateral recharge of the soils in the riparian zone and helped to support the trees moisture requirements through drought periods. Such flows would be beneficial to support saplings that are established but may not substantial recruitment of new seedlings as was shown in this study. Scattered saplings were found on the edges of ephemeral creeks and rivers, and this vegetation could benefit from rules that prevent diversion of these flows. The relationship between the density of observed recruits and presence of a permanent creek/waterhole was weak and not statistically significant (Table 6). Survival also relies on the absence of high grazing pressure, particularly during drought years when other fodder is sparse. Mass recruitment of river red gum recorded in this study was found adjacent ephemeral billabongs and floodplain wetlands away from the riparian zone. These, together with coolibah would have required floodplain inundation for germination and establishment.

Implications for water management

This study has demonstrated that a combination of floods, which appear to disperse seeds and support germination, and sustained rainfall, which supports growth to the sapling stage and beyond, are key components of the watering requirements for large scale floodplain tree recruitment. However, the observed patchiness of recruitment also demonstrates that many environmental factors interact to influence recruitment success.

There are expectations in the Murray–Darling Basin Plan, Basin Wide Environmental Watering Strategy and Queensland water plans that outcomes associated with improved floodplain vegetation condition and community structure should be achieved with water management. This study demonstrates that achieving these outcomes relies on the combination of a range of conditions, many of which cannot be influenced by water planning or environmental watering strategies.

Flow regime is just one factor contributing to tree recruitment, and it can have a positive or negative influence, depending on the magnitude, timing, duration, and return frequency, and their interaction with local landscape topography. In general, high flows associated with floodplain inundation are difficult to influence, and supporting flood attributes that have a positive effect on floodplain vegetation, while avoiding those that have a negative impact is unlikely with the water management options available in the QMDB. Other land-use issues influencing floodplain vegetation, such as grazing intensity, soil conservation or weed control, could be managed in a complimentary way to help support tree recruitment, but existing programs and funding are limited and lack coordination. Plus, the requirement for sustained rainfall coinciding with germination obviously can't be controlled (other than by broad scale climate change mitigation). Understanding of the role of flow in supporting floodplain vegetation recruitment should continue to be refined, however the complex interactions between flow, climate and habitat conditions observed in this study allow us to set realistic expectations of what flow management can achieve.

Importantly, this study showed that a recruitment event associated with relatively infrequent very wet conditions switched the demographics of these tree populations from a risky structure where young trees were relatively absent, to a more long-term sustainable distribution of ages. This improved understanding of temporal variability helps us to refine concepts like ecological resilience, an objective highlighted in the Murray–Darling Basin Plan, but poorly understood in practice. This will allow more appropriate setting and assessment of objectives in the future.

The information gained from this study will be valuable and should be taken into account when considering the following:

- Identifying ecological assets for water plan ecological risk assessments – further work is still required to determine whether the floodplain tree recruitment cycle has a 'critical link' to flow.
- Setting appropriate water plan ecological outcomes, environmental flow objectives and performance indicators.
- Assessment of climate change implications for current water plans.
- The 2025 Basin Plan evaluation in relation to the extent to which it has achieved its environmental objectives for floodplain vegetation.
- Revising conceptualisation and expression of 'expected ecological outcomes' for Northern Basin floodplain vegetation in the 2029 update to the Basin Wide Environmental Watering Strategy.
- Thresholds of Concern for floodplain tree recruitment (i.e. how often do recruitment events need to be provided to minimise risk to populations?). This study shows that relatively infrequent recruitment opportunities support population viability, but further work, including ageing, is required to determine specific thresholds.

Conclusion

This study presented a rare and important opportunity to follow up the fate of tree seedlings in the QMDB where a history of impact on floodplain vegetation has caused concerns for the long-term viability of these species. The study demonstrated that having several consecutive wet periods is key to the initial recruitment and establishment of floodplain tree species in the QMDB. The triple La Niña provided floods that were instrumental in mobilizing and depositing seeds, and moisture and favourable conditions for seeds to germinate, and for seedlings to progress through the juvenile stages to young adults. The event also provided ample grass for herbivores which in turn reduced the grazing pressure on tree saplings. The vulnerability of the recruits to changing weather conditions was evident during dry winter months in 2023 which led to grazing pressure and drought related mortalities. However, more rainfall occurred over much of the basin during the summer months of 2023/2024 which should favour further growth of the recruits.

It is recommended that:

1) Follow-up assessment of the recorded recruitment sites be undertaken in 2024/2025 and subsequent years to document their performance and survival post the La Niña event.

2) Assessment of groundwater availability is undertaken at recruitment sites to determine the potential for further development of recruits under El Niño and neutral ENSO conditions.

3) Work is undertaken to develop capacity to age trees and thus determine likely recruitment date and associated weather conditions at the time of tree recruitment. It is anticipated that the radiocarbon dating

methodology (Ngugi *et al.* 2020, 2024) being tested in Minjerribah (North Stradbroke Island) and the ongoing work on the development of an epigenetic clock for river red gum, if successful, will provide a useful tool.

4) Detailed study to document environmental assets (for example abundance of recruits) along selected river channels that are likely to benefit from environmental flows be conducted to help inform the potential of utilizing this option to support tree health.

5) Future risk assessment be conducted to determine the risk to floodplain tree population stability into the future under various climate change scenarios.

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Appendix 1: Field protocol for assessing species population demographics of floodplain forests and woodlands in the Murray–Darling Basin

Adapted from the stand condition protocol: Cunningham, White, Bowen, Dillewaard, Butler, Ryan & Driver (29 October 2018, draft) and Amended version of Cunningham (2016).

Background

This document sets out the protocol to be followed for establishing survey sites and collecting the necessary field data for the Basin-wide vegetation population demographics condition assessment for the Joint Venture Monitoring and Evaluation (JVM&E) program funded surveys. The protocol provides details for the implementation of the agreed vegetation demographic assessment methodology developed through an inter-State Woody Vegetation Demographic Workshop held at the Arthur Rylah Institute (ARI) in Victoria in February 2019.

1. Protocol for establishing vegetation monitoring sites for species population demographics assessment

Equipment:

- GPS and spare batteries
- Sighting compass
- Maps of floodplains including monitoring site locations
- 1 x 100m surveyor's measuring tapes
- 2 x 50m surveyor's measuring tapes
- 4 x corner poles, 1 x centre pole
- Diameter tape
- Tree measuring calipers
- Aerosol can of coloured tree marking paint
- Datasheets and/or field computer
- Camera

Protocol:

1. Each State will determine priority assessment sites. The site selection may be based on already identified stand condition assessment priority gap sites, filling recruitment information gaps in previously measured sites or other preferred criteria. More sites than those budgeted for should be made available to provide flexibility around access, weather events or other logistical matters in the field. An attempt can be made to locate suitable sites near roads and, where possible, on public lands to minimise access limitations.

2. Identify an assessment plot of 0.25ha at each site. The shape of the plot can vary according to the vegetation distribution at the site being assessed. The target plot shape and size is 50m x 50m. However, rectangular plots are to be used when assessing linear stands (width <50m), which are common along riverbanks and creek-lines of arid floodplains. Potential plot shapes are 62.5m x 40m, 71.4m x 35m, 83.3m x 30m, 100m x 25m.
    - It is important that the sample vegetation to be monitored is subject to 'regular' riverine flooding or has been subject to regular riverine flooding in the past (prior to river regulation or the construction of floodplain structures such as levees). The target tree species that are the focus of the population demographic study are river red gum (Eucalyptus *camaldulensis*), black box (*Eucalyptus largiflorens*), coolabah (*Eucalyptus coolabah*) and river cooba (*Acacia stenophylla*); however, other more restricted floodplain or riparian

species may be encountered such as yapunyah (*Eucalyptus ochrophloia*) or carbeen (*Corymbia tessellaris*).

- A plot may need to be relocated for the following reasons:
    - If the tree cover is predominantly non-eucalypt, go to an alternative site.
    - If the proposed 50m x 50m plot site has fewer than eight target floodplain trees relocate the plot to nearby location or go to an alternative site.

3. Record information as per Table 1.

Table 1. General site description

	Sample	**Description**
Site ID	EDWM03	Unique site identifier that must remain unchanged.
Latitude	-36.414828	The site latitude to six decimal places, as supplied by the MDBA.
Longitude	141.979671	The site longitude to six decimal places, as supplied by the MDBA.
General description of site	Pure woodland stand of *E. camaldulensis* on the floodplain of the Lachlan River approx. 35km downstream of Condobolin. Subject to set stocking by cattle	Record dominant tree species and make notes on vegetation structure and where discernible recent disturbance e.g. fire, flood and/or grazing.
Landscape position	Backplain, dark grey heavy clay soils	Site position within the landscape (riparian, ephemeral creek, wetland, floodplain).

4. Locate a centre pole that is suitable for a central point for the site. Record the GPS location at the point (in GDA94 to six decimal places).

5. Mark the corners of the assessment plot using a marker pole that is easily seen during assessments such as large, white painted surveyor's pegs, and record the GPS locations (in GDA94 to six decimal places) of all corners of the plot.

6. Identify all trees that are located within the assessment plot. A tree is to be included in the assessment if its trunk originates wholly or partly from within the boundaries of the assessment plot. Trees should be marked with a spray to avoid double measuring, particularly in dense stands. The scientific name (or code where applicable) of all trees assessed should be recorded on the datasheet.

7. Several normal (upstream, downstream, left bank, right bank and reach environments) site photographs should also be taken that are representative of the site sampled.

2. Protocol for surveys of species demographics sites dominated by river red gum, black box, coolabah and river cooba

Every tree >10cm DBH within the defined sampling plot must be assessed as live or dead and have DBH recorded. Assessment for trees <10cm DBH (recruitment) should follow the "Assessment of recruits" table in the data format.

It is estimated that an average of three new sites can be surveyed per day in the field considering travel time between sites. Where the survey includes revisiting sites previously used for stand condition assessment to collect recruitment data, more sites can be surveyed in a day. However, the time taken at each location will vary from site to site.

Protocol:

1. Locate the assessment site using the location information provided.
2. Conduct a rapid assessment of disturbance at the site and use the provided data form to record the presence and extent of natural and/or man-made disturbances within the plot (e.g. fire, logging, grazing, weeds, flooding etc.).
3. Select the first tree to be assessed. All trees and recruits within the 0.25ha plot are to be assessed.
4. Measure the DBH of the trees according to the following rules:

- Breast height is 1.3m above ground measured along the stem.
    - For trees on a slope, 1.3m is measured on the uphill side of the tree.
    - For leaning trees, 1.3m is measured on the underside of the lean.
    - Where a shoot of a leaning tree originates below the 1.3m and is taller than 1.3m, measure the DBH just like a multi-stemmed tree.
    - Where a swelling occurs at 1.3m, two points unaffected by swellings or limbs equally spaced above and below 1.3m should be selected, measured, and then averaged to give an estimate of DBH.
- The tape must be at 90° to the axis of the stem at 1.3m.
- Lichen or loose bark should be cleared by hand.
- Measure DBH to the nearest millimetre and record in centimetres to 1 decimal place.
- If DBH is at least 10cm, then record the diameter measurement on the datasheet. Also record if the stem is alive or dead (see point 6 below).
- If the tree has multiple stems at 1.3m, the DBH of each stem >5cm is to be recorded. Where trees have a high number of stems with small diameters, assessors should ensure they captured a minimum of 80% of the basal area of the tree.
- If the tree has multiple stems at 1.3m, and DBH of the stems is <10cm but at least four of the stems are >5cm in DBH, record the DBH of each stem (the equivalent DBH will be >10cm).

5. The DBH of every tree with a diameter >10cm should be measured, regardless of species and the species noted (exceptions may apply depending on tree densities).
6. Assess the tree as live or dead based on the following definitions and record the assessment on the datasheet.

- A tree is defined as ‘dead’ when it has no live (green) foliage.
- A tree is defined as ‘live’ when it has live (green) foliage >50%.
- A tree is defined as ‘senescent’ when it has a severely damaged crown (<50% live foliage intact).
- Every tree with a diameter ≥10cm in the 0.25ha is to be assessed as above.

7. For trees with DBH <10cm, record recruitment of each species, count the individuals and assign each individual to a recruitment stage as provided in the “Assessment of Recruits” table below (exceptions for non-target species may apply where plant densities are prohibitive).

8. Where resources allow, and the number of trees <10cm DBH are few, measure the DBH of each tree with >5cm DBH and count trees with DBH <5cm and use the "Assessment of recruits" table to record the counts.

Data management

The standardised database and metadata format previously used for the Woody Species Demographic Data Deed of Variation project in June 2019 will be used by all jurisdictions to store all the field data. This will ensure that all species demographic data supplied to MDBA are in a consistent format for future references.

Jurisdictional species population demographic analysis will include those data collected during pilot deployment of the demographic methodology with the Stand Condition Assessment case study in 2019, data specifically collected in 2019-2020 for population demographics assessment and including recruitment assessment (the number of individuals < 10 cm DBH; Seedling, Sapling, Juvenile), and legacy demographic data supplied to MDBA in June 2019.

The data will be analysed into size class distributions (i.e. a frequency histogram using bins of 10 cm DBH) and compared to the typical distributions observed for plant species with continuous (i.e. reverse J-curve), and episodic recruitment at Jurisdictional basin-wide or catchment scale.

Further analysis techniques may also be appropriate or complementary (Choi *et al.* 2001; Halpin and Lorimer 2017). The analysis approach shall be finalised once a definition of population viability and benchmarks for each target species are determined.

References

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Appendix 2. Study period flood event summary statistics for river flow gauges associated with field sampling sites

Gauging station	Site IDs	Bankfull threshold ML/d	Number of exceedance events (2020–2023)	Total days of exceedance (2020–2023)	Number of days between last flood and field sampling
416001	BR_Barwon	22500	3	29	260
416202A	BR_DD12	9590	5	44	266
416203A	BR_Callandoon	6022	7	28	268
416204A	BR_BB12 BR_BB14 BR_BB11	8985	4	17	518
416415A	BR_DD4	73353	1	1	606
416206A	BR_Moonie 4 BR_Moonie 3	708	21	180	262
417201B	BR_DD25 BR_DD28 BR_Moonie 1 BR_Nindigully	1028	15	136	266
417204A	BR_DD26 CB_DD14	4553	9	70	265
422201F	CB_DD15 CB_DD16 CB_DD17 CB_DD17A CB_DD18	197367	0	0	NA
422202B	CB_1	15379	1	6	281
422204A	CB_Cubie 2	31017	1	8	587
422206A	CB_Hebel 1	6029	4	42	260
422207A	CB_DD23	606	7	107	256
422208B	CB_Cubie	8087	8	134	223
422209A	CB_Bokhara CB_DD24	2592	2	14	575

422220A	CB_251	20304	10	122	265
422308C	CB_BB06	19267	6	58	272
422333A	CB_BB03	13613	6	56	274
422344A	CB_BB007	21653	5	59	433
422401D	CB_13 CB_117 CB_BBS10 CB_BBS10A CB_MARA_1 CB_MARA_patch1 CB_MUL_4_2	223171	0	0	NA
422404A	CB_19B CB_MARA 20 CB_Mara_ Crossing	2315	7	54	276
423203A	WPN_MUL9 WPN_MUL9-2 WPN_WYNANDRA	60517	2	7	1236
423204A	CB_BBS6 WPN_Augath_2 WPN_BBS9	8202	1	2	605
423205A	WPN_12	46224	1	3	1250
423206A	WPN_Wn18-1324	14820	3	20	859
424201A	WPN_Currawinya1 WPN_Currawinya2 WPN_Currawinya3 WPN_Hungerfood WPN_PAR269 WPN_WP03 WPN_WP06 WPN_WP06_2	12873	7	43	276
No corresponding gauging station	BR_Weir-CB BR_211 BR_BB2 BR_WC1				

	BR_WC2 BR_DD3 BR_Weir-RRG BR_283 BR_BBS20 BR_Moonie 2 CB_34 CB_CMD2 WPN_WN10 WPN_WP01-A WPN_Mungallala 1 WPN_Mungallala 2 WPN_Nebine 3 WPN_Nebine 4 WPN_Nebine1 WPN_Nebine2 WPN_PAR 179 WPN_PAR216-A WPN_Yerrrel1				