

The Living Murray – Turtle and Frog Condition Monitoring in the Barmah–Millewa Forest

Report for the 2025–26 season

K. Howard, L. Durkin and K. Ward

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Report for the 2025–26 season

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Acronyms

ARI	Arthur Rylah Institute for Environmental Research
ARU	Autonomous recording unit (deployed to record frog calls)
AUC	Area under the ROC curve. A prediction of frog call identification accuracy based on the receiver operator characteristic (ROC) curves generated using call validations of the CNN model.
BD	Body depth. A measurement of the deepest section of a turtle.
B–MF	Barmah–Millewa Forest
CNN	Convolutional Neural Network
CPUE	Catch-per-unit-effort
E-flows	Environmental water flows
GBCMA	Goulburn Broken Catchment Management Authority
MDBA	Murray–Darling Basin Authority
NHT	Natural Heritage Trust Program
NP	National Park
PL	Plastron length. A measurement of the length of the underside of a turtle.
ROC	Receiver operating characteristic. A calculation used to assess the accuracy of species identification by the CNN model.
SCL	Straight carapace length. A measurement of the dorsal length of a turtle.
SCW	Straight carapace width. A measurement of the widest point of the turtle.
TLM	The Living Murray
VBA	Victorian Biodiversity Atlas
WMA	Water management area
Wr	Relative weight

Summary

Context:

The Living Murray (TLM) initiative aims to improve the ecological condition of six icon sites by delivering environmental water allocations as managed flows. Barmah–Millewa Forest (B–MF), located on the mid-Murray, is one of the six icon sites where the condition of vegetation, bird, fish, crayfish, turtle and frog populations are monitored annually. During 2025–26, relatively dry conditions prevailed, and little to no environmental water was delivered to Millewa Forest. With a few exceptions due to minor overbank flooding and permanent habitats being inundated in prior years, the majority of Millewa Forest remained dry. Barmah Forest received limited environmental water, delivered from mid-October to mid-December, inundating ~25% of the floodplain. This report presents the eighth year of annual monitoring of turtle and frog populations for TLM in B–MF.

Aims:

With the context of the overarching TLM goal to provide feeding, breeding and nursery habitat for turtles and frogs, the objectives of this project are to:

- undertake annual surveys to monitor the population condition of turtles and frogs in Barmah–Millewa Forest
- report against established monitoring metrics that assess population condition over time
- review and refine selected turtle monitoring metrics.

Methods:

Turtle surveys were carried out at 20 sites across B–MF, over 10 nights in summer 2026, using baited nets. The species, length, weight, and sex of captured turtles were recorded. Turtle population condition was reported using three metrics that track change in recruitment and body condition: (1) the relationship between the proportion of monitored sites with detections of juvenile turtles and inundation scores; (2) the proportion of monitored sites with detections of sub-adult turtles; and (3) mean body condition per species per year. Turtle metrics were also reviewed as part of this work, to refine the approach used or to assess their effectiveness in detecting change. Relationships between metric scores, inundation and site characteristics were evaluated, and predictive models were used to estimate expected metric values, providing context for the interpretation of annual variation in condition scores.

Frog populations were monitored with passive acoustic monitoring at 32 sites – 20 in Barmah (including two opportunistic sites) and 12 in Millewa. Autonomous recording units sampled soundscapes nightly for four months during the peak spring breeding season, from mid-September 2025 until January (Barmah) or February (Millewa) 2026. The acoustic dataset was processed using a custom convolutional neural network (CNN) model, trained to recognise the calls of all frogs that occur, or potentially occur, in B–MF. A subset of the model's output was validated by a human listener to assess the accuracy of the acoustic classifier. The CNN model outputs, and the validated subset, from this year and seven previous seasons, were analysed in a multi-season occupancy model to report two metrics that track change over time: (1) site-level species richness, and (2) calling activity per species across the entire icon site. Minimum species richness per site, confirmed by manual validation, was also reported, as was calling phenology of all species at all sites, across the 2025–26 season.

Results:

Turtle condition metrics ranged from 'poor' to 'average'. The proportion of occupied sites with juvenile turtle detections (turtle Metric 1) declined from 'average' in 2024–25 to 'poor' in 2025–26, most likely due to reduced inundation in the prior year. Sub-adult recruitment (turtle Metric 2) was classified as 'average' for the Broad-shelled Turtle (*Chelodina expansa*) and Murray River Turtle (*Emydura macquarii*), and 'poor' for the Eastern Long-necked Turtle (*C. longicollis*). Adult body condition (turtle Metric 3) remained 'average' for all three species. Compared to 2024–25, body condition declined for the Eastern Long-necked Turtle and increased for the Murray River Turtle and Broad-shelled Turtle. Observed body condition scores were comparable to model-predicted values given the habitat composition and hydrological conditions represented in the survey season.

For frogs, while the six commonly recorded species generally had high occupancy year-to-year, with minimal variation, site-level species richness was relatively low in 2025–26 compared with previous years, with an estimated average of 5 species per site. This is one of the lowest species richness estimates of the past eight years. For all six species, calling activity across the icon site was lower than in the prior year. This pattern was particularly distinct for three species: Eastern Sign-Bearing Froglet (*Crinia parinsignifera*), Peron's Tree Frog (*Pengilleyia peronii*), and Spotted Marsh Frog (*Limnodynastes tasmaniensis*). The Pobblebonk (*Limnodynastes dumerilii*) continued to have the lowest calling activity across years, followed by the Barking Marsh Frog (*Limnodynastes fletcheri*). Frog calling activity was generally higher on the Millewa side of the icon site; nine of the 20 monitored sites in Barmah had very little or no frog calling.

Conclusions and implications:

Turtle populations in B–MF appear to be stable, and any changes in the metrics were consistent with model-predicted values. The decline in juvenile recruitment is likely due to limited floodplain inundation. The refined sub-adult recruitment metric provides a clearer biological interpretation of recruitment, by describing species-specific recruitment only within the subset of monitored sites with detections of that species. An improved understanding of the relative influence of land and water management activities on turtle condition responses would provide valuable context for interpreting the annual recruitment metrics. The long-term predator management program currently underway in Barmah Forest is scheduled to end in 2028 and, upon completion, it is recommended that the state-space modelling framework used to assess the metrics in 2023 is revisited. Evaluating the combined influence of predator management and inundation practices on turtle recruitment will provide context for annual changes in metric values.

Frog calling activity and average species richness per site were depressed in the 2025–26 year likely due to the limited extent of inundation, and possibly also the timing of inundation, with flows delivered to parts of Barmah Forest after mid-October. Returning to an earlier inundation schedule, for example in August, through September and into October (i.e. late winter/early spring), would provide breeding habitat during a more ideal time of year and maximise breeding and recruitment for most locally occurring frog species. The increased frog calling activity recorded at sites in Millewa compared to Barmah, despite Millewa receiving no environmental water, is likely related to the water permanence of monitoring sites. Frog monitoring sites in Barmah are more ephemeral, while in Millewa they are comprised of permanent/semi-permanent wetlands, which likely support the frog assemblage through dry years.

1 Introduction

The Living Murray (TLM) program aims to improve the ecological condition of six priority ‘icon sites’ through the delivery of water for the environment (MDBA 2011). These icon sites were chosen for their significant environmental and cultural values, and consist of (1) Barmah–Millewa Forest, (2) Koondrook–Perricoota and Gunbower Forest, (3) Hattah Lakes, (4) Chowilla and Lindsay–Mulcra–Walpolla Island, (5) Lower Lakes, Coorong and Murray Mouth, and (6) the River Murray Channel. The Living Murray program is coordinated by the Murray–Darling Basin Authority (MDBA) and feeds into the Murray–Darling Basin Plan. The Murray–Darling Basin Plan aims to ensure ‘sustainable and efficient management of water resources’ and has specific environmental targets for vegetation, waterbird and fish communities (MDBA 2014). Since 2006–07, TLM has monitored the ecological condition of the icon sites to assess key indicators of health, and to track progress against each site’s stated ecological objectives (MDBA 2018).

Barmah–Millewa Forest (B–MF) is situated on the mid-Murray River floodplain, with the flow of water down the Murray River and consequently into B–MF, controlled by a series of flow regulating structures including dams, weirs and drop-boards. Altered flow regimes are a major threat to the environmental values of the forest (Walker and Thoms 1993; Ward 2006). Although the condition of fish, birds and vegetation have been monitored at the B–MF icon site since the TLM program commenced, turtle and frog condition monitoring did not begin until the 2018–19 season. TLM condition monitoring of turtle and frog populations has been carried out annually, during spring and summer, for seven, consecutive years: 2018–19, 2019–20, 2020–21, 2021–22, 2022–23, 2023–24, 2024–25. This report details turtle and frog condition monitoring at the B–MF icon site during the eighth survey season, 2025–26.

1.1 Turtle species of Barmah–Millewa Forest

The turtle community in B–MF is comprised of three native species: Broad-shelled Turtle (*Chelodina expansa*), Eastern Long-necked Turtle (*Chelodina longicollis*), and Murray River Turtle (*Emydura macquarii*). All three species overlap in their habitat use, but occupy specific niches. The Eastern Long-necked Turtle is a floodplain specialist (Kennett and Georges 1990) and is detected across a range of habitat and hydrological types in floodplain systems (Ocock et al. 2018, Durkin et al. 2024b). Distributions of the Broad-shelled Turtle and Murray River Turtle are more often restricted to permanent and semi-permanent habitats (Ocock et al. 2018), e.g. backwaters, oxbow lakes and wetlands (Chessman 1988). Within B–MF, our understanding of species-specific habitat use has largely been informed by trapping and is consistent to other studies. In 2020, acoustic tracking programs were established through the TLM intervention monitoring program. Male Murray River Turtles were recorded dispersing widely across the floodplain. Compared to trap records alone, acoustic telemetry has expanded the range of habitat types where this species has been detected (Howard et al. 2025a).

In 2023, TLM turtle monitoring data, along with survey data collected between 2008 and 2017, were analysed with the aims to: (1) investigate the influence of environmental and management covariates on patterns in population dynamics over time; and (2) evaluate the metrics used to report on population dynamics for TLM condition monitoring. This work found that there was a lagged positive relationship between flooding and both juvenile and sub-adult recruitment for the Eastern Long-necked Turtle and the Murray River Turtle. Sub-adult recruitment for the Broad-shelled Turtle and Eastern Long-necked Turtle was especially responsive to consecutive years of flooding. The results provided multiple lines of evidence that landscape-scale flooding positively affects physical condition, recruitment and ultimately also population size for turtles (Gwinn et al. 2023). These analyses have greatly improved our understanding of, and ability to describe, changes to turtle population condition over time (see Gwinn et al. 2023).

1.2 Frog species of Barmah–Millewa Forest

Nine frog species have been recorded in B–MF (McGinness et al. 2014; Victorian Biodiversity Atlas (VBA) 2026), representing three families (Table 1). Six of these species are relatively common and are recorded each year during annual monitoring.

The remaining three species have only rarely been recorded in the icon site. Sloane’s Froglet (*Crinia sloanei*) is listed Endangered nationally under the *Environmental Protection and Biodiversity Conservation Act 1999* (Cth.) and was last recorded in B–MF in October 2024, calling on one night at one site (Hughes Crossing), after an absence of records from the icon site for 23 years (Howard et al. 2025b). Bibron’s Toadlet (*Pseudophryne bibronii*) is listed as Endangered in Victoria under the *Flora and Fauna Guarantee Act 1988* (Vic.) and is known from a single record in 2000 (Ward 2001). The Common Spadefoot Toad (*Neobatrachus*

sudellae) is not listed as threatened, but is a cryptic burrowing species, emerging to call and breed after heavy rainfall (Anstis 2017). Common Spadefoot Toad was last recorded during surveys in B–MF in 2021, and 2019, and prior to that in the year 2000 (McGinness et al. 2014; Durkin et al. 2022). The 2021 and 2019 records were both from the same monitoring site – Two Mile Sandridge. The species was heard calling in 2026 at the Dharnya Centre in Barmah NP (T. Barlow pers. comm.).

Table 1. Frog species of Barmah–Millewa Forest.

*: listed as Endangered nationally. **: listed as Endangered in Victoria.

Family	Scientific name	Common name
Hylidae	<i>Pengilleyia peronii</i> ¹	Peron's Tree Frog
Limnodynastidae	<i>Limnodynastes tasmaniensis</i>	Spotted Marsh Frog
	<i>Limnodynastes dumerilii</i>	Pobblebonk
	<i>Limnodynastes fletcheri</i>	Barking Marsh Frog
	<i>Neobatrachus sudellae</i>	Common Spadefoot Toad
Myobatrachidae	<i>Crinia parinsignifera</i>	Eastern Sign-bearing Froglet/Plains Froglet
	<i>Crinia signifera</i>	Common Froglet
	<i>Crinia sloanei</i> *	Sloane's Froglet*
	<i>Pseudophryne bibroni</i> **	Bibron's Toadlet**

There are no records in B–MF of two species listed as threatened in Victoria, the Growling Grass Frog (*Ranoidea raniformis*¹) and Giant Banjo Frog (*Limnodynastes interioris*), although there are historic records nearby. The Atlas of Living Australia holds Growling Grass Frog records from Barmah Island and the area surrounding Barmah township, from the 1960s and 1970s. The nearest record of the Giant Banjo Frog was from 1993 at Picola North, 5.2 km south of the Barmah National Park boundary (Belbin et al. 2021).

1.3 Objectives

A major goal of TLM is to provide feeding, breeding and nursery habitat for native frogs, turtles and crayfish (MDBA 2012). The specific objectives of this project are to:

1. annually survey turtle and frog populations in B–MF
2. develop and report on metrics that assess population condition over time e.g. changes in recruitment, adult body condition, species presence.

In addition, annual condition monitoring and reporting informs the specific environmental watering objectives for B–MF (GBCMA 2023), which include – by 2033 – to:

- maintain the presence of threatened water-dependent species that are recorded on a regular basis at the Barmah–Millewa Forest icon site (objective BMF4_2023)
- restore representative subpopulations of native water-dependent biota at B–MF (objective BMF7_2023)
- support successful breeding and recruitment of frogs at B–MF (objective BMF11_2023)
- regularly provide refugia to support the long-term survival of water-dependent biota on the managed floodplain of the Barmah–Millewa Forest icon site and Gulpa Creek during drought (objective BMF13_2023).

¹ The genus *Litoria* has recently undergone a taxonomic revision, with *Litoria peronii* and *Litoria raniformis* now placed in the resurrected genera *Pengilleyia* and *Ranoidea*, respectively (Donnellan et al. 2025). Aside from section 1.2, this report uses common names throughout (e.g. Peron's Tree Frog).

2 Methods

2.1 Hydrology and water management area inundation scores

The extent of flooding and environmental water releases throughout B–MF during 2025 were assessed using Murray River water discharge rates from Yarrawonga Weir, as well as the status of the management of regulators (i.e. when they were opened and closed). Due to works in Millewa, regulators remained closed and water was released into Barmah only during 2025–26. The extent of inundation was estimated using field observations and satellite imagery. Barmah–Millewa Forest is divided into 19 water management areas (WMAs) that inundate at different flood intensities due to topographical variation (Appendix 4). Using field observations and satellite imagery, each WMA is coarsely classified annually as having no flooding (score = 0), some flooding (score = 1), a lot of flooding (score = 2) and complete flooding (score = 3) (GBCMA 2023). WMA flood scores are weighted by area and are calculated for each WMA both independently and as a whole-of-forest inundation score, per year. WMA inundation scores that were calculated for one- and two years preceding the survey year were used to assess metric responses to antecedent inundation.

2.2 Condition metrics

2.2.1 Turtle condition metrics

Three recruitment and body condition metrics, which are effective at detecting changes in population trends between years, are reported annually.

Metric 1. Proportion of occupied sites with juvenile turtle detections.

Metric 2. Proportion of species-specific occupied sites with sub-adult turtle detections.

Metric 3. Mean adult body condition per species per year.

2.2.2 Turtle metric evaluation and refinement

As part of the 2025–26 annual reporting process, model-based predictions were incorporated into the turtle condition metrics to aid in the interpretation of observed metric values. In addition, Metric 2 was reviewed to assess whether annual reporting could be improved through refinement of the metric definitions. Full details of model development, comparisons and selection are provided in Appendix 1. An overview of the changes incorporated are listed below:

Metric 1. Proportion of occupied sites with juvenile turtle detections

Model-based predictions of Metric 1 were included in the reporting this year. Previous state-space modelling (Gwinn et al. 2023) found that antecedent flood conditions positively influenced juvenile recruitment. We investigated if a simpler modelling approach could detect similar, lagged inundation effects, and provide insights into how water management affects metric scores over time. Linear models were used to assess relationships between juvenile recruitment and whole-of-forest WMA inundation scores, including lagged and multi-year inundation scores.

Metric 2. Proportion of occupied sites with sub-adult turtle detections

This year, Metric 2 was reviewed and refined. Previously, it was calculated by considering all sites with turtle detections in that year, of any species, to be ‘occupied sites’ (i.e. as the denominator by which the number of sites with sub-adult turtles would be divided by). As each species preferentially occupies different habitats, and surveys may detect only one species at a site, the existing approach could have underestimated sub-adult recruitment. The calculation of this metric was refined, moving to a more species-focussed view, whereby the number of sites with sub-adult detections of species A was divided by the number of sites with any detection of species A, in that year. See Appendix 1 for further details about the refinement.

Metric 3. Mean adult body condition per species per year

Model-based body condition predictions were calculated to assist interpretation of the observed metric scores over time. To account for variation in habitat composition and hydrological conditions among survey years, expected relative weight scores were estimated using a linear model incorporating species, habitat type, hydrology class, whole-of-forest WMA inundation scores, and species-specific responses to inundation as predictor variables. Model predictions were used to generate expected species-specific body condition scores for the habitat and hydrological conditions represented in each survey year.

2.2.3 Frog condition metrics

The analysis of the six-year frog dataset from B–MF carried out in early 2024 suggested several refinements to the monitoring metrics used to report frog condition at this icon site (Durkin et al. 2024a). The refined metrics use data from all monitoring years, analysed in an occupancy modelling framework, to estimate species richness and calling activity, per species per year (see below). Metric 2 is informed by an estimate of ‘unconditional’ calling activity derived by Durkin et al. (2024a), i.e. calling activity given the site is occupied that year, which reflects the average probability a given species: 1) will call on a night during that season; 2) is recorded; and 3) is recognised by the acoustic classifier. The revised calling activity metric uses occupancy modelling outputs and therefore accounts for imperfect detection. Detailed information on each metric can be viewed in Appendix 2.

Metric 1. Average site-level species richness.

Metric 2. Calling activity per species.

While the Environmental Water Management Plan (GBCMA 2023) sets out objective BMF11_2023 to “*support successful breeding and recruitment of frogs at Barmah–Millewa Forest by 2033*”, the above frog condition metrics do not directly address this target. The measurement and tracking of trends in recruitment would require survey techniques in addition to passive acoustic monitoring (e.g. fyke net tadpole surveys and/or in-person searches to document presence and abundance of metamorphs), and a more labour-intensive monitoring program. At present, resource constraints mean these techniques and additional site visits are out-of-scope and, although recruitment is not directly assessed, ongoing persistence and activity of adult frogs is a useful indicator that populations have adequate recruitment and/or immigration.

2.1 Turtle monitoring

2.1.1 Site selection

The turtle monitoring program assesses 25 sites across B–MF: 11 situated in Barmah National Park (NP) (Victoria) and 14 in the Murray Valley NP (NSW) including the Murray River itself. The program employs a staggered ‘two-years-on one-year-off’ design (Howard et al. 2020), with 16 of the 25 monitoring sites surveyed annually when access and conditions permit. Four additional monitoring sites in Barmah NP are surveyed annually through the Barmah Country Natural Heritage Trust Program (NHT) via the Goulburn Broken Catchment Management Authority (GBCMA). These survey data also contribute to annual TLM condition monitoring reporting. A list of the monitoring sites and their survey histories are provided in Appendix 3.

2.1.2 Trapping and processing

Live trapping for all species of turtles was undertaken at 20 sites (Appendix 3; Figure 1). The 2026 surveys were split across two field trips in mid- and late-summer (12–17 January and 9–14 February). At each site, turtles were captured using cathedral nets, and both coarse- (3 cm) and fine-meshed (1 mm) fyke nets baited with beef liver. Traps were deployed at each site for one night only, reducing the likelihood of trap avoidance associated with repeated trapping over consecutive nights (Gwinn et al. 2023). While the nets used can capture all turtle species at all aquatic life stages, capture rates of juvenile turtles were low and therefore this age-class was likely under-represented in our results.

All turtles caught were identified to species and sexed where possible. Eastern Long-necked Turtles are difficult to sex, even as adults, and therefore were not categorised by sex. The following standard measurements were taken using Vernier callipers for each turtle: straight carapace length (SCL), straight carapace width (SCW), plastron length (PL) and body depth (BD). Straight carapace length was measured from the middle of the nuchal scute to the middle of the rear marginal scutes. Straight carapace width was measured at the widest point of the carapace, and plastron length was measured from the middle of the anterior and posterior ends of the plastron. Body depth was measured at the widest section between the mid-carapace and mid-plastron. Turtles were weighed to the nearest gram using an 11 kg balance, or 300 g balance for juveniles. They were also visually assessed for damage to the shell or limbs. Turtles were classified as juvenile, sub-adult or adult based on SCL. Juvenile maximum size was calculated using species-specific growth curves developed by Gwinn et al. (2023) (Metric reporting)

Juvenile recruitment was calculated as the proportion of sampled sites that one or more juveniles were detected at, for all species combined. Observed proportions were compared with model-predicted values generated from relationships with antecedent inundation conditions. Sub-adult recruitment was calculated as the number of sites with sub-adult detections of species A/B/C, divided by the number of sites with any detection of species A/B/C, in that year. Metric scores were compared across years and assessed against the established condition thresholds. Both recruitment metrics were classified as very poor, poor, average, good or very good according to the predefined thresholds.

Adult relative weight (W_r) was calculated using the formula $W_r = (W/W_s) \times 100$, where W is the observed weight and W_s is the species-specific standard weight predicted from length-weight relationships, generated from all individuals captured to date. Relative weight was presented as the mean $\pm$ SE for each species, plotted against thresholds that represent poor, average, and good body condition. Model-predicted condition scores were presented alongside observed values to provide context for differences in habitat composition, hydrological conditions and antecedent inundation among survey years.

Table 2). Female size at sexual maturity was used to classify a turtle as sub-adult or adult (Metric reporting

Juvenile recruitment was calculated as the proportion of sampled sites that one or more juveniles were detected at, for all species combined. Observed proportions were compared with model-predicted values generated from relationships with antecedent inundation conditions. Sub-adult recruitment was calculated as the number of sites with sub-adult detections of species A/B/C, divided by the number of sites with any detection of species A/B/C, in that year. Metric scores were compared across years and assessed against the established condition thresholds. Both recruitment metrics were classified as very poor, poor, average, good or very good according to the predefined thresholds.

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Table 2). Adults included all individuals equal or greater to the female size at sexual maturity. Sub-adults include all individuals greater than the maximum juvenile size and smaller than the size at sexual maturity (Metric reporting

Juvenile recruitment was calculated as the proportion of sampled sites that one or more juveniles were detected at, for all species combined. Observed proportions were compared with model-predicted values generated from relationships with antecedent inundation conditions. Sub-adult recruitment was calculated as the number of sites with sub-adult detections of species A/B/C, divided by the number of sites with any detection of species A/B/C, in that year. Metric scores were compared across years and assessed against the established condition thresholds. Both recruitment metrics were classified as very poor, poor, average, good or very good according to the predefined thresholds.

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Table 2) (Parmenter 1985; Spencer 2002).

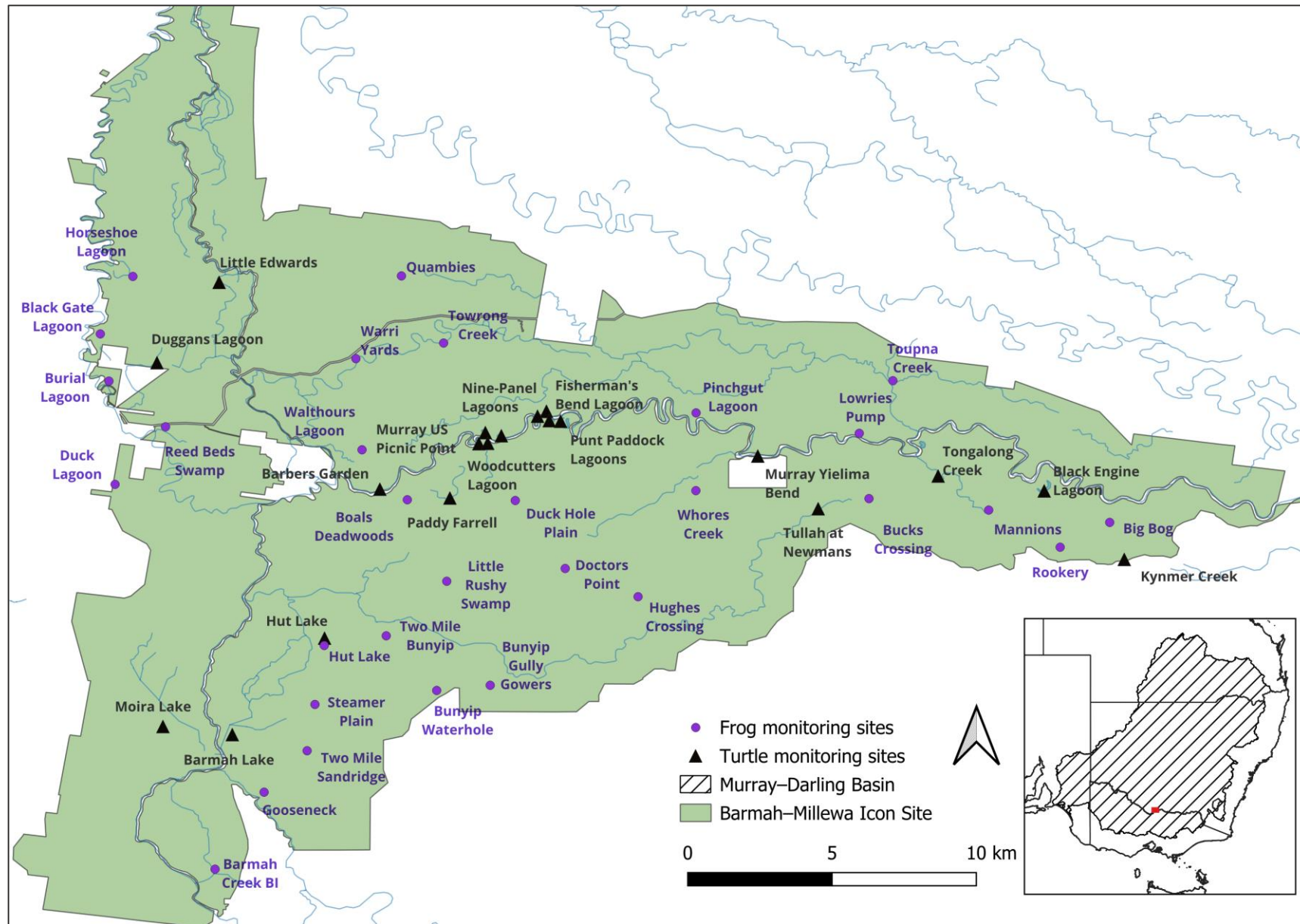


Figure 1. The Living Murray turtle and frog condition monitoring sites in Barmah-Millewa Forest, 2025-26.

2.1.3 Metric reporting

Juvenile recruitment was calculated as the proportion of sampled sites that one or more juveniles were detected at, for all species combined. Observed proportions were compared with model-predicted values generated from relationships with antecedent inundation conditions. Sub-adult recruitment was calculated as the number of sites with sub-adult detections of species A/B/C, divided by the number of sites with any detection of species A/B/C, in that year. Metric scores were compared across years and assessed against the established condition thresholds. Both recruitment metrics were classified as very poor, poor, average, good or very good according to the predefined thresholds.

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Table 2. Size at sexual maturity of male and female turtles for all three species found within Barmah–Millewa Forest.

Size is based on straight carapace length (SCL) and measurements are in cm (Parmenter 1985; Spencer 2002; Gwinn et al. 2023).

Species	Maximum juvenile size (SCL)	Sub-adult size range (SCL)	Size at sexual maturity	
			Male SCL	Female SCL
Broad-shelled Turtle	11.5	11.5 – 22.0	18	22
Eastern Long-necked Turtle	12.9	12.9 – 17.0	15	17
Murray River Turtle	14.0	14.0 – 18.0	15	18

2.1.4 Habitat assessments

At each site, a suite of habitat attributes was recorded to describe water availability, habitat type and habitat quality. This included waterbody type (e.g. river, wetland, creek), waterbody size, occurrence of in-stream woody debris, and average and maximum depth. Average depth was assessed at new survey sites using a minimum of three depth transects, with depth readings every 5 m. Water quality parameters included salinity, pH, temperature, turbidity and dissolved oxygen, measured 10 cm below the water surface using a YSI ProDSS multiparameter meter (YSI Inc., Yellow Springs, OH, USA).

2.2 Frog monitoring

2.2.1 Passive acoustic monitoring

Thirty-two B–MF sites were monitored for frogs during the 2025–26 season – 20 in Barmah NP (Victoria) and 12 in Murray Valley NP (Millewa, NSW) (Figure 1). Two autonomous recording units (ARUs) (AudioMoths v.1.0-1.1, Open Acoustic Devices, UK) housed in water-resistant plastic cases were deployed 100–150 m apart at each site as replicates, and to mitigate the risk of data loss due to theft or malfunction. Two new sites in Barmah were monitored opportunistically this season, due to their proximity to the long-term monitoring site, Hughes Track, where the Endangered Sloane’s Froglet was detected the year prior (Howard et al. 2025b), to increase the acoustic monitoring effort in this area, in the hope of detecting Sloane’s Froglets again. The two new sites are referred to herein as ‘Gulf Tk east’ and ‘Hughes Track’ and received only one ARU each. These opportunistic sites were not included in the re-run of occupancy analyses that use the long-term monitoring sites. In total, 62 ARUs were deployed, cable-tied to saplings ~1.8 m above ground, and programmed to record at regular intervals (one minute in every 30-minute period) between 19:00 and 00:30 Australian Eastern Standard Time, each night of deployment. This schedule yields 12 minutes of acoustic data per night per unit. ARUs were deployed from 9 – 11 September 2025 and retrieved during the turtle condition monitoring fieldtrips, four months later in Barmah, on 18 January 2026, and five months later in Millewa, 10–13 February 2026.

2.2.2 Convolutional neural network model to process acoustic data

After retrieval and collation, all acoustic data were provided to a convolutional neural network (CNN) deep-learning model, developed at the Arthur Rylah Institute for Environmental Research (ARI) to automate frog

species recognition in large bioacoustic datasets (Griffioen et al. 2025). The model was trained using 17 classes: exemplar calls from 15 frog species found in Victoria, including all those that occur in Barmah–Millewa, a ‘frog chorus’ class to recognise loud segments of the acoustic data where >1 frog species is calling simultaneously, and a ‘not a frog’ class encompassing all other sounds, such as birds, insects, and any environmental noise. The model assesses the entire acoustic dataset and provides probabilistic predictions of which species are calling within each 1.5-second segment of each 60-second file. For each file segment, the model assigns a probability to each training class (the 15 frog species, ‘frog chorus’ and ‘not a frog’), that sums to 1 (e.g. 0.0–1.0). For example, the model may predict that a Peron’s Tree Frog call is present with a probability of 1.0 (100% confidence), or that another file segment contains a Barking Marsh Frog call with a probability of 0.8 (80% confidence), and a Pobblebonk call with a probability of 0.2 (20% confidence). To ensure comparability between monitoring years, the same version of the CNN model (v. June 2025) used in the 2024–25 analyses (Howard et al. 2025b) was used to process the 2025–26 data. This ensured that differences among years were not confounded by changes in model performance or detection characteristics.

To evaluate the accuracy of the CNN model in recognition of each frog species, we randomly subset the model outputs, sampling across five probability strata for each species (0–0.2, 0.2–0.4, 0.4–0.6, 0.6–0.8 and 0.8–1), using the statistical package R (R Core Team 2025; Rstudio version 2025.05.0) and validated using the custom-built software tool ARIEL (Arthur Rylah Institute Ecoacoustic Listener). ARIEL allows rapid validation, by an experienced human listener, of the 1.5-second file segments where the model predicts a certain frog species’ call is present. The listener assigns species name tags to agree or disagree with the model’s predictions, generating a validated dataset. This validation process allows estimation of true positive and false positive rates in the model’s outputs. The full processing workflow is described in a previous report, see Howard et al. (2023). In addition to the stratified validation for each frog species, we validated 50 randomly selected 1.5-second segments from each site that the model had classified as ‘not a frog’. We summarised CNN model discriminatory performance using receiver operating characteristic (ROC) curves for each species. ROC curves plot the true positive rate (sensitivity) against the true negative rate (specificity). We calculated the Area Under the Curve (AUC) for each species, along with 95% confidence intervals (calculated with the R package pROC (Robin et al. 2011)) using the methods devised by DeLong et al. (1988). A model with AUC=0.5 indicates that discriminatory ability is no better than random, while AUC=1 indicates perfect discrimination (Liu et al. 2011; Jiménez-Valverde 2012).

We further validated the top 10 highest probability predictions of each species at each site, before combining all validated data, and tabulating species richness per site. Only a small proportion of the broader acoustic dataset was listened to; therefore, this species ‘checklist’ per site should be considered the minimum bounds of species richness.

2.2.3 Occupancy model to report monitoring metrics

The occupancy modelling analyses developed for this dataset in 2024 were re-run to generate estimates of site-level species richness and calling activity across all sites in each year. We opted for use of a ‘stacked’ multi-season model, because not every site had been monitored in every year. A stacked multi-season model effectively models site-year combinations independently (as different sites), accounting for a particular site’s non-independence across years with a site-level random effect (Kellner et al. 2022). Unlike traditional occupancy models that use binary detection histories (detected/not detected), we modelled occupancy and calling activity using a continuous score bounded between 0 and 1 (i.e. the probability scores from the CNN model output) using the methods from Rhinehart et al. (2022). See Durkin et al. (2024a) for further details.

3 Results

3.1 Hydrology

The 2025–26 year was characterised by relatively dry weather and lower-than-forecast rainfall events across the catchment. River flow from Yarrawonga weir remained within channel capacity, except for late-July and early-August. High rainfall in the upper catchments led to a small natural flood event, resulting in forest regulators being briefly opened on both the Barmah and Millewa sides while river heights were above capacity. Rainfall across the catchment in late-August and early-September was lower than forecast; flows were managed within channel capacity and all regulators remained closed. Due to an extensive works program on the forest regulators and new water metering requirements in NSW, no environmental water releases were delivered to Millewa Forest, excepting a small release into Toupna Creek in April 2026. The Mary Ada regulator was partially opened from 31 March to 14 April to support aquatic refuge habitat. Consequently, flow management for Barmah Forest focussed heavily on environmental water releases to maintain seasonally required low-level flooding without the benefit of larger unregulated flow peaks as often occurs.

Regulators remained closed until they were opened for two months in Barmah between mid-October and mid-December 2025, when an environmental water (e-water) allocation was made into Barmah Forest, influencing 25% of the Barmah floodplain. The floodplain marshland environments, and lower terrace River Red Gum (*Eucalyptus camaldulensis*) Forest and associated waterways, experienced a mostly continuous two-month flood (Figure 2). Relatively dry weather conditions meant areas of the forest not influenced by e-water releases remained dry. With a few exceptions due to minor overbank flooding and permanent habitats inundated in prior years, the majority of Millewa Forest remained dry for 2025–26. Environmental water delivery therefore improved the flooding of the lower floodplain, and this is expected to have greatly enhanced water and habitat availability for turtles and frogs beyond that which would have occurred had no environmental water been made available.

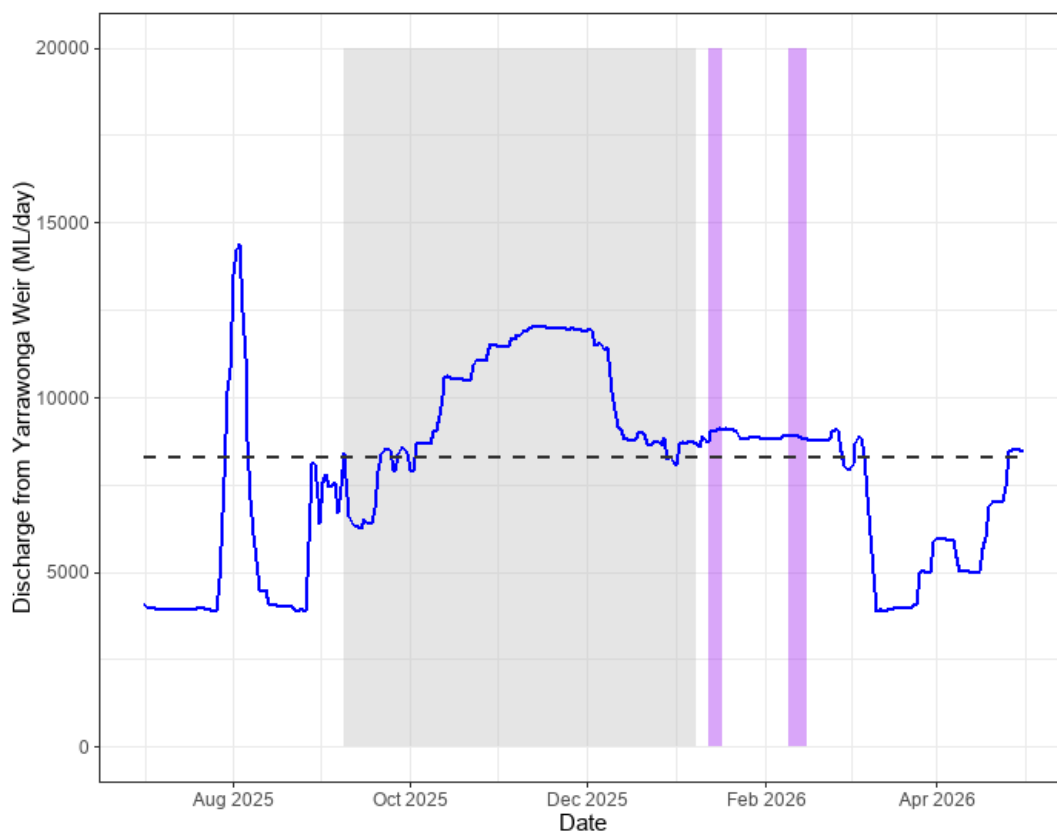


Figure 2. Mean daily discharge (blue line) from Yarrawonga weir into the Murray River, from July 2025 to May 2026 (MDBA 2026b).

The blue line shows the discharge from Yarrawonga. The dashed black line shows the weir discharge rate above which Barmah–Millewa Forest regulators must be opened to regulate in-flows from the river to the floodplain. The grey-shaded

portion of the graph indicates the period of passive acoustic monitoring at frog sites. The purple vertical bands show the timing of turtle surveys.

3.2 Turtle monitoring

3.2.1 Summary of catch and observations

During the 2025–26 survey season, a total of 262 turtles were captured, consisting of 41 Broad-shelled Turtles, 140 Eastern Long-necked Turtles and 81 Murray River Turtles (Table 3). The total number of turtles captured in 2025–26 was comparable to that in 2024–25, but with lower catch rates for the Eastern Long-necked Turtle and higher catch rates for the Murray River Turtle. Floodwater extent has declined annually from 2023–24, with 15% of the floodplain being inundated in spring 2026 (Table 3; Figure 3).

Table 3. Total number of turtles captured during each year of TLM monitoring in Barmah–Millewa Forest.

Note that both the number and type of sites (e.g. permanent wetland, river, creek etc.) sampled each year varied.

	2019	2020	2021	2022	2023	2024	2025	2026
Survey sites	15	19	23	20	18	20	20	20
Flood extent	25%	25%	25%	50%	100%	77%	25%	15%
Broad-shelled Turtle	29	28	40	38	11	53	32	41
Eastern Long-necked Turtle	116	200	191	148	97	121	187	140
Murray River Turtle	42	77	80	83	18	97	36	81
TOTAL	187	305	311	269	126	271	255	262

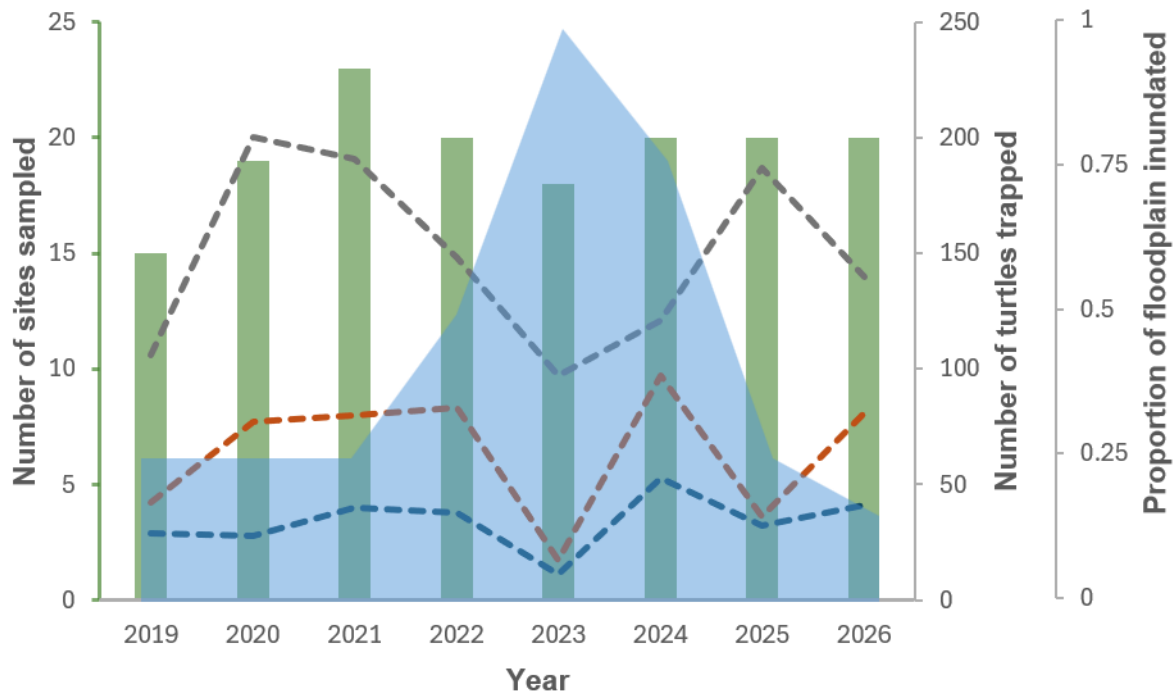


Figure 3. The number of sites sampled, turtles captured per species, and the proportion of floodplain inundated from 2018–19 to 2025–26.

Green columns = number of sites sampled per survey year. Dashed lines show the number of turtles captured per species, where grey = Eastern Long-necked Turtle, orange = Murray River Turtle, and blue = Broad-shelled Turtle. Light blue shaded area = the proportion of the floodplain inundated.

Recapture rates

Twenty-two turtles were recaptured, comprising four Broad-shelled Turtles, nine Eastern-Long-necked Turtles and nine Murray River Turtles. Recapture rates were highest for the Murray River Turtle (i.e. 11% of this year's total catch of this species had been captured and marked in prior years), followed by the Broad-shelled Turtle (9.8%) and Eastern Long-necked Turtle (6.5%). Of the 22 recaptured turtles, 10 were trapped at their original mark and release locations, including eight of the nine recaptured Eastern Long-necked Turtles. The longest period between recaptures was 10 years; a female Murray River Turtle first marked and released at Pinchgut Lagoon in 2016, was re-captured in 2026 at Punt Paddock Big Lagoon.

Recruitment: Juvenile and sub-adult detections

Ten juvenile turtles were captured this year, comprising one Broad-shelled Turtle and nine Eastern Long-necked Turtles. A hatchling Broad-shelled Turtle was trapped at Black Engine Lagoon, the second consecutive year that a hatchling has been detected at this site. Across all species, a total of 36 sub-adult turtles were captured, dominated by Eastern Long-necked Turtles (25) but with an increase in Broad-shelled Turtle and Murray River Turtle sub-adults from two to six and five, respectively.

Recruitment continues to be sporadic across species (Figure 4). Population structure for the Murray River Turtle is consistently dominated by adults. Although the size distributions across all survey years for the Broad-shelled Turtle include sub-adults, the sample sizes for this species are lower. The Eastern Long-necked Turtle is the only species with large sample sizes and consistent detections of sub-adult turtles.

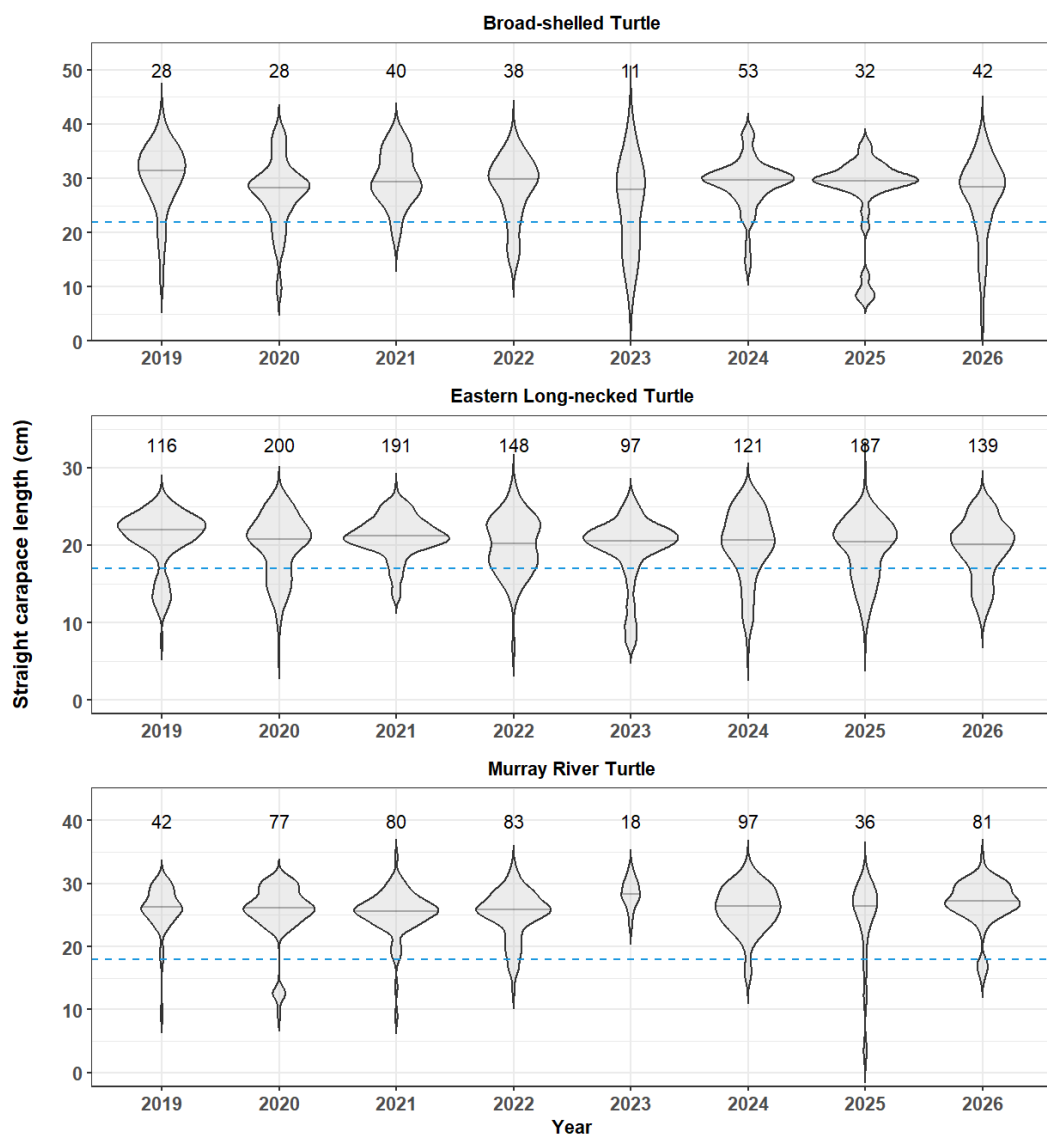


Figure 4. Observed size distributions for the Broad-shelled Turtle, Eastern Long-necked Turtle, and Murray River Turtle per survey year in Barmah–Millewa Forest.

Horizontal lines within each violin plot indicate median size. Sample sizes are displayed above each plot. Blue dashed lines represent size at female sexual maturity. Each column represents a monitoring year, e.g. '2019' is the 2018–19 survey year.

3.2.2 Overview of turtle metric results

Condition metric scores calculated for the 2025–26 season ranged from ‘poor’ to ‘average’ (Table 4). The Broad-shelled Turtle and the Murray River Turtle both recorded ‘average’ sub-adult recruitment, increasing from ‘poor’ in 2024–25. Sub-adult recruitment for the Eastern Long-necked Turtle was classified as ‘poor’, and body condition scores were ‘average’ across all three species (Table 4).

Metric 1 was scored as ‘poor’ with recent recruitment, i.e. juvenile turtles < 3 years old, being recorded at six of the 20 sites sampled. Eastern Long-necked Turtle juveniles dominated the catch, and while juveniles of the Broad-shelled Turtles were detected, none of the Murray River Turtle were.

Metric 2 documents medium-term recruitment, i.e. breeding over the last 4–10 years, using sub-adult turtle detections. Medium-term recruitment indices for the Eastern long-necked Turtle were ‘poor’ while the Broad-shelled Turtle and Murray River Turtle both recorded ‘average’ scores.

Metric 3, which represents mean relative weight as a proxy for adult body condition, recorded a decline in condition for the Eastern Long-necked Turtle, with increases in the body condition for the Broad-shelled Turtle and Murray River Turtle. All three species were classified as having ‘average’ body condition.

Table 4. Overview of the turtle condition metrics for 2025–26.

Metric	Description	Broad-shelled Turtle	Eastern Long-necked Turtle	Murray River Turtle	All species
Recruitment					
Metric 1	Juvenile turtle recruitment				Poor (0.30)
Metric 2	Sub-adult turtle recruitment	Average (0.40)	Poor (0.35)	Average (0.45)	Average
Body condition					
Metric 3	Body condition	Average (97.6)	Average (98.1)	Average (99.0)	Average

3.2.3 Turtle condition indicators

Metric 1. Proportion of occupied sites with juvenile turtles detected (all species combined)

Juvenile recruitment was recorded at six of the 20 sites surveyed. This metric decreased from 0.45 in 2024–25 to 0.3 this survey season and was classified as ‘poor’ (Figure 5). The juveniles captured were dominated by Eastern Long-necked Turtles from Nine-Panel Small (3), Barbers Garden (3), Punt Paddock Small (1) and Tullah Creek (1). Two Broad-shelled Turtle juveniles were detected, one each at Black Engine Lagoon and Duggans Lagoon, and no juvenile Murray River Turtles were captured. Juvenile turtles were detected at two sites in Millewa that were surveyed for the first time this year (Duggans Lagoon and Barbers Garden).

Juvenile recruitment was positively associated with antecedent inundation. The strongest relationship was observed for the forest-wide WMA score two years prior to sampling ($R^2 = 0.43$, $\beta = 0.14$), although a similar positive relationship was also observed three years prior to sampling ($R^2 = 0.47$, $\beta = 0.12$). These results suggest a delayed response in juvenile recruitment to floodplain inundation (Figure 6). Relative to 2021 and 2022, which also had low WMA inundation scores, a higher proportion of sites sampled in 2026 had juvenile turtles detected (Figure 6).

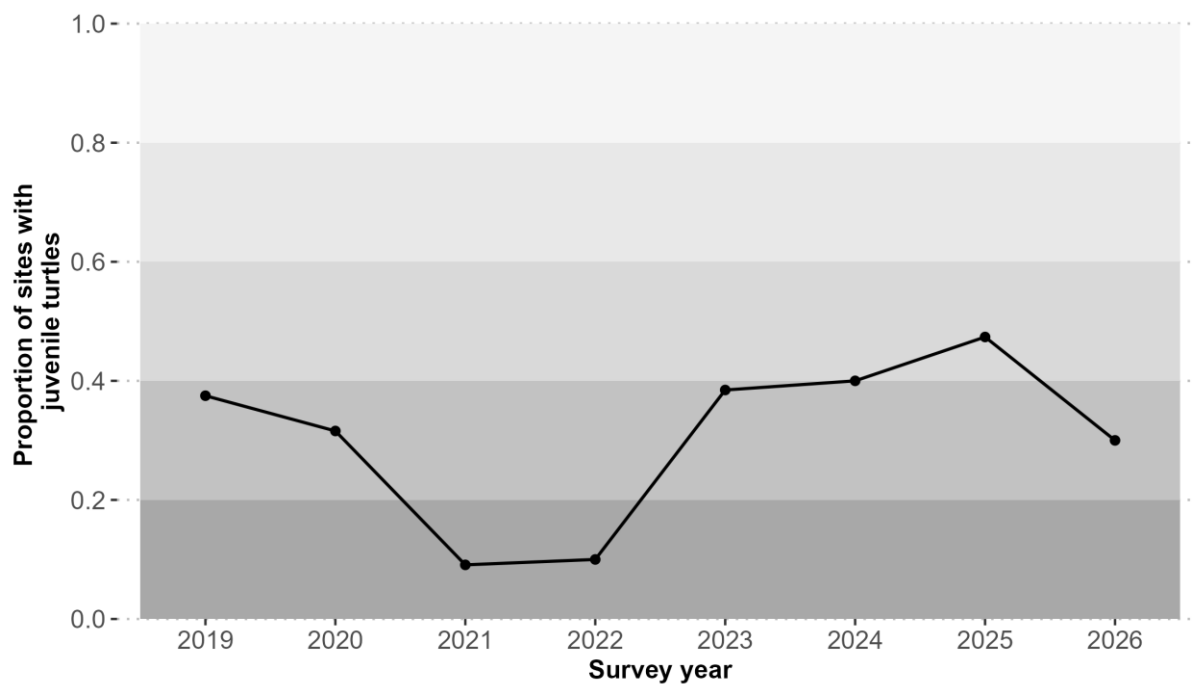


Figure 5. Metric 1: The proportion of occupied sites with juvenile turtle detections (all individuals up to three years since hatching).

Metric score range includes very poor, poor, average, good and very good, where very poor = dark grey and very good = light grey.

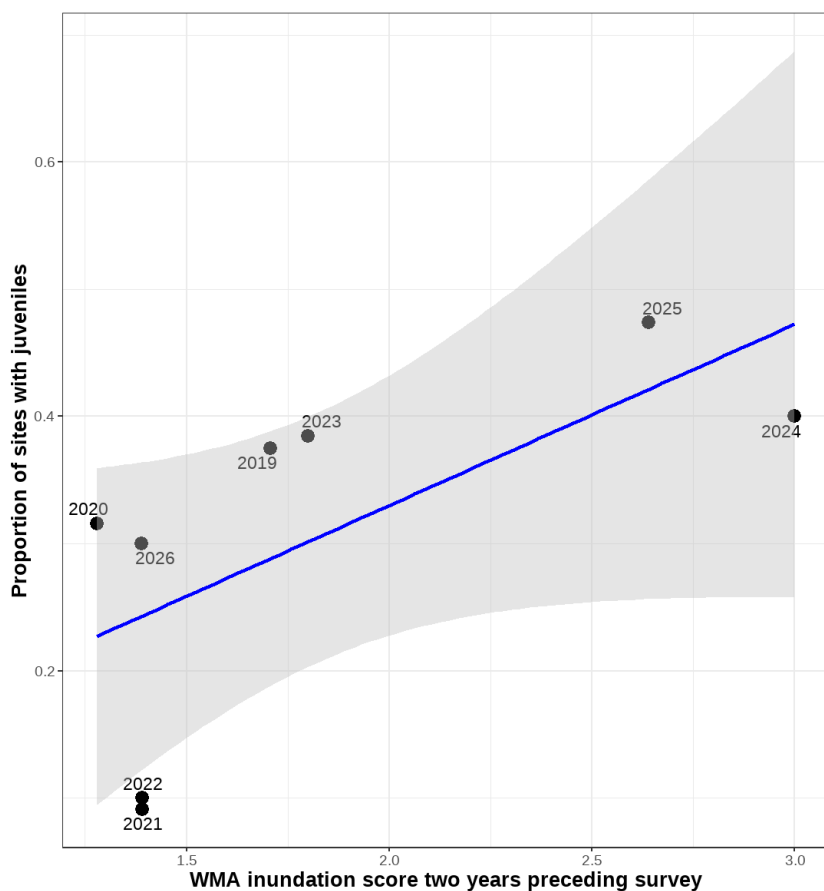


Figure 6. Metric 1. Relationship between the proportion of sites with detections of juvenile turtles and the water management area (WMA) inundation score two years prior to sampling.

Black points = annual observations labelled by survey year. Blue line = fitted linear regression. Grey shaded area = 95% confidence interval around the fitted relationship.

Metric 2. Proportion of species-specific occupied sites sampled with sub-adult turtles detected

Metric 2 was refined to represent the proportion of species-specific occupied sites with sub-adult turtle detections. This approach more directly reflects recruitment within the occupied distribution of each species and provides a more meaningful measure of sub-adult occurrence and recruitment. Exploratory models indicated that Metric 2 was influenced by species, hydrology class and antecedent inundation, but did not fully explain year-to-year variation across all species (Appendix 1).

The proportion of sites with Eastern Long-necked Turtle sub-adults declined from the lower end of 'good' (0.61) in 2025 to 'poor' (0.35) in 2026. The proportion of occupied sites with sub-adult turtles increased in 2026 for both the Broad-shelled Turtle and the Murray River Turtle. Declines in the proportion of sites with sub-adult Broad-shelled Turtles have been recorded annually since 2022. In contrast, an increasing proportion of sites with sub-adult Murray River Turtles has been recorded since 2023, with the highest proportions being recorded for this species in 2026.

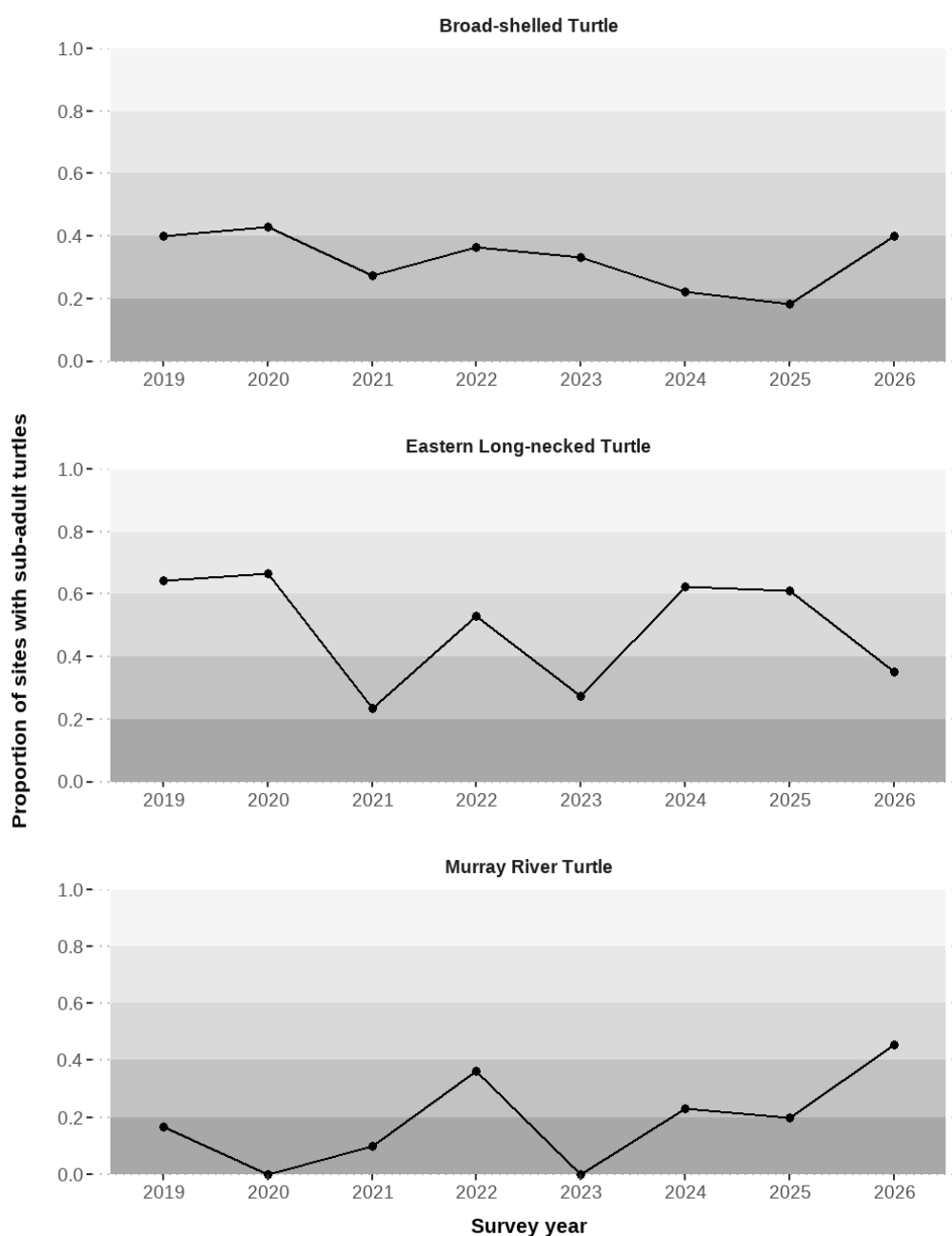


Figure 7. Metric 2: The proportion of species-specific occupied sites with sub-adult turtle detections (all individuals above three years since hatching to female size of sexual maturity).

Metric score range includes very poor, poor, average, good and very good, where very poor = dark grey and very good = light grey.

Metric 3. Mean body condition per species per year

Mean body condition (relative weight) was used to compare the current body condition of adult turtles to the long-term average condition, where values below 95 indicate 'poor' condition, 95–100 indicate 'average condition', and >100 indicate 'good condition'. All three species recorded 'average' condition scores in 2025–26. The body condition score for adult Eastern Long-necked Turtle declined for the third consecutive year – from 'above average' in 2022–23 and 2023–24, to the upper end of 'average' (at 99.4) in 2024–25, and 'average' in 2026 (at 98.1) (Figure 8). Although remaining at 'average', body condition scores increased from 95.4 in 2024–25 to 97.6 for the Broad-shelled Turtle, and from 97.9 in 2024–25 to 99 for the Murray River Turtle (Figure 8).

Annual mean relative weight remains positively associated with the whole-of-forest WMA inundation score ($\beta = 1.18 \pm 0.39$ SE, $p = 0.004$). This relationship was strongest with the same-year inundation score, decreasing with two- and three-year cumulative inundation scores. The responses to inundation differed among species (Species $\times$ WMA interaction, $p = 0.013$), with Eastern Long-necked Turtles showing the strongest response to increasing inundation scores, followed by Murray River Turtles. The Broad-shelled Turtle showed a weak positive response.

Observed condition scores were compared with model-predicted condition scores to assess whether body condition was higher or lower than expected given the habitats surveyed, hydrological classes represented, and the whole-of-forest WMA inundation score. This approach helps distinguish changes in body condition resulting from variation in survey coverage among years from patterns potentially associated with other ecological processes. Body condition scores observed in 2025–26 were slightly higher than model-predicted values for all three species (Table 5), although observed and predicted values were very similar for the Broad-shelled Turtle. The largest deviation between observed and predicted condition in 2025–26 was recorded for the Murray River Turtle.

Annual observed and predicted body condition scores for the Eastern Long-necked Turtle were similar through time, indicating that variation in body condition was largely consistent with differences in habitat composition, hydrology and inundation among years (Figure 9). Similar temporal patterns were observed for the Murray River Turtle, but with higher year-to-year variation. In contrast, the model-predicted condition scores for the Broad-shelled Turtle were frequently higher than observed values, suggesting that factors not included in the model may be influencing body condition in this species.

Table 5. The observed and expected (model-predicted) relative weights (Wr) for each species in 2025–26.

Species	Observed Wr	Expected Wr	Difference
Broad-shelled Turtle	97.6	97.3	0.3
Eastern Long-necked Turtle	98.1	97.4	0.7
Murray River Turtle	99.0	98.0	1.0

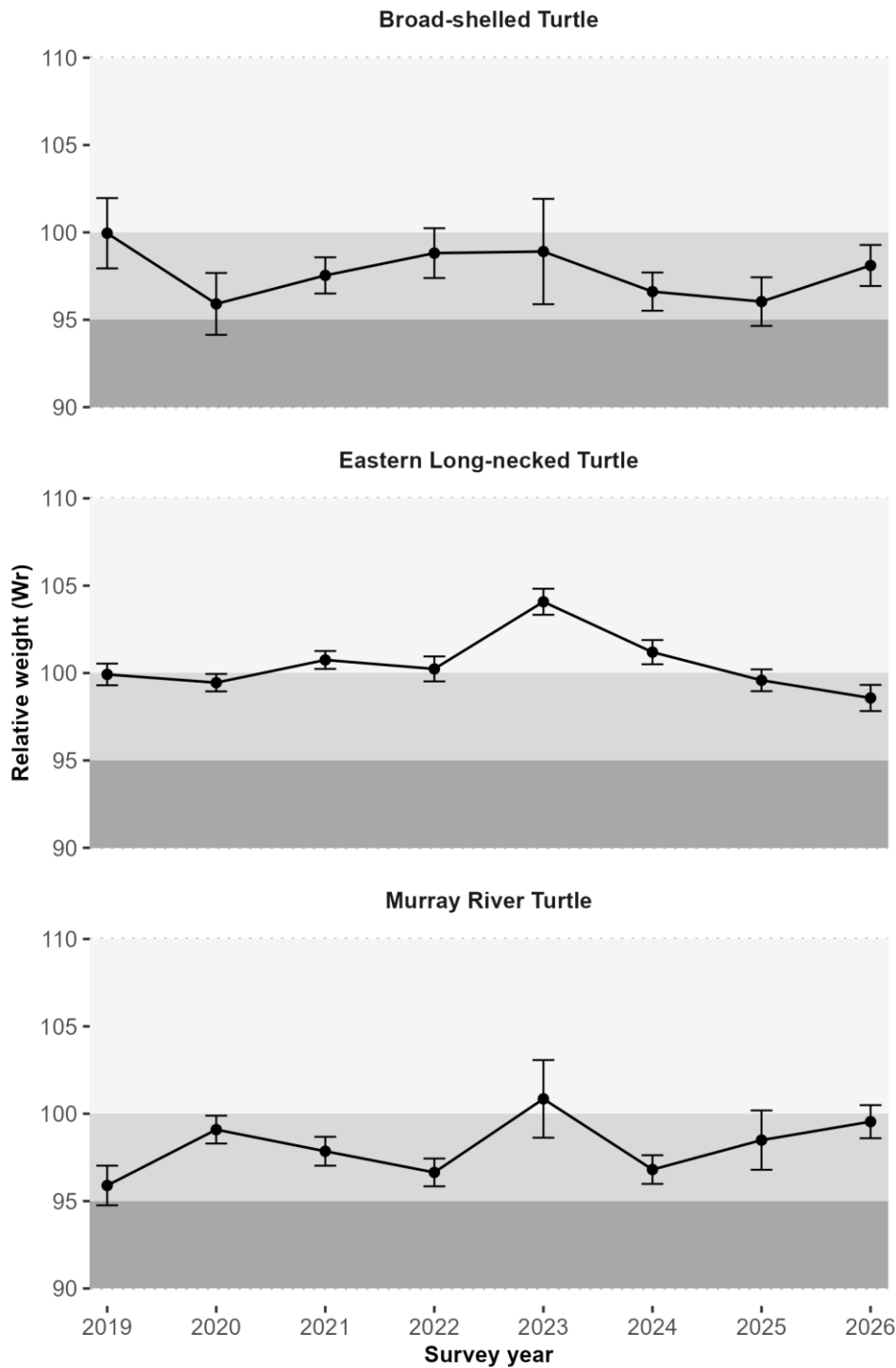


Figure 8. Metric 3: Average body condition (relative weight (Wr) $\pm$ SE) for Broad-shelled Turtle, Eastern Long-necked Turtle, and Murray River Turtle in Barmah–Millewa Forest.
 Dark grey = good condition, mid-grey = average condition, and light grey = poor condition.

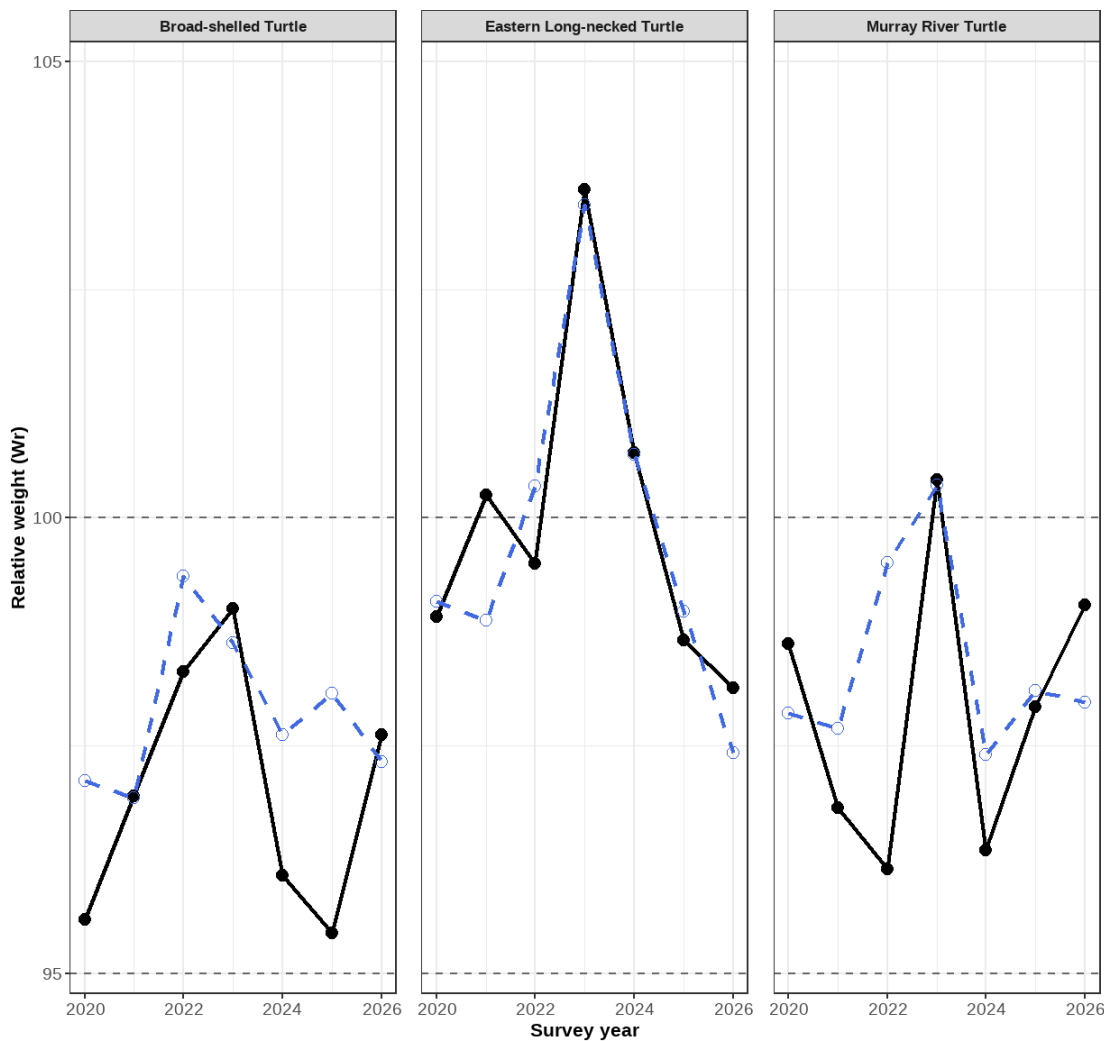


Figure 9. Metric 3: The observed and expected (model-predicted) body condition values (relative weight [Wr]) for each species over time

Black lines = observed relative weight. Blue dashed lines = model predicted weights accounting for water management area (WMA) inundation score and characteristics of sites surveyed annually (habitat type and hydrology class).

3.3 Frog monitoring

The 62 ARUs across the 30 sites recorded for an average of 130 nights each (4.3 months; range 1–156 nights), capturing the spring-summer breeding peak of September–January across all sites. An average of 54 hours of acoustic data were recorded per site, with 561 GB of data and 1,742 hours of audio recorded in total. All units were retrieved; two units failed and yielded no data – one at Big Bog and one at Doctors Point. A further three units recorded only 1–3 nights’ of data before failing: one each at sites the Rookery, Lowries Pump and Black Gate Lagoon.

3.3.1 Model performance

The CNN model produced 1,313,010 predictions of calls of frog species that occur, or potentially occur (e.g. Growling Grass Frog), in the monitored area. The model considered 68,487 files (66% of the total number of files recorded) to contain no frog calls and labelled these files with the class ‘not a frog’. We validated 4,889 (0.4%) of the model-predicted calls, including 1,945 instances of ‘not a frog’. Based on comparison of AUC scores in the ROC plots (Appendix 5), the model performed well at classifying calls of three species: Common Froglets (AUC = 0.88), Peron’s Tree Frogs (AUC = 0.86), and Pobblebonks (AUC = 0.81). Discrimination was moderate-to-good for Barking Marsh Frogs (AUC = 0.79) and Eastern Sign-bearing Froglets (AUC = 0.78), and weaker for recognition of Spotted Marsh Frog calls (AUC = 0.68).

Calls of the Eastern Sign-bearing Froglet were strongly represented in the model output – 32% of the ~1.3 million predicted calls were of this class. Remaining model-recognised calls, in descending order, were the frog chorus class (28%), Peron’s Tree Frogs (15%), Common Froglets (14%), Barking Marsh Frogs (3%), Spotted Marsh Frogs (2%), and Pobblebonks (1%). Less than 0.009% of predictions were of Growling Grass

Frog calls (18 predictions), Sloane's Froglet calls (68 predictions) and Common Spadefoot Toad calls (32 predictions), which were all validated and found to be false positives. That is, calls of those three species were not confirmed present in the 2025–26 season.

3.3.2 Frog condition indicators

Metric 1. Average site-level species richness

This year, 2025–26, estimated site-level species richness was amongst the lowest of the last eight years, with an average of 5.02 species per site (Figure 10). The WMA flood score for many sites was low, with no flooding or only some inundation, similar to the 2019–20 year, which also had low estimated site-level species richness (Figure 10). Occupancy of the six common frog species in B–MF has generally been high across years. This translates to generally high estimates of site-level species richness, with minimal variation. Lower estimates include 4.99 and 4.96 species per site in the 2019–20 and 2023–24 years, respectively (Figure 10). The highest estimate of 5.5 species per site was from the 2024–25 year (Figure 10).

In addition to the model-derived species richness estimates shown in Figure 10, we also report site-level species richness using only the validated dataset. Validation of the CNN model's results was completed by one experienced human listener (L. Durkin), generating a dataset of 4,889 × 1.5-second samples identified to species. True presence data for each species were collated, and minimum species richness per site was tabulated (Table 6).

The most frequent calls in the validated dataset were from Common Froglets (confirmed present at 90% of monitored sites), followed closely by Eastern Sign-bearing Froglets (confirmed at 87% of sites). Peron's Tree Frog and Spotted Marsh Frog calls were confirmed at 63% of sites. Barking Marsh Frog calls were confirmed at 37% of sites, and Pobblebunks at 27% of sites (Table 6).

The maximum number of species recorded per site was six species. All six of the regularly recorded frog species were confirmed at three sites in Barmah (Barmah Creek BI, Boals Deadwoods, and Hut Lake), and at four sites in Millewa (Black Gate Lagoon, Burial Lagoon, Reed Beds Swamp and Walthours Lagoon). This year, the validation resulted in two sites with zero confirmed frog calls: Duck Lagoon in Millewa, and the Rookery in Barmah. The average species richness per site shown in Table 6 (3.7 species) is lower than the average species richness per site depicted in Figure 10 (5.02 species), because the latter estimates were derived from the occupancy model which uses millions of AI-recognised calls across all years, and accounts for imperfect detection using the error rates revealed by the validation process. In contrast, the data shown in Table 6 represent only the 4,889 samples that were manually validated for the 2025–26 year.

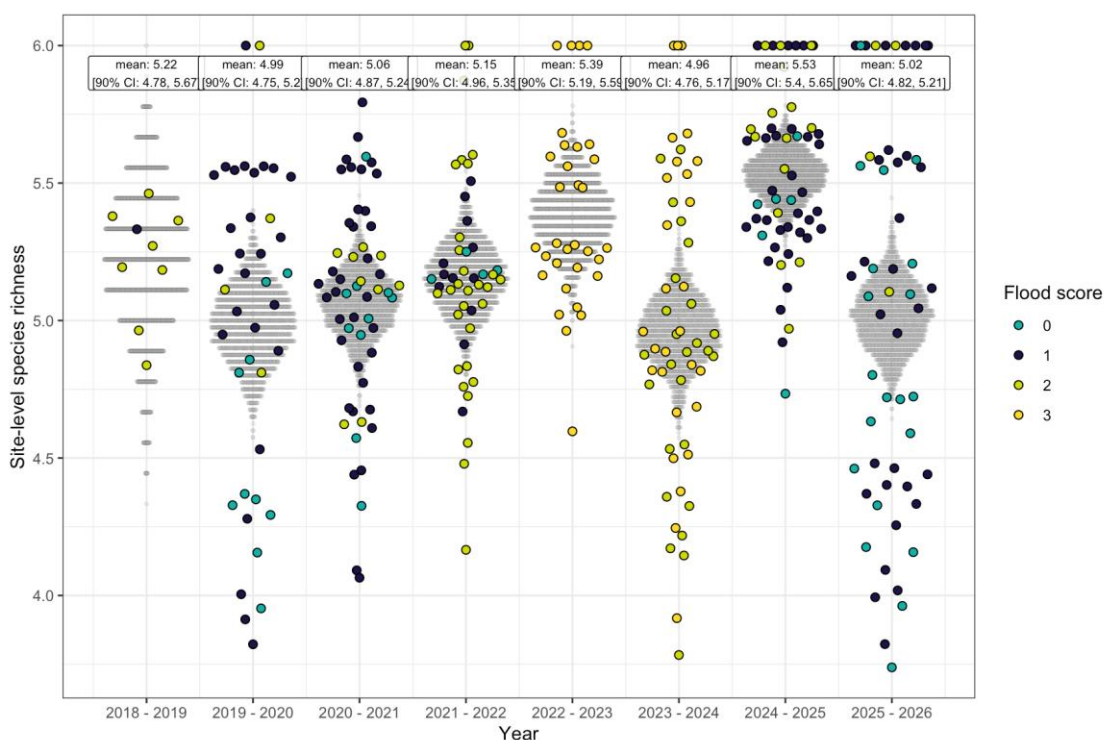


Figure 10. Estimated site-level species richness across sites and years.

Monitored sites are shown by dots, coloured according to how flooded the site's water management area (WMA) was that year. Flood scores: 0, no flooding in the WMA; 1, some flooding; 2, lots of flooding; 3, complete flooding. Grey background bars represent the distribution of posterior samples for the average species richness across all sites from year to year.

Table 6. Site-level species richness, confirmed by validation.

These data represent minimum species richness per site and are the result of listening to a small proportion (0.1%) of model-identified samples of the full acoustic dataset. Dots indicate confirmed presence. Columns are ordered left-to-right in decreasing order of species prevalence. CF: Common Froglet; ESBF: Eastern Sign-bearing Froglet; PTF: Peron's Tree Frog; SMF: Spotted Marsh Frog; BMF: Barking Marsh Frog; PB: Pobblebonk.

	Site	CF	ESBF	PTF	SMF	BMF	PB	No. species
Barmah	Barmah Creek BI	•	•	•	•	•	•	6
	Big Bog		•					1
	Boals Deadwoods	•	•	•	•	•	•	6
	Bucks Crossing	•	•	•	•			4
	Bunyip Gully Gowers	•						1
	Bunyip Waterhole	•	•					2
	Doctors Point	•	•	•	•			4
	Duck Hole Plain	•	•	•	•	•		5
	Gooseneck	•	•	•	•	•		5
	Hughes Crossing	•						1
	Hut Lake	•	•	•	•	•	•	6
	Little Rushy Swamp	•	•		•			3
	Mannions	•	•	•	•		•	5
	Rookery							0
	Steamer Plain	•	•	•	•	•		5
	Two Mile Bunyip	•	•					2
	Two Mile Sandridge	•	•					2
	Whores Creek	•	•	•	•			4
Millewa	Black Gate Lagoon	•	•	•	•	•	•	6
	Burial Lagoon	•	•	•	•	•	•	6
	Duck Lagoon							0
	Horseshoe Lagoon	•	•	•				3
	Lowries Pump	•	•	•	•			4
	Pinchgut Lagoon	•	•		•			3
	Quambies	•	•		•			3
	Reed Beds Swamp	•	•	•	•	•	•	6
	Toupna Creek	•	•	•	•	•		5
	Towrong Creek	•	•	•				3
	Walthours Lagoon	•	•	•	•	•	•	6
	Warri Yards	•	•	•				3
	No. sites detected at:	27	26	19	19	11	8	
	% of monitored sites detected at:	90%	87%	63%	63%	37%	27%	
	Average:							3.7

Metric 2. Calling activity per species

In the 2025–26 season, calling activity across the six detected frog species was reduced relative to the prior year. For three species – the Barking Marsh Frog, Pobblebonk and Common Froglet – the reduction was minimal, with calling activity similar to that in the year prior. For the other three species – the Eastern Sign-Bearing Froglet, Peron's Tree Frog, and Spotted Marsh Frog – calling activity was more substantially reduced relative to that in the prior year. Calling activity of Peron's Tree Frog has fluctuated year-to-year and showed a substantial reduction this year, with rates well below the eight-year median (Figure 11). The Pobblebonk continues to have the lowest calling activity across years, followed by the Barking Marsh Frog (Figure 11).

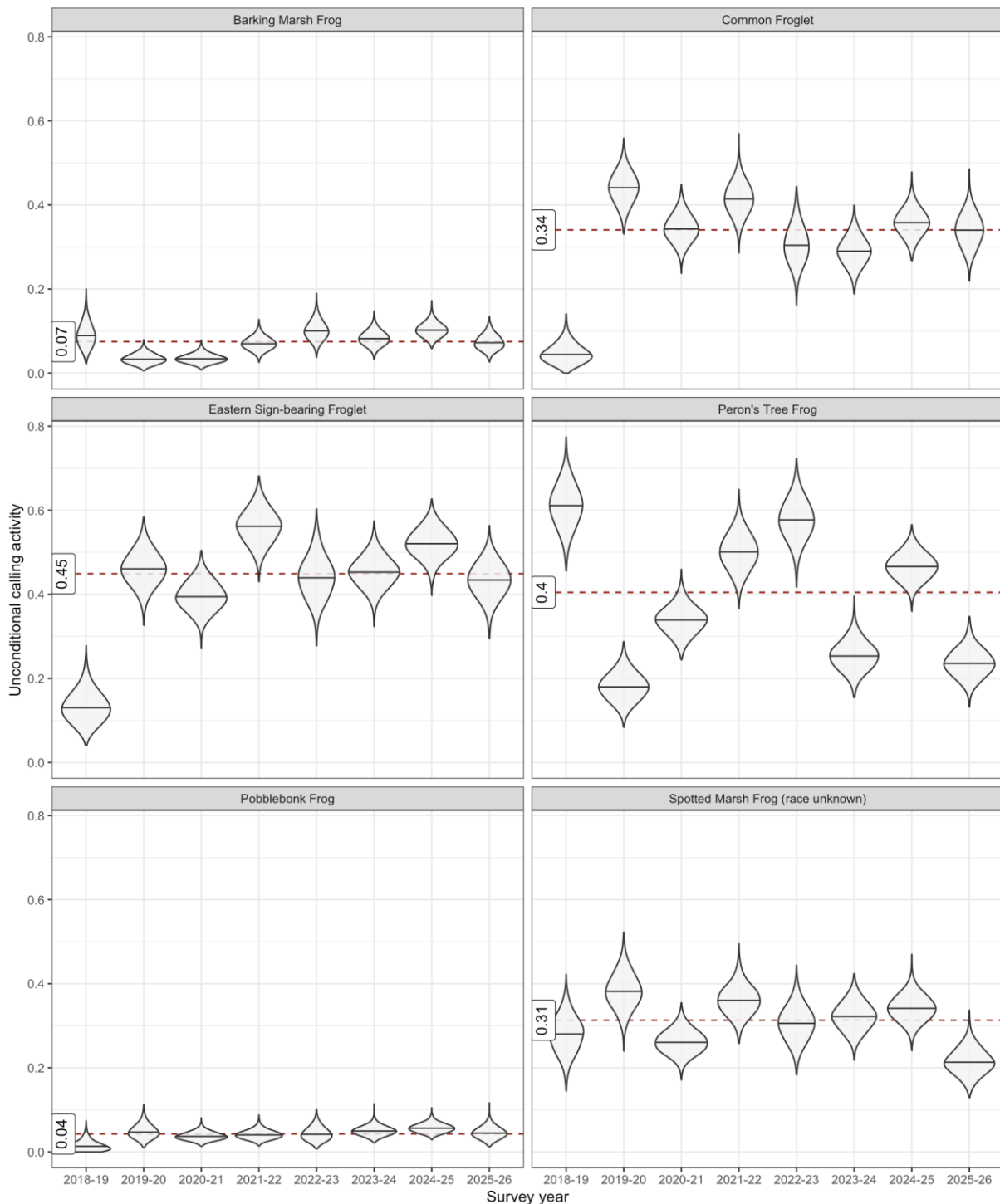


Figure 11. Estimated calling activity across all sites, per year for each species.

Unconditional calling activity considers occupancy estimates and therefore reflects the average probability a given species (1) will call on a night during that season, (2) is recorded, and (3) is recognised by the acoustic classifier. Model posterior predictions are shown by the distribution of the violin plot, with median call rates indicated by horizontal lines. Dashed red-lines indicate the eight-year median.

3.3.3 Calling phenology

The calling phenology of all species across all sites, as predicted by the CNN model, is shown in Figure 12 and Figure 13. In Barmah, calling peaks were evident in both October and November, and varied between sites. Peak calling occurred in October at Barmah Creek BI, Boals Deadwoods, Hut Lake and Mannions, and in November at Bucks Crossing and Whores Creek. At 10 of the 20 monitored sites in Barmah, however, very low frog calling activity was evident this season, including at the two sites monitored opportunistically this year (Gulf Tk east and Hughes Track; Figure 12).

At the 12 monitored sites in Millewa, calling activity tended to peak in September or October, except for at Lowries Pump where calling peaked in November (Figure 13). Two Millewa sites had very little or no frog calls (Duck Lagoon and Horseshoe Lagoon), but the majority of Millewa sites had frog calling activity at generally higher levels than recorded on the Barmah side of the icon site.



Figure 12. The calling phenology of all species and a ‘frog chorus’ class, across all Barmah sites in 2025–26, predicted by the Convolutional Neural Network (CNN) model.



Figure 13. The calling phenology of all species and a 'frog chorus' class, across all Millewa sites in 2025–26, predicted by the Convolutional Neural Network (CNN) model.

4 Discussion

Turtle condition monitoring

The proportion of sites with juvenile turtle detections in 2025–26 declined from that in 2024–25. However, the 2024–25 year was a relatively high benchmark, given it was the highest score recorded for this metric across the entire monitoring program. The dry conditions in Millewa coupled with regulator works meant that key creek lines and wetlands, such as Toupna Creek and Pinchgut Lagoon, were dry. Previous modelling has shown that consecutive years of flooding will increase the proportion of sites with juvenile turtles (Gwinn et al. 2023). Our findings support the original metric evaluations, with antecedent flood conditions positively influencing recruitment, indicating that recruitment of turtles into juvenile age-classes responds positively to inundation over a period of approximately two to three years. As such, the declines observed this season are not unexpected, given the low WMA inundation scores recorded.

Variation in juvenile recruitment scores can likely be attributed to imperfect detection, environmental and management variables currently not accounted for in our model, and variable growth rates which may influence our age/time since hatching estimates. Another potential influential factor are the fox baiting programs, which have been implemented in Barmah NP to minimise predation of nesting turtles and eggs (Howard and Durkin 2025). Previously, limited monitoring data has meant that evaluating the impact of fox baiting activities on recruitment has been challenging (Gwinn et al. 2023). Baiting programs in Barmah encompass two key wetlands; Black Engine Lagoon and Bunyip Hole. At Black Engine Lagoon, a hatchling Murray River Turtle was captured in 2024–25, and a hatchling Broad-shelled Turtle was captured in 2025–26. WMA inundation scores were low in both of these years: 1.39 and 0.45, respectively. Therefore, the detection of hatchling turtles in both years is a promising indication that predator management activities may be contributing to increased nest survivorship at this site. However, if successive years of high WMA inundation scores are required to sustain recruitment, it may be difficult to disentangle the effects that land and water management have on long-term recruitment success. The baiting program is scheduled to continue until 2027–28. Upon completion, it is recommended that data collected through both the predator management and TLM condition monitoring programs are incorporated into the state-space modelling framework developed by Gwinn et al. (2023). This will allow for an assessment of whether sufficient data has accumulated to detect recruitment responses associated with predator management activities and improve our understanding of the interactions between land and water management on turtle recruitment.

This year, the metric used to monitor sub-adult turtle recruitment was refined to assess species-specific site occupancy instead of an 'any-species combined' occupancy measure. The denominator modification did not materially alter the environmental relationships detected by the model. Habitat type, hydrology class and antecedent inundation remained the primary predictors of sub-adult occurrence under both formulations. The species-specific denominator was adopted because it provides a more biologically relevant measure of recruitment within the occupied distribution of each species. A recent study found that naturally low proportions of juvenile and sub-adult turtles may lead to populations being listed as declining (McKnight et al. 2025). Detections of sub-adult turtles have typically been low for the Murray River Turtle and Broad-shelled Turtle in B–MF. Previous measures of recruitment that used historical sub-adult population proportions as an indication of 'good' recruitment, provide a less direct measure of recruitment than the proportion of sites with sub-adult detections. Refining our sub-adult recruitment metric ensures that the spatial extent of sub-adult recruitment is described within the occupied distribution of each species.

Consistent with findings by Gwinn et al. (2023), sub-adult recruitment was positively associated with antecedent WMA inundation scores, particularly three years prior to sampling. However, relationships were weaker than those observed for juvenile recruitment, and annual variation was not fully explained by hydrology, habitat type and inundation alone. Additional factors such as imperfect detection, annual variation in recruitment success, growth rates and predator management activities are also likely to contribute to patterns in sub-adult occurrence.

Measures of sub-adult recruitment are closely linked to juvenile recruitment, with the relationship between recruitment and lagged WMA inundation becoming stronger as turtles transition from the juvenile to sub-adult age classes (Gwinn et al. 2023). Both juvenile and sub-adult classifications are based on the species-specific growth curves developed for B–MF during the 2024 metric evaluations (Gwinn et al. 2023). These classifications represent the best available estimates but are subject to uncertainty, particularly for juvenile turtles where growth rates are more variable and recapture data are limited. As additional recapture data accumulate with ongoing monitoring, it is recommended that the growth models are updated and the age-size classifications refined to improve confidence in the metrics used to monitor juvenile and sub-adult recruitment.

Relative weight, as a measure of turtle condition, continues to be an effective metric to monitor changes in the immediate health of turtle populations. The weighted whole-of-forest WMA inundation score remains positively associated with body condition, reproducing similar species-specific responses observed by Gwinn et al. (2023). Increased floodplain inundation is associated with increased body condition for the Eastern Long-necked Turtle, which is highly responsive to changes in WMA inundation. Higher-than-expected body condition scores were observed for the Murray River Turtle in 2025–26. The regressions used to generate the predicted relative weight scores include data collected in 2009 and 2010, immediately following the prolonged Millennium Drought. Although very little inundation occurred in the lead up to the 2025–26 survey season, the drier conditions were largely restricted to Millewa, with e-water released onto the Barmah floodplain. Excluding survey sites along the Murray River itself, most of the Murray River Turtles captured in Millewa were occupying permanent habitats and over half were captured at Duggans Lagoon. The species was therefore less likely to be affected by the dry conditions. The modelled condition predictions help determine if changes in condition are deviating from what is expected. When accounting for the dry conditions and species-specific responses to inundation, all three species had condition scores comparable to the predicted condition values.

Frog condition monitoring

In 2025–26, acoustic monitoring revealed reduced frog calling activity across the icon site, compared to seven prior years with comparable data. Millewa received no environmental water, and the e-water allocation delivered to Barmah inundated only some areas, affecting ~25% of the floodplain, and only from mid-October. In 2021, 2022 and 2023, inundation began earlier, in either July or August. The timing of inundation has a strong influence on recruitment capacity (Wassens 2010), and e-water delivery this year may have been later than optimal for several of the resident frog species. Re-running the occupancy model with all eight years of acoustic data now available, alongside flood levels received in each WMA, re-iterated the link between site inundation and the number of species likely to occur and call at that site each year. Both Duck Lagoon and the Rookery had zero confirmed frog calls and neither site received e-water during the 2025–26 survey period. It is likely that the limited flooding of most monitoring sites this season resulted in lower calling and breeding activity in frogs across the icon site.

Species richness was reported using both the model-derived predictions and the naïve occupancy (the proportion of sites with at least one detection of a species resulting for direct call validation). As in most prior monitoring years, species richness ranged from 0–6 species per site. The occupancy modelling analyses yielded slightly lower estimates of site-level species richness (5.02 species per site, on average) than in most other monitored years. The naïve species richness derived from the validated call data was also low (an average of 3.7 species). This was the lowest score recorded since the dry 2019–20 year, which had an average of just 3.6 species called per site (Howard et al. 2020). During the five years between the 2019–20 year and the most recent season in 2025–26, the average number of species per site confirmed during validation was between 4.1 and 4.8 (Howard et al. 2021; Durkin et al. 2022; Howard et al. 2023; Durkin et al. 2024; Howard et al. 2025b). Consequently, estimates from both a) having a human listen to a subset of the acoustic data, as well as b) the CNN acoustic classifier model and associated occupancy model, pointed to lower levels of frog calling across the icon site this season.

Frog calling activity was generally higher on the Millewa side of the icon site, despite Millewa receiving no e-water allocations this year. This pattern was evident both in the CNN model's unvalidated output, as seen in the calling phenology plots, as well as in the validated dataset, where the average number of species per site was higher in Millewa (4 species) than in Barmah (3.4 species this year). While at first this result may seem surprising, it may be an artefact of the water permanence of the TLM frog monitoring sites, in Millewa versus Barmah. Of the 20 sites monitored in Barmah this year, 15 of them (75%) are characterised as ephemeral waterbodies. Of the 12 sites monitored in Millewa, six are ephemeral, and six (50%) are permanent or semi-permanent wetlands. Permanent wetlands may provide important refuge habitat for frogs during dry periods, allowing populations to persist when ephemeral wetlands have dried. Amphibian persistence through drought has been shown to be higher in permanent waterbodies than temporary wetlands (Moss et al. 2021), and studies of Murray floodplain wetlands have shown that frog species richness and occupancy patterns vary with wetland hydroperiod, with longer-duration wetlands supporting a greater diversity of frogs (Wassens et al. 2011). The greater proportion of permanent and semi-permanent wetlands among the Millewa monitoring sites may have contributed to the higher frog calling activity and species richness observed there this year, despite the absence of environmental water deliveries.

No rare or threatened species' calls were detected during the 2025–26 season. Detections of species such as the Common Spadefoot Toad and Sloane's Froglet have been very rare over the past eight years of seasonal acoustic monitoring. These species either occur at very low densities, or have limited spatial distributions within the icon site, and/or may occur beyond the boundaries of the icon site and only

occasionally disperse onto the floodplain and call within range of the TLM monitoring autonomous recording units.

4.1 Conclusion

The 2025–26 season marks the eighth year of TLM turtle and frog condition monitoring in B–MF. Consistent annual data collection for both turtles and frogs continues to build rich long-term datasets, allowing more robust analyses to track trends over time.

For turtles, the ecological objectives for the Barmah–Millewa icon site were partially met, with metric scores ranging from ‘poor’ to ‘average’. Body condition scores remain stable and comparable to the model-predicted scores given the sites surveyed and the hydrological conditions this season. The decline in juvenile recruitment is likely due to limited floodplain inundation. The sub-adult recruitment metric has been refined and now describes recruitment within the occupied distribution of each species. Improved understanding of the relative contributions of land and water management activities would provide valuable context for interpreting the annual recruitment metrics. The long-term predator management program in Barmah NP provides an important opportunity to re-assess these relationships. It is recommended that the state-space modelling framework be revisited upon completion of the predator management program, to determine whether sufficient data have been accumulated to evaluate the combined influence of predator management and inundation practices on turtle recruitment.

For frogs, the 2025–26 monitoring season was characterised by relatively low levels of frog calling activity and species richness compared to recent years, likely reflecting the limited extent and timing of inundation across the B–MF floodplain. Despite these conditions, all six frog species regularly recorded at the B–MF icon site were detected during the season, although calling activity and occupancy were generally lower than in previous years. These findings indicate that B–MF continues to support the same assemblage of frogs as in prior years, albeit with reduced calling during this comparatively dry year. Continued environmental watering, together with the retention of permanent and semi-permanent wetland refugia, are likely to remain important for sustaining frog populations and achieving the long-term TLM objectives of maintaining water-dependent species and providing refuge habitat, while creating the conditions necessary for successful breeding and recruitment in wetter years.

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Appendix 1 Turtle condition metrics - review and refinement

Metric reporting was refined in 2024 following the advice of Gwinn et al. (2023). Annual reporting has since focused on metrics describing recruitment and body condition, with relative abundance metrics appraised every three to five years. As part of the 2025–26 annual reporting process, the three turtle monitoring metrics were reviewed to assess their effectiveness in detecting changes in population condition and identify potential refinements. Relationships between metric values, inundation and site characteristics were examined, and model predictions were used to provide environmental context for interpreting annual variation in metric scores.

Annual condition metrics

Recruitment

Metric 1. Proportion of occupied sites with juvenile turtle detections

This metric ranges from a low of 0 to a high of 1 and provides a broad description of juvenile recruitment at the icon site level. Due to the difficulty in detecting hatchling turtles, we define ‘juveniles’ as all individuals up to three years of age (up to 61 mm plastron length (PL) for Broad-shelled Turtles, up to 114 mm PL for Murray River Turtles (Spencer 2002), and up to 90 mm SCL for Eastern Long-necked Turtles (Chessman 2018)). Only one detection of a juvenile-sized individual is required for a site to be considered as supporting successful recruitment.

Linear models were used to assess relationships between juvenile recruitment and whole-of-forest WMA inundation scores, including one-, two- and three-year lag periods. Juvenile recruitment was positively associated with antecedent inundation, with the strongest univariate relationship observed for the two-year lag WMA score ($R^2 = 0.49$, $\beta = 0.14$). A similarly strong positive relationship was observed for the three-year lag WMA score ($R^2 = 0.47$, $\beta = 0.12$), indicating that juvenile recruitment responds to floodplain inundation over multiple years rather than a single discrete antecedent year.

Metric 2. Proportion of occupied sites with sub-adult turtle detections (species-specific)

This metric ranges from a low of 0 to a high of 1 and provides a broad description of recruitment into sub-adult age-classes, per-species, at the icon site level. Sub-adult turtles include Broad-shelled Turtles greater than 6.1 cm PL and smaller than 22 cm SCL, Eastern Long-necked Turtles greater than 9 cm SCL and smaller than 17 cm SCL, and Murray River Turtles greater than 11.4 cm PL and smaller than 18 cm SCL for Murray River Turtles.

In prior monitoring years, Metric 2 has been calculated by considering all sites with turtle detections in that year, of any species, to be ‘occupied sites’. We sought to refine this metric, as the three turtle species do not occur equally across all habitats. An alternative formulation of Metric 2 was considered, with a more species-focussed view, whereby the number of sites with sub-adult detections of species A, is divided by the number of sites with any detection of species A, in that year. Generalised linear models incorporating species, lagged whole-of-forest WMA inundation scores, habitat type and site hydrology classes produced similar ecological conclusions with the existing approach, and the revised approach (Table A1). In both cases, sub-adult occurrence was positively associated with wetland habitats and permanent or semi-permanent hydrological conditions, while the relationship with antecedent inundation was comparatively weak and sensitive to model structure (Table A1).

Table A1. Generalised linear model results assessing the probability of sub-adult turtle occurrence using the existing and revised approach for calculating metric 2.

Existing approach: 'occupied sites' (the denominator) = all sites with turtle detections in that year, of any species.

Revised approach: 'occupied sites' (the denominator) = the number of sites with any detection of that species, that year.

Model variables	Existing approach		Revised approach	
	Estimate	p	Estimate	p
Murray River Turtle * Broad-shelled Turtle	-0.44	0.124	-0.67	0.028
WMA inundation score 2 years prior	0.13	0.288	0.14	0.306
Wetland habitat	1.07	<0.001	0.75	0.027
Permanent hydrology	0.94	0.002	0.65	0.045
Semi-permanent hydrology	1.33	<0.001	1.88	<0.001

The predicted values provide context for interpreting annual Metric 2 reporting, but do not fully explain year-to-year variation in sub-adult occupancy across all species (Figure A1) and therefore do not provide a single definitive statistical basis for selecting a denominator. Previous calculations using all turtle-occupied sites as the denominator were influenced both by each species' habitat preferences and sub-adult occurrence. The species-specific formulation (i.e. the revised approach) was therefore adopted because it provides the clearest biological interpretation of sub-adult recruitment. The revised approach better aligns the metric with its intended purpose: to describe the prevalence of sub-adult recruitment, across sites where the species in question occurs. The predicted values generated by the generalised linear model (Figure A1) are intended to provide context for interpreting annual metric results, rather than to fully explain year-to-year variation in sub-adult recruitment.

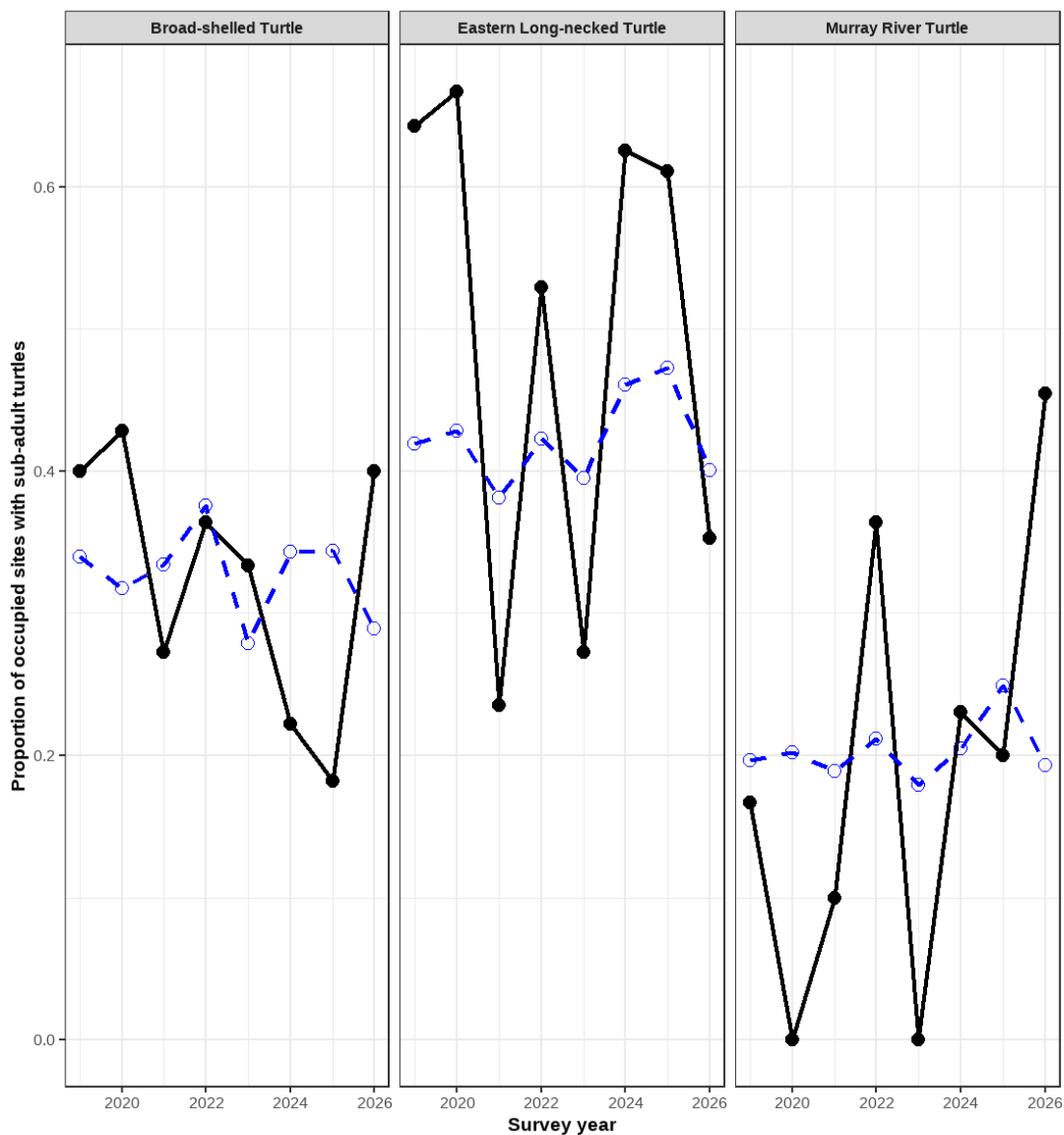


Figure A1. Observed and model-predicted Metric 2 values for each turtle species.

Observed values represent the proportion of species-specific occupied sites where sub-adult turtles were detected. Predicted values were generated from a binomial generalised linear model including species, habitat type, hydrology class and whole-of-forest water management area (WMA) inundation score two years prior to sampling.

Metrics 1 and 2 are presented as proportions and are reported as very poor up to very good (Figure A2).

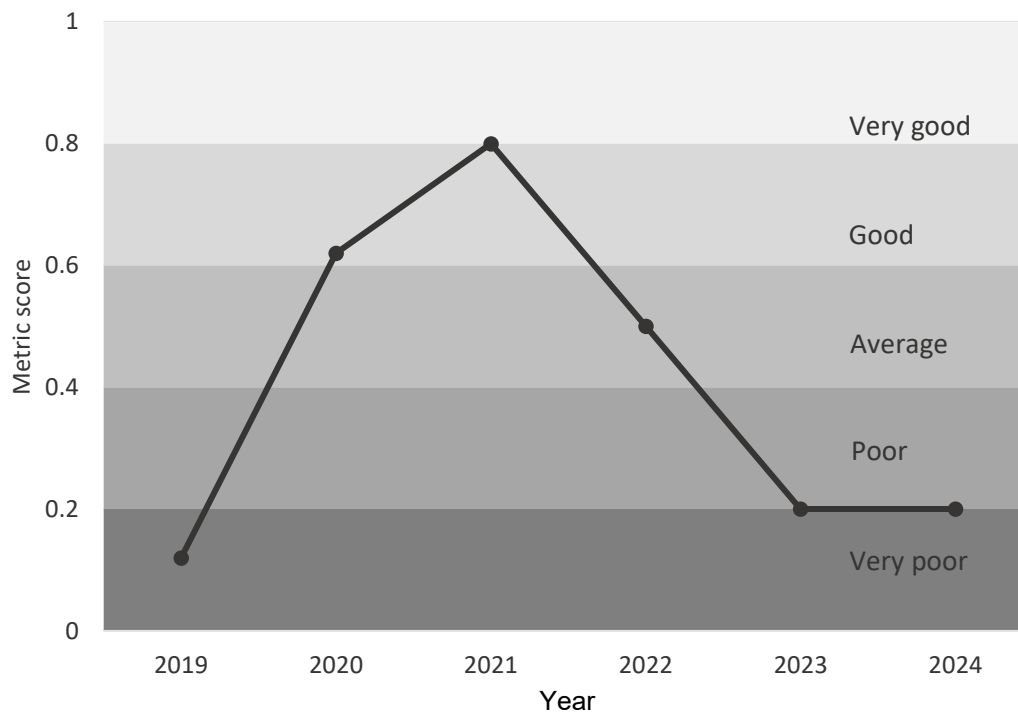


Figure A2. A hypothetical example of the Barmah–Millewa Forest metric reporting format showing a fluctuating condition score.

Body condition metric

Metric 3. Mean body condition per species per year

This metric describes changes in the average adult body condition per species and allows us to track population health and the influence that flow regimes have on body condition. Body condition is represented by the relative weight of an individual to a standard weight predicted by a species-specific length-weight relationship. Body condition analysis was measured in the current study using relative weight (Wr); an index with the formula $Wr = (W/W_s) \times 100$, where W_s is a length-specific standard weight predicted from a species-specific length-weight relationship (Pope and Kruse 2007).

Adult relative weight (Wr) was reviewed to assess whether annual body condition scores could be interpreted in relation to habitat composition, hydrology class and recent inundation conditions. Linear models incorporating species, habitat type, hydrology class and whole-of-forest WMA inundation scores the year immediately preceding surveys were assessed. The strongest model included a species and inundation score interaction, indicating that the relationship between body condition and inundation differed among species (Species $\times$ WMA score; $F = 4.37$, $p = 0.013$). The strongest relationship was observed for the Eastern Long-necked Turtle when compared to the Broad-shelled Turtle ($\beta = 1.13$, $p = 0.038$), indicating that body condition of Eastern Long-necked Turtles is more responsive and increases more rapidly with inundation. Broad-shelled Turtle and Murray River Turtle condition showed comparatively weaker responses to inundation (Figure A3).

Model outputs were used to generate expected species-specific relative weights for the habitat and hydrological conditions represented in each survey year. Metric 3 continues to be reported as the observed mean relative weight for each species; however, model-predicted values provide important context by accounting for differences in habitat composition and hydrological conditions among survey years, assisting in the interpretation of annual changes in body condition.

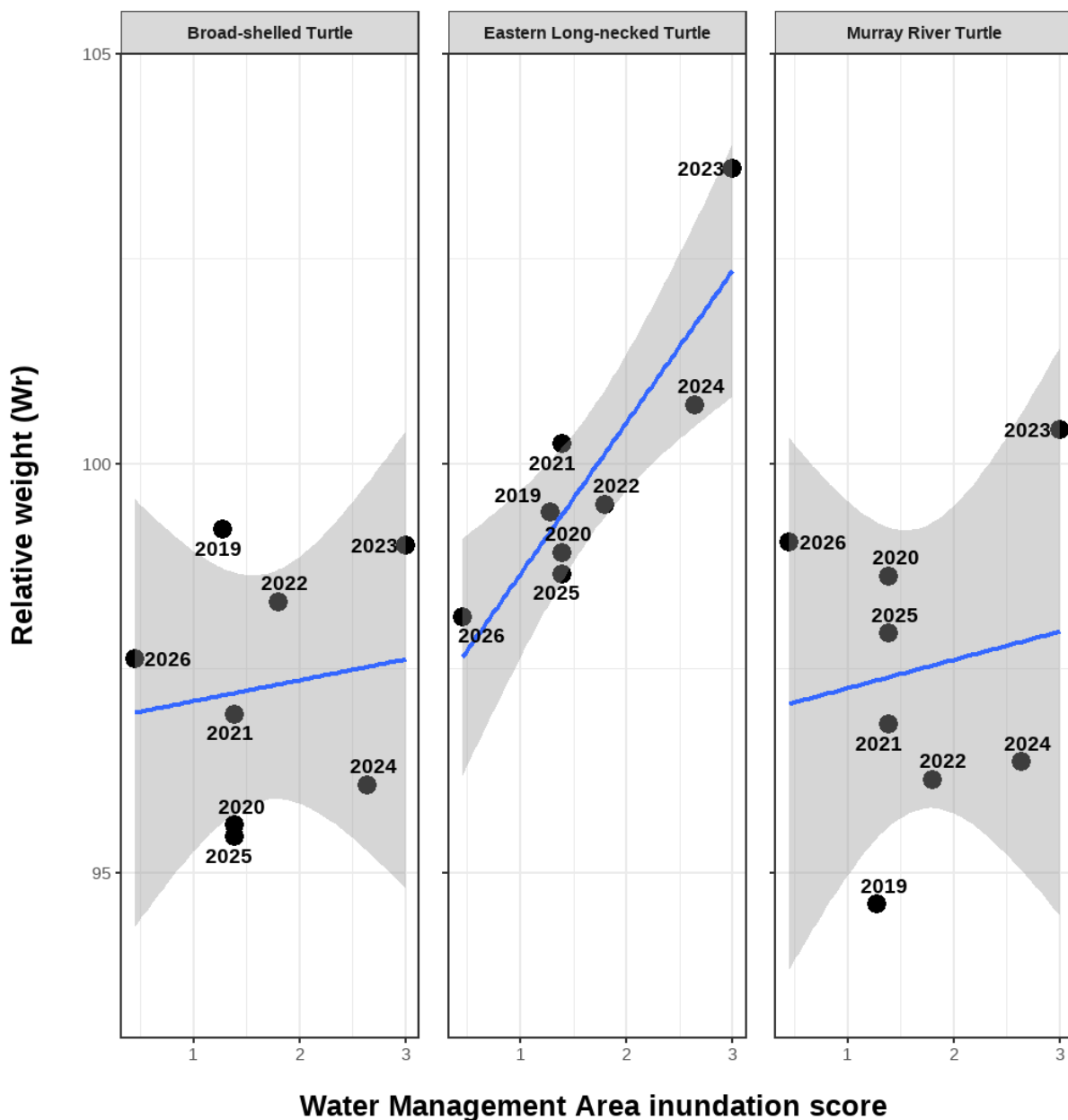


Figure A3. Average adult relative weight per species with respect to water management area (WMA) inundation scores.

Metrics appraised every three to five years

Relative abundance metrics

It is recommended that relative abundance estimates are appraised every three to five years, or following mortality events, because changes to population-level abundance are generally slow to manifest in long-lived species. These metrics include:

Metric 4. Mean catch-per-unit-effort (CPUE) per site

Metric 5. Mean CPUE per site per species

Metric 6. Mean CPUE per species per habitat type and water permanence

Appendix 2 Frog condition metrics

Following analysis of the six-year frog dataset (Durkin et al. 2024), recommendations were made to refine the monitoring metrics used to report frog condition at this icon site. The four-condition metrics previously used to report on frog population condition are now replaced with two metrics that account for imperfect detection and provide model estimates for species richness.

Species richness

Metric 1. Average site-level species richness

This metric provides model estimates of species richness per site for each year. The average species richness across all sites is used as the primary figure to track year-to-year. In addition, the naïve occupancy (the proportion of sites with at least one detection of a species) resulting from the validation exercise (manual listening to a subset of the acoustic dataset) is included to enable direct comparison with previous annual reports.

Metric 2. Calling activity per species

Metric 2 replaces two previous metrics used to describe calling activity and reports on calling activity, per species per year. An 'unconditional' calling activity metric (i.e. calling activity given the site is occupied that year), has been derived and reflects the average probability a given species (1) will call on a night during that season, (2) is recorded, and (3) is recognised by the acoustic classifier. The revised calling activity metric utilises occupancy modelling outputs and therefore also accounts for imperfect detection.

Appendix 3 Frequency of turtle surveys

Table A2. The frequency of surveys at TLM turtle condition monitoring sites from 2018–19 to 2024–25.

F = Forest where B = Barmah and M = Millewa; H = hydrological permanence where P = permanent, S = semi-permanent and E = ephemeral; NHT = Natural Heritage Trust; Crk = Creek.

F	Type	Site	H	2019	2020	2021	2022	2023	2024	2025	2026
B	Creek	Snag Creek	P		•	•			•	•	
B	Creek	Tongalong Creek	P	•	•	•		•	•		•
B	Creek	Gulf Creek	S	•	•	•			•	•	
M	Creek	Toupna East	S	•	•		•	•		•	DRY
B	Retaining Crk	Kynmer Creek	E	•	•		•	•	•		•
B	Retaining Crk	Tullah Creek	S	•	•	•	•	•			•
M	Retaining Crk	Duggans Lagoon	P								•
B	Retaining Crk	Paddy Farrell	P			•	•			•	•
M	River	Yielima	P	•	•	•		•	•		•
M	River	Fisherman Bend	P						•	•	•
M	River	U/S Picnic Point	P						•	•	•
B	Lake	Barmah Lake	P			•	•	•		•	•
B	Lake	Hut Lake									•
M	Lake	Moiria Lake	P			•				•	•
B	FP Wetland	Doctors Point	E	•	•					•	
M	FP Wetland	Duck Lagoon	E		•	•		•	•		DRY
B	Wetland	Bunyip Waterhole	E	•	DRY	DRY	•	•	•		
M	Wetland	Black Gate Lagoon	E	•	•		•	•		•	
M	Wetland	Horseshoe Lagoon	S						•	•	DRY
M	Wetland	Nine Panel Small	S				•	•		•	•
M	Wetland	Nine Panel Large	P	•	•		•	•			•
M	Wetland	Barbers Garden	P								•
M	Wetland	Fisherman Bend	P	•	•	•	•		•	•	•
M	Wetland	Pinchgut Lagoon	P			•	•		•	•	DRY

F	Type	Site	H	2019	2020	2021	2022	2023	2024	2025	2026
B	Wetland	Punt Paddock Small	P		•	•	•				•
B	Wetland	Red Tank Lagoon	P			•	•		•	•	
M	Backwater	Little Edwards	P	•	•		•	•		•	•
M	Backwater	Edwards River	P						•		FLOW
Barmah Country NHT sites											
B	Wetland	Black Engine Lagoon	E	DRY	DRY	DRY	•	•	•	•	•
B	Wetland	Bunyip Hole	E	DRY	DRY	DRY	•	•	•	•	DRY
B	Wetland	Punt Paddock Big	P	•	•	•	•	•	•	•	•
B	Wetland	Woodcutters Lagoon	P		•	•	•	•	•	•	•
Reserve sites											
M	Creek	Gulpa Creek	P			•	•		•		
B	Creek	Budgee Creek	P			•			•		
M	River	Ladgroves	P			•					
M	River	Pinchgut	P	•	•			•			
B	Wetland	Ulupna Island	P		•	•	•				
Total				14	18	19	20	17	20	20	20

Appendix 4 Water management area inundation scores and locations

Table A3. Annual, weighted, water management area (WMA) inundation scores.

F represents the location of the WMA where B = Barmah and M = Millewa. Area = km², Prop. = proportion of Barmah–Millewa Forest that each WMA covers, Max. = the weighted score for each WMA with complete inundation (score = 3).

F	WMA	Area	Prop.	Max	2018	2019	2020	2021	2022	2023	2024	2025
B	Kynmer Creek	31.352	0.0371	0.11	0.04	0.04	0.04	0.07	0.1	0.07	0.04	0.04
B	Tongalong Creek	28.954	0.0343	0.10	0.07	0.03	0.03	0.07	0.1	0.10	0.03	0.04
B	Smiths Creek	53.584	0.0634	0.19	0.13	0.06	0.06	0.13	0.2	0.13	0.06	0.04
B	Yielima	21.959	0.0260	0.08	0.05	0.03	0.03	0.05	0.1	0.05	0.03	0.04
B	Black Swamp	22.553	0.0267	0.08	0.05	0	0	0.03	0.1	0.05	0.00	0
B	Gulf Creek	63.111	0.0747	0.22	0.15	0.07	0.07	0.15	0.2	0.22	0.07	0.04
B	Boals Deadwood	38.147	0.0451	0.13	0.09	0.09	0.09	0.09	0.1	0.14	0.09	0.07
B	Top Island	14.498	0.0172	0.05	0.03	0.02	0.02	0.03	0.1	0.03	0.02	0.04
B	Steamer/War Plain	33.848	0.0401	0.12	0.08	0.04	0.04	0.08	0.1	0.12	0.04	0.04
B	Goose Swamp	21.499	0.0254	0.07	0.05	0	0	0	0.1	0.05	0.00	0
B	Barmah Island	13.463	0.0159	0.05	0.03	0.02	0.02	0.03	0.0	0.03	0.02	0.04
M	Aratula Creek	61.179	0.0724	0.22	0.07	0.07	0.07	0.14	0.2	0.14	0.07	0
M	Plantation	28.458	0.0337	0.10	0.03	0.03	0.03	0.03	0.1	0.07	0.03	0
M	Mary Ada	35.295	0.0418	0.13	0.04	0.08	0.08	0.08	0.1	0.13	0.08	0
M	Edward River	52.603	0.0623	0.19	0.06	0.12	0.12	0.12	0.2	0.19	0.12	0
M	Towrong Creek	38.081	0.0451	0.14	0.05	0.09	0.09	0.09	0.1	0.09	0.09	0
M	St Helena Swamp	78.505	0.0929	0.28	0.09	0.19	0.19	0.19	0.3	0.28	0.19	0.04
M	Gulpa Creek	75.314	0.0891	0.27	0	0.09	0.09	0.09	0.3	0.27	0.09	0.04
M	Moira Lake	132.559	0.1569	0.47	0.16	0.31	0.31	0.31	0.5	0.47	0.31	0.04
	Average area adjusted score	844.962	1.00		1.28	1.39	1.39	1.8	3	2.64	1.39	0.48

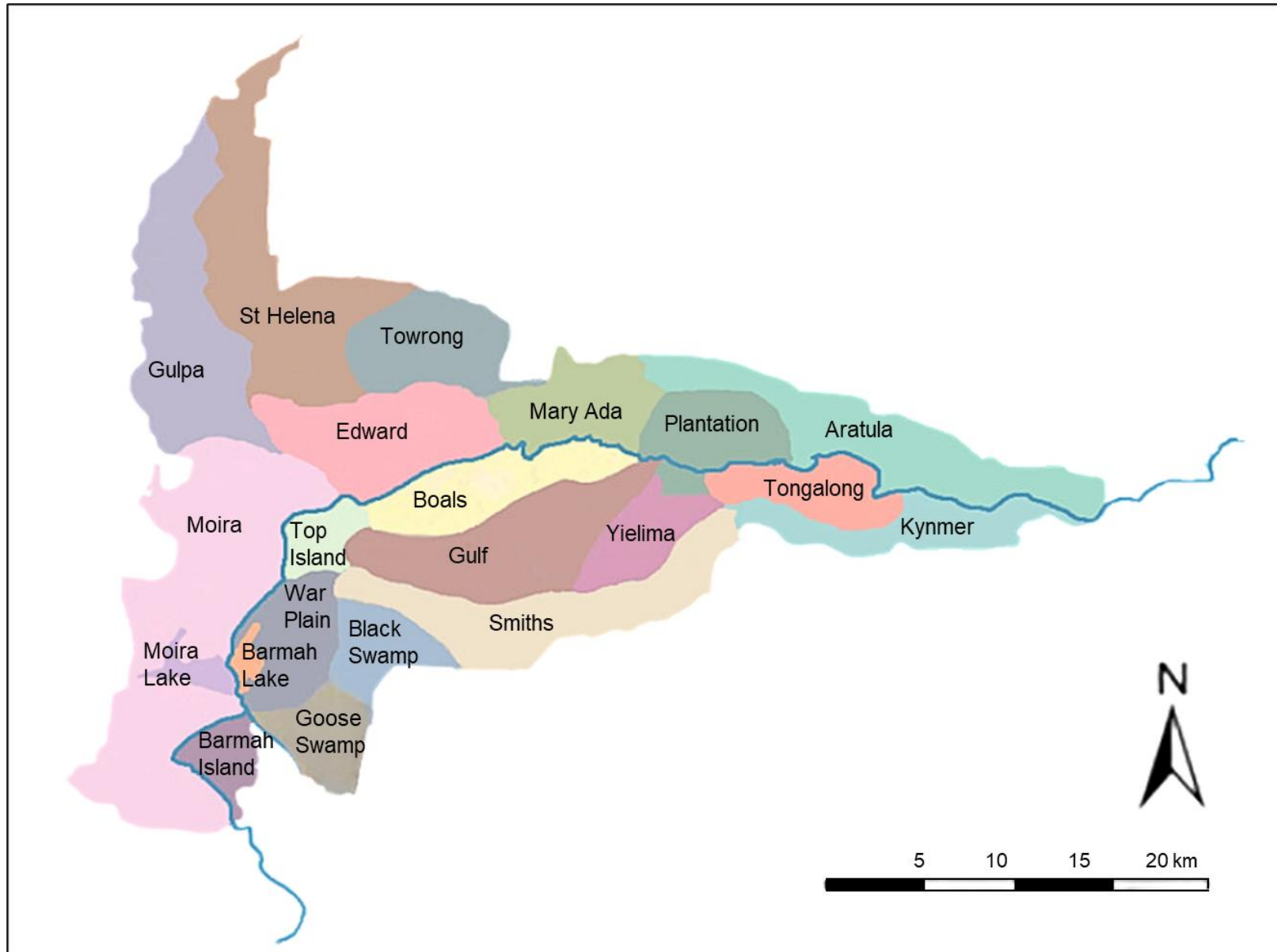


Figure A4. Location of the water management areas (WMA) in Barmah–Millewa Forest.

Appendix 5 Frog call model performance

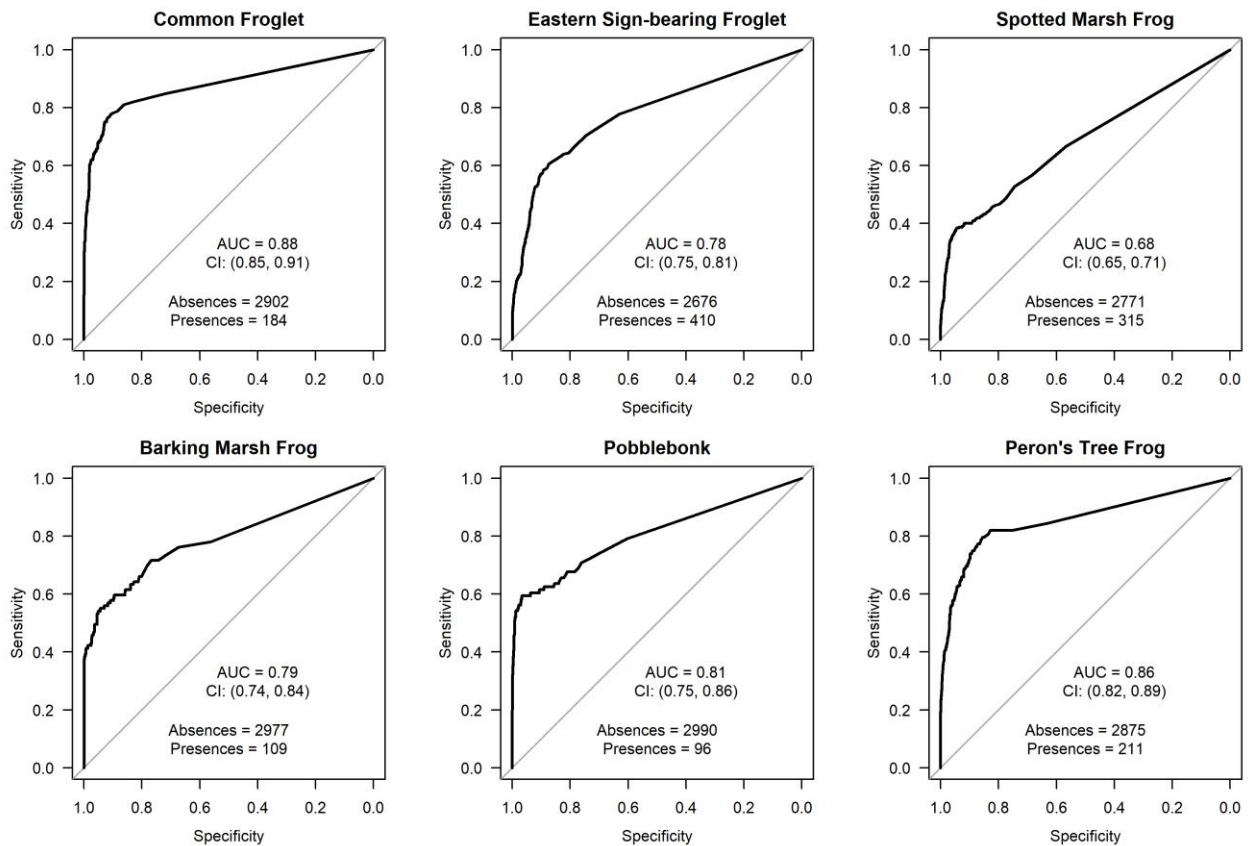


Figure A5. Receiver operating characteristic (ROC) curves showing Convolutional Neural Network (CNN) model discriminatory performance for each species.

The further away from the diagonal the black line travels, the better the classifier performance. The Area Under the Curve (AUC) score indicates performance – higher scores indicate better model accuracy at recognising calls of that species.

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