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Evaluation of flow-dependent frog objectives and targets

Technical report supporting the NSW Basin Plan Matter 8 Reporting 2019 to 2024

Department of Climate Change, Energy, the Environment and Water

Acknowledgement of Country

Department of Climate Change, Energy, the Environment and Water acknowledges the Traditional Custodians of the lands where we work and live.

We pay our respects to Elders past, present and emerging.

This resource may contain images or names of deceased persons in photographs or historical content.

Artist and designer Nikita Ridgeway from Aboriginal design agency Boss Lady Creative Designs created the People and Community symbol.

Cover photo: Peron’s tree frog, *Litoria peronii* observed in the Southern Nature Reserve, Macquarie Marshes (November 2021). Amelia Walcott/DCCEEW

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Contents

List of tables

List of figures

Abbreviations

Term	Definition
BC Act	*Biodiversity Conservation Act 2016* (NSW)
CEWH	Commonwealth Environmental Water Holder
CSU	Charles Sturt University
DCCEEW	Department of Climate Change, Energy, the Environment and Water (NSW)
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999* (Cth)
Flow MER	Flow Monitoring, Evaluation and Research Program (CEWH-funded)
LTIM	Long Term Intervention Monitoring Project
LTWP	long-term water plan
MDB	Murray–Darling Basin
ML/d	megalitres per day
NPWS	National Parks and Wildlife Services (NSW)
NSW	New South Wales
SoS	Saving our Species program (NSW)
WRPA	water resource planning area

Summary

Nearly half of the frog species residing in floodplain wetlands of the Murray–Darling Basin (MDB) breed in response to river flows that inundate wetlands and therefore benefit from the delivery of environmental water. These 'flow-dependent' species are the primary focus of the NSW Department of Climate Change, Energy, the Environment and Water's (the department's) Water for the Environment Frog Monitoring Project (the project). The project objectives are to monitor the response of frogs to wetland inundation by assessing species richness, distribution, relative abundance and breeding activity (including calling activity), and the presence of tadpoles and/or metamorphs (juvenile frogs). Progress towards meeting long-term objectives and targets for flow-dependent frog species was assessed in the Gwydir Wetland system (Gwydir Wetlands), Macquarie Marshes and lower Murrumbidgee (Lowbidgee) floodplain, which contain nationally and internationally significant floodplain wetlands in the NSW MDB.

The department and partners manage water for the environment in the Gwydir, Macquarie–Castlereagh, and Murrumbidgee water resource plan areas (WRPA) in consultation with environmental water advisory groups. Environmental water delivered to inundate floodplain habitats supports the water requirements of vegetation and wetland-dependent fauna including waterbirds, fish and frogs.

Frog survey data has been collected by the department in the Gwydir Wetlands and Macquarie Marshes since 2015 to document outcomes of wetland inundation, which includes the delivery of environmental water. Frog and tadpole spring surveys were completed at established survey sites at both wetland regions from early September to late November from 2015 to 2022. Sites were spread across the water management areas in the Gwydir Wetlands (Gingham, Lower Gwydir, Mehi and Mallowa watercourses) and Macquarie Marshes (north, south and east water management areas). Sites were located on private land, in the Gwydir Wetlands State Conservation Area and Macquarie Marshes Nature Reserve.

Charles Sturt University (CSU) collected frog survey data in the Lowbidgee floodplain through the Commonwealth Environmental Water Holder's Long-Term Intervention and Flow MER (monitoring, evaluation and research) funded projects. Bimonthly surveys were completed between September and March from 2014 to 2023. Sites were spread across the Redbank and Gayini Nimmie–Caira water management areas, to include sites on private land, in Yanga National Park and the Gayini Wetlands that are managed by Traditional Custodians, the Nari Nari Tribal Council.

The extent of wetland inundation and annual water availability fluctuated throughout the 2019 to 2023 assessment period. At the beginning of 2019–20, widespread dry conditions occurred across the NSW MDB, which restricted the extent of inundated wetland habitat for frog breeding, although some environmental water was delivered to maintain critical refuge habitats in the Lowbidgee floodplain and Gwydir Wetlands. Increased wet conditions in the 2020 to 2022 period allowed for the greater delivery of environmental water alongside large, natural inundation events. High catchment rainfall

and inflows resulted in 2 consecutive years of extensive inundation in all 3 wetland regions, with water delivered to maintain the duration of inundation at key sites. These wet conditions expanded the availability of inundated habitat for frog breeding but limited site access for the collection of frog monitoring data.

A Bayesian modelling approach was used to analyse trends in flow-dependent frog indicators (species richness, distribution, abundance and breeding) to assess progress towards NSW long-term water plan (LTWP) ecological objectives and targets. Trends were stable for most indicators assessed in the 3 wetland regions, giving high confidence that the targets had been met. Increasing trends were detected in the distribution, abundance, breeding activity and potential recruitment of the nationally vulnerable southern bell frog (*Litoria raniformis*) in the Lowbidgee floodplain.

1. Introduction

1.1 Flow-dependent frog species

Frogs are important indicators of wetland health (Gibbons et al. 2006; Ocock et al. 2014). They contribute to healthy-functioning wetland systems by providing a nutrient-dense food source and play a predatory role in the wetland food web in both their adult and tadpole life phases. Nearly half of the frog species residing in the floodplain wetlands of the Murray-Darling Basin (MDB) breed in response to inundation (Wassens 2011) and therefore can benefit from the delivery of environmental water. These species are referred to as 'flow-dependent' and are the primary focus of the department's environmental water frog monitoring and evaluation project.

Monitoring flow-dependent frog communities in floodplain wetlands can inform the management of environmental water. Surveys linked to flow events provide evidence of ecological outcomes and insights to better understand the habitat requirements of species. Flow-dependent frog species have limited capacity to withstand drying and therefore rely on floodplain habitats, preferring recently inundated wetlands for breeding. The delivery of environmental water can be used to influence the timing, extent and duration of inundation in floodplain habitats, and therefore support opportunities for breeding and recruitment. Other 'flow-ambivalent' and 'flow-oblivious' frog species may also use these habitats; however, these species require specific triggers (such as local rainfall) to breed, and their breeding is not linked with flows.

Recent work in large floodplain wetland systems in the MDB has demonstrated the important link between the periodic inundation of floodplain habitats and breeding by a subset of frog species (McGinness et al. 2014; Ocock et al. 2014, 2024; Wassens 2011) that can be described as 'flow-dependent' (see Appendix A). These include the southern bell frog (*Litoria raniformis*) which experienced declines in its range associated with reduced wetland inundation (Department of Environment and Conservation, 2005; Wassens, 2008). This species is listed as vulnerable under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and endangered under the NSW *Biodiversity Conservation Act 2016* (BC Act).

1.2 Objectives, targets and expected outcomes

Ecological objectives and targets for flow-dependent frog species were developed as part of the 'Other species' theme (Table 1) (one of 5 themes) in the NSW long term water plans (LTWP) (DPE 2023). Baselines for flow-dependent frog targets were developed using available data and expert opinion (DPE 2023). Key indicators used to set and evaluate flow-dependent frog objectives and targets were species richness, distribution, abundance, breeding activity and potential recruitment. These indicators can be influenced by factors related to inundation such as timing, wetland extent, and duration (Ocock et al. 2024). However, other factors are also likely to contribute to variances in these metrics over time, including species detectability in relation to survey conditions. For further information on the development of the LTWP 'Other species' objectives and targets see DPE (2023).

For the 2019 to 2024 Matter 8 evaluation, objectives and targets for flow-dependent frogs were assessed in 3 Water Resource Plan Areas (WPRA) where NSW and Commonwealth agencies delivered water for the environment in the 2014 to 2023 period. These included the Gwydir, Macquarie–Castlereagh and Murrumbidgee WRPAs that support nationally and internationally significant floodplain wetland systems. This analysis focused on long-term objectives and targets set for flow-dependent frog species in the Gwydir Wetlands, Macquarie Marshes and Lowbidgee floodplain. Frog surveys were also completed in the mid Murrumbidgee wetlands, mid Murray, lower Murray and lower Lachlan but these datasets were not analysed due to lack of data availability at the time of reporting.

Table 1 Summary of 'Other species' objectives and targets listed in the Gwydir, Macquarie–Castlereagh and Murrumbidgee LTWPs for flow-dependent frog species

Ecological objective	Quantified targets for 2024	2024 evaluation (measure of success)
OS1: Maintain species richness and distribution of flow-dependent frog communities	In the 2019 to 2024 period, detect all 6 flow-dependent frog species known from each wetland region based on comprehensive surveys over the 2015 to 2017 period (Gwydir Wetlands and Marshes Marshes) and 2014 to 2019 period (Lowbidgee floodplain).	In the 2019 to 2024 period maintain: • species richness of flow-dependent frog species • relative abundance of each species • number of sites each species detected.
OS2: Maintain successful breeding opportunities for flow-dependent frog species	In the 2019 to 2024 period, maintain proportion of wetland sites where breeding activity of flow-dependent frog species is detected compared to the 2015 to 2017 period (Gwydir Wetlands and Macquarie Marshes) and 2014 to 2019 period (Lowbidgee floodplain).	In the 2019 to 2024 period maintain: • number of sites with breeding activity (calling, tadpoles, egg masses and metamorphs) • number of sites with breeding success (tadpoles/metamorphs).
OS3: Maintain distribution and breeding for the endangered southern bell frog	In the 2019 to 2024 period, maintain proportion of sites where southern bell frogs are detected, and where potential recruitment is detected on a 3-year rolling average in the Lowbidgee floodplain.	In the 2019 to 2024 period: • maintain number of sites southern bell frogs detected • detect bell frogs 5 out of 5 years • maintain number of sites with potential recruitment (tadpoles).

2. Methods

2.1 Wetlands monitored

Gwydir Wetlands

The Gwydir Wetlands system (Gwydir Wetlands) covers floodplain areas west of Moree in the northern MDB and includes the Gingham, lower Gwydir and Mehi–Mallowa watercourses (Figure 1). Parts of these wetlands are recognised internationally under the Ramsar Convention for supporting unique wetland habitat, rare and threatened species, and providing important habitat for waterbirds (Ramsar Sites Information Service, 1999). The Gwydir Wetlands Ramsar site includes Old Dromana and Goddards Lease, now part of Gwydir State Conservation Area, and the privately-owned Crinolyn and Windella properties. Frog surveys were completed by the department from September 2015 to November 2022 at 16 sites across the Gingham, lower Gwydir and Mehi–Mallowa watercourses, including parts of the Gwydir State Conservation Area (Figure 1).

Macquarie Marshes

The Macquarie Marshes are located in the northern MDB with areas recognised under the Ramsar Convention as unique wetland habitat that supports rare and threatened species and provides important habitat for waterbirds (Ramsar Sites Information Service, 2011). The Macquarie Marshes Ramsar site includes most of the Macquarie Marshes Nature Reserve and some private properties. Alteration to the natural flow regime and changes to land use have caused declines in the condition and extent of wetland habitat in the Macquarie Marshes (DEECW 2010). Frog surveys were completed by the department from September 2015 to November 2022 at 14 sites across the east, north and south marsh water management areas, including parts of the Macquarie Marshes Nature Reserve (Figure 1).

Lowbidgee floodplain

The lower Murrumbidgee (Lowbidgee) floodplain stretches west from Hay to Balranald, in south-western NSW (Figure 1). It supports nationally important wetlands that provide critical habitat for threatened waterbird and frog species including the nationally listed southern bell frog (EPBC Act). The Murrumbidgee River is one of the most regulated rivers in Australia. This regulation has affected the extent of wetlands in its lower floodplain (Kingsford and Thomas 2004). Frog surveys were completed by Charles Sturt University from September 2014 to November 2022 (Wassens et al. 2023) at 8 sites across the Gayini Nimmie–Caira wetlands and neighbouring Yanga National Park (Figure 1). There has also been dedicated southern bell frog acoustic monitoring since 2017 through the department's Saving our Saving Species program which has covered 7 to 24 sites annually (DPIE 2021).

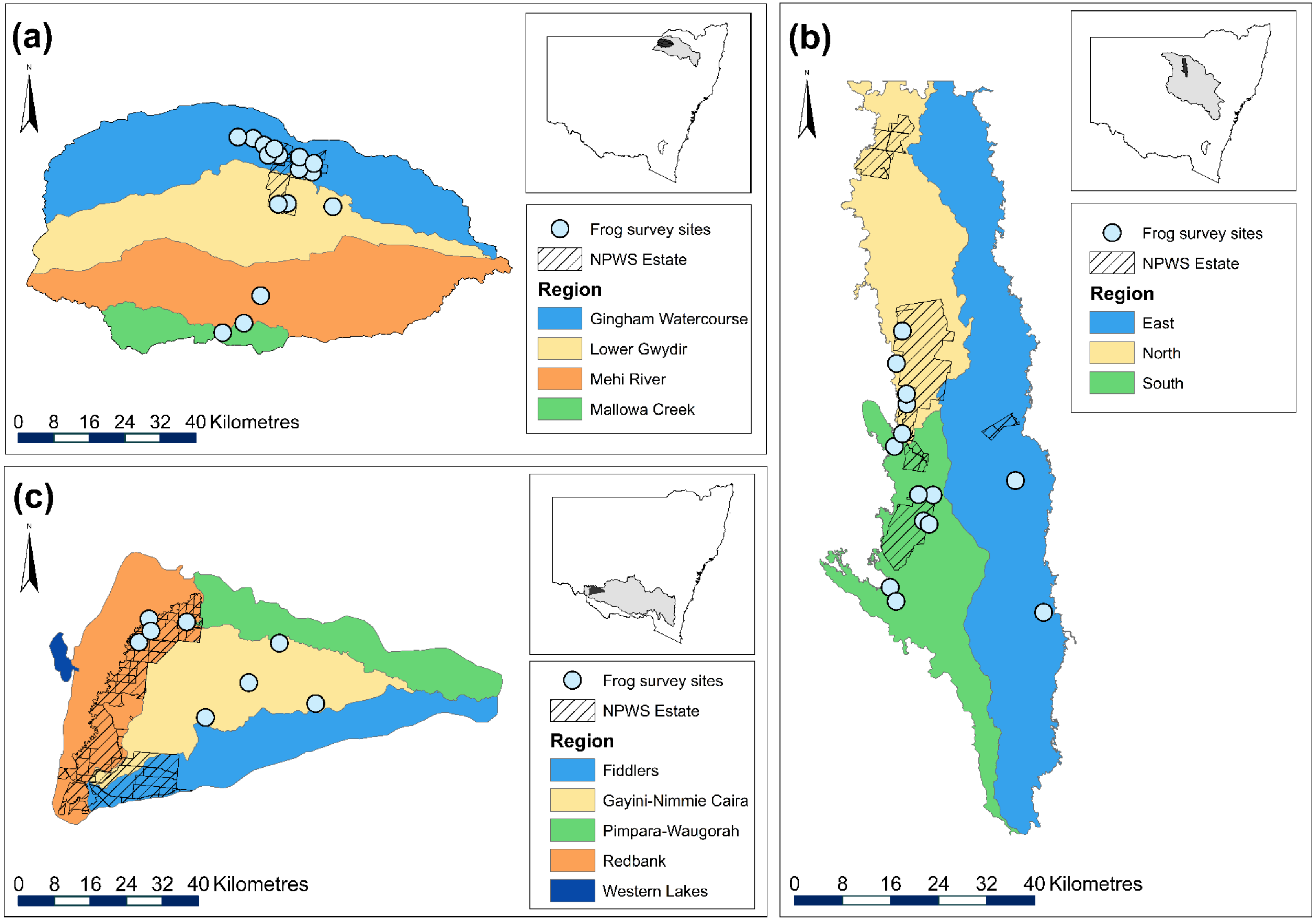

Figure 1 **Locations of the (a) Gwydir Wetlands (b) Macquarie Marshes and (c) Lowbidgee floodplain wetland regions in the NSW MDB (inset) including distribution of survey sites, NSW National Parks and Wildlife Services (NPWS) reserve estate and water management areas**

2.2 Survey coverage

The status of flow-dependent frog communities in the Gwydir Wetlands, Macquarie Marshes and Lowbidgee floodplain was assessed using survey data collected annually through 3 monitoring programs:

1. NSW Department of Climate Change, Energy, the Environment and Water (DCCEEW) Water for the Environment Monitoring, Evaluation and Reporting (MER) program which has supported on-ground frog surveys in the Gwydir Wetlands and Macquarie Marshes since 2015 (Ocock et al. 2024).
2. Commonwealth Environmental Water Holder (CEWH) Long Term Intervention Monitoring (LTIM) and Flow MER (Monitoring, Evaluation and Research) projects that have supported on-ground frog surveys by Charles Sturt University (CSU) in Lowbidgee floodplain since 2014 (Wassens et al. 2019).
3. NSW DCCEEW's Saving our Species (SoS) program which has supported the southern bell frog project with on-ground and acoustic surveys in the Lowbidgee floodplain since 2017 (DPIE 2021).

Survey methods used to collect data are summarised in Table 2. These included repeated surveys over both the baseline and assessment periods (in the LTWPs). For all 3 monitoring programs, the timing of surveys encompassed the peak breeding season of most flow-dependent frog species and provided good coverage of responses to wetland inundation. Similar survey methods have been used across the 3 survey regions by the department and CSU. These survey methods provide data for meaningful evaluation of the richness and distribution of flow-dependent frog species over time (LTWP objective OS1), as well as evidence on breeding activity (calling males, and presence of tadpoles and/or metamorphs) to evaluate distribution of breeding activity and relative breeding success (LTWP objective OS2). Fyke nets installed overnight at each survey site (Lowbidgee floodplain only) provided good coverage of tadpole occurrence compared with the other monitoring programs.

The SoS southern bell frog project monitors wetland sites that received environmental water (known as 'priority sites') as well as additional sites that might support the species in the future (known as 'surveillance sites'). The number and spatial arrangement of sites surveyed varies across water years depending on water availability (Waudby et al. 2020; Waudby et al. 2021a; Waudby et al. 2021b). The combined CSU and SoS monitoring programs provide comprehensive spatial coverage for the Lowbidgee floodplain. Acoustic monitoring is the primary form of data collection for the southern bell frog. Information on their calling activity is captured for 5 minutes every hour for the core breeding season (September to March). Nocturnal visual and aural surveys are completed at a subset of sites later in the season or as wetlands dry to collect data on recruitment. However, these surveys are not necessarily completed at all sites in all years due to limited site access.

Table 2 **Summary of the survey methods used by the different frog monitoring programs across the 3 wetland regions. Refer to the resources in the 'further details' column for more information on site descriptions and additional data collected on habitat and survey conditions**

Monitoring program	Start date	Wetland region(s)	No. sites	Timing	Summary of frog survey methods	Further details
DCCEEW Water for the Environment MER project	2015	Gwydir Wetlands and Macquarie Marshes	16 (Gwydir Wetlands) 14 (Macquarie Marshes)	Annual spring surveys in September and November Generally covers the early stages of inundation and detection of metamorphs	**Tadpoles:** small-mesh sized net is slowly swept through the water in different microhabitats within the wetland for approximately 10–20 minutes (sweep netting). Captured tadpoles are counted, identified to species and stage of development, and are released. **Adults and metamorphs:** Nocturnal aural and visual encounter transect surveys for equivalent of one person-hour transect. Snout-vent length is measured for key species to assess size distribution.	Standard methods for monitoring flow-dependent frogs (DCCEEW 2024a).
CSU surveys funded through CEWH LTIM/ Flow MER program	2014	Lowbidgee floodplain	8	Annual bimonthly surveys in September, November, January and March Covers the active breeding time for flow-dependent frog species.	**Tadpoles:** Two large and 2 small double-winged fyke nets are set overnight and all tadpoles identified to species and stage of development (along with turtles and fish) and released back into the wetland. **Adults and metamorphs:** Nocturnal visual encounter surveys for 40 minutes, plus 3 x 2-minute aural surveys at 10-minute intervals. Snout-vent length is measured for key species to assess size distribution.	Murrumbidgee Monitoring, Evaluation and Research Plan (Wassens et al. 2019).

Monitoring program	Start date	Wetland region(s)	No. sites	Timing	Summary of frog survey methods	Further details
DCCEEW SoS Southern bell frog project	2017	Lowbidgee floodplain	Varies annually, Priority sites: 7 to 22 sites Surveillance sites (varies annually)	Acoustic: 5 minutes every hour, September–March Covers active breeding season of southern bell frogs and flow responses	**Adults:** Call recorders set to record 5 minutes every hour during core calling period (September to March) (Waudby et al. 2020; Waudby et al. 2021a; Waudby et al. 2021b). **Adults and metamorphs**: Nocturnal aural and visual encounter surveys were completed opportunistically in late summer–early autumn or when wetlands were drying to collect information on young frogs (potential recruitment).	NSW DCCEEW SoS southern bell frog monitoring plan (Waudby, 2019).

2.3 River flows and inundation

Catchment rainfall, river flows and wetland inundation varied considerably across the 3 wetland regions during the 2019 to 2023 assessment period, which influenced annual water availability and environmental water deliveries (Table 3). At the beginning of 2019–20, widespread dry conditions occurred across the MDB. This resulted in restricted areas of inundated wetland habitat for frog breeding. Some environmental water was delivered to maintain critical refuge habitats in the Lowbidgee floodplain and Gwydir Wetlands. Increased wet conditions in the 2020 to 2022 period allowed for greater volumes of environmental water to be delivered alongside natural large-inundation events. High catchment rainfall and inflows resulted in 2 consecutive years of extensive inundation in all 3 wetland regions with water delivered to maintain wetland duration at key sites (Figure 2 and Figure 3). These wet conditions vastly expanded the availability of inundated wetland habitat for frog breeding but restricted site access for collecting frog monitoring data.

Table 3 Summary of river flows and inundation in each of the monitored wetland regions 2019 to 2023

Wetland region	Water year	Wetland conditions
Gwydir Wetlands	2019–20	First half of the water year was dry with no rain or natural flows into the wetlands. Rainfall in February 2020 resulted in average annual rainfall. Environmental water was delivered to both river and wetland assets with inundating flows delivered to the wetlands following rain in the second half of 2019–20.
	2020–21	Widespread rain in late 2020 resulted in above average rainfall. Wetlands were inundated by environmental water delivered from December 2020 to February 2021. During March 2021, unregulated flows entered the system resulting in extensive flooding.
	2021–22	Widespread rainfall, natural inflows and the delivery of environmental water provided high wetland habitat availability.
	2022–23	Moderate to very wet conditions across the catchment. High water availability and inundation for the second consecutive year.
Macquarie Marshes	2019–20	High temperatures and lack of rainfall led to record dry conditions at the start of this water year. There was a small environmental water delivery to riverine and wetland assets in December 2019. The Macquarie River resumed flowing following heavy rainfall in January 2020, and managed flows were also delivered during the remainder of the water year.
	2020–21	Rainfall continued from late 2020 to 2021 resulting in above average annual rainfall. Water for environment was used to supplement natural flows to inundate wetlands from August 2020 to March 2021.

Wetland region	Water year	Wetland conditions
	2021–22	Widespread rainfall, natural inflows and the delivery of environmental water provided high wetland habitat availability.
	2022–23	Weather during late 2022 was influenced by a La Niña climate cycle, resulting in generally cool and wet conditions until early 2023. Some rainfall events also occurred in autumn in the catchment. High water availability and inundation for the second consecutive year.
Lowbidgee floodplain	2019–20	Above average high temperatures and below average rainfall, and very low water availability with most environmental water used to support drought refuge habitat in the Lowbidgee floodplain.
	2020–21	Higher rainfall increased water availability and subsequently higher volumes of environmental water was delivered, targeting wetland habitat in the Lowbidgee floodplain, including waterbird breeding habitat.
	2021–22	High unregulated flows, along with targeted environmental water delivery, inundated much larger areas than observed in 2020–21 (2 to 3 times larger).
	2022–23	Very wet La Niña conditions were experienced in spring–summer 2022–23 with above average rainfall and below average temperatures. Very high levels of inundation were recorded across the floodplain. Environmental water was delivered to support waterbird breeding, increase distribution of bitterns and southern bell frogs, support fish movement and improve water quality.

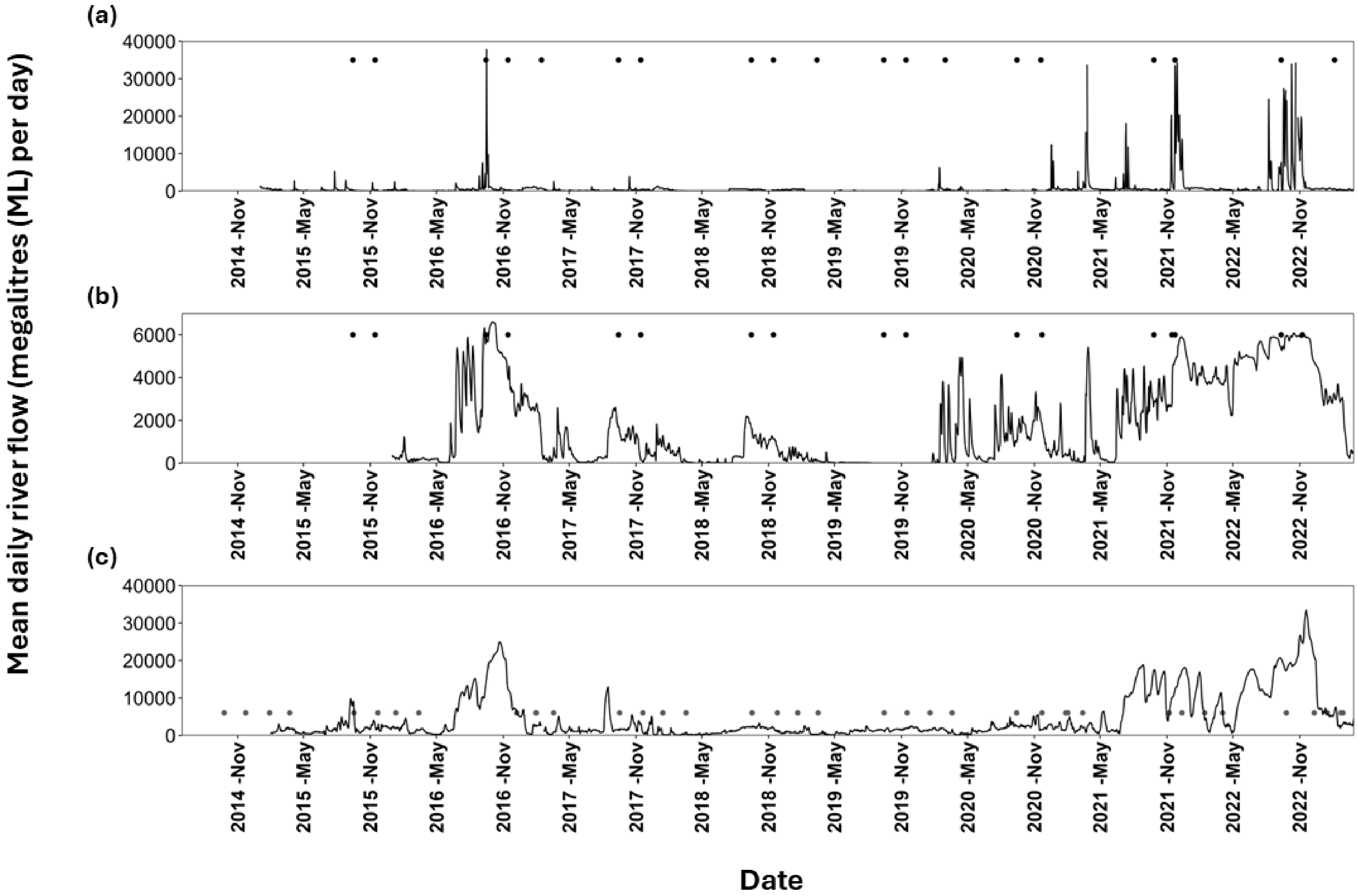

Figure 2 **Mean daily river flow rates (megalitres (ML) per day) from upstream gauging stations (gauge numbers: (b) 418004 [Gwydir], (b) 421090 and 421088 [Macquarie combined], (c) 410040 [Lowbidgee]) indicative of wetland inundation extent and duration in each region over the study period, including timing of frog surveys (closed circles)**

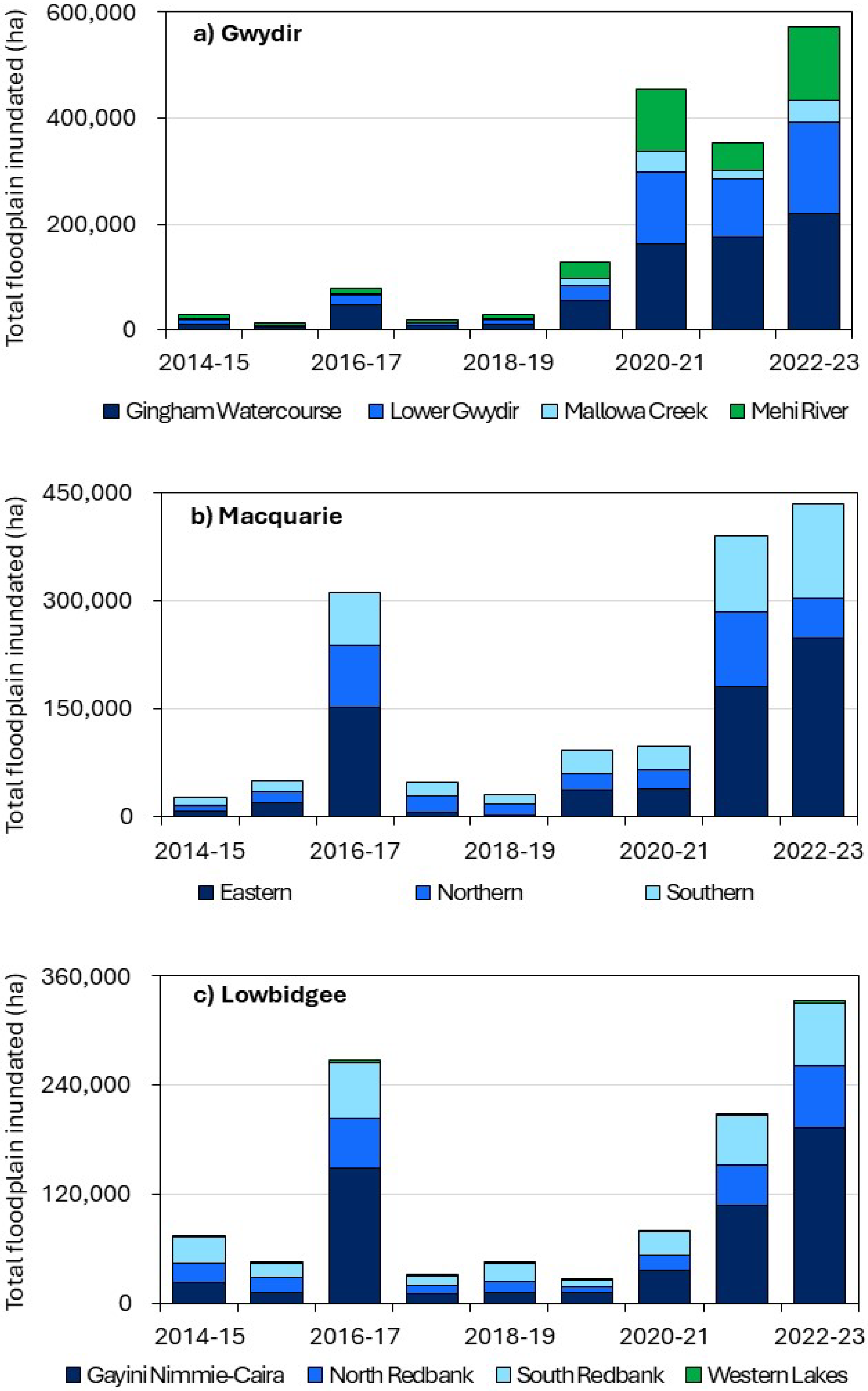

Figure 3 **Total area of floodplain inundated in each wetland region (hectares) in each water year from 2014 to 2023: (a) Gwydir Wetlands (b) Macquarie Marshes and (c) Lowbidgee floodplain. Note the different y-axis scale for each wetland region. The annual cumulative inundated area (in hectares) for each wetland region for 2014 to 2023 was based on inundation mapping from Sentinel imagery undertaken by DCCEEW**

2.4 Information reliability

The reliability of the data collected on frogs in the Gwydir Wetlands, Macquarie Marshes and Lowbidgee floodplain is considered ‘good’. Refer to Appendix B for assessment of data reliability for each indicator. The same indicators were used from the NSW DCCEEW and CSU ground survey datasets. Both the CSU and SoS datasets were used to assess the southern bell frog objective and targets for the Lowbidgee floodplain (Table 4). Consistent methods were used at sites throughout the water management areas and completed at regular intervals including the baseline and current (2019 to 2022) assessment periods. For the CSU and DCCEEW datasets, the same sites were surveyed repeatedly over time, except during periods of very high flows and for some sites in the Gwydir Wetlands due to changing landholder permission.

Frog survey sites in the 3 wetland regions incorporated a range of habitat types. There were fewer sites in some water management areas. Therefore, some parts of each system were under-represented (i.e. East Marsh, Macquarie Marshes, Mehi River, Gwydir Wetlands, northern part of the Redbank system, Lowbidgee floodplain) (Figure 1). During periods of high flows and prolonged very dry conditions, some sites were not surveyed. Alternative sites were surveyed in the Lowbidgee floodplain region. A change in landholder permissions in the Gwydir Wetlands meant loss of access to a small number of survey sites in recent years and so alternative sites were surveyed.

Table 4 Indicators and survey metrics used from each monitoring dataset

Datasets	Wetland regions	Indicator	Metric
NSW DCCEEW ground	Gwydir Wetlands & Macquarie Marshes	Species richness	Total number of flow-dependent frog species detected (and number of sites where each species was detected)
		Abundance	Total abundance of flow-dependent frog species (and relative abundance of each species)
		Breeding activity	Proportion of sites where breeding activity was recorded (calling, frog spawn, tadpoles, metamorphs)
CSU ground	Lowbidgee floodplain	Species richness	Total number of flow-dependent frog species detected (and number of sites where each species was detected)
		Abundance	Total abundance of flow-dependent frog species (and relative abundance of each species) proportion of sites where breeding activity was recorded (calling, frog spawn, tadpoles, metamorphs)
		Breeding activity	Proportion of sites where breeding activity was recorded (calling, frog spawn, tadpoles, metamorphs)

Datasets	Wetland regions	Indicator	Metric
CSU ground, SoS ground and acoustic	Lowbidgee floodplain	Southern bell frog distribution and breeding activity	Proportion of sites where southern bell frog breeding activity and potential recruitment was recorded

2.5 Trend assessment

Data collected from ground surveys since 2014 in the Lowbidgee floodplain and since 2015 in the Gwydir Wetlands and Macquarie Marshes were analysed for trends in indicators associated with flow-dependent frog communities (Table 4). Species richness, distribution and abundance were derived from night-time transect data. The presence of breeding activity by flow-dependent frogs was calculated by combining data on calling, presence of egg masses, tadpoles and metamorphs/juveniles from night-time transect data and daytime sweep-netting surveys.

A Bayesian approach was used to model trends in ecological indicator variables based on time-series data. This approach has been advocated as more reliable than traditional hypothesis testing when assessing trends for several reasons. See McBride (2019) for a detailed discussion and explanation on this approach. Two types of trends were modelled:

1. long-term trends, which show continuous trends across consecutive years from the start of surveys to the present year
2. current status comparisons with baseline, which compare the years following a baseline period set out in the LTWPs to that baseline period.

The statistical package 'rstanarm' (Goodrich et al. 2020) in R program version 4.3.2 (R Core Team 2023) was used to conduct generalised linear models and generalised linear mixed models, depending on whether the model included species as a random variable.

Bayesian models were run at 4,000 iterations to give a posterior sample size of 8,000. This was to prevent instances of Markov chains not converging (see Goodrich et al. 2020). The slope was then estimated from the posterior distribution, and trend direction and likelihood were determined using Markov chain Monte Carlo simulations. The probability mass function was altered gradually to define credible intervals from which an estimated slope of zero was excluded (as per the trend assessment procedure outlined by McBride [2019]). These predetermined credible intervals illustrate the direction (+/–) and likelihood of a trend, with the outcome of the trend analysis being simplified into the form of a report card.

Report cards were used to describe whether a given ecological indicator was increasing, declining or stable (see Table 5). This was based on the method proposed by Mastrandrea et al. (2010). Depending on the type of trend (i.e. long-term or current status comparison to baseline), the direction and likelihood of the trend were determined from the relationship between the mean of the sample population and either an estimated slope of zero (for long-term trends) or the mean of the posterior distribution of the sample population from the baseline period (for current status comparisons to baseline). For detailed notes on interpretation of model outputs see Appendix C and detailed results of the analysis are provided in Appendix D.

Table 5 **Reporting categories were used to describe whether each flow-dependent frog indicator was increasing, declining or stable based on the method proposed by Mastrandrea et al. (2010)**

Outcome	Report card category	Likelihood of increase/decrease (%)	Code
Virtually certain increase	Increasing	100 to 99	↑↑↑↑
Extremely likely increase	Increasing	99 to 95	↑↑↑
Very likely increase	Increasing	95 to 90	↑↑
Likely increase	Increasing	90 to 66	↑
About as likely as not	Stable	66 to 66	=
Likely decrease	Declining	–66 to 90	↓
Very likely decrease	Declining	–90 to 95	↓↓
Extremely likely decrease	Declining	–95 to 99	↓↓↓
Virtually certain decrease	Declining	–99 to 100	↓↓↓↓

3. Results

3.1 Objective 1: Maintain species richness and distribution of flow-dependent frog communities

Trends in species richness

The first set of objectives and targets for flow-dependent frog species in the 3 wetland regions are described in Table 6. To meet the species richness targets, all 6 flow-dependent frog species observed during the baseline period in each wetland region needed to be detected.

In the Macquarie Marshes this needed to occur over a 5-year rolling period. This target was met across all 3 wetland regions with all catchment-specific flow-dependent frog species detected each year in the Gwydir Wetlands and Lowbidgee floodplain (Table 6). In the Macquarie Marshes, the total number of flow-dependent species fluctuated between 4 and 6 species from 2015 to 2019, with all 6 species observed in the 3 most recent spring survey periods (2020 to 2022). Species not detected consistently in the Macquarie Marshes every water year were *Limnodynastes salmini* (4 of 8 years) and *L. latopalmata,* which was observed every year except for spring 2019 (Figure 4). Trends in species richness were stable in the 3 wetland regions. This was the case for both long-term trends (using all available data) and when comparing the current and baseline periods, with between zero and 15% likelihoods of an increase or decrease (Table 7).

Table 6 Flow-dependent frog species richness and distribution objectives and targets set in the Gwydir, Macquarie–Castlereagh and Murrumbidgee LTWPs

Objective	WRPA	Wetland region	Target 5 years (2024)
OS1: Maintain species richness and distribution of flow-dependent frog communities	Gwydir	Gwydir Wetlands	Detect all 6 flow-dependent frog species known from the Gwydir Wetlands based on comprehensive surveys over the 2015 to 2017 period.
	Macquarie–Castlereagh	Macquarie Marshes	Over a 5-year rolling period, detect in each assessment period, all 6 flow-dependent frog species known from the Macquarie Marshes based on comprehensive surveys over the 2015 to 2017 period.
	Murrumbidgee	Lowbidgee floodplain	Detect all 6 flow-dependent frog species known from the Lowbidgee wetlands based on comprehensive surveys over the 2014 to 2019 period.

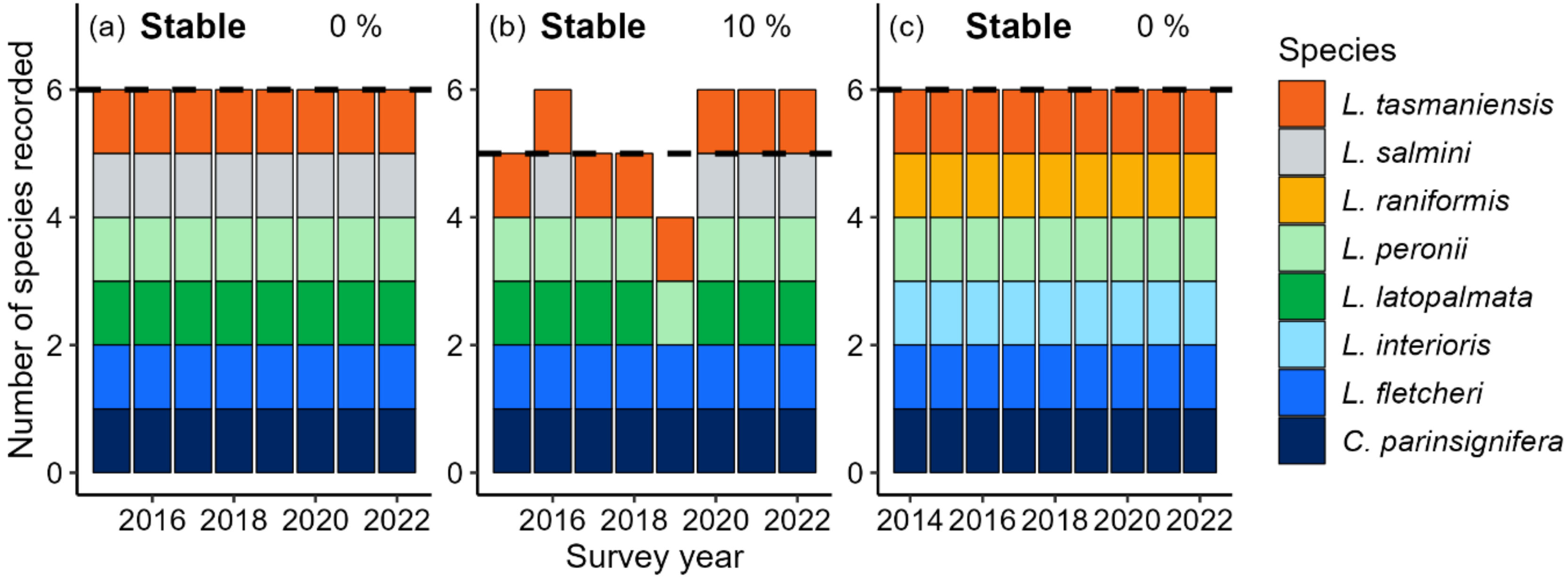

Figure 4 **Number of flow-dependent frog species recorded during each survey period in the 3 wetland regions and results of Bayesian analysis for total number of species. The dashed line represents the median values from the baseline period (2015 to 2017 for (a) Gwydir Wetlands and (b) Macquarie Marshes, and 2014 to 2019 for (c) Lowbidgee floodplain). The overall trend in all catchment-specific flow-dependent frog species is being maintained as 'stable' in the current assessment period (2019 to 2023 period) compared to the baseline period**

Table 7 Results of Bayesian trend analysis for species richness trends for all flow-dependent frogs in each wetland region. The overall trend in all catchment-specific flow-dependent frog species being maintained as stable, and the likelihood of this outcome (increase or decrease) is also shown

Indicator	Wetland region	Timeframe	Likelihood of increase or decrease (%)	Overall trend	Code
Species richness	Gwydir Wetlands	Current vs baseline	0%	Stable	=
		Long term	0%	Stable	=
	Macquarie Marshes	Current vs baseline	10%	Stable	=
		Long term	15%	Stable	=
	Lowbidgee floodplain	Current vs baseline	0%	Stable	=
		Long term	0%	Stable	=

Trends in species distribution and total abundance

Long-term trends in individual species in each wetland region were also assessed. Trends varied for the catchment-specific species, with the majority being stable or increasing, and declining trends detected in 2 species in the Lowbidgee floodplain (Figure 5). The distributions of all 6 flow-dependent species were stable in the Gwydir Wetlands and Macquarie Marshes, with a very likely increase in *L. salmini* distribution in the Gwydir Wetlands from 2019 to 2022 (85% likelihood) (Figure 5). In the Lowbidgee floodplain, distributions of *L. interioris* and *L. raniformis* showed a virtually certain increase (97 to 99% likelihood), while 2 common species *L. tasmaniensis* and *C. parinsignifera* showed a likely decrease (70 to 80% likelihood). All other species distributions showed stable long-term trends (Figure 5). See Table 18 in Appendix D for detailed results of the analysis for each species.

The total abundance of frogs across all species recorded each spring was stable in the Macquarie Marshes and Lowbidgee floodplain but declining in the Gwydir Wetlands (Table 8, Figure 6). These trends were consistent over the long term and when comparing the current and baseline periods, with an 85% and 99% likelihood of decline in the Gwydir Wetlands, respectively. The declining trend observed in the Gwydir Wetlands is due to the particularly high abundance of *L. tasmaniensis* recorded in 2016; however, trends in abundance were not formally analysed at a species level. The number of southern bell frogs *(L. raniformis)* observed increased significantly from 2018 onwards in the Lowbidgee floodplain.

Table 8 Results of Bayesian trend analysis for total abundance of flow-dependent frogs in each wetland region. The modelled trend directions (i.e. stable, increasing or decreasing) and the likelihood of these outcomes (increase or decrease) are shown

Indicator	Wetland region	Timeframe	Likelihood of increase or decrease (%)	Overall trend	Code
Abundance	Gwydir Wetlands	Long term	–85%	Likely decrease	↓
		Current vs baseline	–99%	Virtually certain decrease	↓↓↓↓
	Macquarie Marshes	Long term	25%	Stable	=
		Current vs baseline	20%	Stable	=
	Lowbidgee floodplain	Long term	25%	Stable	=
		Current vs baseline	60%	Stable	=

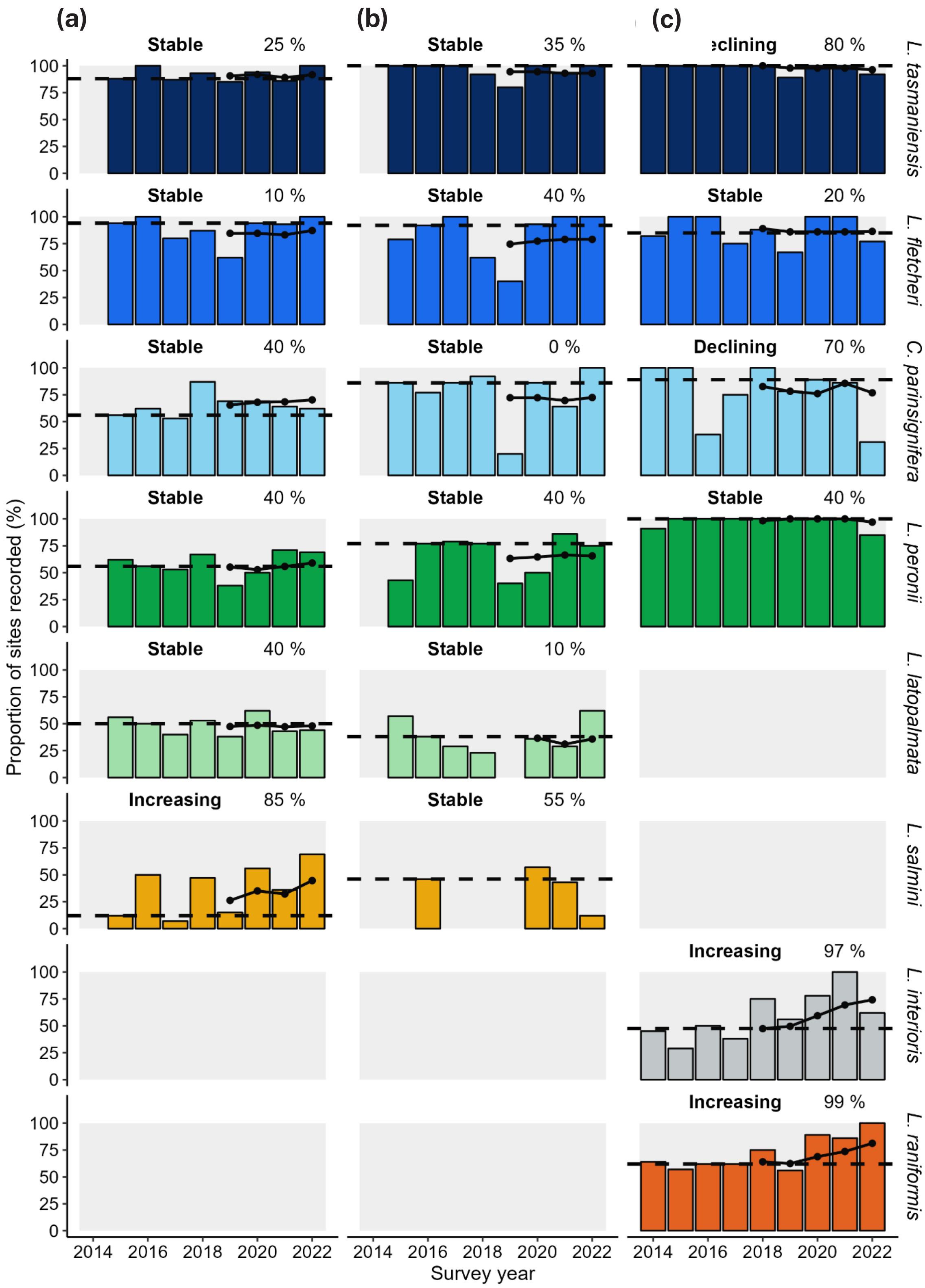

Figure 5 **Distribution of flow-dependent frog species detected in monitored wetlands in the northern [(a) Gwydir Wetlands and (b) Macquarie Marshes] and southern [(c) Lowbidgee floodplain)] MDB in the 2014 to 2022 period (based on proportion of sites each species was detected each spring). The dashed line shows the median value. The solid line shows a 5-year rolling average**

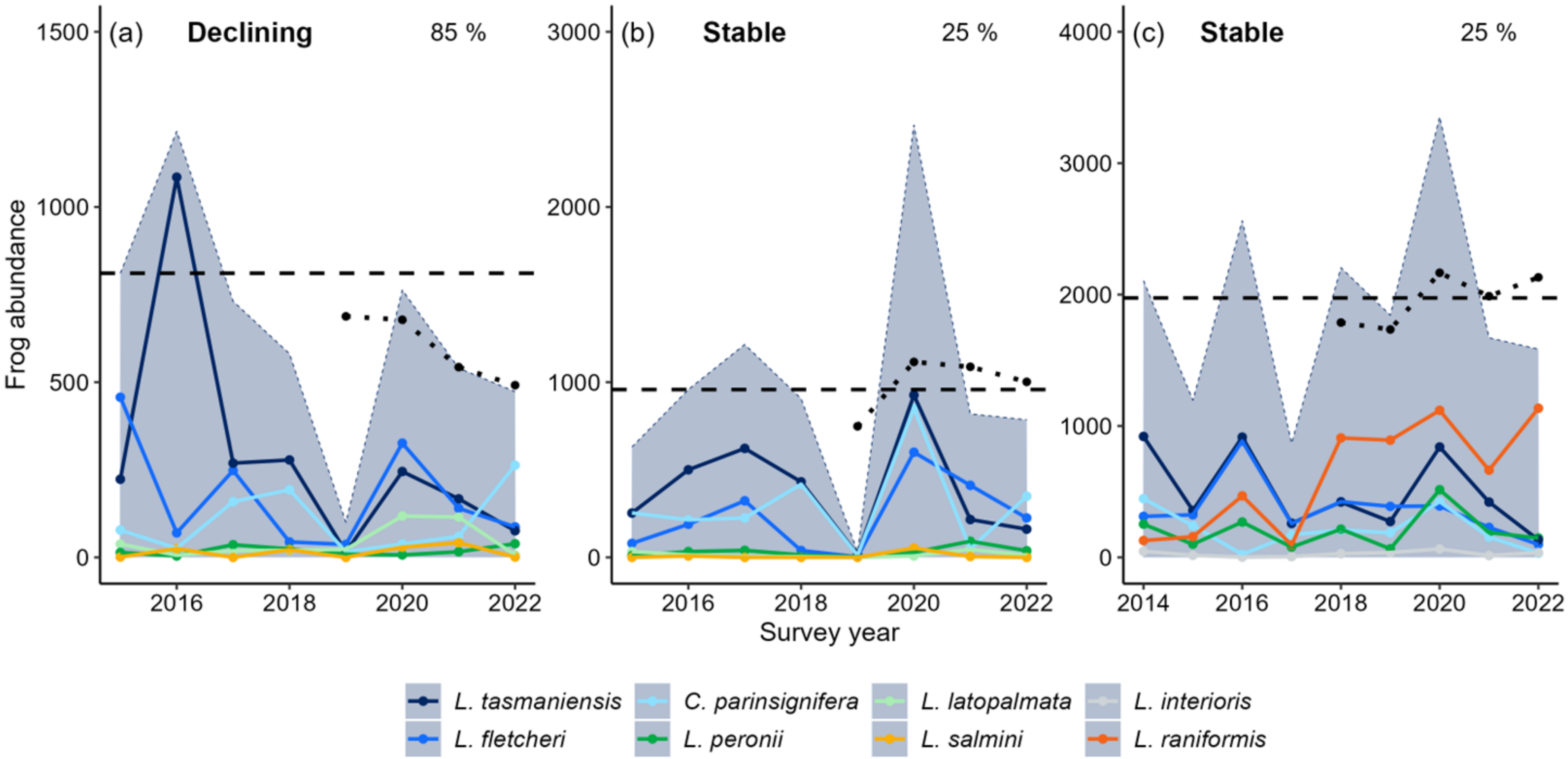

Figure 6 **Trends in total abundance of all frog species and abundance of each of 6 flow-dependent frog species recorded in each wetland region (a) Gwydir Wetlands (b) Macquarie Marshes and (c) Lowbidgee floodplain each spring from 2014 to 2022. Note that different species were recorded in the Lowbidgee floodplain compared to the Gwydir Wetlands and Macquarie Marshes. The dashed line shows the median value. The dotted line shows a 5-year rolling average**

3.2 Objective 2: Maintain successful breeding opportunities for flow-dependent frog species

The second set of objectives and targets are described in Table 9. The targets for breeding opportunities were to maintain the proportion of sites where breeding activity (calling, egg masses, tadpoles, metamorphs/juveniles) was detected compared with the baseline, and to maintain this proportion of sites where breeding was detected in a 5-year rolling period compared with the baseline period in the Macquarie Marshes (Table 9).

Table 9 Flow-dependent frog breeding targets set in the Gwydir, Macquarie–Castlereagh and Murrumbidgee LTWPs

Objective	Water Resource Plan Area	Wetland region	Target 5 years (2024)
OS2: Maintain successful breeding opportunities for flow-dependent frog species	Gwydir	Gwydir Wetland system	Maintain proportion of wetland sites where breeding activity (calling, egg masses, tadpoles, metamorphs/juveniles) of flow-dependent frog species is detected in the Gwydir Wetlands compared to the 2015 to 2017 period.
	Macquarie–Castlereagh	Macquarie Marshes	Over a 5-year rolling period, maintain proportion of wetland sites where breeding activity of flow-dependent frog species is detected in the Macquarie Marshes compared to the 2015 to 2017 period.
	Murrumbidgee	Lowbidgee floodplain	Maintain proportion of sites where breeding activity (calling, tadpoles, metamorphs) of flow-dependent frog species is detected in the Lowbidgee wetlands compared with the 2014 to 2019 period.

Trends in breeding activity

Long-term and current trends in breeding activity of flow-dependent frog species were stable across the Gwydir Wetlands and Lowbidgee floodplain. Long-term trends were also stable in the Macquarie Marshes, however there was a decline in breeding activity in the current period when compared with the baseline as breeding was not recorded in spring 2019 due to very dry conditions (Figure 7, Table 10). As a result, the LTWP target for the Macquarie Marshes was not met as the proportion of sites (5-year average) with breeding activity was lower than the average for the baseline period (2015 to 2017) when breeding activity was detected at all sites surveyed.

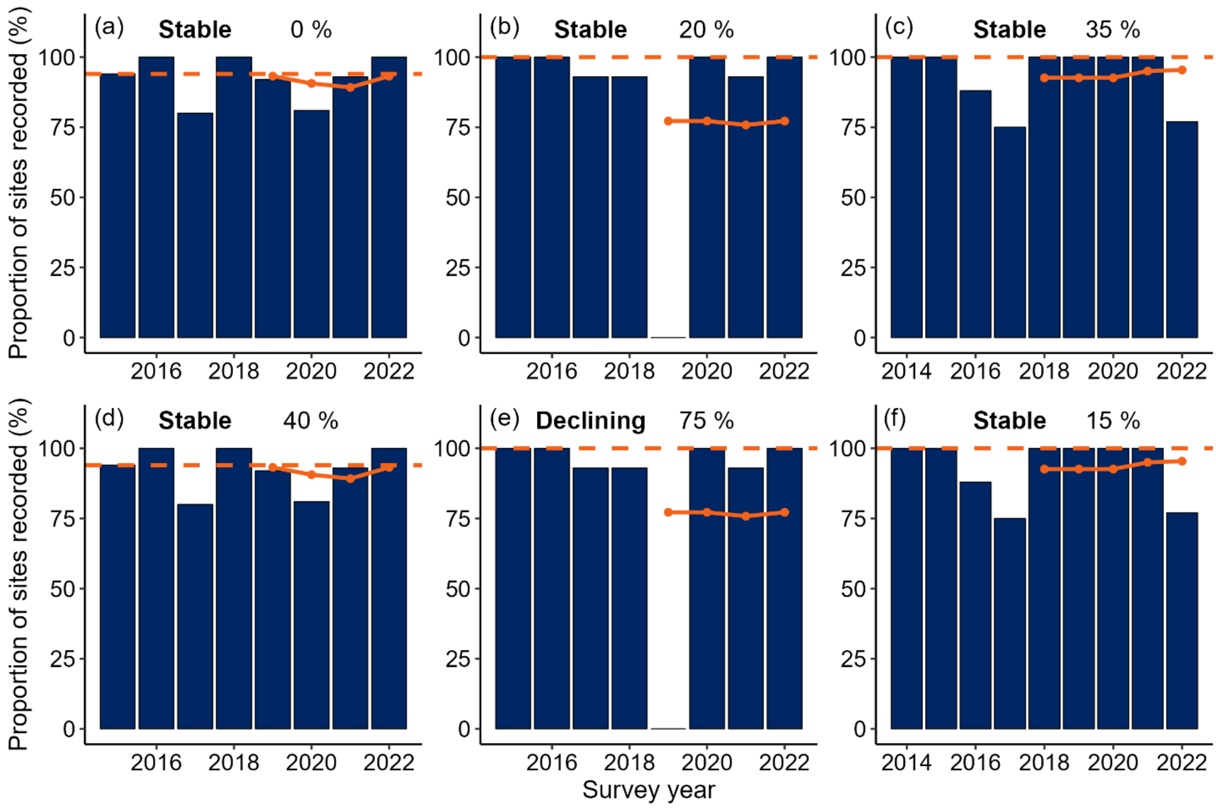

Figure 7 **Proportion of surveyed sites that supported breeding activity in flow-dependent frog species in the Gwydir Wetlands (a and d), Macquarie Marshes (b and e) and Lowbidgee floodplain (c and f) each spring in the 2014 to 2022 period. Graphs a to c show long-term trends across all years and graphs d to f show trends in current assessment period compared to the baseline periods. The dashed line shows the median value of the baseline period (2015 to 2017). The dotted line shows a 5-year rolling average. Modelled trend directions (i.e. stable, increasing or decreasing) and the likelihood of these outcomes are shown**

Table 10 **Results of Bayesian trend analysis for breeding activity for all flow-dependent frogs in each wetland region. The modelled trend directions (i.e. stable, increasing or decreasing) and the likelihood of these outcomes (increase or decrease) are shown**

Indicator	Wetland region	Timeframe	Likelihood of increase or decrease (%)	Overall trend	Code
Breeding activity	Gwydir Wetlands	Long term	0%	Stable	=
		Current vs baseline	40%	Stable	=
	Macquarie Marshes	Long term	20%	Stable	=
		Current vs baseline	–75%	Likely decrease	↓
	Lowbidgee floodplain	Long term	35%	Stable	=
		Current vs baseline	15%	Stable	=

Trends in breeding success

Maintenance of successful breeding opportunities over the long term and in the current assessment period was also assessed. Evidence of successful breeding outcomes was restricted to the proportion of sites where metamorphs were recorded in the Gwydir Wetlands and Macquarie Marshes, and where tadpoles were detected in the Lowbidgee floodplain (as metamorphs were not consistently identified in this dataset). Trends in successful breeding outcomes were stable in the Gwydir Wetlands and Macquarie Marshes. In the Lowbidgee floodplain, trends were likely to be increasing over the long term (80% likelihood) and showed a virtually certain likelihood to be increasing when comparing the current status with the baseline period (99% likelihood) (Figure 8, Table 11). For the Macquarie Marshes, there was also a slight increase in the 5-year rolling average.

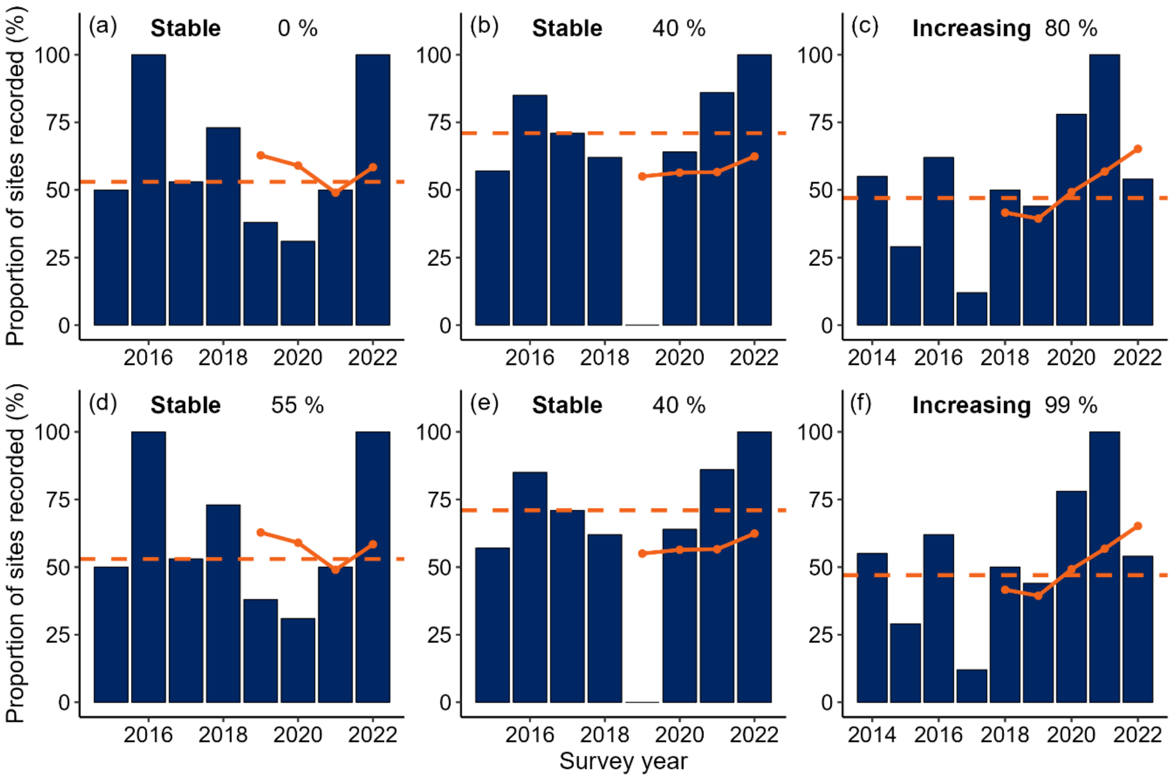

Figure 8 **Proportion of surveyed sites that supported breeding success in flow-dependent frog species in the Gwydir Wetlands (a and d), Macquarie Marshes (b and e) and Lowbidgee floodplain (c and f) each spring in the 2014 to 22 period. Graphs a to c show long-term trends across all years, and graphs d to f show trends in current assessment period compared to the baseline periods. The dashed line represents the median value, and the dotted line shows a 5-year rolling average**

Table 11 **Results of Bayesian trend analysis for breeding success (tadpoles and/or metamorphs) for all flow-dependent frogs in each wetland region. The overall trend in all catchment-specific flow-dependent frog species being maintained, and the likelihood of this outcome (increase or decrease) is also shown**

Indicator	Wetland region	Timeframe	Likelihood of increase or decrease (%)	Overall trend	Code
Breeding success (metamorphs)	Gwydir Wetlands	Long term	0%	Stable	=
		Current vs baseline	55%	Stable	=
	Macquarie Marshes	Long term	40%	Stable	=
		Current vs baseline	40%	Stable	=
Breeding success (tadpoles)	Lowbidgee floodplain	Long term	80%	Likely increase	↑
		Current vs baseline	99%	Virtually certain increase	↑↑↑↑

3.3 Objective 3: Maintain and increase number of wetlands occupied by the endangered southern bell frog

The third set of objectives and targets focused on the southern bell frog in the Murrumbidgee WRPA. They are described in Table 12.

Table 12 **Objectives and targets set for southern bell frogs in the Murrumbidgee NSW LTWP**

Objective	WRPA	Wetland region	2024 5-year target
OS3: Maintain and increase number of wetland sites occupied by the endangered southern bell frog.	Murrumbidgee	Lowbidgee floodplain	Sites where southern bell frogs are known to be present: proportion of known sites where southern bell frogs are detected is maintained on a 3-year rolling average. Southern bell frogs detected in catchment annually.
	Murrumbidgee	Lowbidgee floodplain	Known sites of southern bell frog recruitment: proportion of known sites where potential recruitment is detected is maintained on a 3-year rolling average.

Note: Southern bell frog is listed as Endangered in New South Wales (*Biodiversity Conservation Act 2016*)

Trends in southern bell frogs

Bayesian trend analyses showed that distribution, breeding activity, breeding success and abundance of southern bell frogs were increasing with high likelihood in the Lowbidgee floodplain over the 2014 to 2022 and 2019 to 2022 periods (Figure 9, Table 13). These outcomes exceeded the 2024 targets to maintain detection and the proportion of sites where potential recruitment occurred on a 3-year rolling average. These outcomes therefore met the overarching objective to maintain and increase the number of wetland sites occupied by southern bell frogs in the Lowbidgee floodplain. Southern bell frogs were also detected in each year, therefore meeting the target to detect the species every year in the reporting period.

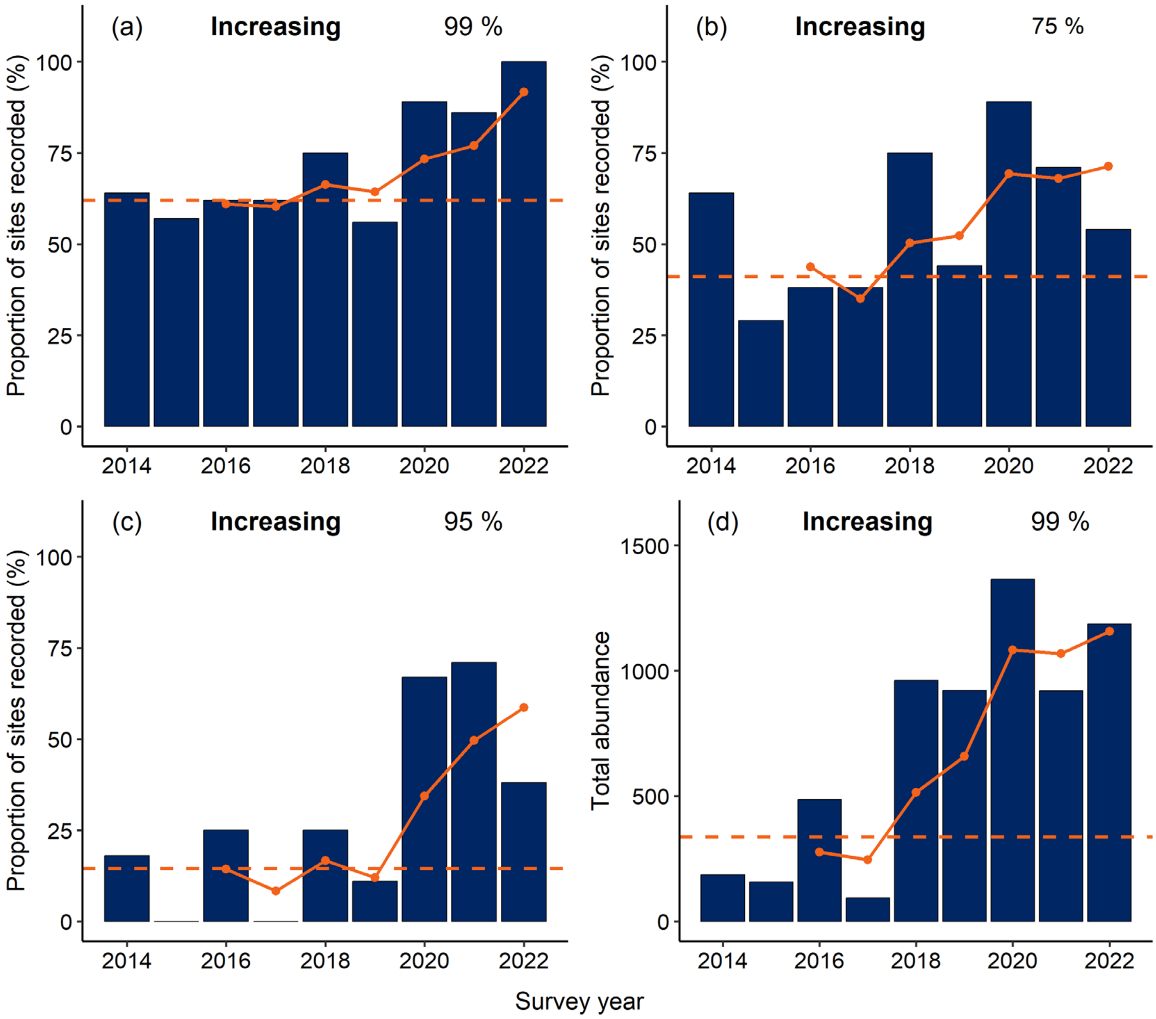

Figure 9 **Summary of trends for the nationally vulnerable southern bell frog (Litoria raniformis) in the Lowbidgee floodplain: (a) proportion of sites recorded, (b) proportion of sites where breeding was recorded, (c) proportion of sites where successful breeding outcomes were recorded (tadpoles), and (d) total abundance. The dashed line shows the median values from the baseline period (2014 to 2019). The dotted line shows the LTWP target a 3-year rolling average. Long-term trends are reported for the 2014 to 2022 period. Data collected by CSU as part of the CEWH-funded Murrumbidgee LTIM/Flow MER programs**

Table 13 **Results of Bayesian trend analysis for southern bell frog indicators in the Lowbidgee floodplain. The overall trend for each indicator over the long term and in the current assessment period, and the likelihood of these outcomes (increase or decrease) are also shown**

Indicator	Timeframe	Likelihood of increase or decrease (%)	Overall trend	Code
Distribution	Long term	99%	Virtually certain increase	↑↑↑↑
	Current vs baseline	99%	Virtually certain increase	↑↑↑↑
Breeding activity	Long term	75%	Likely increase	↑
	Current vs baseline	95%	Extremely likely increase	↑↑↑
Breeding success	Long term	95%	Extremely likely increase	↑↑↑
	Current vs baseline	99%	Virtually certain increase	↑↑↑↑
Abundance	Long term	99%	Virtually certain increase	↑↑↑↑
	Current vs baseline	99%	Virtually certain increase	↑↑↑↑

The SoS southern bell frog program was initiated to monitor sites that received environmental water ('priority sites') to support southern bell frog populations (Figure 10) as well as additional sites that might support the species in the future ('surveillance sites'). The number and spatial arrangement of SoS sites surveyed varied across water years depending on water availability. Following a slight initial decrease, the 3-year rolling average for southern bell frog presence at priority sites increased from 2021 to 2023, which is consistent with the increasing trends determined from the data collected by CSU.

The increase in the number of sites where southern bell frogs were detected over the last decade was supported by compiling records from the CSU monitoring programs (LTIM/Flow MER programs), the department's SoS southern bell frog project and other incidental observations (from the department's waterbird surveys). These demonstrated that the data exceeded the 2024 targets to maintain detection on a 3-year rolling average. An initial 3-year rolling average of 5.7 sites was recorded for 2019–20 increasing to a 3-year average of 22.3 sites in 2022–23 (2020–21: 10, 2021–22: 17.7). Total sites where southern bell frogs were detected increased from 7 sites in 2007 to 2009 to 54 sites in 2019 to 2023 (Figure 11). The increase in southern bell frog detections coincided with increases in inundation from natural flows and the delivery of environmental water. Environmental water was delivered in most years over the

2007 to 2012 period and was the only source of inundation in 2019 to 2021. Two consecutive large-inundation events occurred in 2021 to 2023 when water for the environment was delivered following natural high flows to maintain inundation duration at key sites (Figure 11).

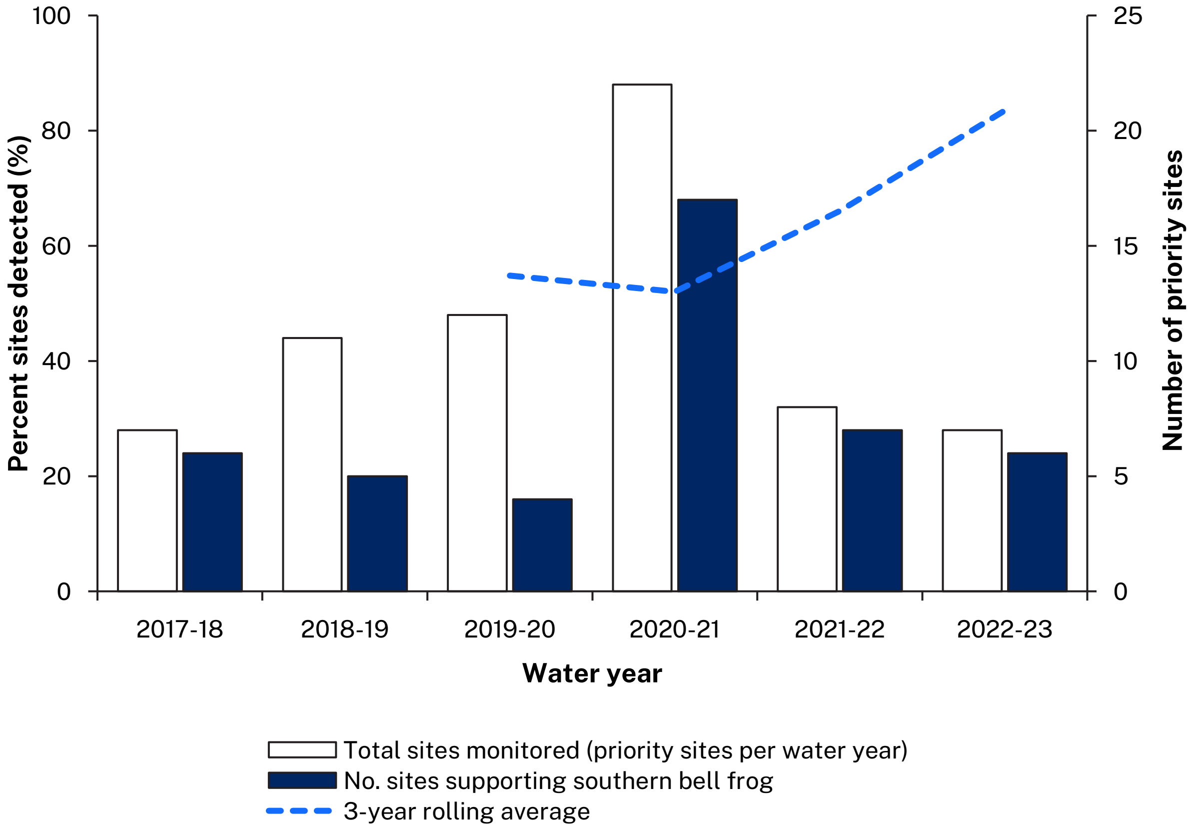

Figure 10 **Southern bell frog distribution recorded in the Lowbidgee floodplain in each water year in the 2017 to 2022 period through the SoS monitoring program. The total number (and spatial arrangement) of priority wetland sites monitored varied across water years, expanding in 2020–21. Note: due to very high levels of inundation, sites with acoustic data available are presented in 2022–23 (not necessarily only 'priority' sites)**

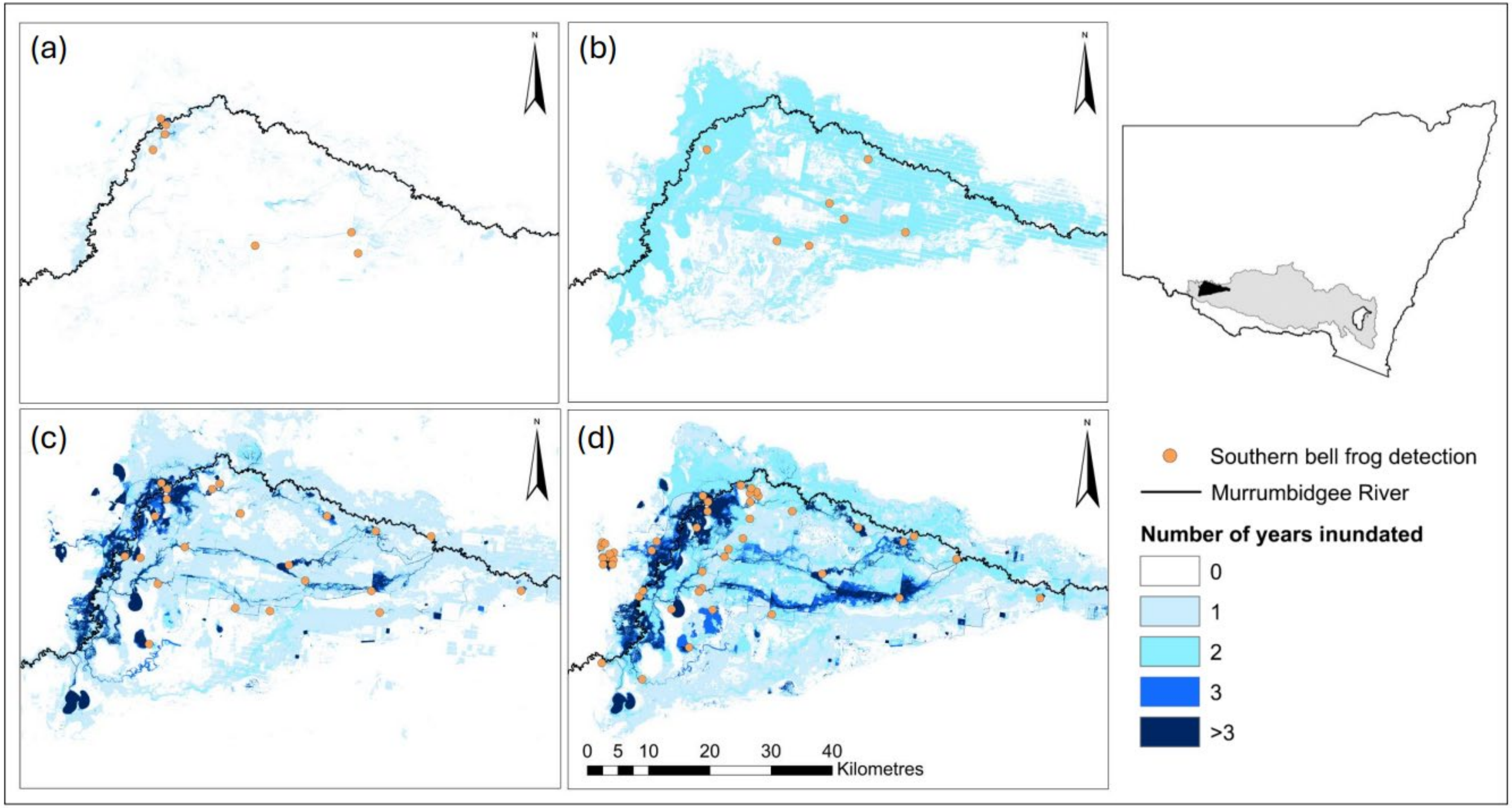

Figure 11 The distribution of sites where southern bell frogs (orange dots) were detected in the Lowbidgee floodplain in the Murrumbidgee WRPA in the NSW MBD (inset) during (a) 2007 to 2010 (7 sites), (b) 2010 to 2012 (8 sites), (c) 2014 to 2019 (21 sites) and (d) 2019 to 2023 (54 sites) periods. Note the inundation maps indicate the number of times the location (pixel) was annually inundated in each monitoring period

4. Discussion

4.1 Current status and trends of flow-dependent frog species in monitored wetlands

The reliability of the frog data collected in the Gwydir Wetlands, Macquarie Marshes and Lowbidgee floodplain was assessed as ‘good’. This is largely because consistent methods were used with spatial spread over regular timeframes that included data collected before and during the assessment period. Trends were mostly stable, both long term and when comparing the current and baseline periods, giving high confidence that the targets were met (Table 18). Increasing trends in the distribution, abundance, breeding activity and potential recruitment of the endangered (NSW listing) southern bell frog were detected in the Lowbidgee floodplain. The delivery of environmental water to provide refuge habitat in dry periods and extend inundation duration where possible in wetter periods, has likely contributed to the stable and increasing trends observed for flow-dependent frogs in these wetland regions.

4.2 Is this result expected and why are we seeing these outcomes?

Nearly all frogs recorded during the repeated surveys over the 2019 to 22 period were flow-dependent frog species. This was also the case in the previous 2014 to 2019 reporting period (Walcott et al. 2020). Detections of these species and their breeding activity fluctuated according to patterns in wetland inundation in each wetland region. The availability of wetland habitat varied considerably over the course of the 2019 to 2023 reporting period. At the beginning of 2019–20, widespread dry conditions occurred across the MDB providing little wetland habitat for frog breeding with some environmental water delivered to maintain critical refuge habitats in the Lowbidgee floodplain and Gwydir Wetlands. This was particularly pronounced in the Macquarie Marshes where there was no inundation at sites routinely monitored in spring 2019, and therefore no breeding. Delivery of environmental water created drought refuges in the Lowbidgee floodplain and Gwydir Wetlands and supported breeding activity at these sites. Increasing wet conditions in the 2020 to 2022 period allowed for delivery of more environmental water alongside natural large-inundation events. High catchment rainfall and inflows resulted in 2 consecutive years of extensive inundation with water delivered to maintain inundation durations at key sites.

Analyses of frog survey data collected for wetlands in the northern MDB (Gwydir Wetlands and Macquarie Marshes) from 2015 to 2020 identified 2 key features of the flow pulse linked to breeding success for flow-dependent frog species living in these systems (Ocock et al. 2024). The extent of inundation (related to the size of a flow event) was the most important driver of breeding activity (indicated by calling activity). Whereas the volume of river flow in the preceding months (reflecting duration of high river flows) was most important factor for increasing breeding success.

Where the delivery of water increased the duration of inundation, this contributed to stable and positive trends for flow-dependent frogs. This was consistent across all indicators (species richness, distribution and breeding) across most regions. The declining trend for frog abundance in the Gwydir Wetlands suggests the strong impact of the extended dry conditions in the 2019–20 period on populations.

4.3 How has the Basin Plan (i.e. environmental water) contributed?

The delivery of environmental water during dry times in the reporting period provided refuge habitat for some flow-dependent frogs. It also provided breeding opportunities by enhancing inundation extent and duration when water was available. Targeted watering of key sites provided refuge habitat in an otherwise dry landscape at several key sites during the very dry conditions in 2019–20. These included several sites in the Lowbidgee floodplain and Gwydir Wetlands, with flow-dependent frogs detected at sites in response to water delivery. Following the very dry conditions, multiple deliveries of environmental water were made across the wetland regions to complement natural inflows. These deliveries extended the duration of inundation, with widespread frog breeding activity and success observed as a response. In some cases, environmental water was solely used to inundate the wetlands (e.g. Lowbidgee floodplain in 2020–21), supporting flow-dependent frog breeding, including southern bell frogs, in an otherwise dry landscape (Wassens et al. 2022).

The approach to deliver environmental water to provide refuge and to extend the duration of inundation has likely contributed to the stable trends observed for flow-dependent frogs in these catchments. For example, in the Murrumbidgee WRPA there were 8 watering actions where southern bell frogs were listed as one of the primary watering objectives in the 2019 to 2023 period. This approach likely improved the status of this species, with southern bell frogs recorded at more wetlands over the last decade (Figure 3, DPIE 2021; Wassens et al. 2023; Waudby et al. 2021a).

Large natural inundation events are also important for providing extended breeding opportunities for a broad range of frog species (Wassens 2008; Ocock et al. 2016). They are also important for increasing the overall abundance of frogs and for connecting otherwise isolated populations. These large events have important carryover effects for frog communities in successive years. Conversely, prolonged dry periods between inundation events can result in significant population declines and local extinctions (Mac Nally et al. 2014).

4.4 What is being done to meet and monitor objectives in the future?

Extended dry periods threaten flow-dependent frog species in wetlands in the MDB. Providing refuge habitat for key species such as the southern bell frog is critical for long-term recovery and is likely to benefit all flow-dependent species. Targeted watering of key wetland habitats over spring and summer for at least 3 to 4 months is also important to support regular successful breeding in flow-dependent frog species. This is particularly important for southern bell frogs in the southern MDB.

There are significant knowledge gaps for flow-dependent frog species in other wetland systems with limited monitoring data available for the lower Lachlan, mid Murrumbidgee and NSW Murray wetlands. There are also limited data on the distribution of the endangered Sloane's froglet (*Crinia sloanei)* (EPBC Act and BC Act) in floodplain wetlands that are river-fed, which is identified as an additional target under the 'Other Species' theme in the NSW Murray-Lower Darling LTWP (DPIE 2020d).

Recent work using frog monitoring data collected in the MDB has improved understanding of the responses of flow-dependent frog species to flows, and helped to guide the management of environmental water (Ocock et al. 2024), including for threatened species (Heard, 2023). This has included the development of metapopulation models for the southern bell frog in Coleambally, lower Murray and the Great Cumbung Swamp (lower Lachlan) regions (Heard 2021, 2022a, 2022b, 2023).

Commitment to long-term monitoring of frog species is essential for maintaining the spatial coverage of current monitoring programs for flow-dependent frog species in the NSW MDB. It is also important for supporting on-ground management and comprehensive evaluation of objectives and targets set in the LTWP 'Other Species' theme for 2029. The department expanded its annual frog monitoring project in 2023 to include the lower Lachlan to complement the 2021 expansion of the southern bell frog SoS project into this region. Further work is required to monitor and evaluate the responses of the endangered Sloane's froglet to environmental watering in the mid Murray region.

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Acknowledgements

We acknowledge the Traditional Custodians of wetlands in the NSW MDB and recognise their continuing connection to land, waters and culture. We pay our respects to their Elders past, present and emerging. We also thank the many landholders who support our surveys and allow access to their wetlands. Frog surveys were completed by staff from DCCEEW including NPWS. Funding for acoustic data collection from 2017 to 2024 was provided through the NSW Saving our Species Program (SoS) southern bell frog conservation project. Acoustic and ground surveys were approved under NSW NPWS Scientific Licence and DCCEEW Animal Ethics and Care Committee. CSU provided frog ground survey data collected in the Murrumbidgee as part of the CEWH-funded Flow MER and LTIM programs.

Appendices

Appendix A: Frog functional groups

Table 14 Frog species observed in wetlands in the NSW MDB arranged into 3 groups based on their habitat and breeding preferences (functional group). Note that there are additional species associated with instream habitats not included here (see DPE, 2023 for more detail)

Functional group	Scientific name	Common name	Broad habitat group	Breeding activity timing group
Flow-dependent	*Crinia parinsignifera*	Eastern sign-bearing Froglet	Ground non-burrowing lowland	Flexible
	Limnodynastes fletcheri	Barking marsh frog	Ground non-burrowing lowland	Flexible
	Limnodynastes interioris	Giant banjo frog	Burrowing	Flexible
	Limnodynastes salmini	Salmon striped frog	Ground non-burrowing lowland	Flexible
	Limnodynastes tasmaniensis	Spotted marsh frog	Ground non-burrowing lowland	Flexible
	Litoria latopalmata	Broad-palmed frog	Ground non-burrowing lowland	Spring–summer flexible
	Litoria peronii	Peron's tree frog	Arboreal-lowland	Spring–summer flexible
	Litoria raniformis	Southern bell frog	Ground non-burrowing lowland	Spring–summer flexible
Flow-ambivalent	*Litoria caerulea*	Green tree frog	Arboreal-lowland	Rain–spring–summer
	Litoria rubella	Desert tree frog	Arboreal-lowland	Rain–spring–summer
Flow-oblivious (burrowing species)	*Cyclorana alboguttata*	Striped burrowing frog	Burrowing	Rain–spring–summer
	Cyclorana cultripes	Knife-footed frog	Burrowing	Rain–spring–summer

Functional group	Scientific name	Common name	Broad habitat group	Breeding activity timing group
	Cyclorana platycephala	Water-holding Frog	Burrowing	Rain–spring-summer
	Cyclorana verrucosa	Warty water-holding frog	Burrowing	Rain–spring–summer
	Neobatrachus sudelli	Sudell's frog	Burrowing	Rain–winter–summer
	Notaden bennettii	Crucifix frog	Burrowing	Rain–spring–summer
	Uperoleia rugosa	Wrinkled toadlet	Burrowing	Rain–spring–summer

Appendix B: Information reliability assessment

Table 15 **Summary of information reliability assessment for datasets used to evaluate flow-dependent frog species richness, abundance and breeding activity. Reliability of data to assess flow-dependent frog species richness, abundance, and breeding activity for 3 monitored NSW MDB wetland regions (Gwydir Wetlands, Macquarie Marshes and Lowbidgee floodplain)**

Methods	Question	Answer and justification	Score out of 2
Methods used	Are the methods used appropriate to gather the information required for evaluation?	Yes	2
		Frog surveys in floodplain habitats which receive water for the environment have been completed throughout all 3 monitoring programs. The survey methods include nocturnal timed transects in spring-summer which are appropriate for detecting flow-dependent frog species and supports a meaningful evaluation of flow-dependent frog species richness and distribution over time (OS1). The ground survey methods are also effective in detecting multiple lines/indicators of evidence on breeding activity (calling males, and presence of tadpoles and/or metamorphs) providing insights into the distribution of breeding activity and relative breeding success (OS2). Fyke-netting, conducted only in the Lowbidgee floodplain, provided good coverage of tadpoles compared with the other monitoring programs.	
Standard methods	Has the same method been used over the sampling program?	Yes	2
		The same methods for surveying flow-dependent frog species were completed each year by experienced surveyors in each wetland region allowing for meaningful comparison across the baseline and assessment periods, which included a range of hydrological conditions.	
Representativeness			
Space	Has sampling been conducted across the spatial extent of the studied process or biota within the [wetland	Somewhat	1
		Frog survey sites in the 3 wetland regions incorporated a range of habitat types. Established survey sites were revisited during repeat surveys each year in each wetland system over both the baseline and assessment periods. There were fewer sites in some water management areas and therefore some parts of each system were under-represented (e.g. East Marsh,	

Methods	Question	Answer and justification	Score out of 2
	being assessed] with equal effort?	Macquarie Marshes; Mehi River, Gwydir Wetlands; North Redbank system, Lowbidgee floodplain). During periods of high flows some sites were not accessible on ground and a change in landholder permissions in the Gwydir Wetlands resulted in a loss of a small number of survey sites in recent years.	
Time	Has the duration of sampling been sufficient to represent change over the assessment period?	Yes	2
		Frog surveys in the Gwydir Wetlands and Macquarie Marshes commenced in 2015-16. Data from the 2015-17 period was used to establish a baseline for setting objectives and targets for both regions. Frog surveys in the Lowbidgee floodplain commenced in 2014-15 and the 2014-19 period was used to establish a baseline for setting objectives and targets for this region. Data has been collected every year since allowing for comparison between the baseline and assessment periods.	
Repetition			
Space	Has sampling been conducted at the same sites/area over the assessment period?	Somewhat	1
		Established survey sites were revisited in each wetland system over both the baseline and assessment periods. During periods of high flows and prolonged very dry conditions, some sites were not surveyed (alternative sites were surveyed in the Lowbidgee floodplain region). A change in landholder permissions in the Gwydir Wetlands meant loss of a small number of survey sites in recent years and so alternative sites were surveyed.	
Time	Has the frequency of sampling been sufficient to represent change over the assessment period?	Yes	2
		Repeated annual spring surveys were completed in September and November (2 trips per region per year) in the Gwydir Wetlands and Macquarie Marshes, and bimonthly between September and March in the Lowbidgee floodplain (4 trips per year). This timing encompassed the peak breeding season of most flow-dependent frog species. In the Gwydir Wetlands, additional summer surveys were completed at a subset of sites in some years (this was included in assessment of the species richness target). The 4 sets of surveys done	

Methods	Question	Answer and justification	Score out of 2
		completed in the Lowbidgee floodplain each year provided very good temporal coverage of flow-dependent frog breeding responses to wetland inundation. The spring and summer surveys provided good coverage of flow-dependent frog breeding responses to wetland inundation. These repeat surveys accounted for variability in inundation extent within a year and between years, and detection of breeding activity (male calling activity) each year and breeding success (tadpoles and/or metamorphs).	
Final score		10/12	
Information reliability		Good	

Note

The Gwydir Wetlands and Macquarie Marshes data was collected through the DCCEEW Water for the Environment MER Program. The Lowbidgee floodplain data was collected by CSU through the Commonwealth Environmental Water Office Long Term Intervention and Flow MER (Monitoring, Evaluation and Research) projects.

Table 16 **Summary of information reliability assessment for datasets used to evaluate southern bell frog distribution and breeding activity. Reliability of data to assess the distribution and breeding activity of the endangered southern bell frog in the Lowbidgee floodplain. Ground survey data was collected by CSU through the Commonwealth Environmental Water Office Long Term Intervention Monitoring and Flow MER (Monitoring, Evaluation and Research) programs**

Methods	Question	Answer and justification	Score out of 2
Methods used	Are the methods used appropriate to gather the information required for evaluation?	Yes	2
		A combination of ground surveys and acoustic monitoring data was used to gather information on the distribution and breeding activity of southern bell frogs in the Lowbidgee floodplain. These complementary survey methods (nocturnal timed transects and acoustic monitoring) are appropriate for and help improve detection of the southern bell frog. Along with the seasonal timing of the surveys and monitoring, these methods allow for meaningful evaluation of southern bell frog distribution and breeding between the baseline and assessment periods (OS3a). The ground survey methods are also effective in detecting multiple lines/types of breeding evidence (calling males, and presence of tadpoles and/or metamorphs) providing insight into the distribution of breeding activity and relative breeding success of southern bell frog (OS3a).	
Standard methods	Has the same method been used over the sampling program?	Yes	2
		The same methods for surveying flow-dependent frog species were completed in the same survey sites each year by experienced surveyors in the CSU monitoring program allowing for meaningful comparison across the baseline and assessment periods, which included a range of hydrological conditions. The methods included timed nocturnal surveys (30 minutes equivalent) and tadpole netting surveys in each site. The SoS program included deployment of acoustic recorders and ground surveys at priority wetlands and a selection of surveillance sites prior to water delivery to assess calling activity over the breeding season. When southern bell frogs were not heard	

Methods	Question	Answer and justification	Score out of 2
		calling during the initial 5-minute listening period, timed searches were completed for 30 minutes (equivalent) at a subset of sites each year.	
Representativeness			
Space	Has sampling been conducted across the spatial extent of the studied process or biota within the [wetland being assessed] with equal effort?	Somewhat	1
		The spatial coverage of the combined monitoring programs was comprehensive to include a range of habitat types and priority southern bell frog sites across the Redbank and Gayini Wetland systems. We used the CSU ground data to assess the distribution, breeding activity and abundance of southern bell frogs and netting data to assess breeding success but survey coverage was limited to 8 individual wetland sites which did not include the northern part of the Redbank system.	
Time	Has the duration of sampling been sufficient to represent change over the assessment period?	Yes	2
		CSU frog surveys in the Lowbidgee floodplain commenced in 2014-15 and data has been collected every year since allowing for comparison between the baseline and assessment periods. SoS monitoring commenced in 2017-18 and acoustic and ground data has been collected every year since.	
Repetition			
Space	Has sampling been conducted at the same sites/area over the assessment period?	Somewhat	1
		Established survey sites in the CSU monitoring program were revisited over both the baseline and assessment periods. There was limited ground access in spring and early summer 2022 due to high river flows. There was some variation in the ground and acoustic survey locations monitored in the SoS program each year as the sampling programs focused on different wetlands from year to year according to which areas were receiving environmental water and wetlands which could be accessed on ground.	

Methods	Question	Answer and justification	Score out of 2
Time	Has the frequency of sampling been sufficient to represent change over the assessment period?	Yes	2
		The CSU monitoring program supported bimonthly ground and netting surveys between September and March (4 trips per year). This timing encompassed the peak breeding season of the southern bell frog. The SoS program supported continuous acoustic monitoring from prior to water delivery until mid-March or when wetlands dried. This provided fine-scale temporal coverage of southern bell frog calling at select sites, capturing responses to flows over the entire breeding season. Complementary ground surveys were also completed 1-3 times at most sites each water year (from October to March) at targeted watered sites, as well as sites in proximity. Some acoustic recorders did not record over the whole monitoring period each year due to technical issues. There was also limited ground access in spring and early summer 2022 due to high river flows which prevented and/or delayed deployment of acoustic recorders and delayed ground surveys till summer. Therefore, there were gaps in coverage for some sites in both the CSU and SoS monitoring programs.	
Final score		10/12	
Information reliability		Good	

Acoustic and ground survey data was collected through the NSW DCCEEW's Saving our Species Program southern bell frog project.

Appendix C: Bayesian model interpretation

A Bayesian modelling approach was used to determine trends in ecological indicator variables. Outputs from this analysis included Bayesian modelling plots that showed the credible intervals (starting at zero) until an estimate of zero was excluded to provide information for 3 reporting categories (Table 5) as per the trend assessment procedure outlined by McBride (2019). The mean of the posterior distribution and credible intervals were used to determine if trends were increasing, stable or declining (Figure 12). This same approach was used to compare the current reporting period (2019–23) with the baseline period (2012–16) (Figure 13 and Figure 14).

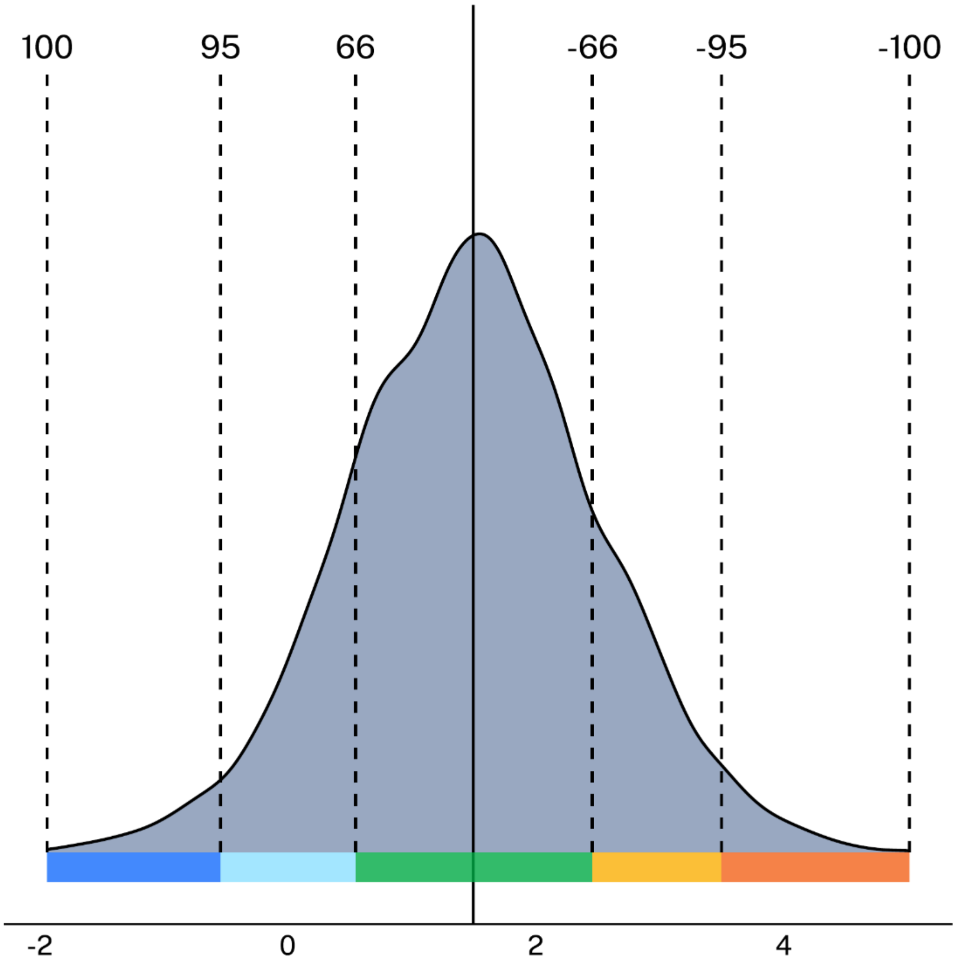

Figure 12 **Trend analysis outcomes were estimated by gradually increasing the credible intervals (starting at zero) until an estimated slope of zero was excluded and then simplified into one of 3 trend report card: increasing, stable, or declining (see Table 5). If the mean of the sample distribution is located to the left of an estimated slope of zero, the trend is negative (declining), while positive if it is located to the right (increasing)**

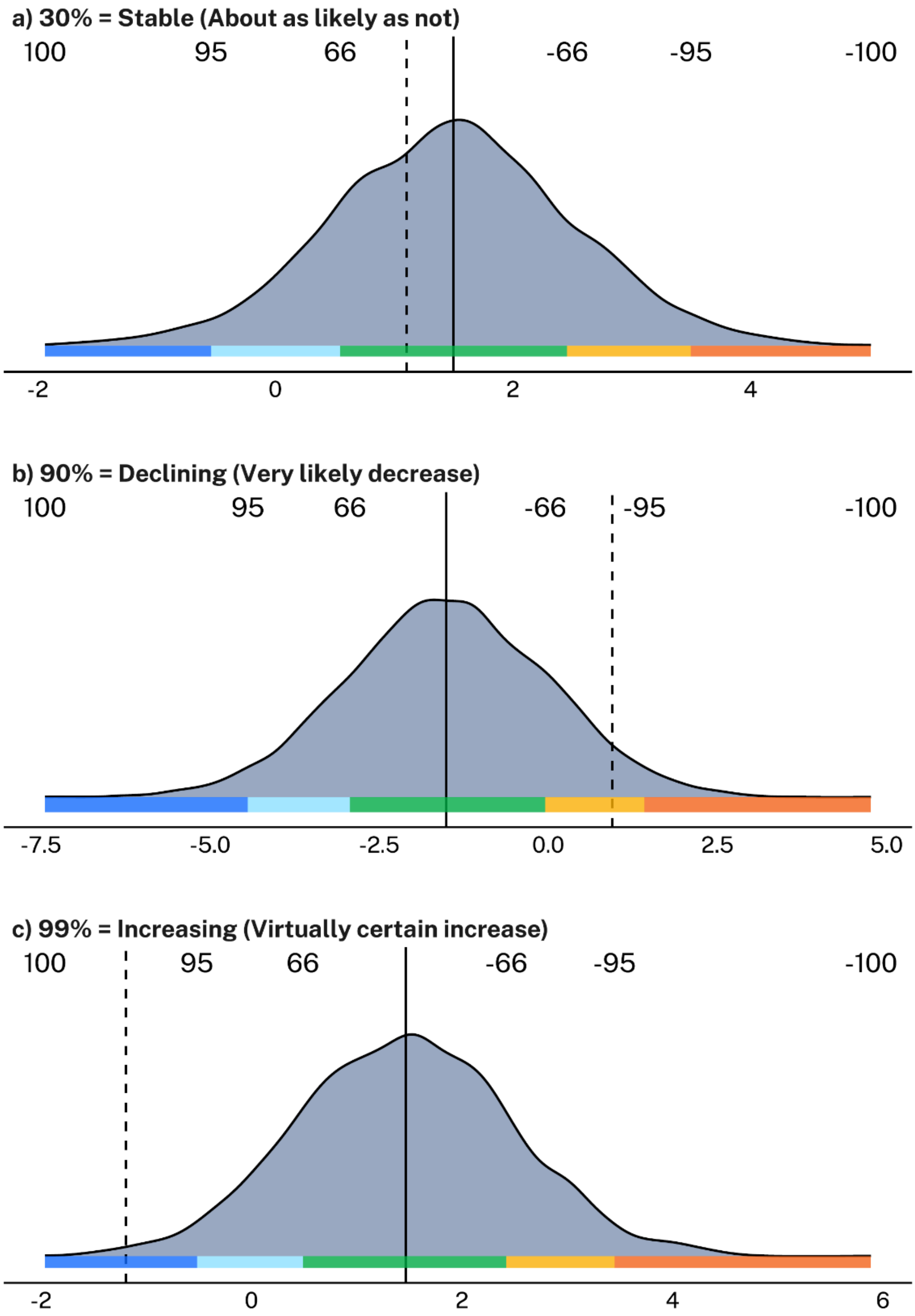

Figure 13 An example of (a) stable (b) declining and (c) increasing long-term trends. The outcome is determined by the location of the mean of the posterior distribution (solid black line) and credible intervals (small dotted black line) relative to an estimated slope of zero (dashed black line)

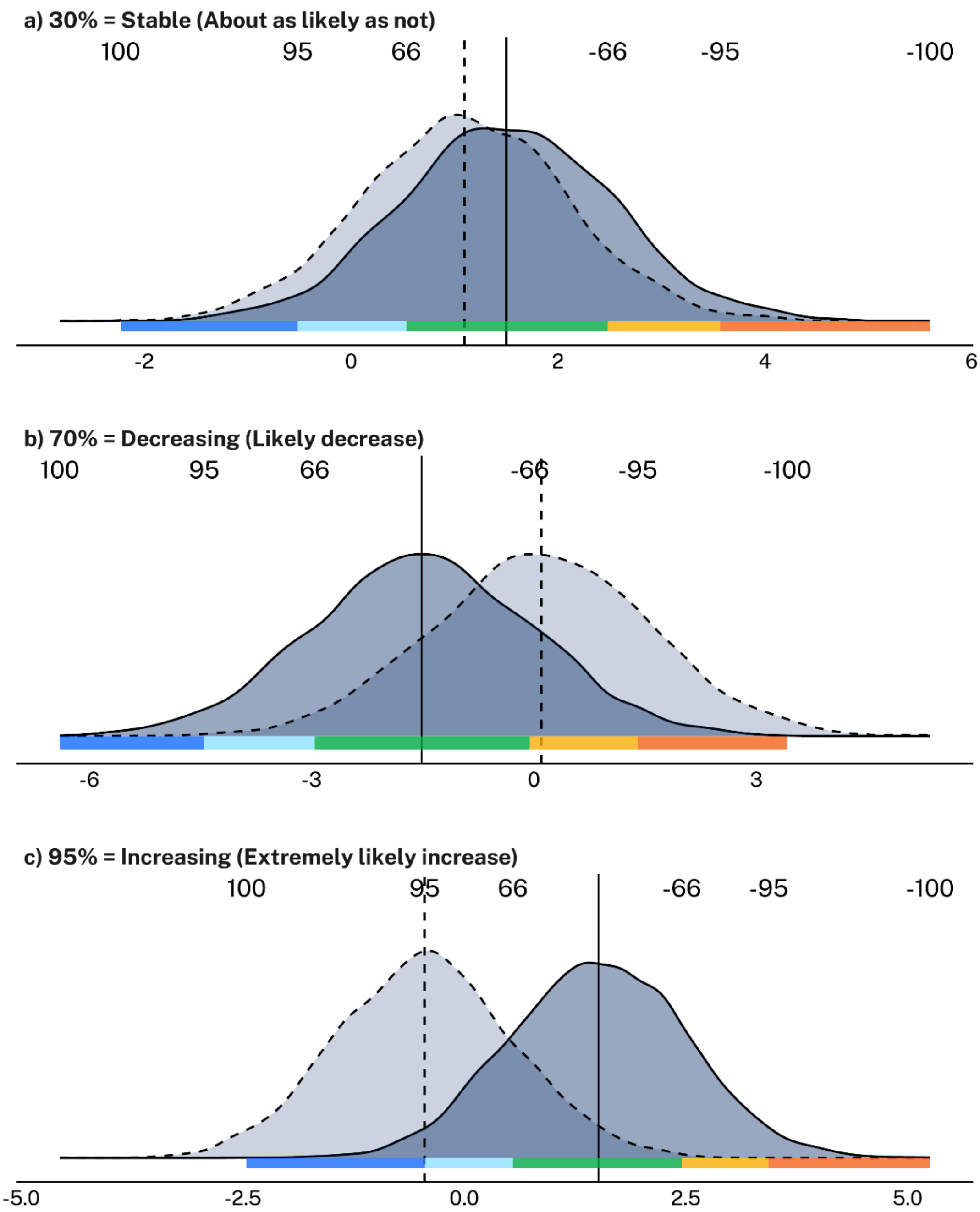

Figure 14 **An example of (a) stable (b) declining and (c) increasing trends comparing the current to the baseline period. The outcome is determined by the location of the mean of the posterior distribution (solid black line) and credible intervals (small dotted black line) relative to the mean of the posterior distribution of the sample population from the baseline period (dashed black line)**

Appendix D: Bayesian model outputs

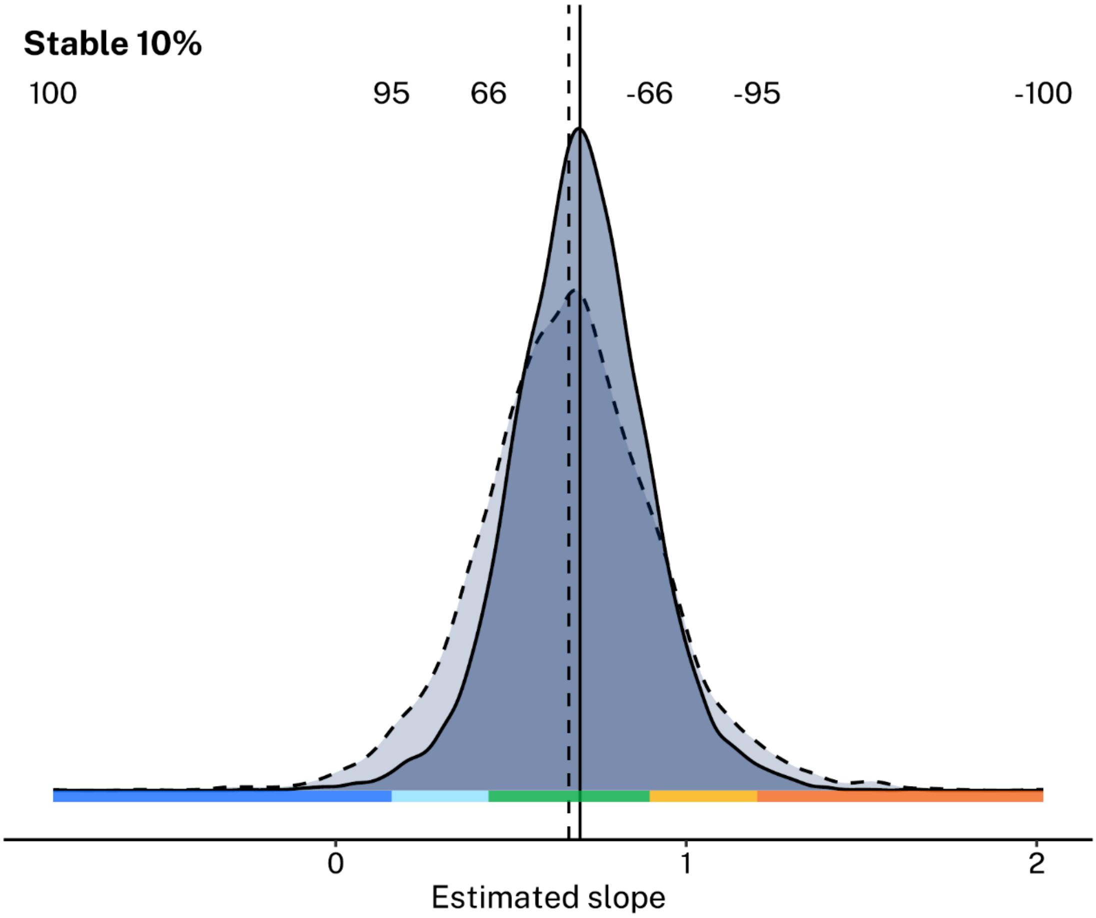

Figure 15 **Bayesian plot for flow-dependent frog species richness in the Macquarie Marshes. (Note: all flow-dependent frog species were detected each water year in the Gwydir Wetlands and Lowbidgee floodplain). The outcome is determined by the location of the mean of the posterior distribution (solid black line) relative to the mean of the posterior distribution of the sample population from the baseline period (dashed black line)**

Table 17 **Bayesian modelling assessment of species richness trends for all flow-dependent frogs in each wetland region. The likelihood of improvement in annual species richness of all catchment-specific flow-dependent frog species, their confidence rating**

Wetland region	Species	Timeframe	Likelihood of outcome	Status	Code
Gwydir Wetlands	*L. tasmaniensis*	Current vs baseline	0%	Stable	=
	L. tasmaniensis	Long-term	25%	Stable	=
	L. fletcheri	Current vs baseline	50%	Stable	=
	L. fletcheri	Long-term	10%	Stable	=
	C. parinsignifera	Current vs baseline	99%	Stable	=
	C. parinsignifera	Long-term	40%	Stable	=
	L. peronii	Current vs baseline	30%	Stable	=
	L. peronii	Long-term	40%	Stable	=
	L. latopalmata	Current vs baseline	10%	Stable	=
	L. latopalmata	Long-term	40%	Stable	=
	L. salmini	Current vs baseline	94%	Very likely increase	↑↑
	L. salmini	Long-term	85%	Likely increase	↑
Macquarie Marshes	*L. tasmaniensis*	Current vs baseline	−95%	Extremely likely decrease	↓↓↓
	L. tasmaniensis	Long-term	35%	Stable	=
	L. fletcheri	Current vs baseline	−70%	Likely decrease	↓
	L. fletcheri	Long-term	40%	Stable	=
	C. parinsignifera	Current vs baseline	0%	Stable	=
	C. parinsignifera	Long-term	0%	Stable	=
	L. peronii	Current vs baseline	0%	Stable	=
	L. peronii	Long-term	40%	Stable	=

Wetland region	Species	Timeframe	Likelihood of outcome	Status	Code
	L. latopalmata	Current vs baseline	30%	Stable	=
	L. latopalmata	Long-term	10%	Stable	=
	L. salmini	Current vs baseline	50%	Stable	=
	L. salmini	Long-term	55%	Stable	=
Lowbidgee floodplain	*L. tasmaniensis*	Current vs baseline	25%	Stable	=
	L. tasmaniensis	Long-term	−80%	Likely decrease	↓
	L. fletcheri	Current vs baseline	60%	Stable	=
	L. fletcheri	Long-term	20%	Stable	=
	C. parinsignifera	Current vs baseline	55%	Stable	=
	C. parinsignifera	Long-term	−70%	Likely decrease	↓
	L. peronii	Current vs baseline	−70%	Likely decrease	↓
	L. peronii	Long-term	40%	Stable	=
	L. interioris	Current vs baseline	99%	Virtually certain increase	↑↑↑↑
	L. interioris	Long-term	97%	Extremely likely increase	↑↑↑
	L. raniformis	Current vs baseline	99%	Virtually certain increase	↑↑↑↑
	L. raniformis	Long-term	99%	Virtually certain increase	↑↑↑↑

Table 18 Summary of trends in flow-dependent frog indicators in each wetland region. Trend directions are classed as increasing (shades of blue), stable (green), declining (shades of orange) as per Table 5. The likelihood values (%) provide confidence values for the direction of the trends (increasing or decreasing) (see Appendix C)

Table 18a Gwydir Wetlands

Indicator	Current vs baseline	Long term
LTWP objective OS1		
Species richness	=	=
Distribution:		
C. parinsignifera	=	=
L. fletcheri	=	=
L. latopalmata	=	=
L. peronii	=	=
L. salmini	↑↑	↑
L. tasmaniensis	=	=
Abundance	↓↓↓↓	↓
LTWP objective OS2		
Breeding activity	=	=
Breeding success	=	=

Table 18b Macquarie Marshes

Indicator	Current vs baseline	Long term
LTWP objective OS1		
Species richness	=	=
Distribution:		
C. parinsignifera	=	=
L. fletcheri	↓	=
L. latopalmata	=	=
L. peronii	=	=
L. salmini	=	=
L. tasmaniensis	↓↓↓	=
Abundance	=	=
LTWP objective OS2		
Breeding activity	↓	=
Breeding success	=	=

Table 18c Lowbidgee floodplain

Indicator	Current vs baseline	Long term
LTWP objective OS1		
Species richness	=	=
Distribution:		
C. parinsignifera	=	↓
L. fletcheri	=	=
L. interioris	↑↑↑↑	↑↑↑
L. peronii	↓	=
L. raniformis	↑↑↑↑	↑↑↑↑
L. tasmaniensis	=	↓
Abundance	=	=
LTWP objective OS2		
Breeding activity	=	=
Breeding success	↑↑↑↑	↑
Distribution	↑↑↑↑	↑↑↑↑
LTWP objective OS3		
Breeding activity	↑↑↑	↑
Breeding success	↑↑↑↑	↑↑↑
Abundance	↑↑↑↑	↑↑↑↑

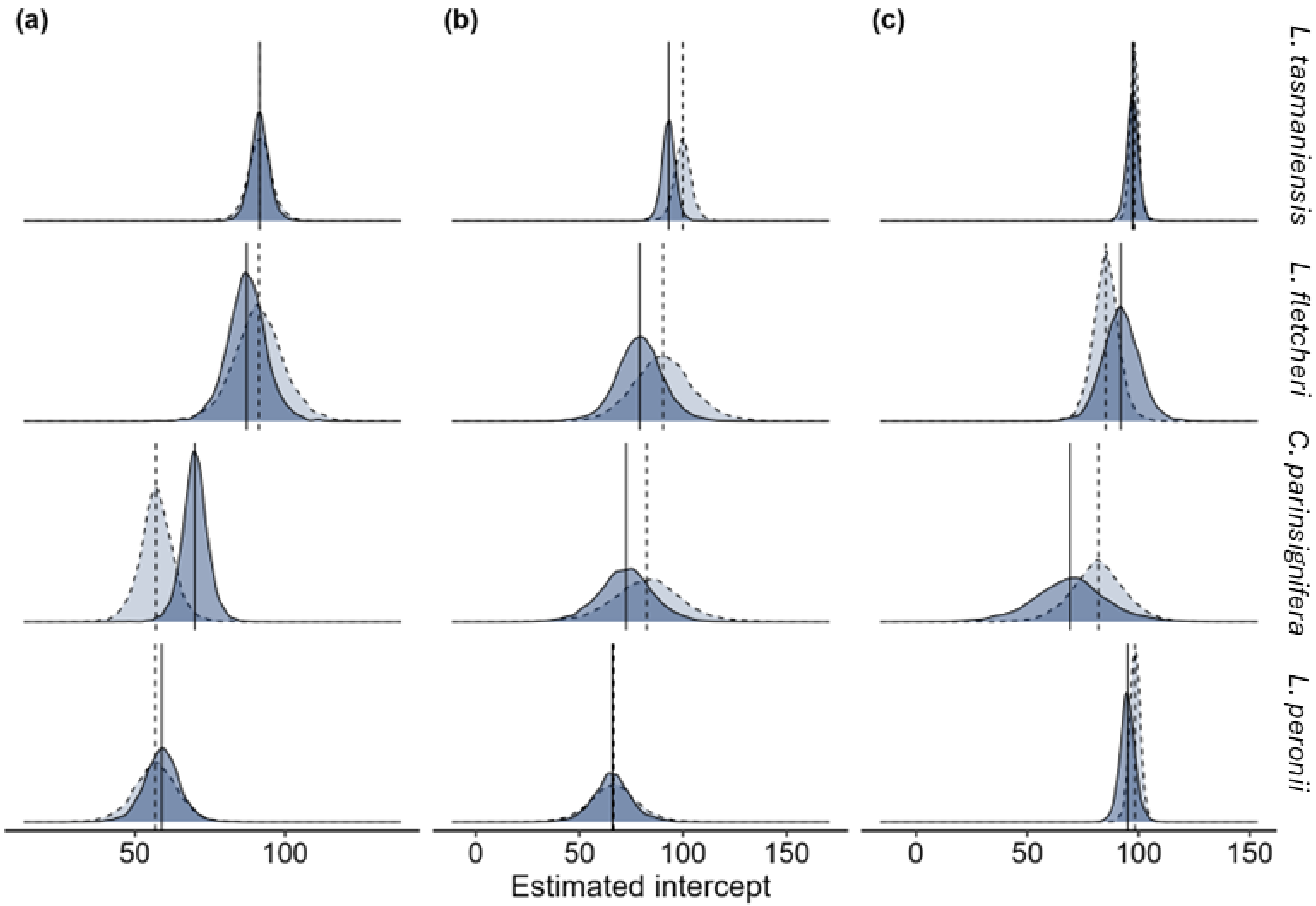

Figure 16 **Bayesian plots for individual flow-dependent frog species distributions in the (a) Gwydir Wetlands, (b) Macquarie Marshes and (c) Lowbidgee floodplain. The outcome is determined by the location of the mean of the posterior distribution (solid black line) relative to the mean of the posterior distribution of the sample population from the baseline period (dashed black line)**

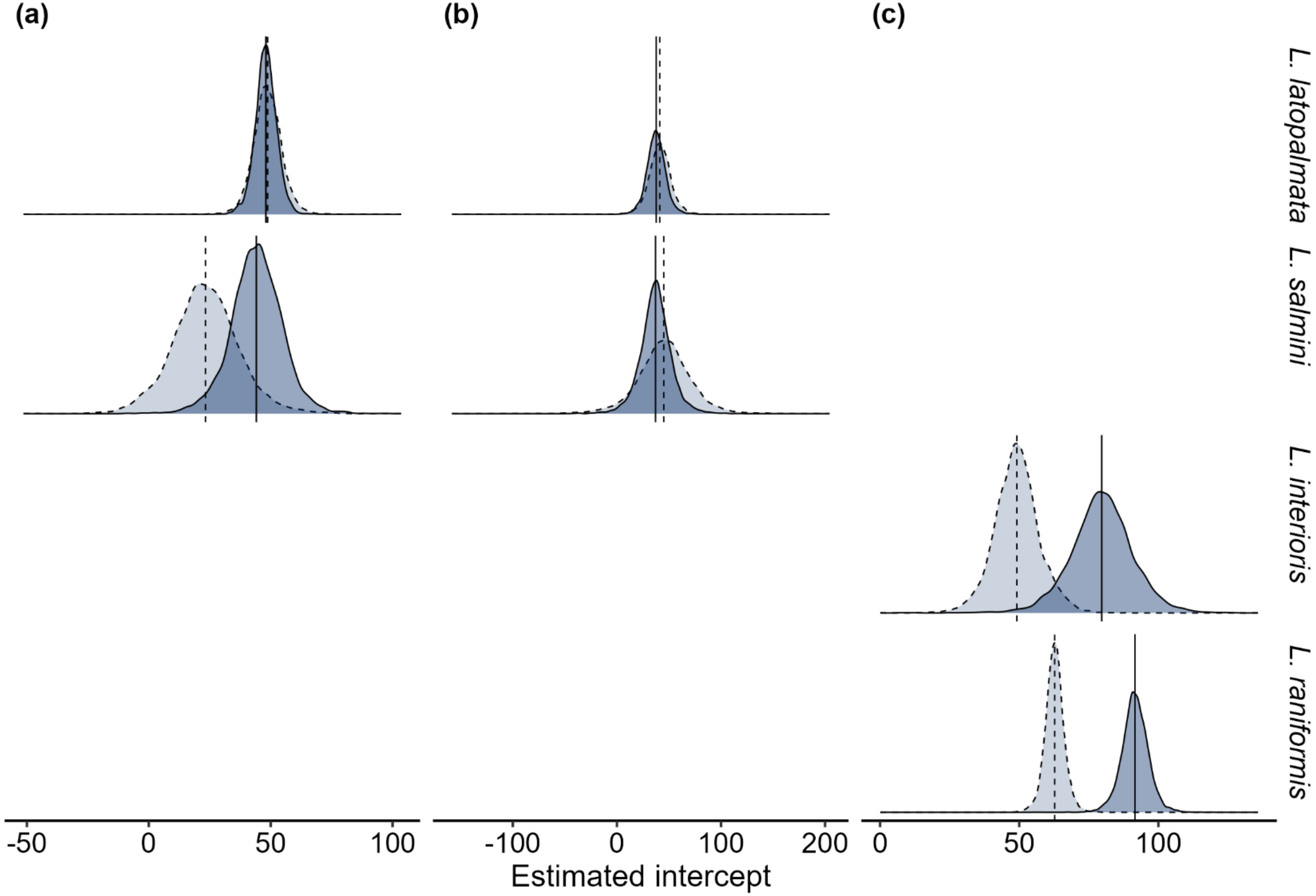

Figure 17 **Bayesian plots for individual flow-dependent frog species distributions in the (a) Gwydir Wetlands, (b) Macquarie Marshes and (c) Lowbidgee floodplain. The outcome is determined by the location of the mean of the posterior distribution (solid black line) relative to the mean of the posterior distribution of the sample population from the baseline period (dashed black line)**

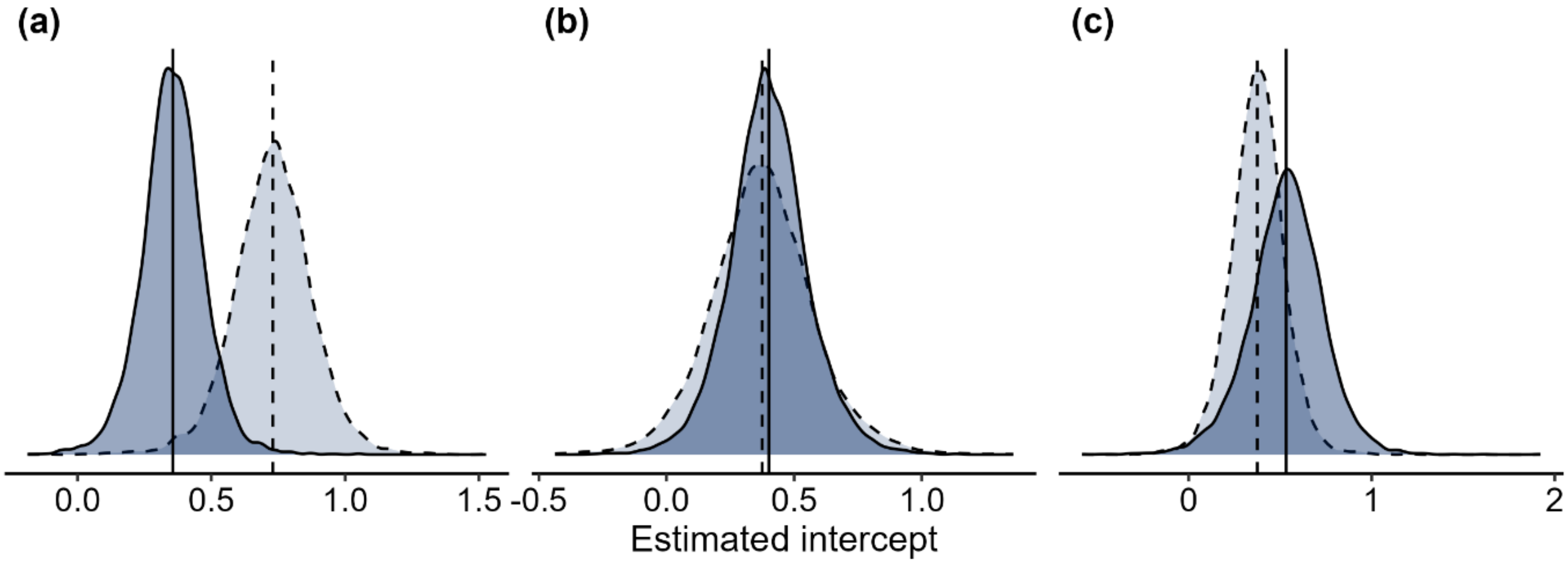

Figure 18 **Bayesian plots for abundance of flow-dependent frogs in the (a) Gwydir Wetlands, (b) Macquarie Marshes and (c) Lowbidgee floodplain. The outcome is determined by the location of the mean of the posterior distribution (solid black line) relative to the mean of the posterior distribution of the sample population from the baseline period (dashed black line)**

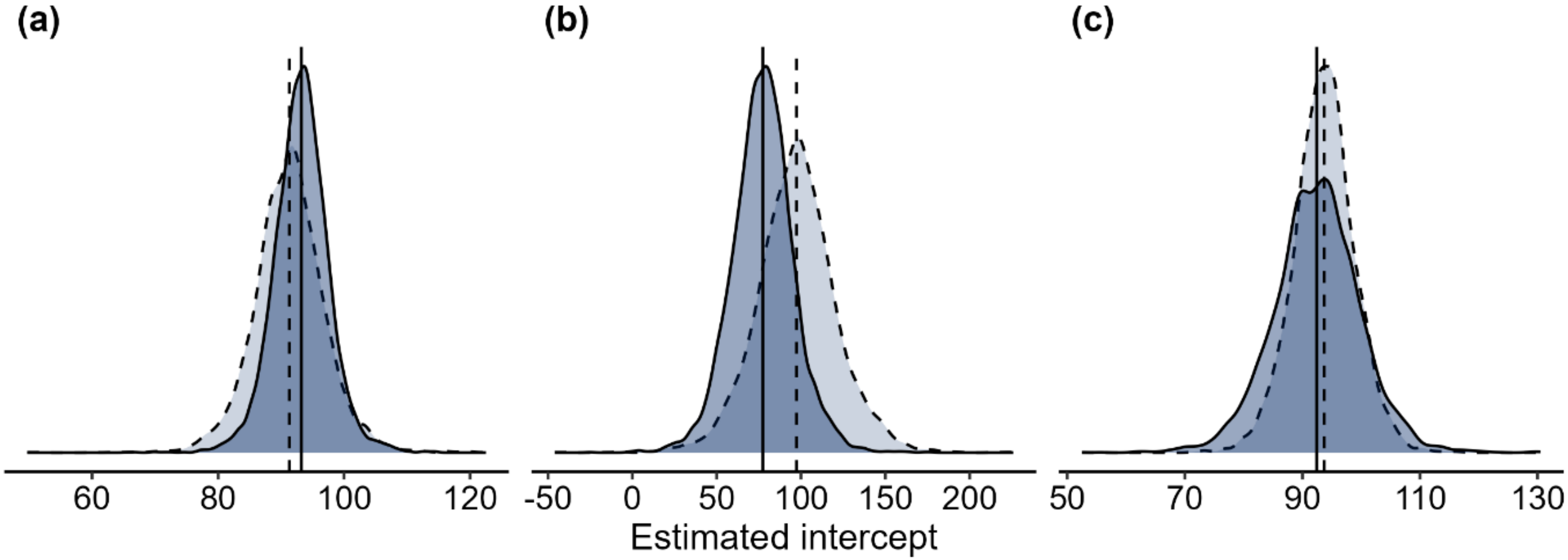

Figure 19 Bayesian plots for flow-dependent frog breeding in the (a) Gwydir Wetlands, (b) Macquarie Marshes and (c) Lowbidgee floodplain. The outcome is determined by the location of the mean of the posterior distribution (solid black line) relative to the mean of the posterior distribution of the sample population from the baseline period (dashed black line)

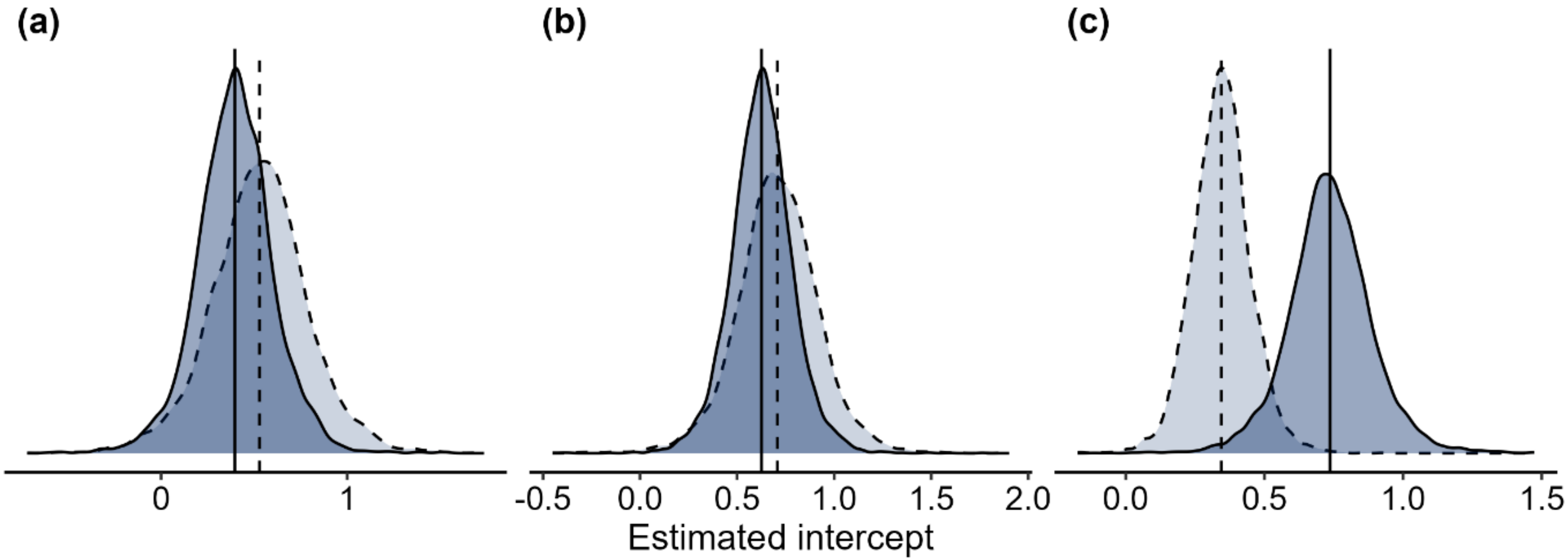

Figure 20 **Bayesian plots for flow-dependent frog breeding outcomes (metamorphs/tadpoles detected) in the (a) Gwydir Wetlands, (b) Macquarie Marshes and (c) Lowbidgee floodplain. The outcome is determined by the location of the mean of the posterior distribution (solid black line) relative to the mean of the posterior distribution of the sample population from the baseline period (dashed black line**

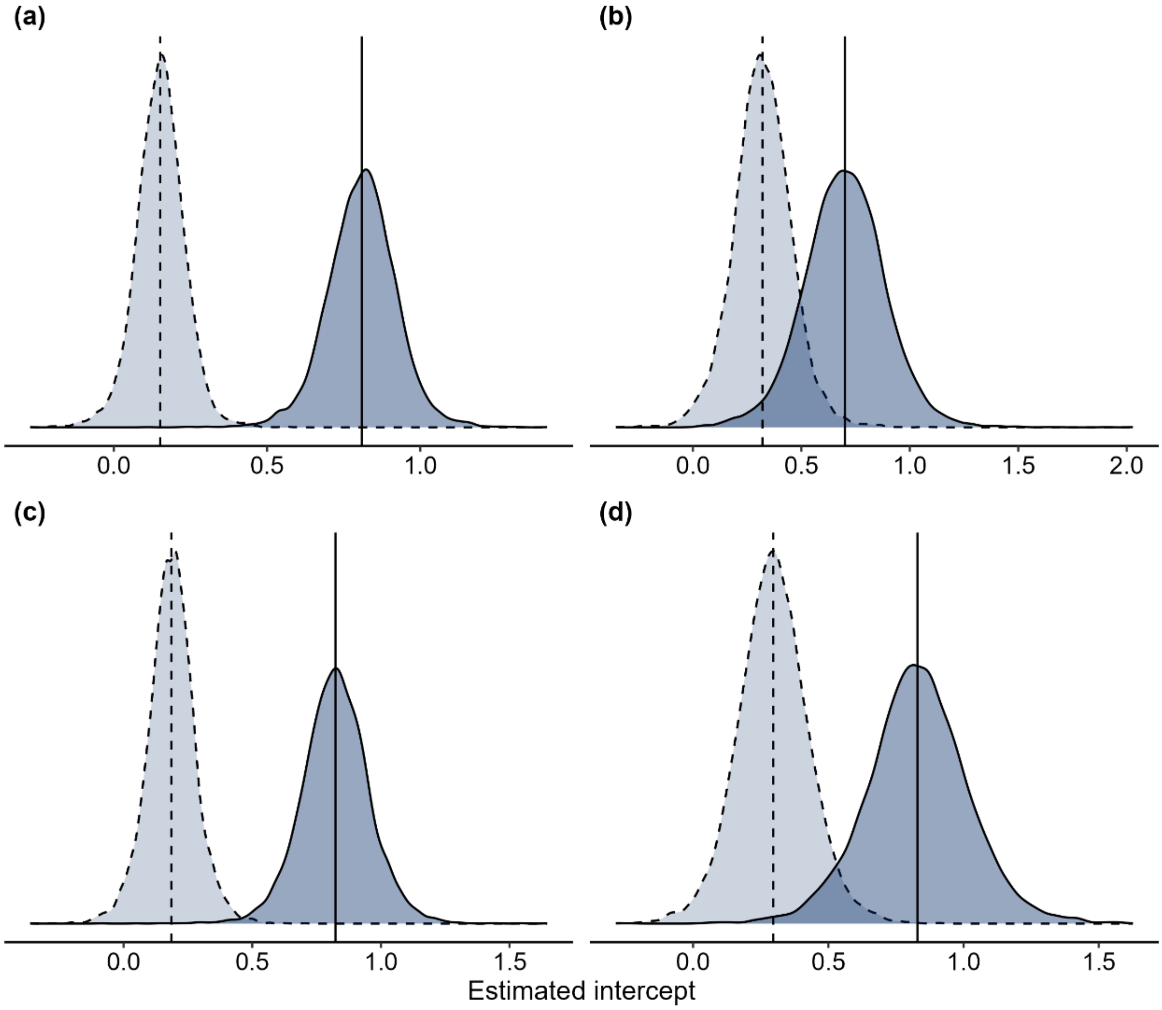

Figure 21 **Bayesian plots for the southern bell frog (*Litoria raniformis*) in the Lowbidgee floodplain: (a) total abundance (b) proportion of sites where breeding was detected (c) proportion of sites detected and (d) proportion of sites where successful breeding outcomes were recorded (tadpoles). The outcome is determined by the location of the mean of the posterior distribution (solid black line) relative to the mean of the posteriors distribution of the sample population from the baseline period (dashed black line)**