Monitoring Australasian bitterns in south-western NSW

Technical report supporting 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This resource may contain images or names of deceased persons in photographs or historical content.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: Australasian bittern, *Botaurus poiciloptilus*. Malcolm Carnegie, Lake Cowal Foundation

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Abbreviations

Term	
BC Act	*Biodiversity Conservation Act 2016* (NSW)
BLED	band limited energy detector
BWS	Basin-wide environmental watering strategy
CSU	Charles Sturt University
dB	decibels
DCCEEW	Department of Climate Change, Energy, the Environment and Water (NSW)
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999* (Cth)
Hz	hertz
LTWP	long-term water plan
MDB	Murray–Darling Basin
ML/d	megalitres per day
NPWS	National Parks and Wildlife Service (NSW)
NSW	New South Wales
PCT	plant community type
SNR	signal-to-noise ratio
SoS	Saving our Species Program (NSW)
WRPA	water resource planning area

Summary

The NSW Department of Climate Change, Energy, the Environment and Water (the department) monitors the health of wetlands in the Murray–Darling Basin (MDB), including outcomes from environmental water deliveries. Monitoring is done in collaboration with partner agencies and research groups across 4 main themes: flows and connectivity, wetland vegetation, waterbirds, and other species (frogs). The ecological objectives and targets for the waterbird theme are outlined in the NSW long-term water plans (LTWP) and align with the expected ecological outcomes specified in the Murray–Darling Basin Authority's Basin-wide environmental watering strategy.

The LTWPs have objectives and targets for maintaining waterbird species richness, which include threatened species. The Australasian bittern *(Botaurus poiciloptilus)* is a nationally endangered waterbird species dependent on wetlands for feeding and breeding (Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*). Once common across south-eastern Australia, the number of these birds has declined across their range in response to changes to natural flow regimes. Major strongholds for Australasian bitterns in the MDB include floodplain wetlands in the Lachlan, Murrumbidgee and NSW Murray–Lower Darling Water Resource Plan Areas (WRPA).

Australasian bittern records were extracted from acoustic data collected in 6 wetland regions as part of the NSW Saving our Species (SoS) southern bell frog conservation project. The monitoring sites include natural floodplain wetlands, farm dams and irrigation channels in the Lachlan, Murrumbidgee and NSW Murray. Acoustic recorders were deployed on the edge of each wetland site to record continuously during spring and summer months. A detector was developed using Raven Pro software to identify Australasian bittern calls from the acoustic data. Manual verification of the acoustic data was undertaken to confirm bittern detections and ensure high confidence in the processed data.

Results of the acoustic analysis were used to identify sites that supported Australasian bitterns in the 2019 to 2023 period. Australasian bitterns were confirmed at 15 monitored sites in the lower Murrumbidgee (Lowbidgee) floodplain, 14 sites in the lower Lachlan, 5 sites in the mid Murray and 2 sites in the Coleambally Irrigation Area. Australasian bitterns were not detected in monitored sites in the mid Murrumbidgee and NSW lower Murray wetland regions. The habitats that reliably supported Australasian bitterns included river red gum and lignum shrubland plant community types (PCT).

Bittern calling activity for the 2021–22 and 2022–23 water years was investigated in most detail. Daily calling activity was primarily nocturnal, peaking at 3 am to 5 am and 8 pm to 9 pm. The calling window extended from September to February. In 2021–22, the first date of calling for most sites was in October, with peak calling activity recorded between November and December. High river flows meant high water depths potentially delayed bittern breeding activity in 2022–23 as peak calling activity was not recorded until January and February in the Lowbidgee floodplain and mid Murray wetland regions. Acoustic and complementary survey records in the Lowbidgee

floodplain indicated bittern breeding responses were very limited during an extended dry period in 2019–20. Higher bittern activity was observed during a managed environmental watering event in 2020–21 and during large natural inundation events in 2021–22 and 2022–23.

The results of this study have improved the understanding of the distribution of Australasian bitterns in the southern MDB. They have also shown the value of acoustic monitoring for assessing Australasian bittern responses to inundation in remote floodplain wetlands. Ongoing monitoring is needed to document the outcomes of environmental water delivery to priority bittern sites identified in the lower Lachlan, Lowbidgee floodplain and mid Murray regions. Further work is also needed to identify priority sites for Australasian bitterns in the northern MDB.

1. Introduction

The Australasian bittern (*Botaurus poiciloptilus*) is listed as an endangered species under both Commonwealth (*Environment Protection and Biodiversity Conservation Act 1999*, EPBC Act) and NSW legislation (*Biodiversity Conservation Act 2016*, BC Act). The estimated population is only 1,300 individuals (Herring et al. 2021). The species is listed in the 'Landscape' management stream of the NSW Saving our Species (SoS) program, whereby management actions across its range are predicted to benefit its recovery. Australasian bittern populations have undergone large declines in the past 50 years due to loss of wetland habitat and alterations to natural flow regimes, which are identified as key threatening processes for the species.

Floodplain wetlands in the NSW Murray–Darling Basin (MDB) provide important habitat for Australasian bitterns. However, relatively little is known about their distribution and habitat preferences, including their responses to wetland inundation. As Australasian bitterns are dependent on floodplain wetlands for feeding and breeding, the delivery of environmental water over the spring and summer months can be an important management intervention (Wassens et al. 2024; Znidersic and Towsey 2023). By restoring parts of the natural flow regime, environmental water delivery can provide breeding and feeding habitat, addressing one of the most important threats to the species.

Wetlands that Australasian bitterns frequent in the MDB are often remote and difficult to access. Despite males having a loud 'booming' call, they are generally nocturnal, and difficult to detect and count accurately. Acoustic recording devices address some of the challenges associated with detecting Australasian bitterns. Recorders are particularly useful in remote areas and can capture data over long periods causing minimal disturbance compared to other survey methods (O'Donnell and Williams 2015). Male bittern calling is a proxy for breeding activity, with males establishing territories where they can pair with one or more females. Their loud, low-frequency booming calls can carry over great distances and are easily distinguished from other waterbird species. Their unique call also makes them a good candidate species for the development and use of an automated detector to significantly reduce data processing times.

This report presents the results of acoustic monitoring for the 2019 to 2023 reporting period in floodplain wetlands in the NSW Murray, Murrumbidgee and Lachlan WRPAs. This monitoring was undertaken as part of the SoS conservation project for the threatened southern bell frog (*Litoria raniformis*) (EPBC Act, BC Act)(Waudby 2019). The southern bell frog project is focused on priority wetlands in south-western NSW that receive environmental water (Figure 1). Many of these sites overlap with Australasian bittern habitats. Both species have similar habitat requirements and southern bell frogs can be an important food source for the Australasian bittern (Menkhorst, 2012).

Six wetland regions in the NSW MDB were monitored through the SoS southern bell frog project. These included the Lowbidgee floodplain and Great Cumbung Swamp (lower Lachlan, Figure 1), which provide significant habitat for Australasian bitterns.

These wetland regions were the focus of detailed analysis of Australasian bittern calling activity for an SoS Australasian bittern research project. Wetland sites in the NSW mid Murray wetland region were also surveyed but did not include Millewa Forest in the Murray Valley National Park (Figure 1). Barmah–Millewa Forest provides important habitat for Australasian bitterns but is monitored through the Murray–Darling Basin Authority's The Living Murray Program (see Belcher et al. 2017; Znidersic and Towsey 2023). Results of the SoS acoustic monitoring were used to document wetland sites in the mid Murray that supported Australasian bitterns outside of Barmah–Millewa Forest. The SoS acoustic information and complementary acoustic and ground survey data collected in the Lowbidgee floodplain was also used to document responses to inundation in the 2017 to 2023 period.

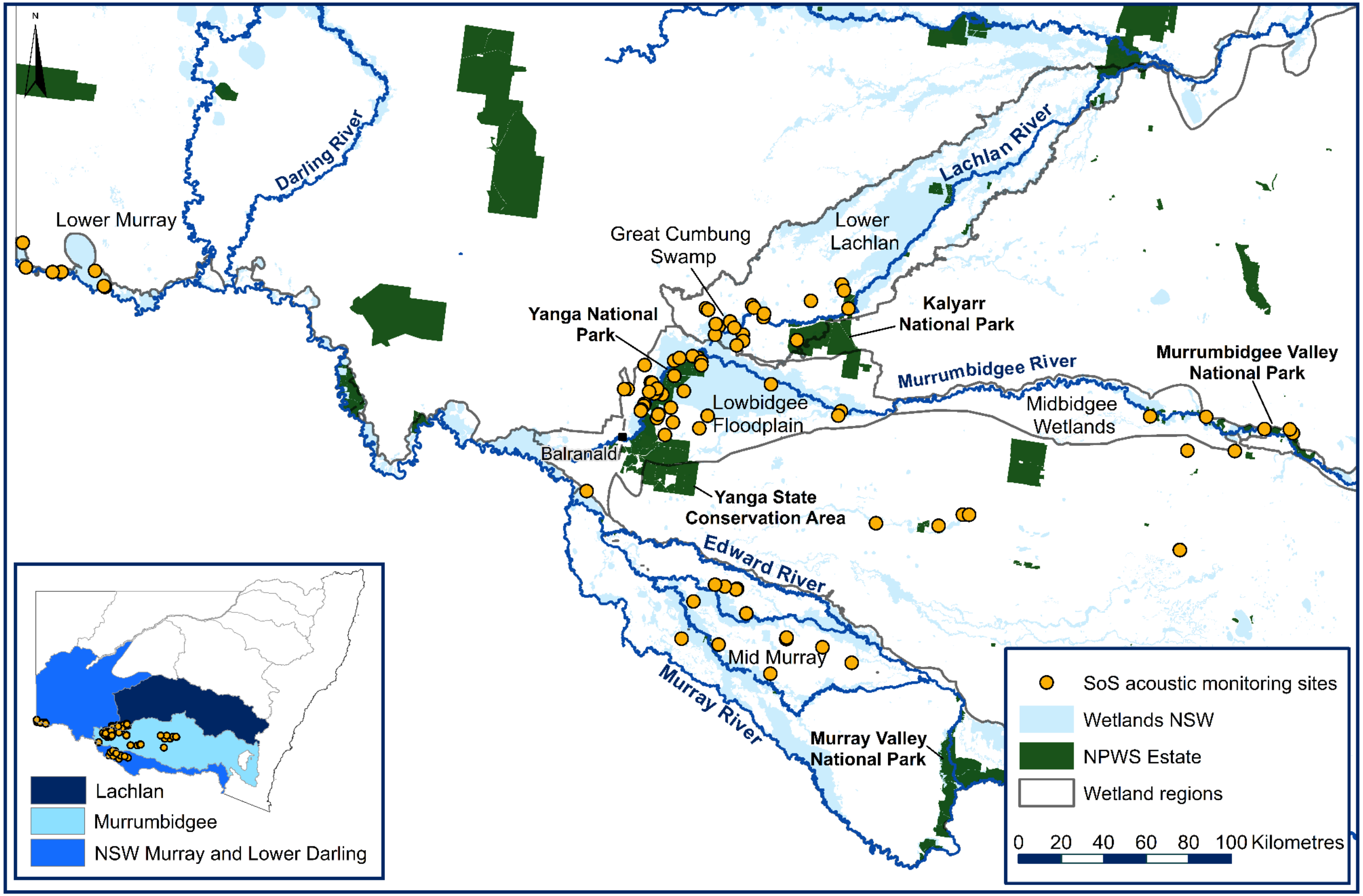

Figure 1 **Location of SoS acoustic monitoring sites in the NSW Murray–Lower Darling, Murrumbidgee and Lachlan WRPAs in the southern NSW MDB (inset)**

2. Methods

2.1 Wetlands monitored

Acoustic monitoring sites were established in 6 wetland regions in south-western NSW (Table 1, Figure 1):

- Lowbidgee floodplain, mid-Murrumbidgee wetlands and Coleambally Irrigation Area wetland regions (Murrumbidgee WRPA)
- lower Lachlan wetland region including the Great Cumbung Swamp and Booligal Wetland System (Lachlan WRPA)
- mid Murray and lower Murray wetland regions (Murray–Lower Darling WRPA).

In total, 101 wetland sites were surveyed across the 6 wetland regions as part of the SoS southern bell frog project. The ongoing SoS monitoring began in 2017 at priority southern bell frog sites that receive environmental water and nearby surveillance sites (Waudby 2019). Wetland sites are on private land and within the NSW reserve system including Yanga National Park and Murrumbidgee Valley National Park in the Murrumbidgee WRPA, and Kalyarr National Park in the Lachlan WRPA (Figure 1).

The SoS southern bell frog monitoring sites cover a range of habitats including natural floodplain wetlands, farm dams and irrigation channels. These sites contain a mix of wetland vegetation types dominated by river red gum (*Eucalyptus camaldulensis*), black box (*Eucalyptus largiflorens*), common reed (*Phragmites australis*), lignum shrubland (*Duma florulenta*), cumbungi (*Typha* sp.), and/or sedgelands (*Eleocharis* spp. and *Juncus* spp. (Figure 2).

Data from as many SoS sites as possible (80 in total) were processed for the purpose of the SoS Australasian bittern research project (Table 1). Acoustic data was only available for the lower Lachlan wetland region from 2021 onwards (Waudby et al. 2021). There was restricted ground access for the 2022–23 surveys due to very high river flows in the wetland regions in spring 2022. This limited the amount of acoustic data available for the Lowbidgee floodplain, lower Lachlan and mid Murray regions in the 2022–23 water year (Table 1).

Table 1 **Total number of acoustic sites monitored through the SoS southern bell frog project (and total number of sites analysed for the Australasian bittern project) in 6 wetland regions for the 2019 to 2023 reporting period**

WRPA	Wetland region	Number of sites monitored (number of sites analysed)			
		2019–20	2020–21	2021–22	2022–23[a]
Lachlan	Lower Lachlan[b]	–	–	19 (17)	5 (5)
Murrumbidgee	Lowbidgee floodplain	13 (13)	23 (23)	21 (17)	7 (7)
	Mid-Murrumbidgee wetlands	3 (3)	4 (4)	5 (5)	6 (2)
	Coleambally Irrigation Area	4 (2)	9 (3)	15 (8)	5 (3)
NSW Murray–Lower Darling	Lower Murray	5 (5)	2 (2)	10 (5)	5 (2)
	Mid Murray	21 (3)	25 (4)	31 (14)	15 (5)

Notes

a. Survey coverage was reduced in all regions in 2022–23 due to limited ground access following extended high river flows during spring and early summer.
b. Acoustic monitoring started in the lower Lachlan in 2021–22.

(a)

(b)

(c)

Figure 2 **Australasian bittern habitat types include (a) lignum shrubland wetlands, (b) river red gum and tall spike-rush wetlands and (c) common reedbeds. Credit: A Borrell and C Amos/DCCEEW**

2.2 Data collection

The presence/absence of calling male Australasian bitterns was assessed with Song Meter (SM4) acoustic recorders (Wildlife Acoustics Inc., Maynard Massachusetts), deployed as part of the SoS southern bell frog project. Core breeding months of the southern bell frog are October to February, so most of the acoustic recorders were deployed each year during this period. In most cases the acoustic recorders were installed prior to, or not long after, environmental water releases and were left in place until the sites dried down in late summer or early to mid-autumn. Most sites had one acoustic recorder, however a small number of sites in each wetland region had more than one recorder to ensure different habitat types were monitored.

Acoustic recorders were placed on the edge of wetlands close to where water was expected to reach (if sites had not yet filled) and were fixed to trees or star pickets using cable ties at a height of between 130 cm and 170 cm (Figure 3). This followed the standard procedure recommended by Lumsden et al. (2022). Acoustic recorders were configured to record for the first 5 minutes of every hour for 24-hour periods, at a 24,000 Hz sample rate. Where possible, batteries and security digital (SD) cards were replaced every 3 to 4 months. Acoustic recorder firmware was updated annually, before deployment (Waudby 2019).

Figure 3 An acoustic recorder and monitoring camera were installed at the SoS southern bell frog monitoring sites. Credit: H Waudby/DCCEEW

2.3 Complementary survey data

Complementary survey data was captured by Charles Sturt University (CSU), following the same acoustic monitoring methods as in the SoS project to monitor frog species in wetland sites in the Murrumbidgee catchment. The CSU acoustic recorders were also set to record for the first 5 minutes of every hour for 24-hour periods. The methods used by CSU involved deploying SM4 acoustic recorders at 8 wetland sites in the Lowbidgee floodplain and 4 sites in the mid-Murrumbidgee Wetlands over the 2016 to 2023 period. This data was analysed to extract Australasian bittern call records to investigate their responses to varying water depths in monitored sites (Wassens et al. 2024). This work was part of the Commonwealth-funded Flow Monitoring Evaluation and Research (Flow-MER) Program. Incidental ground survey records of Australasian bitterns were also captured as part of CSU's routine fish, frog and waterbird ground surveys at the 12 wetland sites and department-led biannual spring and summer ground surveys across 36 wetland sites in the Lowbidgee floodplain and mid Murrumbidgee (Wassens et al. 2019).

Additional targeted ground surveys were carried out in the Lowbidgee floodplain from 2016 onwards (DPE 2022b; Herring 2023) and in the lower Lachlan from 2022 (Znidersic 2023). These ground surveys were undertaken to identify calling Australasian bitterns and Australian little bitterns. The surveys were conducted by experienced observers 2 hours after dawn or before dusk. Two rounds of surveys were completed: one in spring (October/November) and one in early summer (December). Where feasible, triangulation surveys were undertaken by 2 observers to determine the location of booming males. The number of calling male bitterns at a wetland was estimated by comparing records taken by each observer including the time of calling, number of booms, and the estimated distance and compass bearing to a calling bittern. Kayaks were used to undertake area searches in larger wetlands to pinpoint the location of calling males and to survey otherwise inaccessible areas (see Herring 2023; Znidersic 2023).

A 5-year SoS project was also carried out by the Murray–Darling Wetlands Working Group from 2018 to 2023. The project involved targeted ground surveys for Australasian bitterns and 3 other endangered waterbirds in the Gayini Wetlands in the Lowbidgee floodplain. Core wetland areas in the Gayini Wetlands were surveyed monthly, over spring and summer, to collect data on threatened species abundance and habitat use (DPE 2022b).

2.4 Information reliability

Both acoustic and targeted ground survey data were used to identify sites that supported Australasian bitterns in the Lowbidgee floodplain in the 2019 to 2023 period. Data coverage was most comprehensive for the ground surveys and acoustic monitoring (commencing 2016 and 2017, respectively) in the Lowbidgee floodplain (Herring 2017; Waudby 2019) compared to the other wetland regions. Both the SoS and CSU acoustic datasets were collected using consistent methods at sites spread across the Lowbidgee floodplain. A key benefit of the acoustic monitoring was the ability to collect fine-scale data during very wet conditions in the 2021–22 and 2022–23 water years when wetlands were inaccessible. Appendix B provides a detailed assessment of the Lowbidgee floodplain acoustic data and complementary survey data, based on the information reliability scoring system established by Battisti et al. (2014).

2.5 Data processing

Development of the detector and validation dataset

Automated signal recognition software is essential for analysing large amounts of data collected through acoustic monitoring (Cornell Lab of Ornithology, 2022). A detector was developed using Raven Pro software to extract Australasian bittern calls from acoustic datasets, with the Band Limited Energy Detector (BLED). As a first step, examples of Australasian bittern calls were compiled and analysed. These included records compiled through the SoS southern bell frog project (Walcott and Waudby 2018; Waudby, Dyer, et al. 2021; Waudby et al. 2020; Waudby, Healy et al. 2021). The spectrogram (window) pre-set view was configured in Raven Pro to the frequency range where Australasian bittern calls can most easily be identified (0–<500 Hz) (O'Donnell and Williams, 2015). To adjust the Raven Pro detector, sample Australasian bittern calls were selected, focusing on the loudest (brightest) part of the call on the spectrogram. Key variables of interest were minimum (low freq [Hz]) and maximum call frequency (high freq [Hz]), and length of call (delta time [s]) (Figure 4).

Variability across the test calls (252 in total) was measured by comparing the minimum and maximum frequency, and call duration. This information was used to adjust the detector settings. Test data was compiled from a range of sites to check the detector. A subset of data was selected from each test site for periods between 7 pm and 8 am for 3 survey dates (15 October, 15 November and 15 December) for each year surveyed. Following these tests, complete datasets for 3 sites were scanned to check if the validation of all detections was feasible. The total number of call detections was further tested by slightly decreasing the frequency range to 123–163 Hz. Interestingly, this corresponded to a higher total number of detections for the 3 entirely scanned test sites but did not adequately cover the variability in calls. When testing the detector in 'interactive' mode, there was a signal-to-noise ratio threshold of approximately 12 dB, above which calls were typically more likely to be accurate. Therefore, adjustments were made to these settings. The final detector settings used for this study are shown in Table 2.

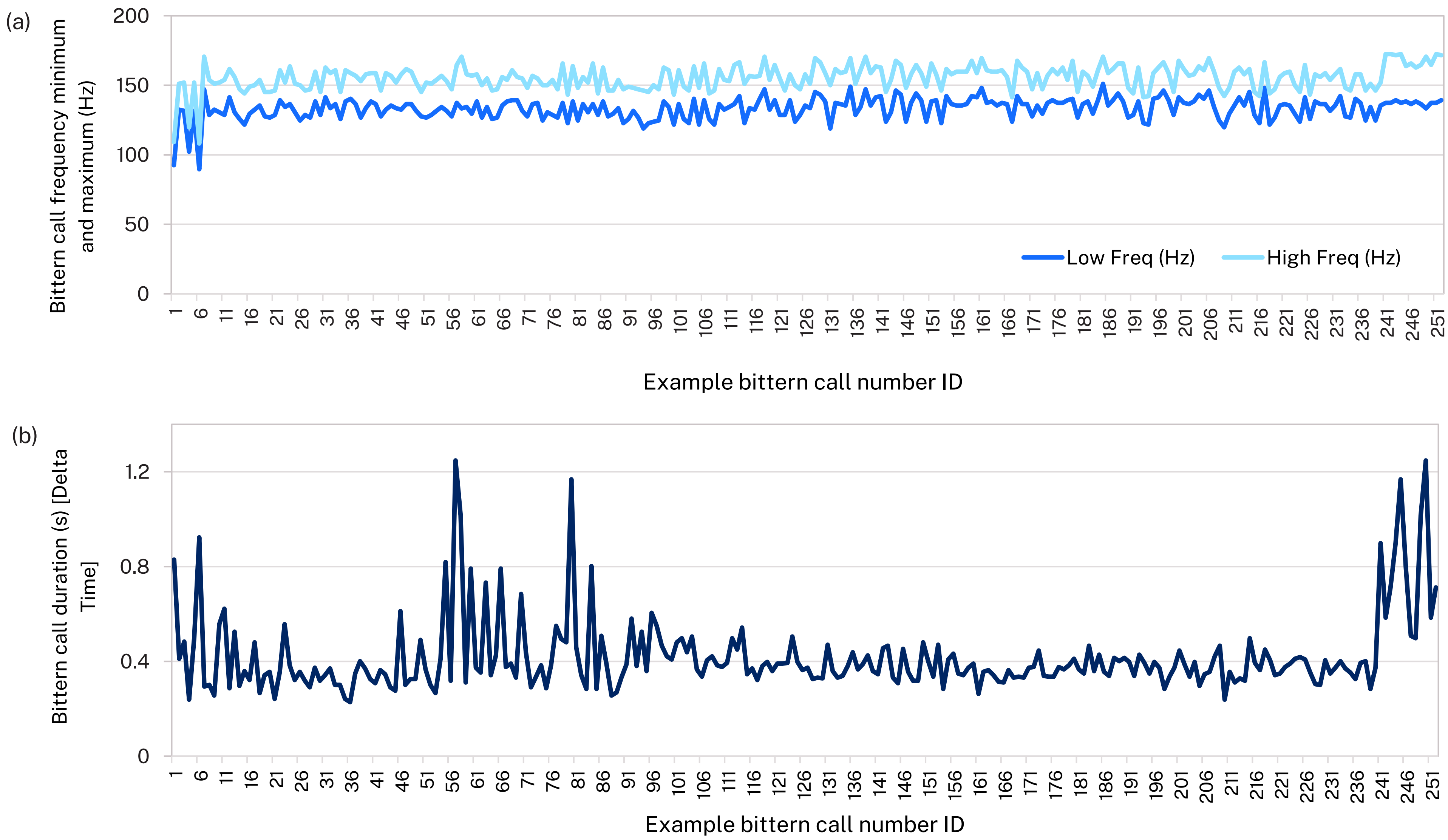

Figure 4 **Key bittern call variables assessed to guide the development of the detector: (a) minimum and maximum frequency (Hz) and (b) call duration (seconds)**

Table 2 **Raven Pro detector settings used for the Australasian bittern acoustic data analysis**

Parameters	Detector settings
Minimum frequency	120 Hz
Maximum frequency	165 Hz
Minimum duration	0.23267 s
Maximum duration	0.98883 s
Minimum separation	0.87250 s
Signal-to-noise ratio	12 dB

Validation of automated detections

A detailed description of the steps followed for processing and validating the acoustic data in the Raven Pro software is shown in Appendix B. The final detector settings described in Table 2 were used for all acoustic files recorded at each site. Manual validation of each automated result was undertaken to determine if the detection was a bittern call or not. The automated detector varied in its efficiency for detecting bitterns, depending largely on the various other sounds present in the environment such as wind, road noise and calls of other species (see Appendix B). The average detection rate was 17% for all sites but up to 97% for sites with high calling activity in the 2021 to 2023 datasets. This meant the manual validation step was very important for confirming true detections.

Bittern boom trains or call sequences consist of several inhalations followed by additional booms (usually 3 to 5 booms, but they can range between one and 10 booms) (Gilbert et al. 1994, Figure 5a). Inhalations are not always visible or audible, largely depending on the distance of the bittern from the recorder and weather conditions. Some males also produce unstructured faint booms, called 'poor booms' (Gilbert et al., 1994, Figure 5b). These calls are thought to be more prevalent at the beginning of the breeding season, although some males continue to produce these calls throughout the entire season (Puglisi et al. 2001).

Each detection was visually inspected and, if required, was listened to by an experienced observer to confirm whether it was a bittern call. If a boom was detected, it was given a 'one' and if a detection was not a boom, it was marked with a 'zero' in the annotation column of the output files (see Appendix B). All detections were validated for the 2021–22 and 2022–23 datasets, which approximated to 20,406 hours of acoustic data (or 244,869 5-minute files). Validation to confirm the presence/absence of bitterns only and first date of calling was done for the monitoring data collected in years prior to 2021–22.

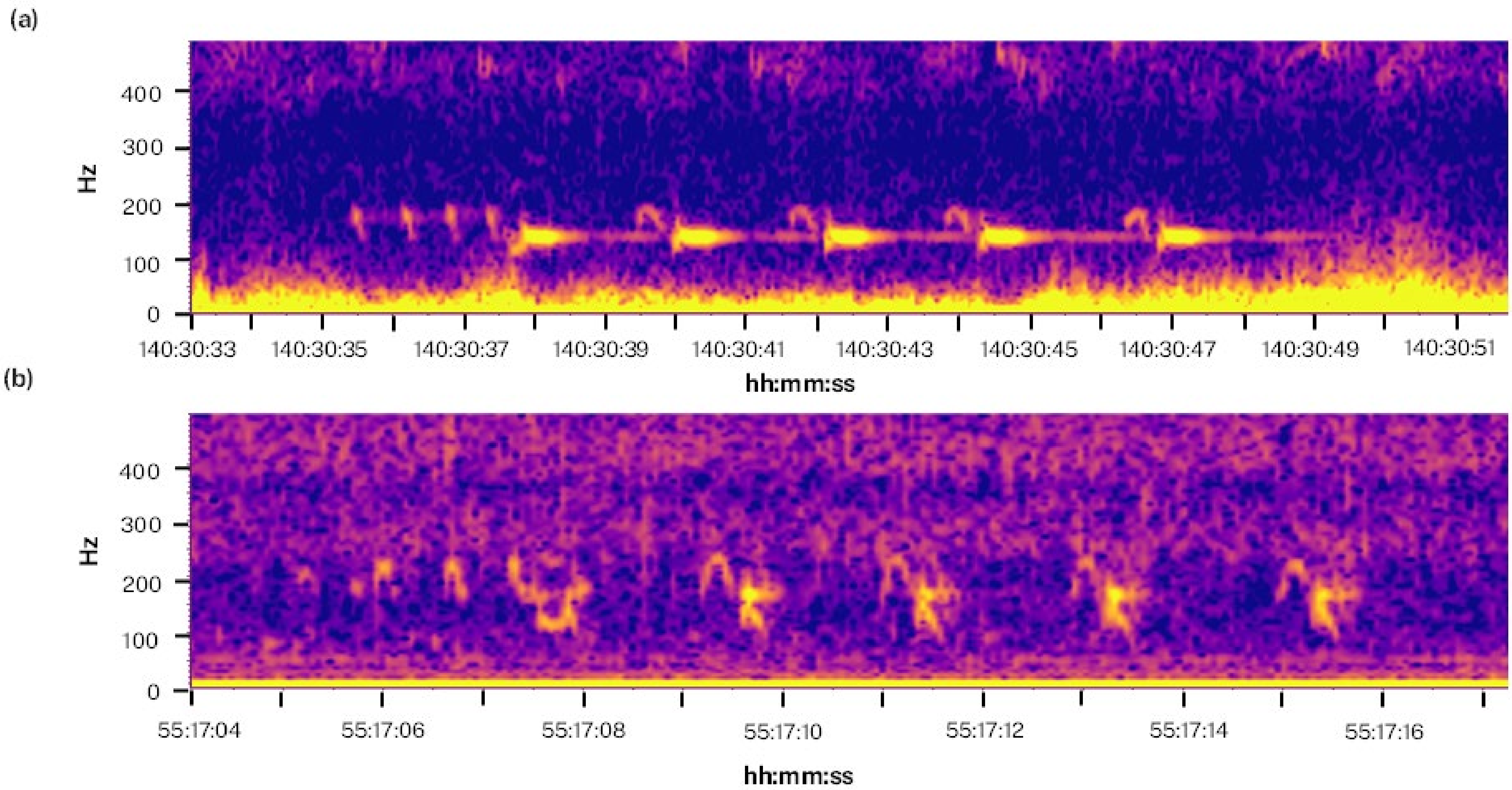

Figure 5 **Example spectrograms displayed in the Raven Pro software showing: (a) bittern calls (boom train) where 4 inhalations were recorded prior to 5 loud booms, with additional small inhalations before each boom and (b) a sequence of 5 poor booms. Additional example spectrograms can be found in Appendix B**

2.6 Data analysis

Once the acoustic verification process was complete, the results and associated measurements were used to extract important metrics from the SoS acoustic datasets. For the 2021–22 and 2022–23 datasets these metrics included:

- first date of calling
- peak calling date
- last date of calling
- total calls per day
- range of energy values (volume) of calls (for sites where bitterns were detected).

The first and last detection dates do not indicate that bitterns were calling for the entire period, only for the recording window. Only the first date of calling was determined for data collected in the 2019–20 and 2020–21 water years.

Australasian bittern calls can carry over large distances, with estimates ranging between 1 km and 9 km (Graff, 2014; Marchant and Higgins, 1990). Variations in recording distances are likely a result of wetland type and vegetation structure. The energy values (volume) were used to provide information on the relative distance of a 'booming' bittern from an acoustic recorder. Energy values, expressed in decibel (dB), were automatically calculated for each call detection by Raven Pro to assess distance of calls from the recorder, ranging from 20 dB (loud, close calls) down to –35 dB (faint, distant calls). The energy value represents the volume of a call and corresponds to proximity of calling bitterns to a recorder (Knight and Bayne, 2019). The minimum and maximum decibel (dB) values of calls were recorded for each site. These values were used to assign a confidence rating for whether the bittern was close to the recorder (and detected at the site) or if the calls were only distant (and the birds were offsite).

Based on the maximum decibel values the confidence ratings were as follows:

- high confidence rating for sites where individuals were recorded close to the recorder (≤ 20dB to ≥ –9 dB)
- medium confidence rating for sites where individuals were onsite (≤ –10 to ≥ –14 dB)
- low confidence rating for sites where individuals were more likely calling from adjacent habitats rather than in the wetland being monitored (≤ –15 dB to ≥ –20 dB).

While field validation of these confidence categories was not undertaken as part of this project, the categories were important for identifying habitats reliably used by bitterns. The average detection rate of the automated detector was most reliable for sites where detections had high energy values and bitterns were thought to be onsite (20%) compared to the sites with only distant bittern calls (8%).

Information on the inundated area for monitored sites in the Lowbidgee floodplain and lower Lachlan was available through the department's flows and connectivity theme (DCCEEW, 2025). Inundation maps for single dates are produced from Sentinel-2 satellite imagery captured every 5 days with a 10 m spatial resolution. Satellite images that are either free of cloud or contain low cloud are used to map the inundated area for key wetland regions in the NSW MBD. In this approach, inundated areas are classified into water, mixed (pixels containing water in vegetation) and wetland vegetation (vegetation that is covering water) (Heath et al. 2024; DCCEEW, 2025; Thomas et al. 2015). The final inundation maps are recoded into inundation, off-river storage, and cloud. Mapped image dates available for 2021–22 and 2022–23 was used to calculate the inundated area (in hectares) in a 1,000 m buffer around each site where bitterns were detected. This information was used to show changes to inundation extent at confirmed bittern sites in the Lowbidgee floodplain and lower Lachlan. The most current NSW State Vegetation Type Map (DCCEEW, 2022) was also used to determine the dominant plant community type (PCT) (in hectares) in a 1,000 m buffer around confirmed bittern sites.

3. Results

3.1 Habitat use

Australasian bitterns were detected at 44 wetland sites in 4 regions monitored as part of the SoS program in the 2019 to 2023 period. Of these 44 sites, 8 sites recorded low bittern activity. For these sites it was likely bitterns were calling from a distance and not using habitat near the recorders. Australasian bitterns were detected at approximately 50% of the sites analysed in each water year, except during 2019–20 when few bitterns were detected (Table 3). This coincided with very dry conditions in spring and summer months across much of the MDB.

Overall, detection rates were higher in the Lowbidgee floodplain and lower Lachlan compared to the Coleambally Irrigation Area and mid Murray regions. Australasian bitterns were not detected in the mid Murrumbidgee and lower Murray wetland regions in the 2019 to 2023 period (Table 3, Figure 6 and Figure 7). Sites which reliably supported bitterns in the 2019 to 2023 period comprised forested and freshwater wetlands dominated by river red gum and lignum shrubland PCTs (Figure 8a) with lignum being the dominant mid-stratum species (Figure 8b).

Table 3 Detection rates of Australasian bitterns in the 2019 to 2023 reporting period in the 6 monitored wetland regions. The number of sites bitterns were detected in the acoustic data (and number of sites analysed) are presented

WRPA	Wetland region	2019–20	2020–21	2021–22	2022–23
Lachlan	Lower Lachlan[a]	–	–	15 (17)	3 (5)
Murrumbidgee	Lowbidgee floodplain	1 (13)	14 (23)	13 (17)	3 (7)
	Mid-Murrumbidgee wetlands	0 (3)	0 (4)	0 (5)	0 (2)
	Coleambally Irrigation Area	0 (2)	1 (3)	1 (8)	0 (3)
NSW Murray–Lower Darling	Lower Murray	0 (5)	0 (2)	0 (5)	0 (2)
	Mid Murray	0 (3)	0 (4)	5 (14)	5 (5)
	Total number of sites	1 (26)	15 (36)	34 (66)	11 (24)

Note

a. SoS acoustic monitoring commenced in the lower Lachlan in 2021–22

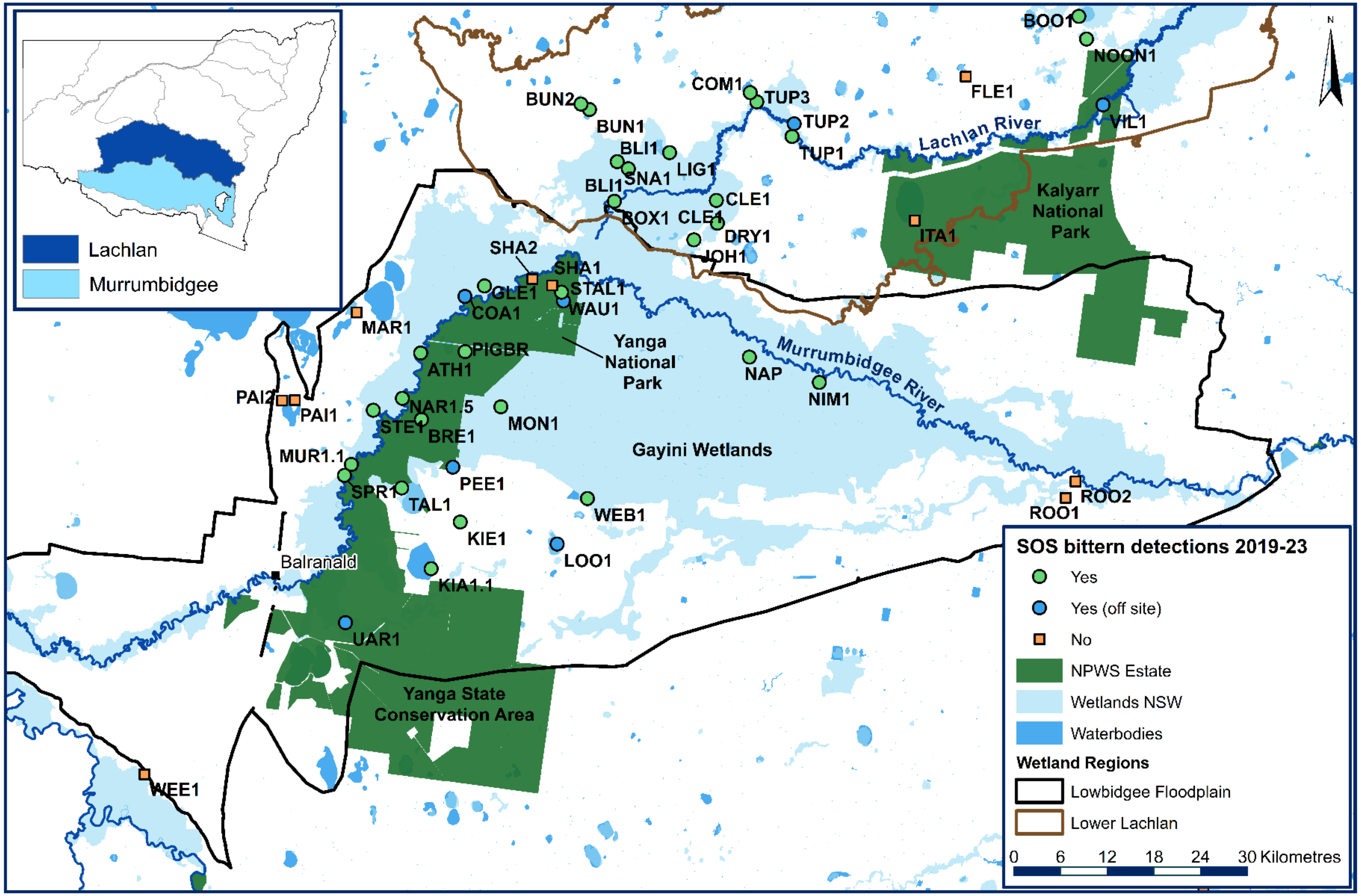

Figure 6 Distribution of SoS acoustic monitoring sites where Australasian bitterns were detected and not detected in the 2019 to 2023 period in the lower Lachlan and Lowbidgee floodplain, and their locations in the Lachlan and Murrumbidgee WRPAs in the NSW MDB (inset)

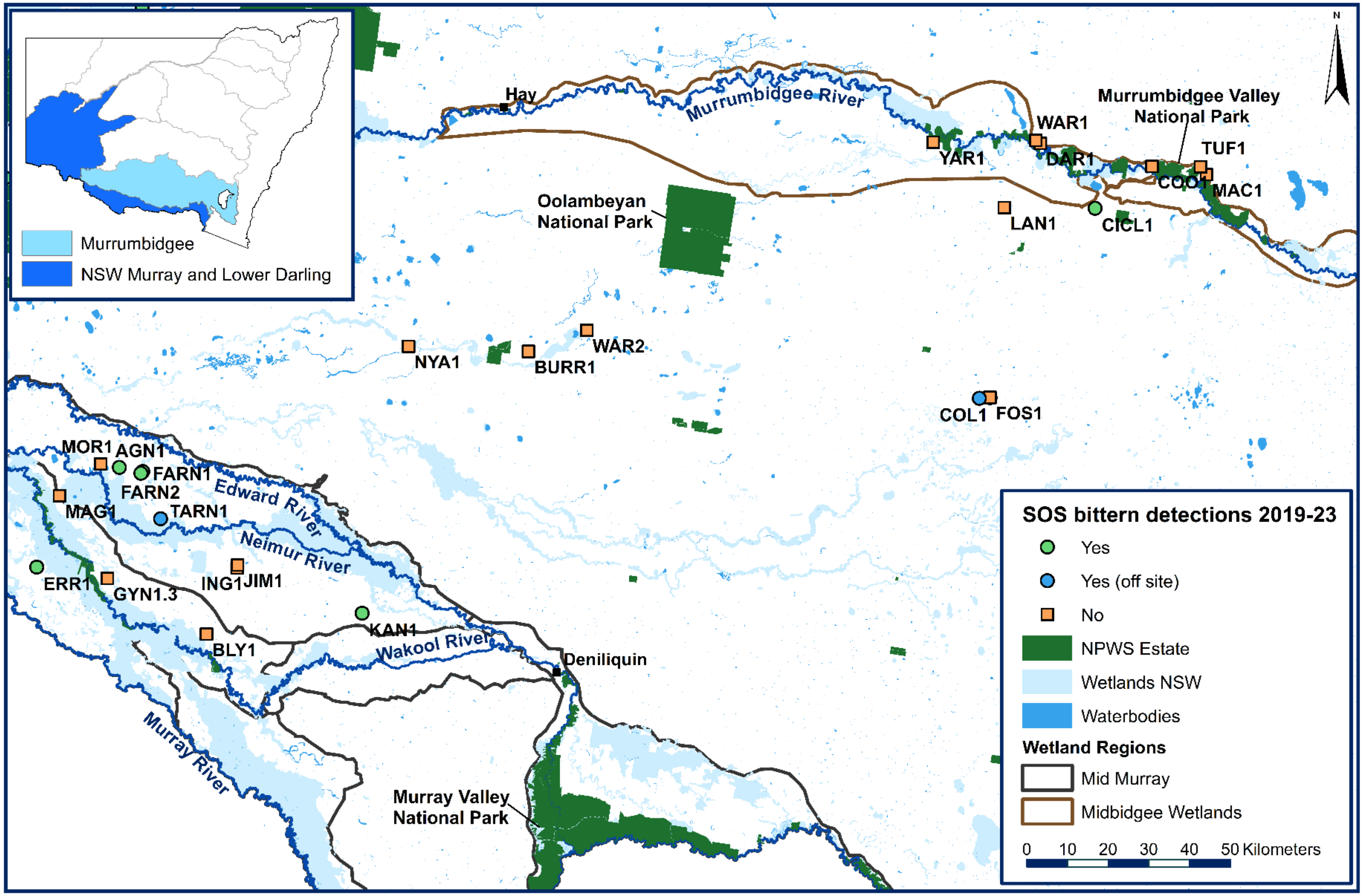

Figure 7 **Distribution of SoS acoustic monitoring sites where Australasian bitterns were detected and not detected in the 2019 to 2023 period in the mid Murray, mid-Murrumbidgee and Coleambally Irrigation Areas, and their locations in the Murrumbidgee and Murray–Lower Darling WRPAs in the NSW MDB (inset)**

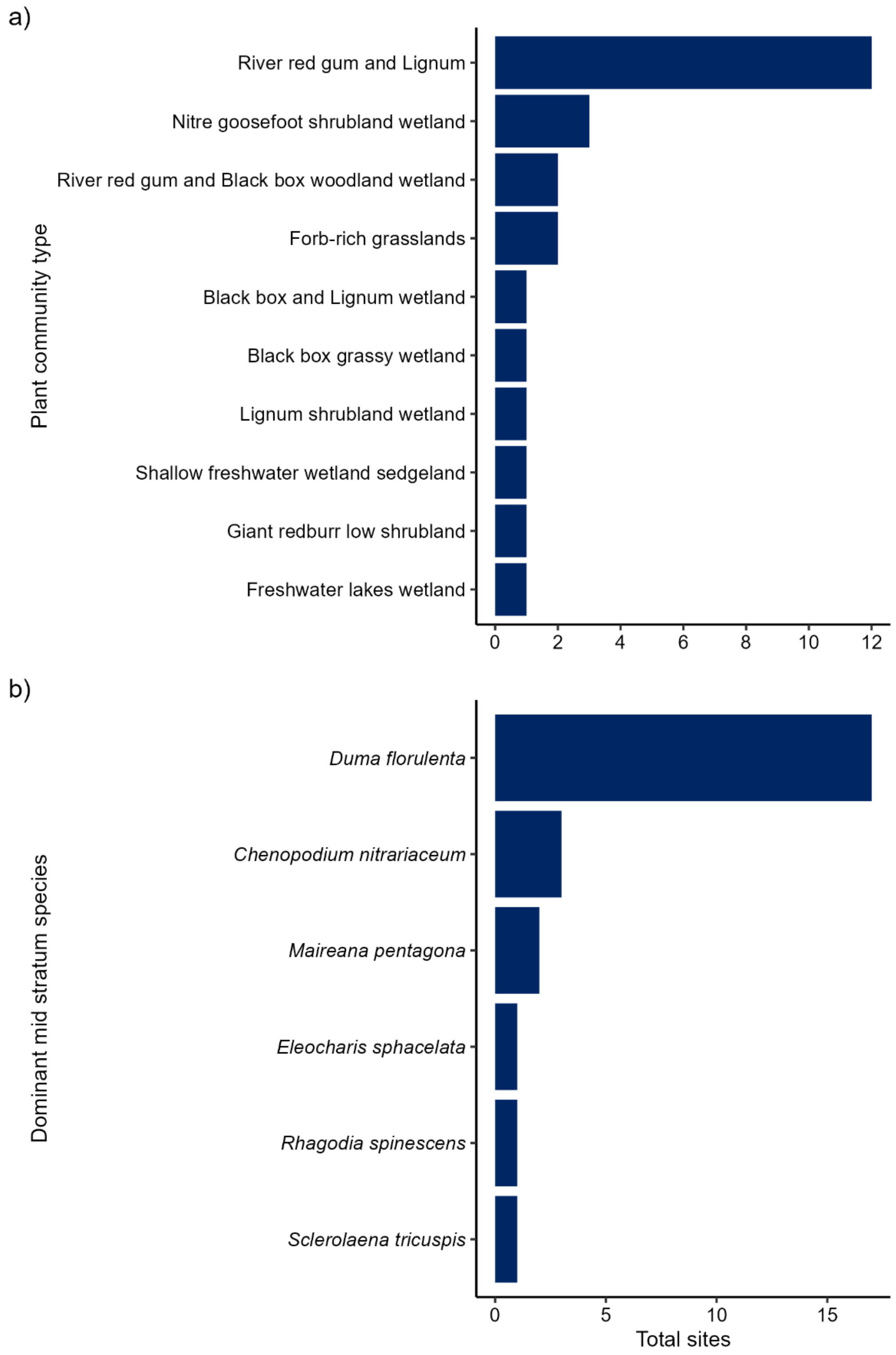

Figure 8 **Frequency of dominant (a) PCTs and (b) mid-stratum species recorded in a 1,000 m buffer around each of the 25 monitored sites that supported high Australasian bittern activity in the 2019 to 2023 reporting period**

3.2 Calling activity

Australasian bittern calling activity varied across individual sites, wetland regions and water years. High calling activity (>1,000 total booms detected) was recorded at 17 sites in the 2021 to 2023 period (see Figure 9). High detections of birds were recorded at 8 sites in the Lowbidgee floodplain and 7 sites in the Great Cumbung Swamp (lower Lachlan). High detections were also recorded at individual sites in the Coleambally Irrigation Area and mid Murray region. Low bittern calling activity was detected at 2 sites in the lower Lachlan, 4 sites in the Lowbidgee floodplain and at one site in the mid Murray region (see Figure 9 and Appendix C for more details about each site). These sites had a low number of booms (generally less than 50 per site each season, Figure 9 and Appendix C), and/or the calls were detected from bitterns calling offsite.

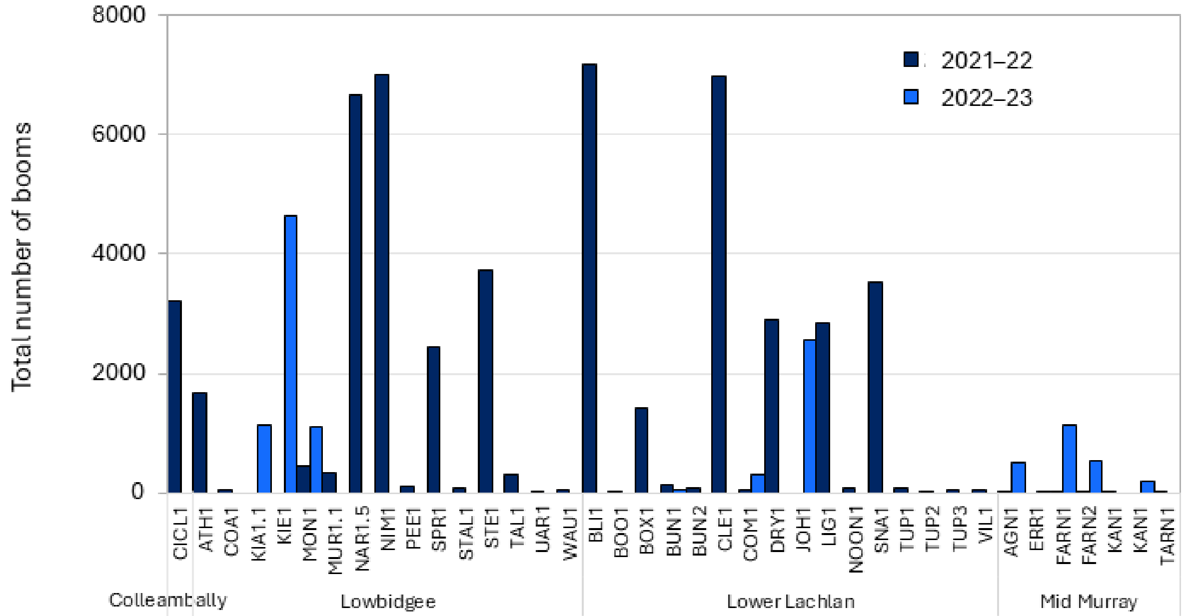

Figure 9 **Total number of Australasian bittern detections (number of booms) recorded at all sites analysed for the 2021–22 and 2022–23 monitoring seasons. Note: not all sites were monitored in each water year. There was restricted site access in spring 2022 meaning fewer sites were monitored in 2022–23**

Daily calling activity was primarily nocturnal, peaking between 3 and 5 am and 8 and 9 pm. This pattern was consistent across the 4 wetland regions where bitterns were detected, and across both the 2021–22 and 2022–23 monitoring seasons (Figure 10). The calling window for Australasian bitterns extended from September to February. The first date of calling varied between sites and across wetland regions. Calling began in October and November for most sites in the Lowbidgee floodplain, Coleambally Irrigation Area, and lower Lachlan regions. The first date of calling was delayed until January for most sites in the mid Murray region (Figure 11a). For high activity sites in the Lowbidgee floodplain and lower Lachlan regions there was reliable calling most nights (up to 300 booms) over the entire recording period (see Figure 12, Figure 13 and Figure 14). Australasian bittern calling was limited to one or 2 nights at 3 of the 5 mid Murray sites during 2021–22. However, increased bittern calling activity was recorded at 4 of the 5 mid Murray sites during 2022–23 (ranging from 15 to 54 days in total per site, Figure 9). See Appendix C for detailed results.

Peak calling activity was recorded in November and December 2021 for most sites in the Lowbidgee floodplain, Coleambally Irrigation Area and lower Lachlan regions. For mid Murray sites, peak calling activity was recorded in January 2022 (Figure 11b). High river flows potentially delayed bittern calling activity in the Lowbidgee floodplain and mid Murray regions during 2022–23. Peak calling was recorded in January and February 2023 (Figure 11b), which was later than in the other monitored regions. However, due to a limited number of monitored sites in the Lowbidgee floodplain and lower Lachlan in 2022–23, it was not possible to fully assess peak calling dates in these regions.

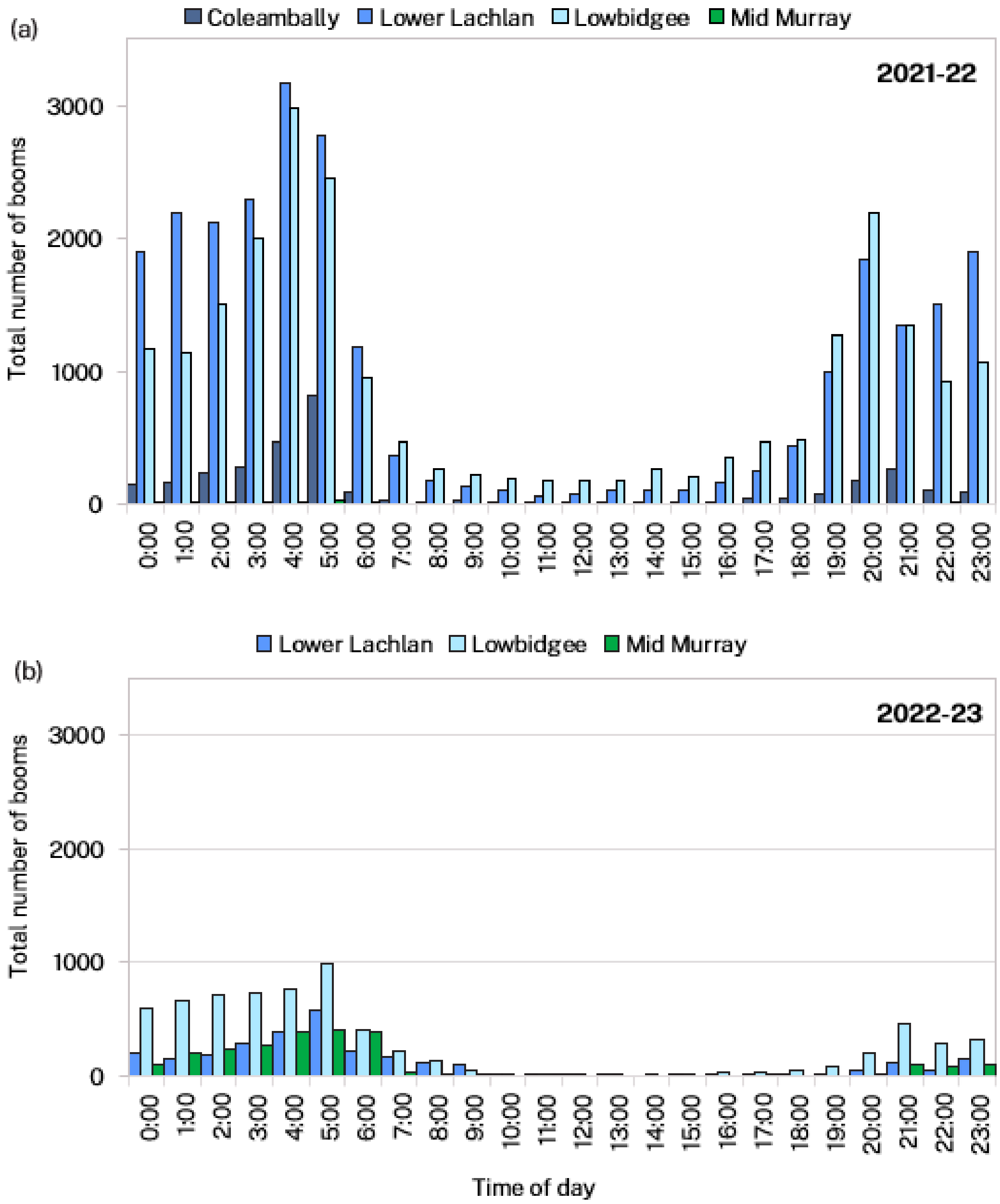

Figure 10 **Total number of bittern booms detected across the 24-hour recording schedule during 2 monitoring seasons, (a) 2021–22 and (b) 2022–23, across all sites analysed. Note: fewer sites were monitored in total during 2022–23 compared to 2021–22. This summary includes 63,639 confirmed bittern detections recorded across 43 sites in the Coleambally Irrigation Area, lower Lachlan, Lowbidgee floodplain and mid Murray wetland regions in spring and summer months. Site access was restricted during 2022–23 meaning fewer sites were monitored and therefore the total number of detections is lower than 2021–2**

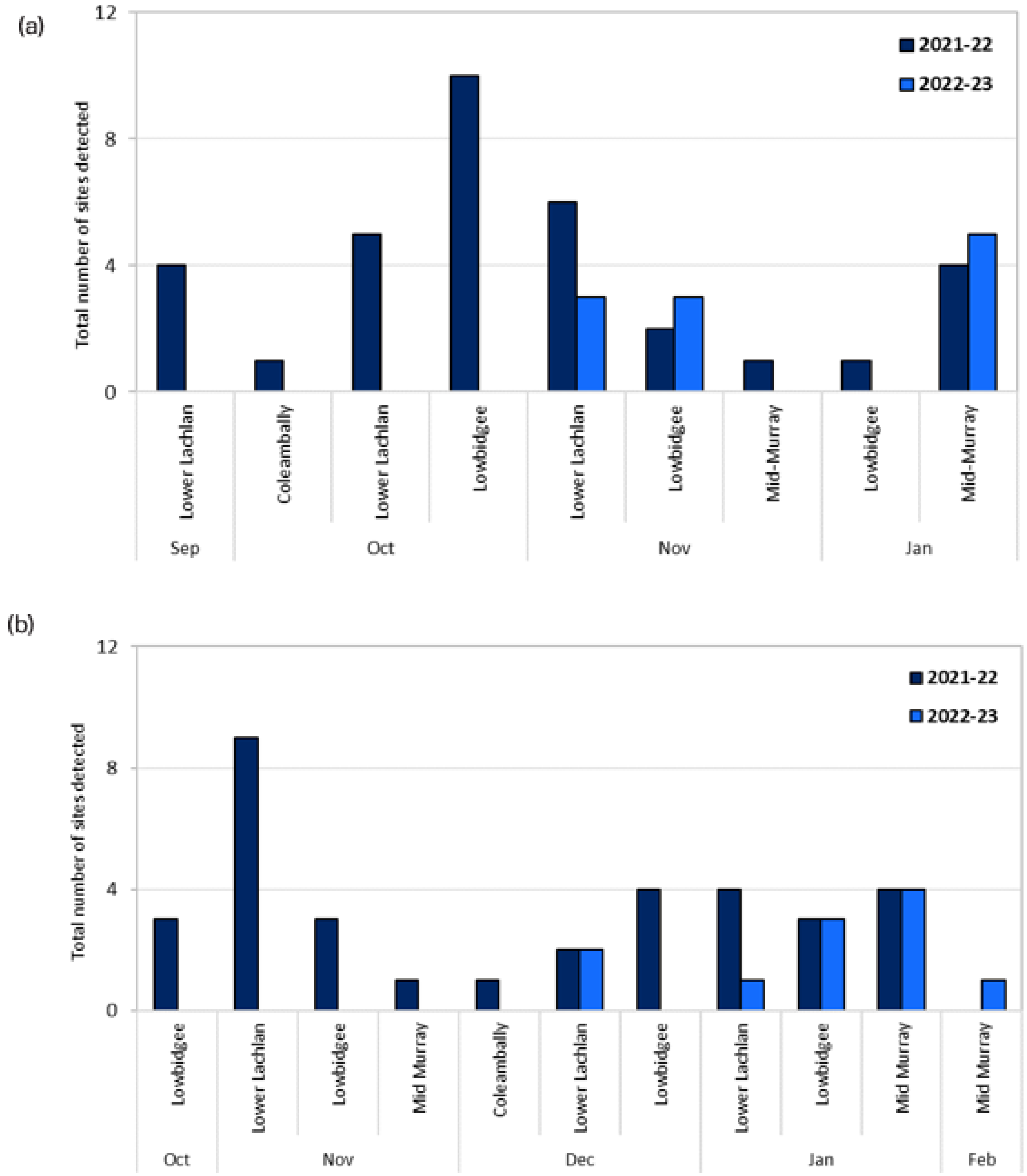

Figure 11 **Timing of (a) when calls were first detected and (b) peak calling was recorded (total number of sites per month) in each wetland region for the 2021–22 and 2022–23 datasets. Note: most recorders were deployed in October 2021 in the 2021–22 season, excluding the lower Lachlan recorders which were deployed in September 2021. Limited recorders were deployed in 2022–23 with many not deployed until late (November 2022) as high river flows limited ground access**

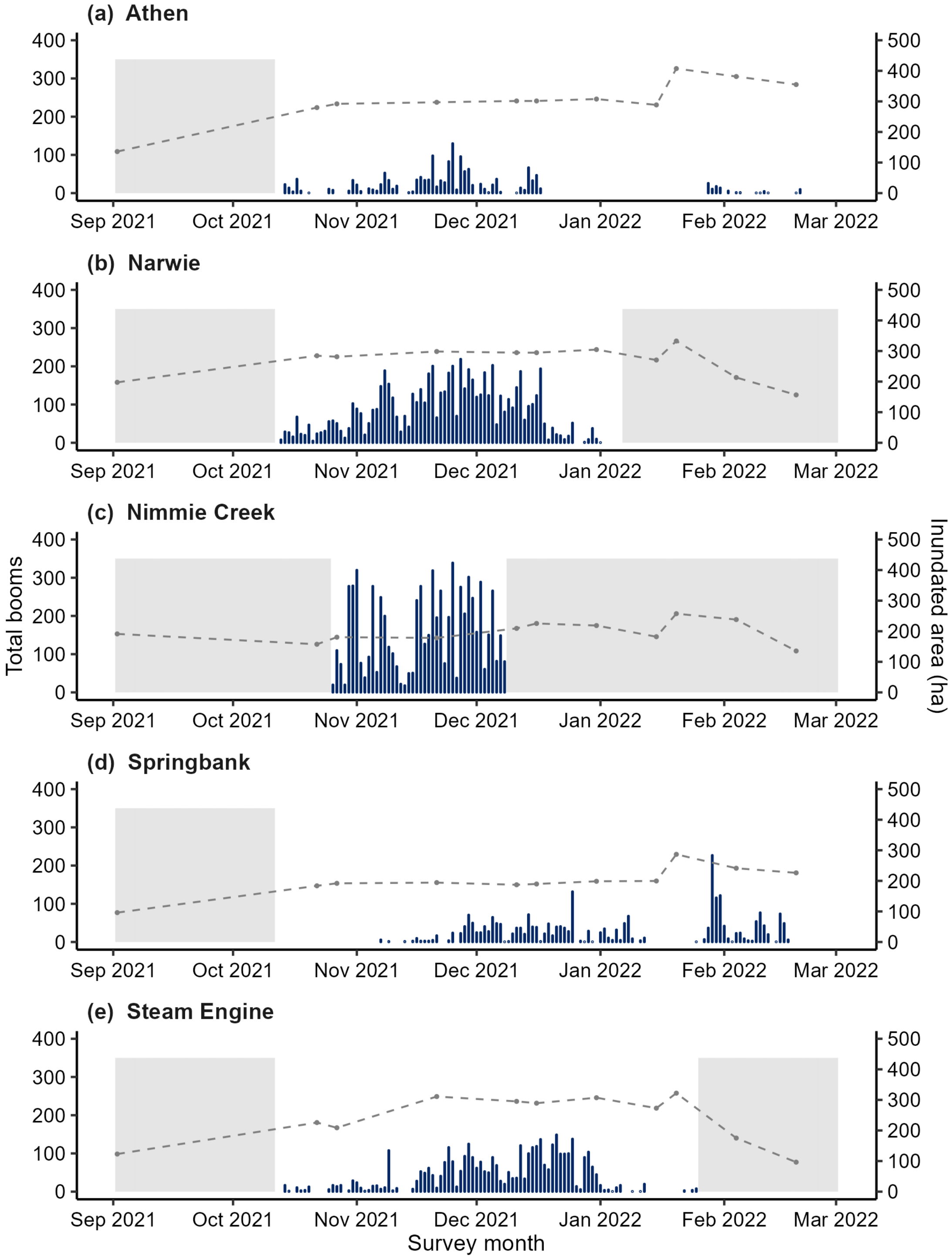

Figure 12 **Total number of booms recorded per day (filled bars) and inundated area for 5 monitored sites (in a 1,000 m buffer) (dashed line) where Australasian bitterns were recorded reliably (high number of detections with high energy values) in the Lowbidgee floodplain in 2021–22. Shaded areas represent missing data**

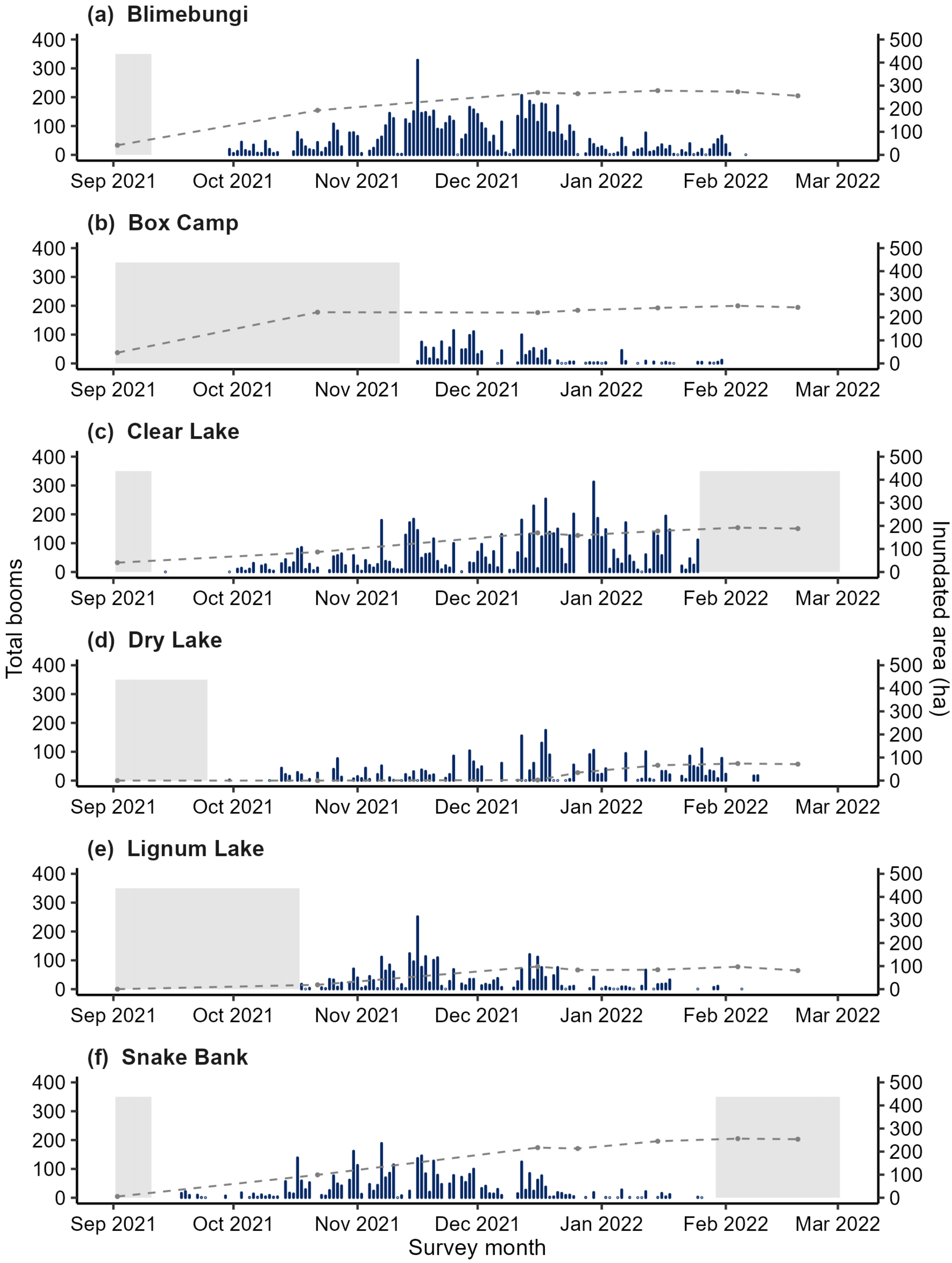

Figure 13 **Total number of booms recorded per day (filled bars) and inundated area (in a 1,000 m buffer) (dashed lines) for 6 monitored sites where Australasian bitterns were recorded reliably (high number of detections with high energy values) in the Great Cumbung Swamp in 2021–22. Shaded areas represent missing data**

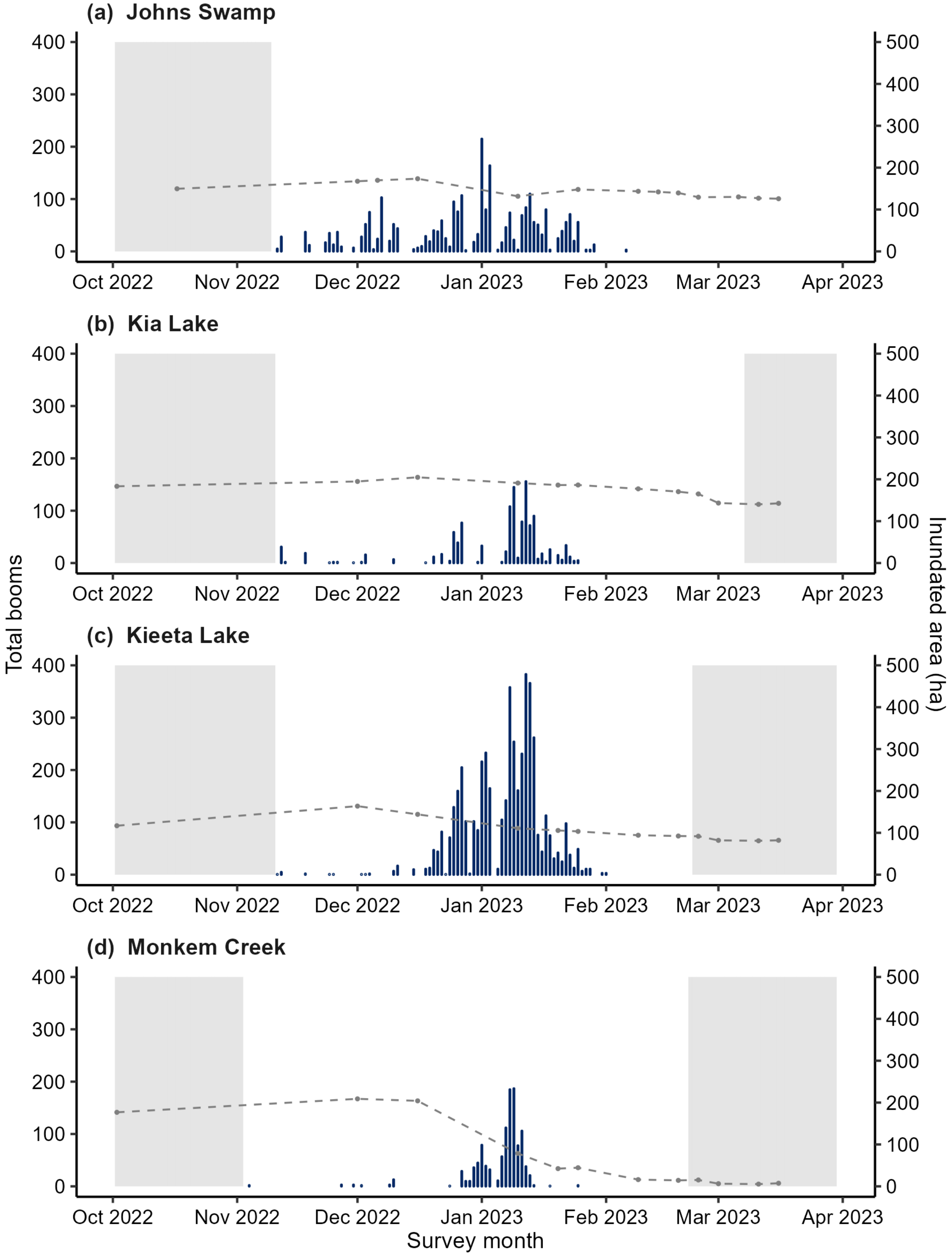

Figure 14 **Total number of booms recorded per day (filled bars) and inundated area (in a 1,000 m buffer) (dashed line) for 4 monitored sites where Australasian bitterns were recorded reliably (high number of detections with high energy values) for monitored sites in the Lowbidgee floodplain and Great Cumbung Swamp in 2022–23. Shaded areas represent missing data**

3.3 Responses to inundation

The SoS acoustic monitoring project provided evidence that Australasian bitterns were using wetland habitats in the Lowbidgee floodplain that received environmental water in the 2019 to 2023 period (Table 4). In total, 17 of the SoS monitoring sites supported Australasian bitterns and these sites all received discretionary environmental water during this period. Compilation of all available ground and acoustic records for the Lowbidgee floodplain showed responses to wetland conditions in each water year (Table 5). There were 25 individual sites in the Lowbidgee floodplain where Australasian bitterns were detected in the 2019 to 2023 period through acoustic monitoring and/or complementary ground records. This did not include Emu (Loorica) Lake (LOO1), North Stallion Swamp (STAL1) and Uara Creek (UAR1) (see Figure 6 for site locations) where SoS acoustic records indicated birds were offsite (Table 5).

Table 4 Summary of detections of Australasian bitterns in SoS acoustic monitoring data collected in wetland sites in the Lowbidgee floodplain that received environmental water in the 2019 to 2023 period

Water year	Annual inundated area (ha)[a]	Total number of monitored sites	Total number of sites with bittern detections	Number of monitored sites that received ewater[b]	Number of bittern sites that received ewater[b]
2019–20	15,732	13	1	11	1
2020–21	46,503	23	14	24	14
2021–22	131,121	17	13	8	4
2022–23[c]	255,859	7	3	6	3

Notes

a. Cumulative inundated area was determined from Sentinel satellite imagery (Department of Climate Change, Energy, the Environment and Water, 2020).
b. Environmental watering is based on information in (Waudby et al. 2020, 2021, 2022) and J Maguire, NSW DCCEEW pers. comm.
c. Survey coverage was reduced in all regions in 2022–23 due to limited ground access during extended high river flows over spring and early summer. High flows were also recorded in 2021–22.

Rainfall, river flows and floodplain inundation varied considerably in the Murrumbidgee catchment over the 2019 to 2023 period (Figure 15, Figure 16). Australasian bittern calling (breeding) responses were very limited during an extended dry period in 2019–20. At this time, 15,732 ha of inundation was recorded across the entire Lowbidgee floodplain, and bitterns were only detected at 4 sites (Table 5). In 2020–21, bittern activity was detected at 20 sites in response to increased inundation when a managed environmental water delivery inundated a cumulative area of 46,503 ha. High natural rivers flows were recorded in the 2021–22 and 2022–23 water years (Figure 15) which inundated large areas of floodplain habitat (Table 4). During this very wet 2-year period, Australasian bitterns were detected at 20 sites in total (out of 29 sites monitored) in the Lowbidgee floodplain (Table 5, Figure 16).

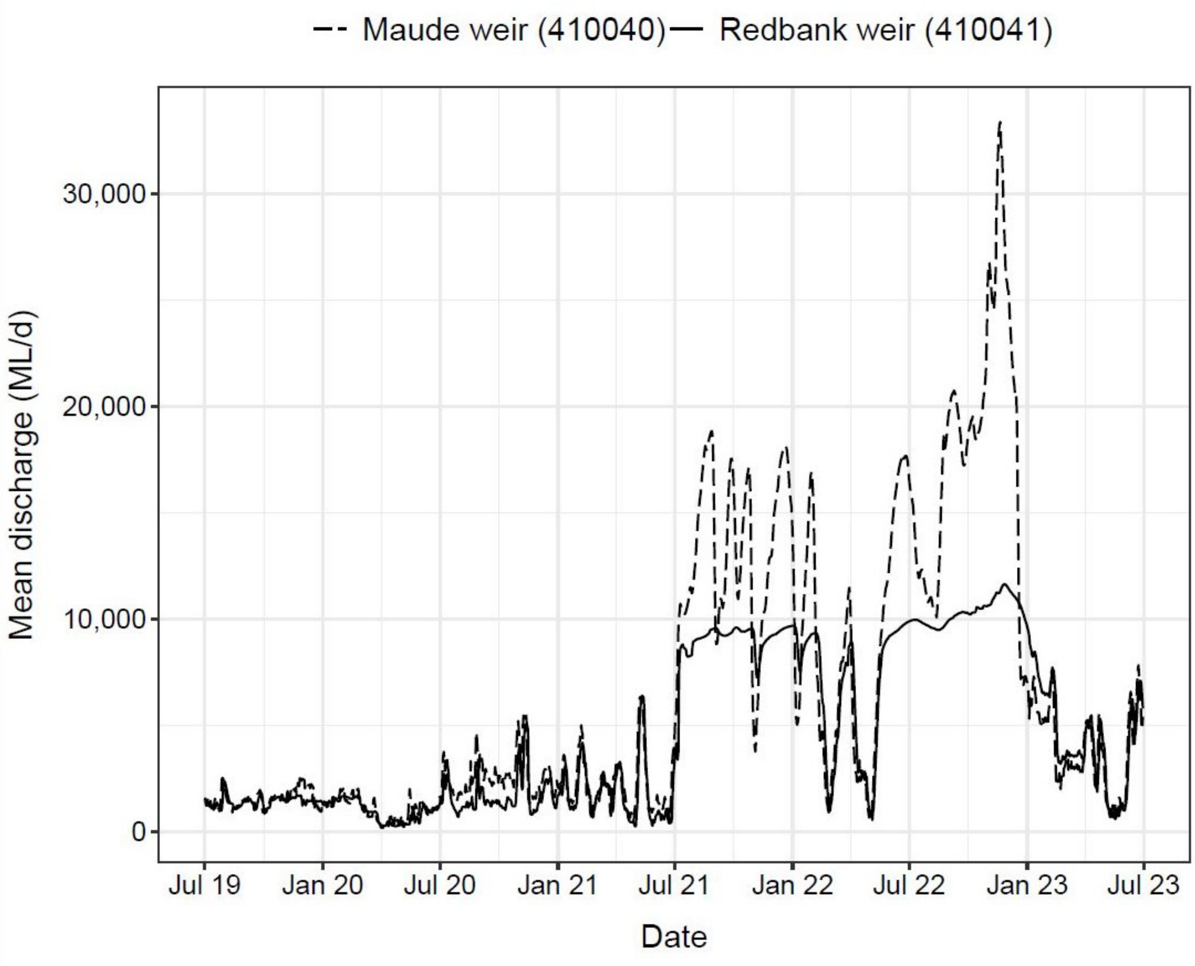

Figure 15 **River flows (ML/d) recorded at the downstream Maude weir (410040) and Redbank weir (410041) gauges on the Murrumbidgee River in the 2019 to 2023 period. Source: WaterNSW 2024**

Table 5 **Summary of Australasian bittern acoustic and ground survey records available for sites monitored in the Lowbidgee floodplain in the 2016 to 2023 period**

Water management area	Site name	2016–17	2017–18	2018–19	2019–20	2020–21	2021–22	2022–23
Gayini Nimmie-Caira	Banim (Avalon) Swamp	N	N	N	N	N	N	N
	Bala Rookery (Eulimbah Swamp)	Y[c,e]	Y[e]	N	Y[b,c,d,e]	Y[c,d,e]	Y[d,e]	Y[b,d,e]
	Fairfax Floodway (Suicide Bank)	–	–	–	Y[d,e]	Y[d,e]	Y[d,e]	Y[d,e]
	Dinan (Kia) Lake	–	–	N	–	N	Y[c,d]	Y[a,c,d]
	Kieeta Lake	–	–	–	–	–	–	Y[a]
	Emu (Loorica) Lake	–	–	–	–	Y[a]*	–	–
	Nap Nap Swamp	N	N	Y[b]	Y[b]	N	Y[b]	N
	Nimmie Creek	–	–	–	Y[a]	Y[a]	Y[a]	–
	Bayil (Telephone) Bank	Y[b]	N	N	N	Y[e]	Y[e]	N
	The Rookery	–	–	–	N	N	N	–
	Websters Bank	–	–	–	–	Y[a]	–	–
Redbank	Athen	–	–	Y[a]	N	Y[a]	Y[a]	–
	Breer Swamp	–	–	Y[c]	N	Y[a,b,c,d,e]	N	N
	Coates Swamp	–	N	Y[a]	N	Y [a]	Y[a,e]*	N
	Glenn Dee	–	–	–	–	Y[a]	–	–
	Lake Marimley	–	–	–	N	–	–	–
	Little Piggery	–	–	–	–	Y[e]	–	–
	Mercedes Swamp	Y[b]	N	Y[b,e]	N	N	N	N
	Monkem Creek	–	N	Y[a]	N	Y[a]	Y[a]	Y[a,c]
	Murrundi Swamp	–	–	Y[a]	N	N	Y[a,c]	–
	Narwie Swamp	Y[c,e]	Y[a]	Y[a]	N	N	Y[a,c]	Y[c]
	North Stallion	–	N	N	–	–	Y[a]*	–
	Pee Vee Creek	–	–	Y[a]	N	Y[a]*	Y[a]*	Y[a,c]
	Piggery Bridge	–	–	Y[c]	–	Y[a,c]	N	N

Water management area	Site name	2016–17	2017–18	2018–19	2019–20	2020–21	2021–22	2022–23
	Piggery Lake	–	–	N	N	Y[b,c]	N	N
	Pococks Swamp	–	–	–	–	N	–	–
	Shaws Swamp	–	–	–	–	N	–	–
	Springbank	–	–	N	N	Y[a,c]	Y[a]	–
	Steam Engine	Y[c]	Y[a]	Y[a]	N	Y[a,c,e]	Y[a,c,e]	Y[c,e]
	Tala Lake	–	–	–	–	Y[a]	Y[a]	–
	Tarwillie Swamp	–	–	–	–	N	–	–
	Two Bridges	–	N	Y[b,c,e]	N	Y[c,e]	Y[b,c]	N
	Uara Creek	–	–	–	–	N	Y[a*]	N
	Waugorah Lagoon	–	N	N	N	N	N	N
	Waugorah Lake	–	–	N	N	Y[a,b,c,e]	Y[a,b,e]	N
	Yanga Creek	–	–	–	–	–	–	N
Western Lakes	Paika Lake	–	–	–	–	–	N	N
	Paika Reedbeds	–	–	–	–	–	Y[f]	N
Total number of monitored sites where bitterns detected		**5**	**3**	**11**	**4**	**20**	**18**	**8**
Total number of bittern monitoring sites		**7**	**12**	**21**	**22**	**32**	**28**	**23**

Notes

a. SoS acoustic record (*acoustic record was distant, so bird suspected to be offsite).

b. CSU acoustic record (Wassens et al. 2024).

c. Ground survey record (Herring 2023).

d. MDWWG ground survey record (DPE 2022b).

e. CSU and/or NSW DCCEEW incidental ground survey record.

f. Landholder incidental record (photograph).

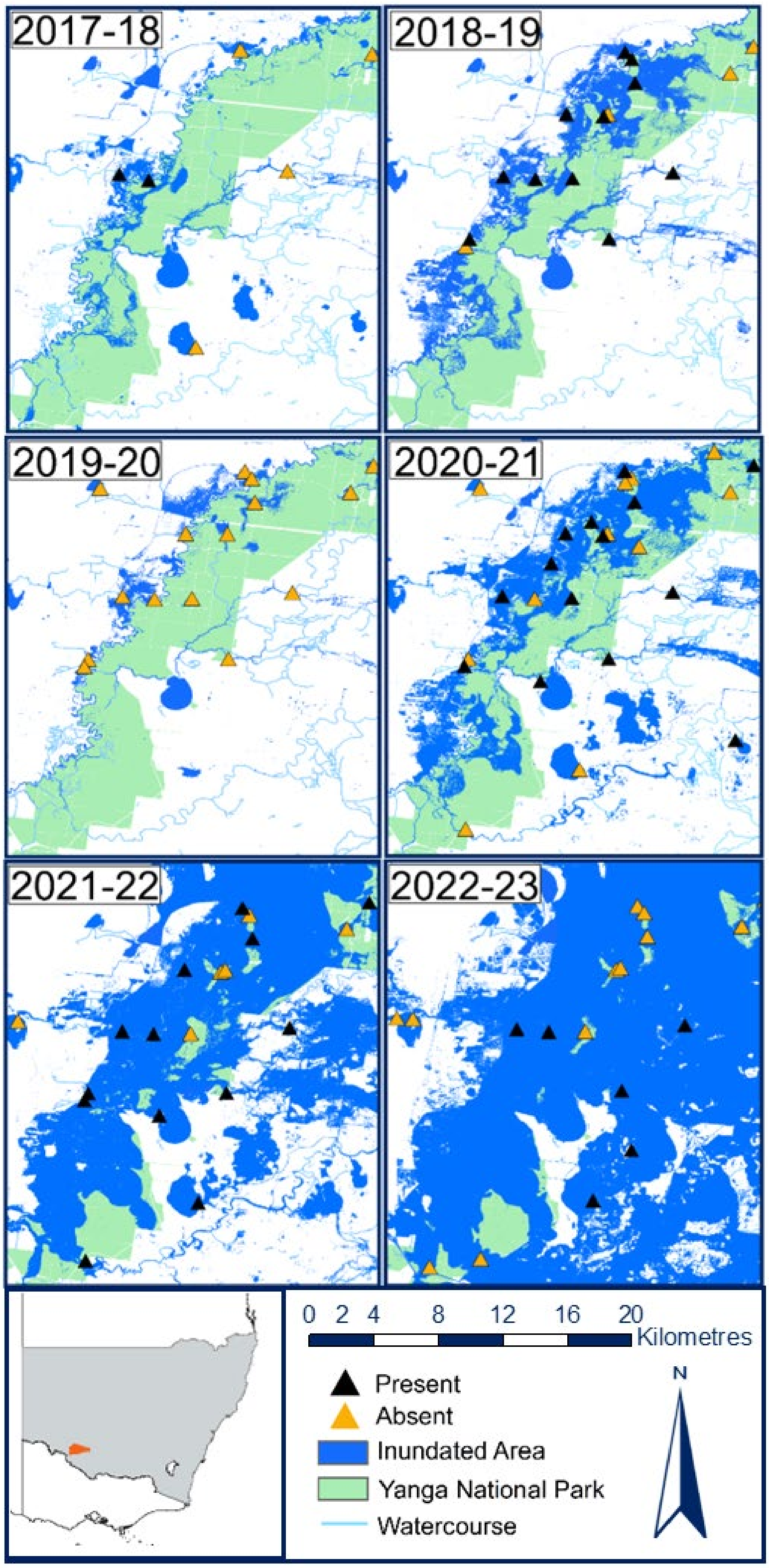

Figure 16 **Six years of ground and acoustic monitoring results of the Australasian bittern in the Lowbidgee floodplain, encompassing Yanga National Park, the western portion of the Gayini Wetlands and neighbouring private land in south-western NSW (inset). The cumulative extent of inundation for each water year is based on mapping from Sentinel satellite imagery (DCCEEW, 2025)**

4. Discussion

Greater ground and acoustic survey coverage in the past 5 years has revealed new locations in the MDB that support Australasian bitterns. The SoS research project provided insights into Australasian bittern distribution and habitat use in 4 wetland regions in south-western NSW. The project also demonstrated the value of acoustic monitoring for assessing Australasian bittern responses to inundation in remote floodplain wetlands.

Acoustic monitoring offers an important opportunity to assess the outcomes of environmental water delivery for Australasian bitterns, including habitat use and breeding periods. Recent surveys in the Lowbidgee floodplain showed the number of bittern sites had increased following consecutive years of environmental watering. High natural river flows during 2021 to 2023 inundated large areas of wetland creating increased breeding and feeding opportunities for bitterns in the wetland regions.

Australasian bitterns, like many waterbird species, are highly mobile and can use a range of habitats in the MDB. The SoS acoustic data showed that small wetland sites in the mid Murray, and creek lines in the Lowbidgee floodplain can provide habitat for bitterns at certain times. These sites may provide habitat corridors for bitterns dispersing between large breeding sites such as Barmah–Millewa Forest and the Gayini Wetlands.

Despite the lack of continuous recording data, the acoustic monitoring 5-minute-per-hour recording schedule consistently detected bitterns in a range of habitats. This included sites where calling occurred for only a few days or where bittern calls were only distant indicating birds were using neighbouring habitats. The acoustic recorders also confirmed male birds can start calling as early as September at some sites and calling activity had stopped by early autumn. CSU's complementary acoustic monitoring also showed that some male birds continue to call in winter months in the Gayini Wetlands (Wassens et al. 2024).

Peaks in daily calling activity occurred between 3 and 5 am and between 8 and 9 pm, indicating that ground surveys during these periods would have detected bitterns. These findings support the approach for ground survey protocols close to dusk and dawn, as close as possible to peak calling periods. High calling activity detected at the beginning and end of monitoring records at several sites suggests that the recording period needs to be initiated earlier. In future studies the acoustic recorders should be deployed in August and left in place until at least early March to capture the start and end of bittern calling activity.

There were a small number of occasions with discrepancies between the ground and acoustic records. The calling individual may have been beyond the range of the recording unit on these occasions, or the acoustic recorders may have failed to detect bitterns at these sites due to the dense tree canopy reducing call transmission. This would not have been an issue for most sites in the SoS monitoring program as they largely consist of open vegetation with limited mid-storey vegetation. A range of factors are likely to influence the transmission of calls, including habitat structure and background noise (Darras et al. 2016). Calibrating the detection radius of acoustic recorders in representative habitats would assist with quantifying the effect of vegetation characteristics on recording quality and the reliability of bittern detections. This process would also assist with validating the onsite/offsite categories developed in this study based on the energy values of calls.

Recommendations

Key recommendations for the Australasian bittern monitoring project include:

1. Deploy acoustic recorders prior to environmental water deliveries (e.g. in August) to more accurately identify the start of calling and extend deployment until at least early March to assess when bitterns depart the wetland after breeding, or whether they continue to utilise a wetland if it is inundated.
2. Maintain consistent recording periods across all sites to allow for improved comparison of geographic variation in calling activity.
3. Schedule manual surveys to coincide with peak calling activity for each wetland region to complement the acoustic monitoring program and ground-truth acoustic monitoring results.
4. Calibrate the recording radius of acoustic monitors at each (or representative) sites.
5. Install water-depth loggers alongside acoustic recorder units to investigate fine-scale responses to wetland inundation.
6. Consider use of continuous acoustic recorder units to provide more accurate measures of first calling date, peak calling activity and bittern abundance in relation to flow metrics.

Ongoing acoustic and ground monitoring is required to document the outcomes of environmental water delivery to priority bittern sites identified in the lower Lachlan, Lowbidgee floodplain and mid Murray regions. Further work is also needed to identify important bittern sites in wetland regions in the northern MDB that have ground survey records of Australasian bitterns but no dedicated monitoring projects.

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Appendix A: Information reliability assessment

Table 6 Information reliability assessment for datasets used to evaluate the occurrence of the endangered Australasian bittern in the Lowbidgee floodplain for purpose of NSW Matter 8 reporting

	Question	Answer and justification	Score out of 2
Methods			
Methods used	Are the methods used appropriate to gather the information required for evaluation?	Yes	2
		A combination of ground and acoustic monitoring data was used to gather information on the occurrence of Australasian bitterns in the Lowbidgee floodplain. Australasian bitterns are a difficult species to monitor as they are a nocturnal, cryptic species and so a range of methods are required to assess presence/absence. Using a combination of ground and acoustic survey data improves confidence in the detection of the species.	
Standard methods	Has the same method been used over the sampling program?	Yes	2
		The ground surveys have been conducted by the same observers using the same methods over the sampling program. The methods for acoustic monitoring were the same for both the CSU and NSW SoS programs, where recorders were deployed in each site over spring and summer months using a 5-minute per hour recording schedule.	

	Question	Answer and justification	Score out of 2
Representativeness			
Space	Has sampling been conducted across the spatial extent of waterbirds within the wetland being assessed with equal effort?	Somewhat	1
		Bitterns nest in dense vegetation over large areas that are difficult to cover equally on ground and/or with acoustic arrays. Coverage of both sampling programs was limited to the distance with which calls of male bitterns can be detected. This detection distance varies with wetland type and structure. The assessment focused on the western end of the Lowbidgee floodplain which includes wetlands in Yanga National Park and the North Redbank system known to support bitterns. This area had the best spatial coverage for ground and acoustic monitoring programs. Ground and acoustic data was also available for the neighbouring Gayini Wetlands, which also provide important breeding habitat for Australasian bitterns. Sampling in the Gayini Wetlands was limited to only a relatively small number of sites in this large lignum shrubland area.	
Time	Has the duration of sampling been sufficient to represent change over the assessment period?	Somewhat	1
		Ground survey and acoustic monitoring data was available from 2017 onwards to include the 2019–23 reporting period. Only incidental ground survey records were available prior to 2016.	
Repetition			
Space	Has sampling been conducted at the same sites/area over the assessment period?	Somewhat	1
		There was some variation in the ground and acoustic surveys locations each year as the sampling programs focused on different wetlands from year to year according to which areas were receiving environmental water and which	

	Question	Answer and justification	Score out of 2
		wetlands could be accessed on ground. There was limited ground access in spring and early summer 2022 due to high river flows.	
Time	Has the frequency of sampling been sufficient to represent change over the assessment period?	Yes	2
		Acoustic recorders were deployed over spring and summer to cover the bittern breeding season when male bitterns make booming calls to attract females to their territories. The ground surveys were done during peak calling times in late spring-early summer. 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 January 2023. Therefore, there were gaps in coverage for some sites in both the ground and acoustic monitoring programs in the Lowbidgee floodplain.	
Final score		**9/12**	
Information reliability		**Fair**	

Note

Acoustic survey data was collected through SoS and CSU monitoring programs. Targeted ground survey data was collected by contractors funded by the department's Water for the Environment program and through CSU's and the department day-time ground survey programs.

Appendix B: Steps for processing acoustic files

Opening the acoustic files

To open an acoustic file or multiple files, open the Raven Pro 1.6.4 software and choose File > Open Sound Files, then select the required file(s) and click ‘Open’. Note, where more than one channel was recorded, only one channel was selected per site. This was done by checking which channel appeared to have the clearest signal from the wetland. The ‘Configure New Sound Window’ dialogue box will pop-up (Figure 17). There is an option to choose an already adjusted and saved ‘Window pre-set’ from the drop-down list (called ‘Bittern’ in this example). For more information on how to create and save a window pre-set, see the New Zealand bittern monitoring protocol (O’Donnell and Williams, 2015).

To open multiple sound files, select ‘Page sound’ from the ‘Paging’ pane. For ‘Page size’, enter the length of sound required to be loaded in the sound window at any given time. Here, 300 seconds was chosen as each sound file was 5 minutes long. Note, ‘minutes’ can also be selected from the drop-down list. The ‘Page increment’ was set to 100 per cent and ‘Step increment’ to 10 per cent (default). Finally, select ‘Open as file sequence in one window’ from the ‘Multiple Files’ pane. A more detailed description of these settings, and other software related settings, can be found in the Raven Pro 1.4 User’s Manual (Charif et al. 2010).

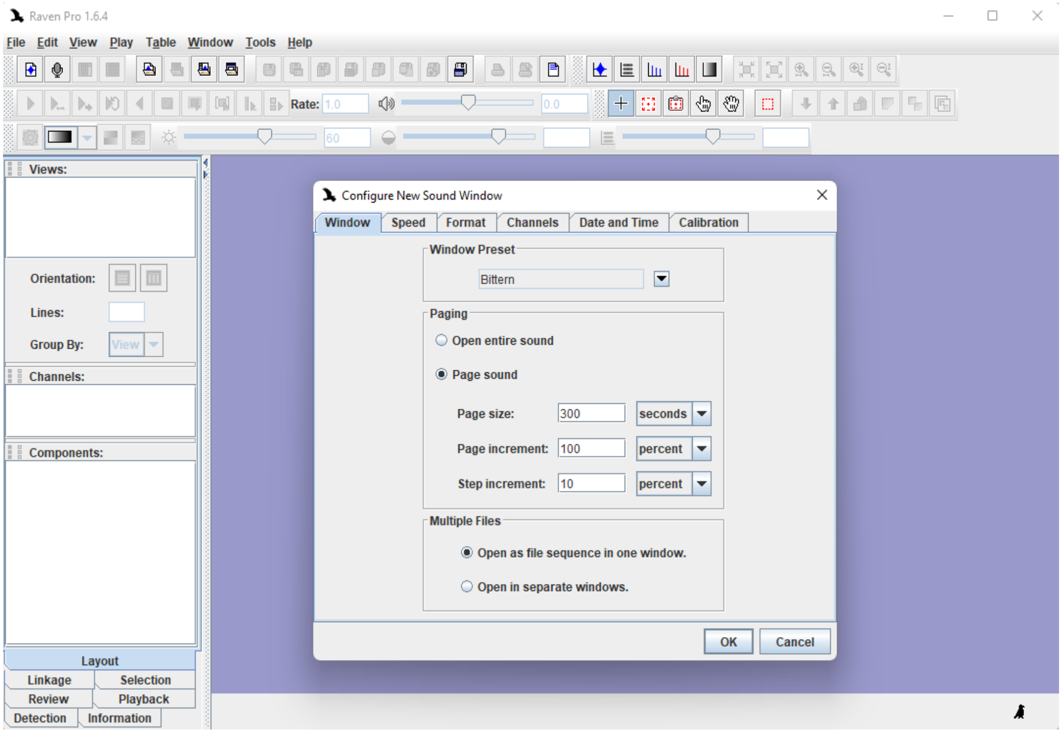


Figure 17 **Preview of ‘Configure New Sound’ window in Raven Pro software showing the detector**

Steps involved for adjusting the detector parameters can be found in Section 2.5 'Data processing', in the 'Development of the detector and validation dataset' section.

In summary, the detector (also referred to as 'Band Limited Energy Detector') settings were adjusted based on the assessment of boom frequency and duration variation. Once satisfied with the capacity of the selected detector settings to identify booms, the detector was used in an interactive mode to scan entire datasets for each site. To open the detector, right click anywhere on the spectrogram > 'Select Interactive Detector' > 'Band Limited Energy Detector' (Figure 18). As a final step, in a pop-up window, the 'Run Full' mode needs to be selected to run the detector on the entire dataset.

The final detector settings were as follows:

- minimum frequency: 120 Hz
- maximum frequency: 165 Hz
- minimum duration: 0.23267 s
- maximum duration: 0.98883 s
- minimum separation: 0.8725 s

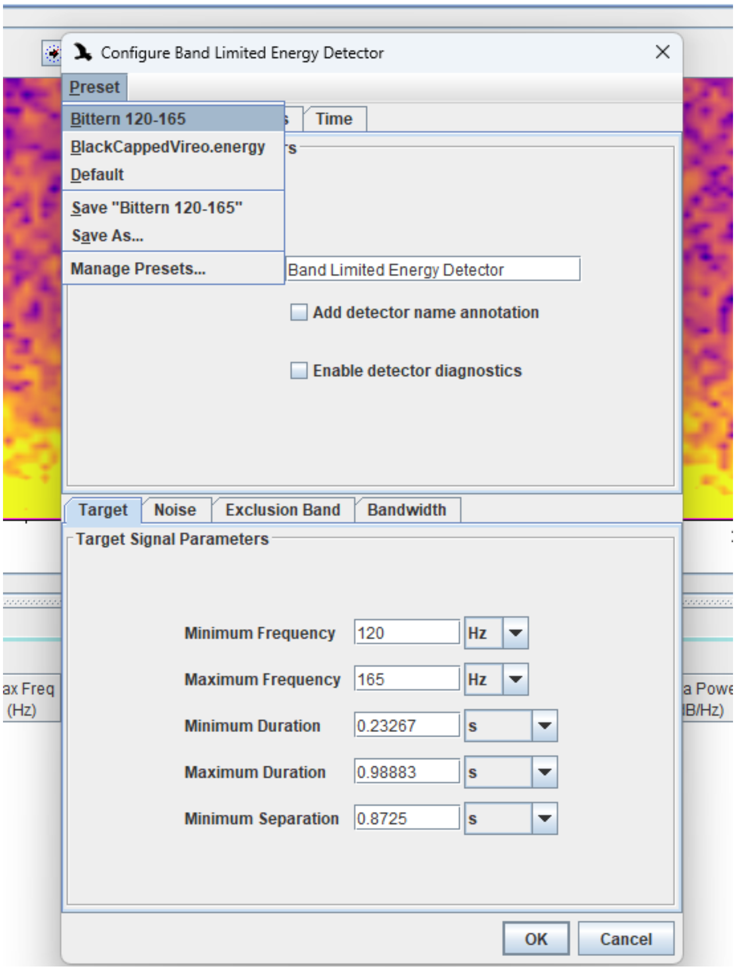


Figure 18 **Screenshot of Raven Pro showing the 'Target' tab and the parameters used to set up the detector**

Under the ‘Noise’ tab, the following parameter was selected:

- Signal-to-Noise Ratio (SNR) threshold (dB): 12.0 and check ‘above’ (see Figure 19).

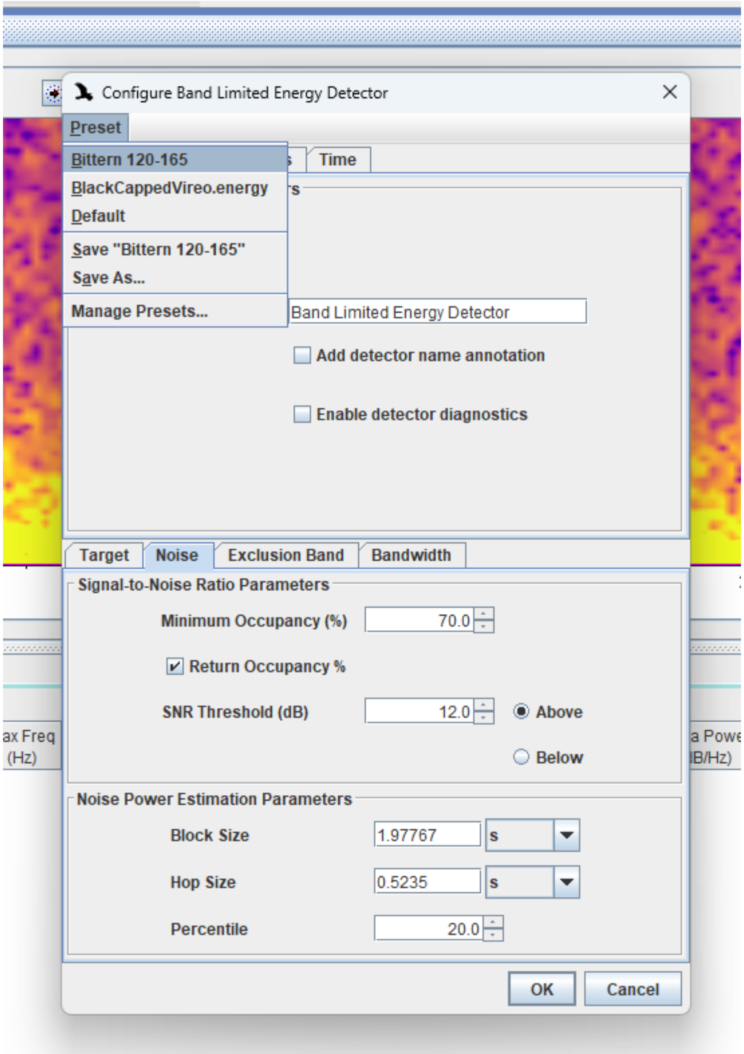


Figure 19 **Screenshot of Raven Pro showing the ‘Noise’ tab and the parameters used to set-up the detector**

Using the ‘Progress Manager’ function

The detector can be run in the background while continuing to use Raven Pro, for example, when validating detections previously produced. The ‘Progress Manager’ keeps track of the background task(s), such as the progress of the detector, allowing the user to check how close the task(s) is to completion (Figure 20). To open ‘Progress Manager’, click Window > ‘Progress Manager’. The ‘Progress Manager’ dialogue box disappears when anywhere else on the screen is clicked. However, the process of opening the dialogue box can be repeated at any time. The ‘Progress Manager’ automatically appears on the screen when the process of data scanning is finished, prompting the user to save the results.

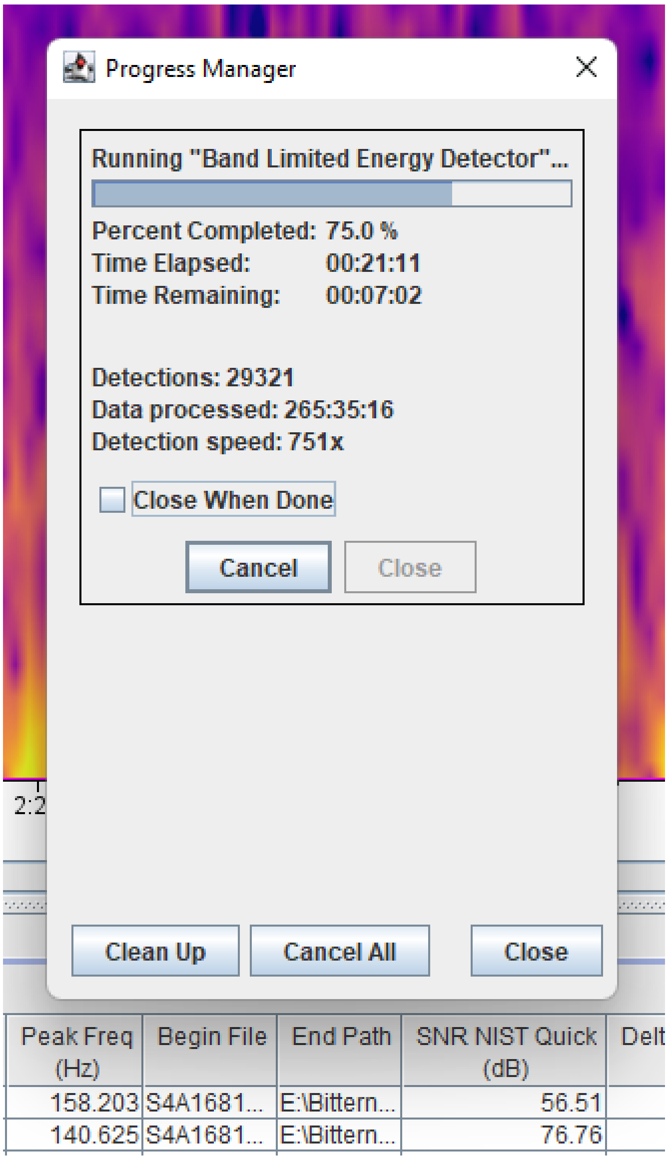


Figure 20 **Screenshot of Raven Pro showing the Progress Manager dialogue box**

Saving the detections and the corresponding selection table

Measurements of the detections appear in the 'Selection Table' at the bottom of the sound window after the detector has finished running (Figure 21). The 'Progress Manager' box will show 100%. Detection verification can now commence. The selection table should be saved before closing the software. Alternatively, the selection table can be saved, the software closed, and the validation process completed later. To save a selection table, click File > Save Selection Table "Band Limited Energy Detector" > choose Visible Selections (which will only save detections for Channel 1). When reopening the selection table, it is important to open the same acoustic files for which the selection table was originally generated.

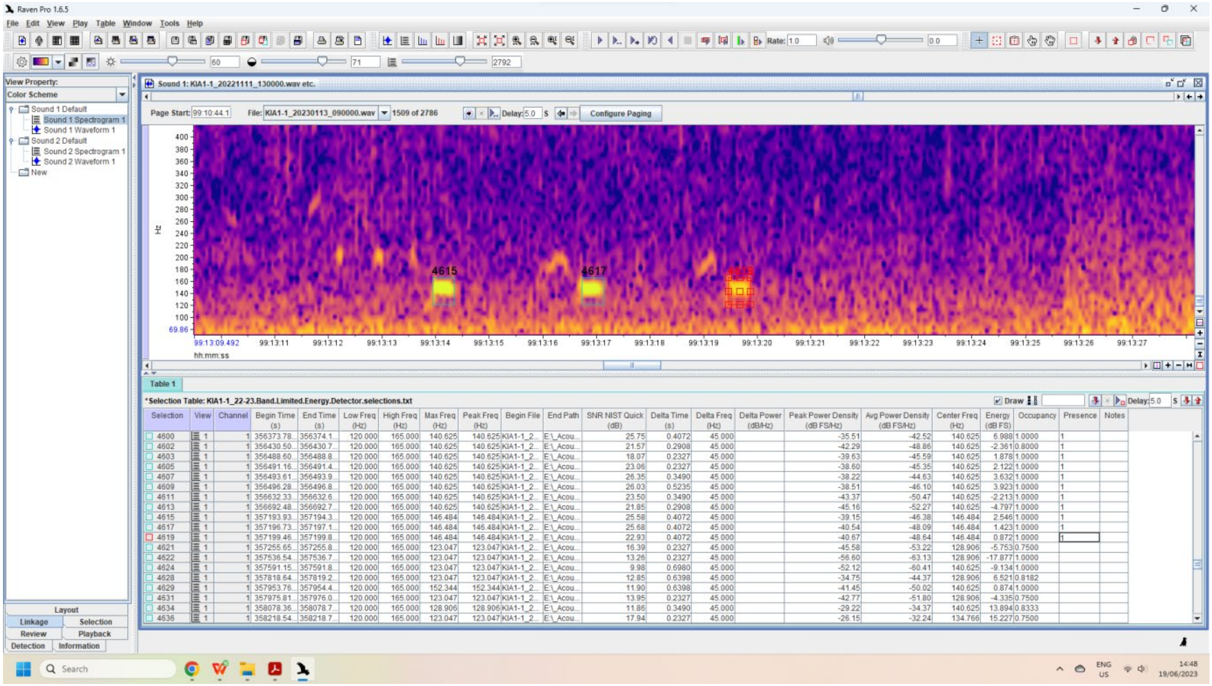


Figure 21 Spectrogram with a bittern boom train and the corresponding selection table

Additional measurements

The default selection table includes the following attributes:

- begin time (s)
- end time (s)
- low Frequency (Hz)
- high Frequency (Hz).

Depending on the aims and objectives of the project, additional measurements can be added to the selection table. To do this, right click on the selection table's header and go to 'Choose Measurements' (Figure 22). For this study, the following additional measurements of each detection were selected and added to the selection table as per recommendations by O'Donnell and Williams (2015) (see Figure 22).

- begin Time (s)
- end Time (s)
- low frequency (Hz)
- high frequency (Hz)
- average power density (dB F S/Hz)
- centre frequency (Hz)
- delta frequency (Hz)
- delta power density (dB/Hz)
- delta time (s)
- end file

- end path
- energy (DB F S)
- max frequency (Hz)
- peak frequency (Hz)
- signal-to-noise ratio (SNR) threshold (dB)
- begin file

This list of measurements can be saved as part of the configuration process of the window pre-set, so the 'Bittern' pre-set can simply be opened and all these measurements will automatically appear in the selection table.

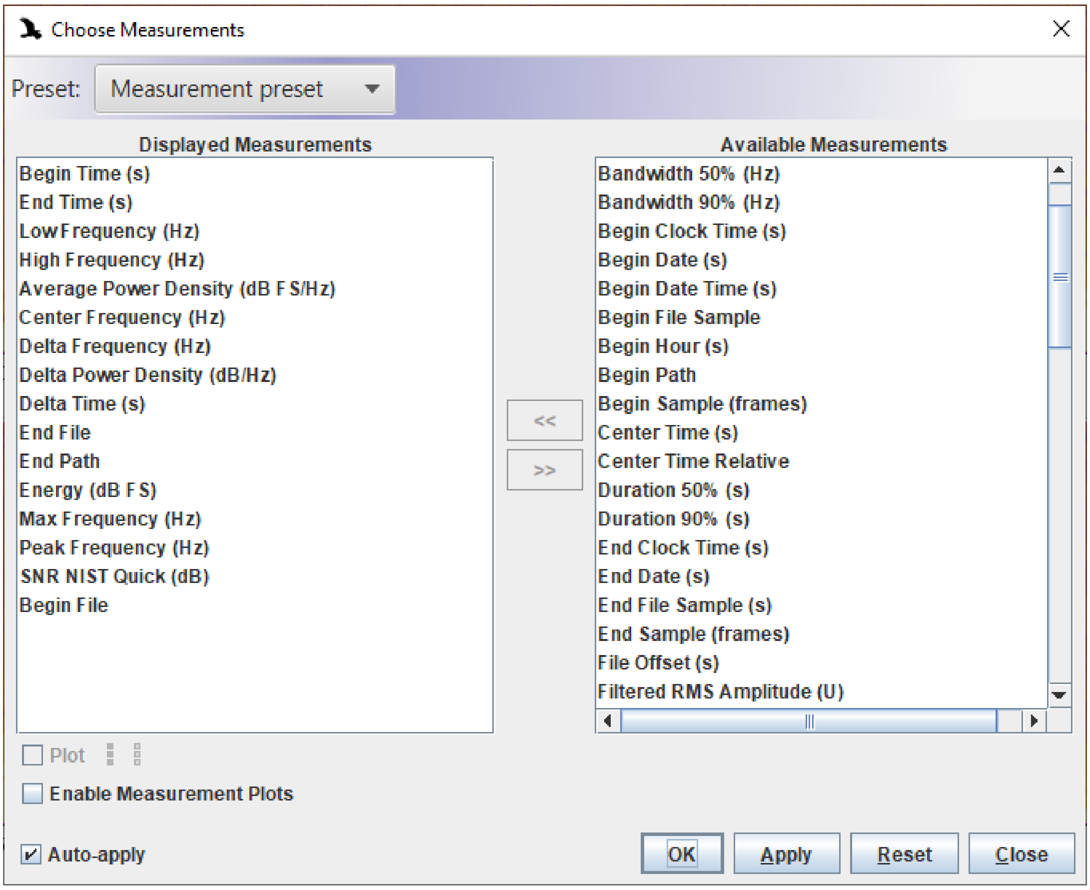


Figure 22 **Screenshot of Raven Pro showing how to choose additional measurements**

The measurements' parameters can be copied and pasted into a Microsoft Excel table by highlighting the required values/rows, right clicking, and selecting 'Copy Selected Cells'. Otherwise, the selection table can be saved as a text file (.txt) from where it can be opened in Microsoft Excel for further data analysis.

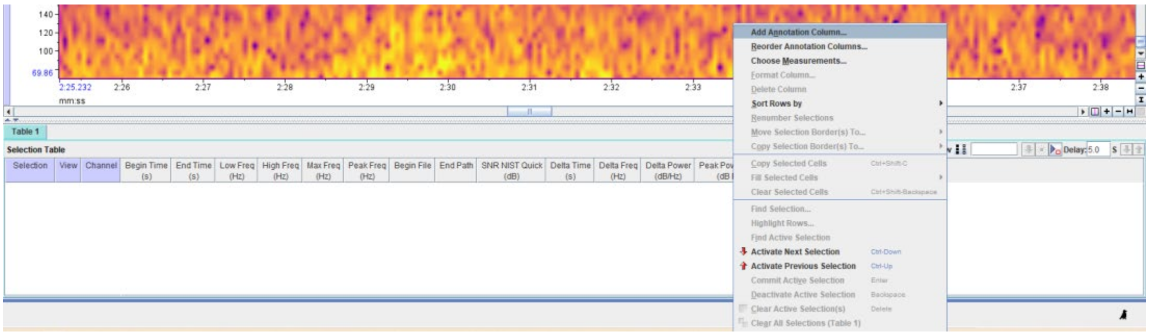
Annotation column(s)

Additional notes and other information can be added during the validation process by recording in the 'Annotation Column(s)'. To add an annotation column to the selection table, right click on any of the selection tables header and go to 'Add Annotation

Column' (Figure 23a). In this example, 2 annotation columns were added to each selection table (Figure 23b):

- 'Presence': 1 = if the sound was a bittern boom; 0 = if the sound was not a bittern boom; 0.5 = if in doubt and the sound needed cross checking)
- 'Notes': to record any comments where needed on the detection.

(a)



(b)

Figure 23 **Screenshots in Raven Pro showing (a) how to add annotation column(s) to the selection table and (b) the annotation columns 'Presence' and 'Notes' in the selection table**

Validating the detections

Clicking anywhere in the selection table will bring up the corresponding detection on the spectrogram. Using the mouse and/or the up/down/left/right arrows, the user can easily move between the rows and columns of the selection table. The validation process requires going through each detection to determine if a given detection is a bittern boom or not, by typing '1' or '0' in the 'Presence' annotation column. Detections with any uncertainty were marked as '0.5' (see section above). A second observer is then required for any detections with uncertainty as some calls can be distant and/or confused with other similar sounds such as swans, swamphens, and vehicle noise (see example spectrograms below). Comments were recorded in the 'Notes' annotation column (such as listing the nature of uncertain calls and some of the false detections for future reference, if needed). Notes about some detections is helpful for future cross checking of detections. It also allows for information about a given call to be accessed without the need to open the software to check and listen to calls of interest. Once the verification process was complete, the selection table, and associated measurements, were saved and could be opened in Microsoft Excel for subsequent data analysis.

Example spectrograms

Observers can learn to identify true bittern detections based on the spectrograms through the process of validating detections for large volumes of acoustic data. For calling males close to the recorder these can be seen as very clear regular sequences of calls (or ‘boom trains’) (Figure 24a). At times the calls can be quite faint (Figure 24b, c) and difficult to identify when there is a large amount of background noise (Figure 24d). In some instances, bittern detections can also be confused with other waterbird species such as black swans (*Cygnus atratus*) and purple swamphens (*Porphyrio porphyrio*) and bellows of cattle (Figure 25). For these examples the observers often need to manually validate the detection by listening to the calls.

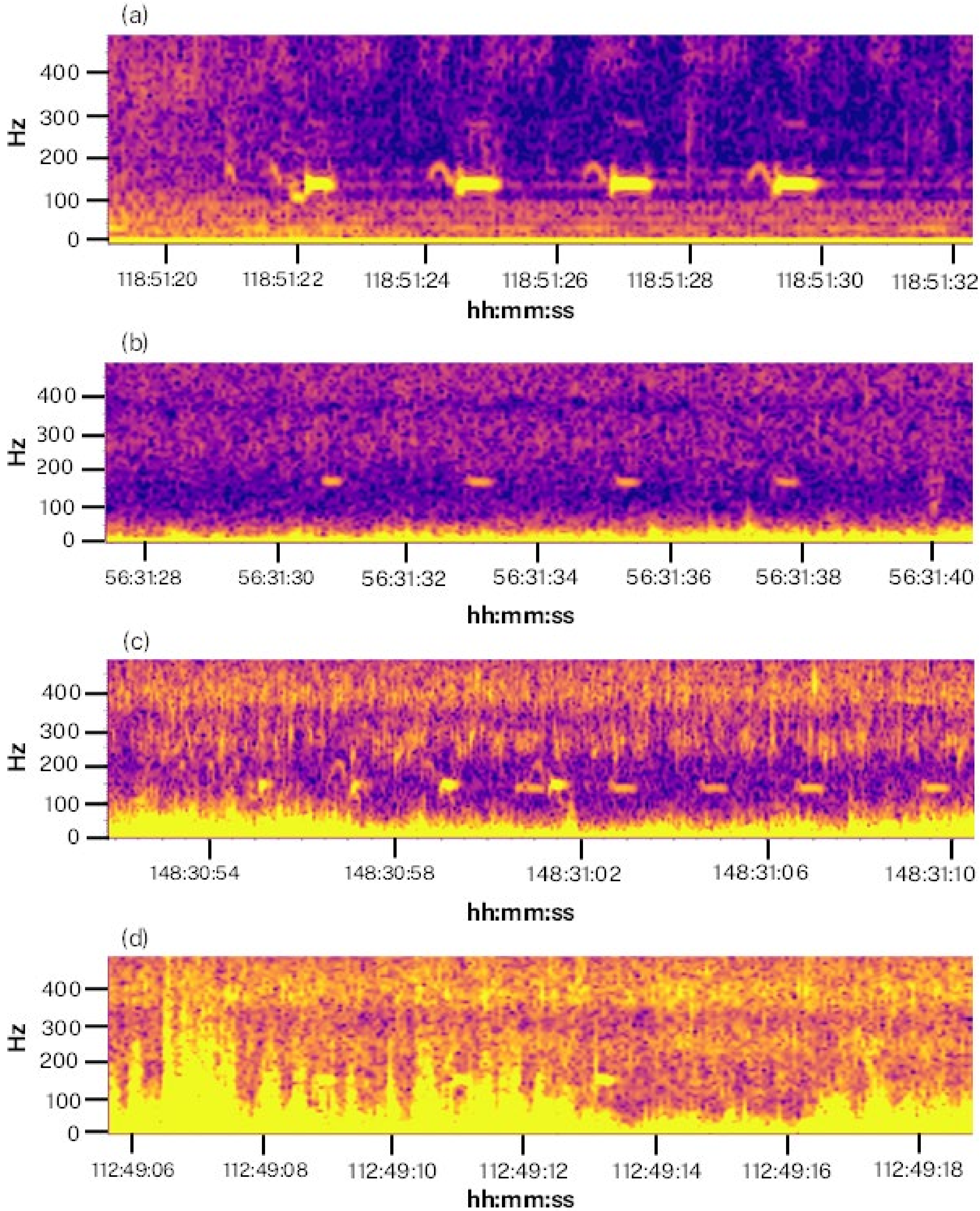


Figure 24 **Example spectrograms showing variability between Australasian bittern boom sequences: (a) clear boom train (the brighter the colour of the boom(s) the closer the bittern is to the recorder); (b) faint boom train (booms are more distant compared to the example in (a); (c) a sequence of 4 poor booms followed by 5 typical booms; and (d) booms are harder to spot and hear when there is high background noise such as wind**

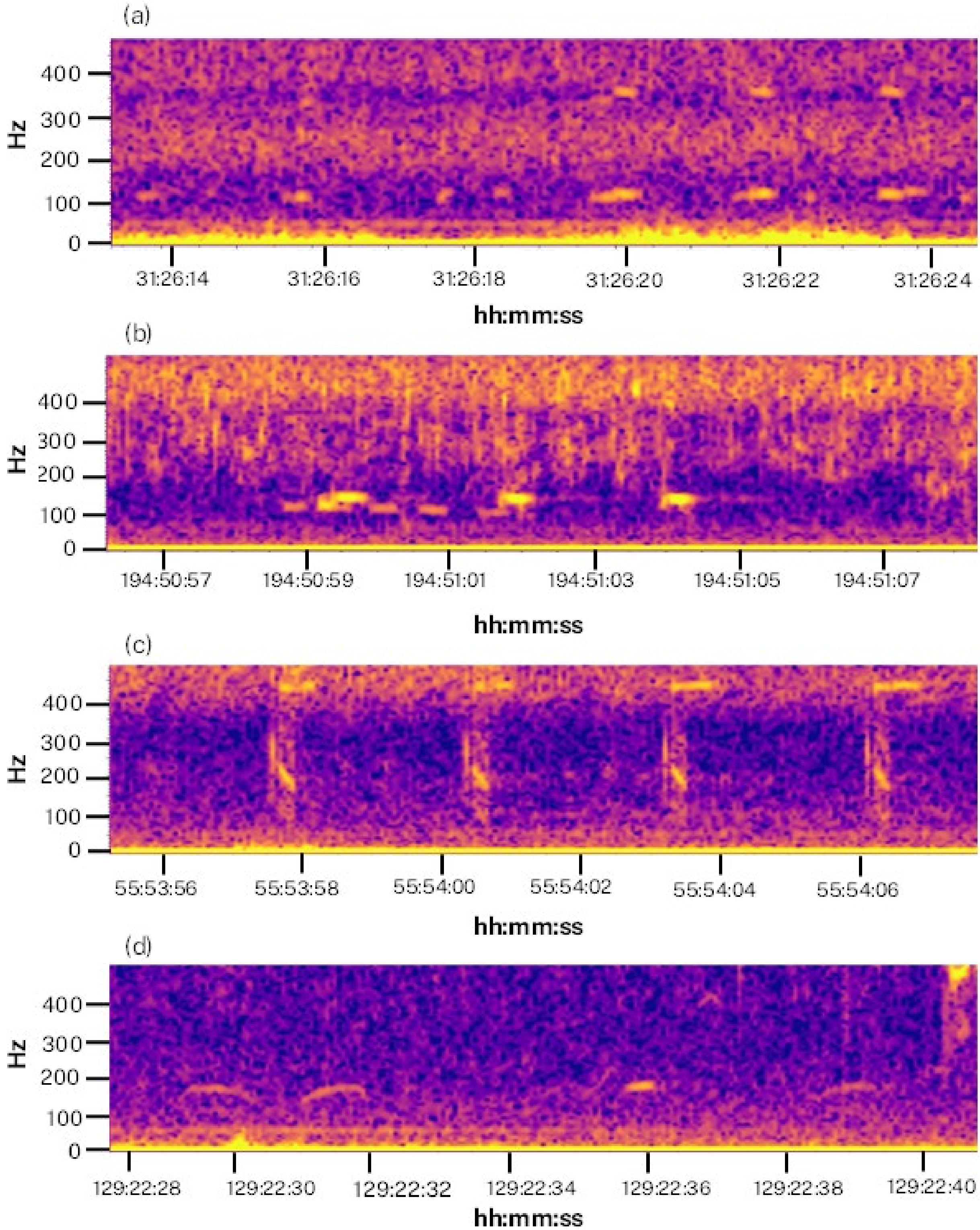


Figure 25 Example spectrograms showing other species and sounds that can be confused with Australasian bittern calls: (a) black swans calls; (b) a call sequence of 3 Australasian bittern booms (brighter yellow) alongside calls of black swans (shown below the 3 bittern booms on the spectrogram); (c) purple swamphen calls; and (d) low deep bellows of nearby cattle

Appendix C: Summary of Australasian bittern detections

Table 7 Summary of NSW SoS Coleambally Irrigation Area acoustic monitoring data processed for 2021–22 and 2022–23

Water year	Site name	Site code	Total record-ing days	Total number of 5-min files tested	Total number of detections	Total number of booms^	First detection date	Peak calling date	Last detection date	Confidence rating
2021–22	Burraburoon*	BURR1	59	1,374	9,065	0	NA	NA	NA	NA
2021–22	Irrigation main storage	CICL1	139	3,249	1,3221	3201	26/10/21	17/12/21	02/01/22	High
2021–22	Max Collie's swamp*	COL1	93	2,184	7,060	0	NA	NA	NA	NA
2021–22	Foster's Swamp*	FOS1	95	2,216	3,175	0	NA	NA	NA	NA
2021–22	Lander's wetland*	LAN1	49	1,130	409	0	NA	NA	NA	NA
2021–22	Nyangay Creek*	NYA1	58	1,368	7,129	0	NA	NA	NA	NA
2021–22	Wargam big lake*	WAR1	46	1,037	4,472	0	NA	NA	NA	NA
2021–22	Wargam little lake*	WAR2	47	1,062	9,246	0	NA	NA	NA	NA
2022–23	Irrigation main storage	CICL1	124	2,938	11,225	0	NA	NA	NA	NA
2022–23	Wargam big lake	WAR1	119	2,839	8,551	0	NA	NA	NA	NA
2022–23	Wargam little lake	WAR2	6	124	536	0	NA	NA	NA	NA

Notes: First and last detection dates do not indicate that bitterns were calling for the entire period. ^Total number of booms were confirmed as true detections. The confidence rating relates to whether birds were on site or not (high ratings were for sites where calls were loud and close to the recorder, while low rating was given to sites where calls were only distant). * Site received discretionary environmental water as advised by J Maguire (NSW DCCEEW).

Table 8 Summary of NSW SoS Lowbidgee floodplain acoustic monitoring data processed for 2021–22 and 2022–23

Water year	Site name	Site code	Total recording days	Total number of 5-min files tested	Total number of detections	Total number of booms^	First detection date	Peak calling date	Last detection date	Confidence rating
2021–22	Nimmie Creek*	NIM1	44	1,018	7,255	7,015	26/10/21	25/11/21	08/12/21	High
2021–22	Narwie Swamp	NAR1.5	87	2,052	8,742	6,668	13/10/21	27/11/21	01/01/22	High
2021–22	Steam Engine Swamp	STE1	102	2,354	9,338	3,736	14/10/21	21/11/21	25/01/22	High
2021–22	Springbank	SPR1	155	3,645	5,089	2,429	07/10/21	29/01/22	14/03/22	High
2021–22	Athen	ATH1	175	4,108	6,381	1,664	14/10/21	25/11/21	20/02/22	High
2021–22	Monkem Creek*	MON1	176	41,75	6,479	431	12/10/21	24/12/21	31/01/22	High
2021–22	Murrundi Swamp	MUR1.1	115	2,774	2,117	343	25/10/21	29/01/22	16/02/22	High
2021–22	Lake Tala	TAL1	145	3,353	3,208	296	09/10/21	25/11/21	01/02/22	High
2021–22	Waugorah Lake	WAU1	191	4,433	5,953	58	13/10/21	14/10/21	25/11/21	Medium
2021–22	Pee Vee Creek*	PEE1	132	3,084	1,761	103	14/10/21	07/12/21	29/01/22	Low
2021–22	North Stallion Swamp	STAL1	4	78	143	60	13/10/21	14/10/21	14/10/21	Low
2021–22	Coates Swamp	COA1	16	330	218	33	13/10/21	14/10/21	29/01/22	Low
2021–22	Uara Creek*	UAR1	97	2,227	963	2	28/01/22	28/01/22	29/01/22	Low
2021–22	Paika Lake*	PAI1	62	1,463	2,571	0	NA	NA	NA	NA
2021–22	Paika Reedbeds*	PAI2	62	1,463	2,074	0	NA	NA	NA	NA

Water year	Site name	Site code	Total recording days	Total number of 5-min files tested	Total number of detections	Total number of booms^	First detection date	Peak calling date	Last detection date	Confidence rating
2021–22	Rookery wetland*	ROO1	100	2,337	16,692	0	NA	NA	NA	NA
2021–22	House wetland*	ROO2	88	2,103	13,029	0	NA	NA	NA	NA
2022–23	Kieeta Lake*	KIE1	104	2,467	7,700	4,628	11/11/22	12/01/23	01/02/23	High
2022–23	Kia Lake*	KIA1.1	117	2,786	3,249	1142	12/11/22	12/01/23	25/01/23	High
2022–23	Monkem Creek*	MON1	111	2,641	3,104	1107	4/11/22	09/01/23	25/01/23	High
2022–23	Paika Lake*	PAI1	105	2,410	5,387	0	NA	NA	NA	NA
2022–23	Paika Reedbeds*	PAI2	140	3,327	4,563	0	NA	NA	NA	NA
2022–23	Pee Vee Creek*	PEE1	134	3,201	7,600	0	NA	NA	NA	NA
2022–23	Uara Creek	UAR1	5	82	29	0	NA	NA	NA	NA

Notes: First and last detection dates do not indicate that bitterns were calling for the entire period. ^Total number of booms were confirmed as true detections. The confidence rating relates to whether birds were on site or not (high ratings were for sites where calls were loud and close to the recorder, while low rating was given to sites where calls were only distant). *Site received discretionary environmental water as advised by J Maguire (NSW DCCEEW).

Table 9 Summary of NSW SoS mid-Murrumbidgee wetlands acoustic monitoring data processed for 2021–22 and 2022–23

Water year	Site name	Site code	Total recording days	Total number of 5-min files tested	Total number of detections	Total number of booms	First detection date	Peak calling date	Last detection date	Confidence rating
2021–22	Coonancoocabil Lagoon	COO1	95	2,210	2,117	0	NA	NA	NA	NA
2021–22	McCaughey's Lagoon	MAC1	129	3,036	2,985	0	NA	NA	NA	NA
2021–22	Turkey Flats	TUF1	97	2,295	3,609	0	NA	NA	NA	NA
2021–22	Wilbriggie Lagoon	DAR1	135	3,156	3,087	0	NA	NA	NA	NA
2021–22	Yarrada West Lagoon	YAR1	147	3,457	2,719	0	NA	NA	NA	NA
2022–23	Coonancoocabil Lagoon	COO1	73	1,727	6,307	0	NA	NA	NA	NA
2022–23	McCaughey's Lagoon	MAC1	83	1,958	1,895	0	NA	NA	NA	NA

Table 10 **Summary of NSW SoS lower Lachlan acoustic monitoring data processed for 2021–22 and 2022–23**

Water year	Site name	Site code	Total recording days	Total number of 5-min files tested	Total number of detections	Total number of booms^	First detection date	Peak calling date	Last detection date	Confidence rating
2021–22	Blimebungi Inlet*	BLI1	187	4,428	45,805	7201	30/09/21	16/11/21	06/02/22	High
2021–22	Clear Lake*	CLE1	137	3,260	16,531	6974	14/09/21	30/12/21	25/01/22	High
2021–22	Snake Bank*	SNA1	141	3,322	6,039	3525	18/09/21	07/11/21	26/01/22	High
2021–22	Dry Lake*	DRY1	200	4,759	18,323	2913	30/09/21	18/12/21	09/02/22	High
2021–22	Lignum Lake	LIG1	178	4,247	14,737	2844	18/10/21	16/11/21	05/02/22	High
2021–22	Box Camp*	BOX1	154	3,647	8,536	1408	16/11/21	25/11/21	31/01/22	High
2021–22	Tupra pumphouse*	TUP3	179	4,246	2,871	53	03/11/21	07/01/22	28/01/22	High
2021–22	Lake Bunumburt*	BUN1	217	5,160	9,579	138	03/10/21	20/11/21	18/01/22	Medium
2021–22	Overflow from Lachlan River (Tupra)	TUP1	202	4,806	2,627	80	26/10/21	07/01/22	27/01/22	Medium
2021–22	Noonamah	NOON1	178	4,219	14,999	63	03/10/21	21/11/21	06/01/22	Medium
2021–22	Bunumburt Black Box Lake	BUN2	217	5,161	18,315	62	26/10/21	21/11/21	18/01/22	Medium
2021–22	Lake Comayjong	COM1	179	4,247	12,480	26	03/11/21	07/01/22	07/01/22	Medium
2021–22	Lake Bullogal	BOO1	179	4,248	12,060	19	16/11/21	21/11/21	24/11/21	Medium

Water year	Site name	Site code	Total recording days	Total number of 5-min files tested	Total number of detections	Total number of booms^	First detection date	Peak calling date	Last detection date	Confidence rating
2021–22	Lachlan River at the Ville	VIL1	99	2,351	896	44	16/11/21	21/11/21	07/12/21	Low
2021–22	Tupra house pond	TUP2	202	4,804	15,107	22	27/10/21	07/01/22	07/01/22	Low
2021–22	Fletcher's Dam	FLE1	99	2,343	9,312	0	NA	NA	NA	NA
2021–22	Lake Ita	ITA1	80	1,890	10,580	0	NA	NA	NA	NA
2022–23	Johns Swamp	JOH1	142	3,389	9,602	2571	11/11/22	01/01/23	06/01/23	High
2022–23	Lake Comayjong	COM1	140	3,335	5,381	300	23/11/22	07/12/22	25/01/23	Medium
2022–23	Bunumburt Big Lake	BUN1	139	3,320	11,065	36	30/11/22	30/01/23	10/12/22	Low
2022–23	Bunumburt Back Lake	BUN2	67	1,592	2,221	0	NA	NA	NA	NA
2022–23	Lake Ita	ITA1	140	3,341	10,515	0	NA	NA	NA	NA

Notes: First and last detection dates do not indicate that bitterns were calling for the entire period. ^Total number of booms were confirmed as true detections. The confidence rating relates to whether birds were on site or not (high ratings were for sites where calls were loud and close to the recorder, while low rating was given to sites where calls were only distant). *Site received discretionary environmental water as advised by J Lenehan (NSW DCCEEW). Note many sites filled by translucency flows and high river flows.

Table 11 Summary of NSW SoS mid Murray acoustic monitoring data processed for 2021–22 and 2022–23

Water year	Site name	Site code	Total recording days	Total number of 5-min files tested	Total number of detections	Total number of booms^	First detection date	Peak calling date	Last detection date	Confidence rating
2021–22	Farnley1*	FARN1	127	3,023	13,445	25	06/01/22	07/01/22	07/01/22	High
2021–22	Farnley2*	FARN2	71	1,662	10,489	22	06/01/22	07/01/22	16/02/22	Medium
2021–22	Lake Agnes*	AGN1	143	3,422	12,351	2	06/01/22	06/01/22	06/01/22	Medium
2021–22	Tarnbank*	TARN1	120	2,853	9,112	17	22/11/21	22/11/21	07/12/21	Low
2021–22	Kangaroo Creek*	KAN1	117	2,756	7,364	5	29/01/22	29/01/22	29/01/22	Low
2021–22	Blytheswood Park*	BLY1	63	1,491	5,075	0	NA	NA	NA	NA
2021–22	Errendunda*	ERR1	94	2,216	7,488	0	NA	NA	NA	NA
2021–22	Gynong*	GYN1.3	100	2,374	8,031	0	NA	NA	NA	NA
2021–22	Ingelbrae*	ING1	115	2,730	11,390	0	NA	NA	NA	NA
2021–22	Jimaringle Creek*	JIM1	139	32,78	9,221	0	NA	NA	NA	NA
2021–22	Magpie Creek*	MAG1	141	3,354	8,498	0	NA	NA	NA	NA
2021–22	Morton's Swamp*	MOR1	157	3,664	6,120	0	NA	NA	NA	NA
2021–22	Morton's Swamp*	MOR1.1	63	1,488	3,549	0	NA	NA	NA	NA

Water year	Site name	Site code	Total recording days	Total number of 5-min files tested	Total number of detections	Total number of booms^	First detection date	Peak calling date	Last detection date	Confidence rating
2021–22	Wee Wee Creek	WEE1	94	2,216	1839	0	NA	NA	NA	NA
2022–23	Farnley1*	FARN1	100	4,443	9537	1141	02/01/23	28/01/23	25/02/23	High
2022–23	Farnley2*	FARN2	142	3,310	15943	534	03/01/23	25/01/23	17/02/23	High
2022–23	Lake Agnes*	AGN1	99	2,340	9268	510	03/01/23	5/02/23	10/02/23	High
2022–23	Kangaroo Creek	KAN1	127	3,016	4512	182	21/01/23	25/01/23	05/02/23	High
2022–23	Errendunda	ERR1	122	2875	7466	6	18/01/23	18/01/23	18/01/23	Medium

Note: First and last detection dates do not indicate that bitterns were calling for the entire period. ^Total number of booms were confirmed as true detections. The confidence rating relates to whether birds were on site or not (high ratings were for sites where calls were loud and close to the recorder, while low rating was given to sites where calls were only distant). *Site received discretionary environmental water as advised by J Dyer (NSW DCCEEW).

Table 12 **Summary of NSW SoS lower Murray acoustic monitoring data processed for 2021–22 and 2022–23**

Water year	Site name	Site code	Total recording days	Total number of 5-min files tested	Total number of detections	Total number of booms	First detection date	Peak calling date	Last detection date	Confidence rating
2021–22	Cliffhouse wetland	CLIF1	80	1,847	6,528	0	NA	NA	NA	NA
2021–22	Frenchman's Creek	FRE1	105	2,496	2,912	0	NA	NA	NA	NA
2021–22	Lake Henry, Wingillie Station	WIN1	140	3,327	6,363	0	NA	NA	NA	NA
2021–22	Nampoo wetland	NAM1	68	1,584	1,010	0	NA	NA	NA	NA
2021–22	Rick Webster's wetland	RICKS	124	859	3,692	0	NA	NA	NA	NA
2022–23	Lake Victoria Station wetland	VIC1	19	431	487	0	NA	NA	NA	NA
2022–23	Tareena Lagoon (mid)	TARM1	187	4,428	11,767	0	NA	NA	NA	NA