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Seasonal patterns in male Australasian Bittern *Botaurus poiciloptilus* calling at Bool Lagoon Game Reserve and Hacks Lagoon Conservation Park, South Australia

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Abstract. Acoustic monitoring is widely used to support Australasian Bittern *Botaurus poiciloptilus* recovery, providing valuable records of potential breeding activity. We analysed calling patterns from recordings at Bool Lagoon Game Reserve and Hacks Lagoon Conservation Park, South Australia, across the 2022–2023 and 2023–2024 wet seasons. Specifically, we examined call distributions relative to sunrise and sunset and timing after inundation. At Bool Lagoon there were quite sharp peaks of calling within 1–2 hours of dawn and dusk (>84% of calls during these periods) but at Hacks Lagoon calling was spread more broadly through the night and morning. Booming began 22 and 7 days post-inundation in 2022–2023, and 34 and 24 days post-inundation in 2023–2024 at Bool and Hacks Lagoons, respectively. A late-season rise in water levels in 2023–2024 triggered a smaller peak in calling. These findings reveal temporal and site-specific variation in Australasian Bittern calling in response to hydrological conditions and can inform conservation efforts to maintain water levels supporting the species' 60-day booming and 79-day breeding periods.

Introduction

The Australasian Bittern *Botaurus poiciloptilus* is a partially nocturnal, cryptic, and nomadic species, which historically has been observed in three countries – Australia, New Caledonia and New Zealand (Williams & Brady 2014; BirdLife International 2016). Its status in New Caledonia, however, is uncertain, with no recent public observations (Ekstrom *et al*. 2002). In Australia, its population is distributed across coastal and inland wetlands in the continent's south, predominantly in the south-east, Tasmania, and in the south-west of Western Australia (Maddock 2011; Western Australian Department of Biodiversity, Conservation and Attractions 2018; Commonwealth of Australia 2022; Fitzsimons 2022). It has been classified as globally threatened since 2016 because of the declining trajectory of its small remaining population (750–2500 individuals: BirdLife International 2016; O'Donnell *et al*. 2017; Herring *et al*. 2021a; Commonwealth of Australia 2022). The lack of rigorous baseline data and understanding of the species' breeding behaviour in natural systems have been identified as barriers to effective conservation efforts aimed at reversing declining trajectories (Kushlan 2000, 2007, 2019; Williams & Brady 2014; Commonwealth of Australia 2022).

Australasian Bitterns spend much of their life cycle in freshwater habitats comprised of a mosaic of dense wetland vegetation and open water. In the austral spring–summer, males maintain a territory in these habitats, producing a low-frequency call (up to 500 Hz), referred to hereafter as a 'boom', both to attract females and to intimidate rivals (Marchant & Higgins 1990; O'Donnell 2011; Herring *et al.* 2019). Detection of these booms can serve as a proxy for observations of breeding (Williams *et al.* 2019) as it is assumed that males call mostly in wetlands that meet their reproductive needs (i.e. inundation for a specific duration and at a certain time, vegetation that supports nesting and feeding etc.). Traditional survey methods for booming activity of Australasian Bitterns include on-ground visual and listening surveys, conducted primarily at dusk (Williams *et al.* 2019). Programmable audio recorders are now increasingly used for such vocally active species to improve spatial and temporal coverage of survey efforts (Williams *et al.* 2018; Rowe *et al.* 2023).

Most recovery efforts for Australasian Bitterns across their range have involved acoustic monitoring in some form, meaning that the locations of potential breeding events are well documented (Herring *et al.* 2019; Commonwealth of Australia 2022). Few studies, however, have investigated breeding events at high granularity. Information on the duration, timing and frequency of booming activity has largely been lacking, impacting our ability to examine environmental thresholds and triggers for breeding. Further, few wetland management regimes account for the life histories of such species. The *Water Allocation Plan for the Lower Limestone Coast Prescribed Wells Area* (South East Natural Resources Management Board 2019), for example, provides a framework for the sustainable management of groundwater resources across South Australia's Lower Limestone Coast region, aiming to balance use for consumption with ecological integrity. Although a main objective of this plan is to protect groundwater-dependent ecosystems (e.g. Bool Lagoon Game Reserve and Hacks Lagoon Conservation Park), it does not explicitly account for all significant hydrological requirements for threatened species (including Australasian Bittern) or recommend protective measures that maintain these requirements.

Here, we investigate temporal patterns in Australasian Bittern booming, based on recordings from Bool Lagoon Game Reserve and Hacks Lagoon Conservation Park, South Australia. Specifically, we aimed to characterise male calling behaviour by examining (1) the distribution of booms with respect to sunrise and sunset, and (2) the distribution of booms over the wet seasons of 2022–2023 and 2023–2024 for these wetlands. In so doing, we produce insights into the peak booming periods for this species, how rapidly booming commences following wetland inundation, and responses to 'pulse flows' in natural wetland systems. We then discuss the implications of the data for local conservation actions and additional protective measures.

Methods

Study area

Bool Lagoon Game Reserve and Hacks Lagoon Conservation Park constitute a large (3221 ha: Figure 1), seasonal, freshwater wetland complex in South Australia's Limestone Coast region (37°06′54.4″S, 140°41′33.1″E). Despite Hacks Lagoon receiving water via Mosquito Creek (drainage area 121,500 ha), this complex is largely groundwater-dependent, with the extent of seasonal inundation determined by saturation of the local water table (Smith *et al.* 2015). Recently, reductions in rainfall, intensifying demands on groundwater, combined with increasing water consumption in the headwaters of Mosquito Creek (South Australian Department for Environment and Heritage 2006), have likely altered the hydrological dynamics of this complex. Nevertheless, during a typical 'wet season' (September–January), Bool and Hacks Lagoons have vast expanses of aquatic vegetation (Figure 1), including Water Ribbons *Triglochin procerum,* sedges (Jointed Rush *Machaerina articulata*, Bare Twig-rush *M. juncea*, Fine Twig-rush *M. arthrophylla*) and reeds (Cumbungi *Typha domingensis,* Common Reed *Phragmites australis*). Given this, and a steady supply of large-bodied frog species (e.g. Growling Grass Frog *Litoria raniformis,* Eastern Banjo Frog *Limnodynastes dumerilii* and Striped Marsh Frog *Limnodynastes peronii*) as potential prey, Bool and Hacks Lagoons are widely considered important sites for the Australasian Bittern (Commonwealth of Australia 2022), regularly supporting reproduction (Marchant & Higgins 1990). Recent surveys detected as many as 13 males booming across the complex between September and December 2022 (Clarke-Wood *et al.* 2024).

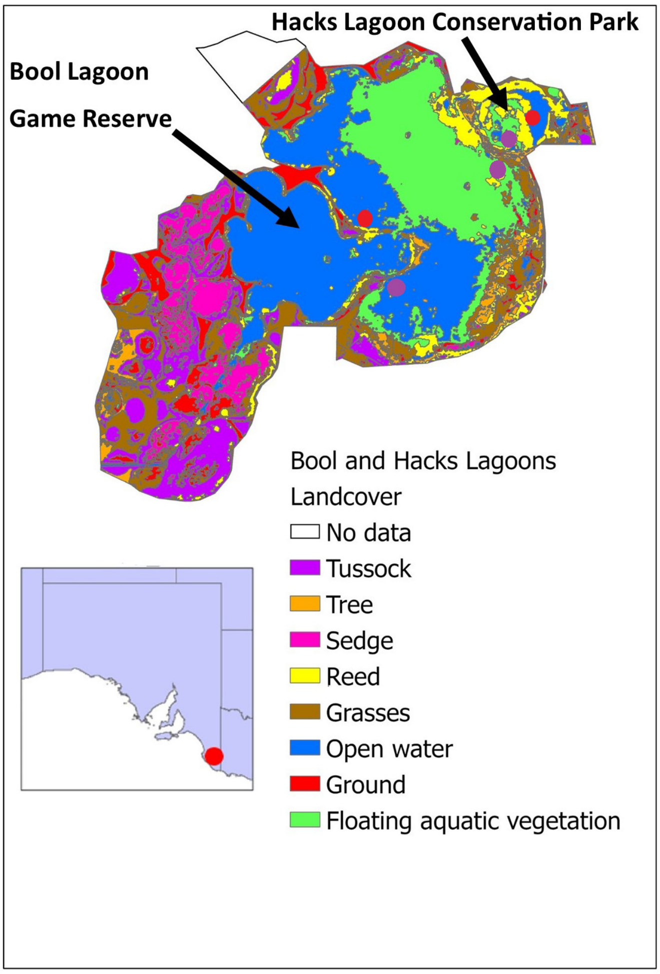

Figure 1. Bool Lagoon Game Reserve and Hacks Lagoon Conservation Park in south-eastern South Australia. Red spots indicate the location of acoustic monitors and purple spots indicate surface water gauges. Various landcover types across the lagoons are also shown (Lynker Analytics & Friends of Bool and Hacks Lagoons 2022; Australian Bureau of Statistics 2023).

Acoustic surveys

Male Australasian Bittern booms were recorded using two solar-powered bioacoustic recorders (solar-BAR: Frontier Labs Australia 2024) calibrated to sample at a rate of 32 kHz. These recorders were maintained by a local environmental group (the Friends of Bool and Hacks Lagoons), who deployed them in proximity to reedbeds in both Bool Lagoon (37°07'00.9"S, 140°41'45.2"E) and Hacks Lagoon (37°05'59.8"S, 140°43'36.7"E), at a height of 180 cm above the ground/wetland bed and ~1.5 m away from any obstructions to reduce sound attenuation. Australasian Bitterns had previously been detected via listening surveys at these locations.

Using the online eco-acoustics platform Arbimon (Aide *et al.* 2013), we listened to and visually searched spectrograms of collected recordings (split into 1-minute segments) to find a high-quality sample of an Australasian Bittern boom. Then, using Arbimon's pattern-matching feature, we developed a template of this boom, and derived a subset of all 1-minute segments containing a sound that matched the template with 90% confidence. Each of the resulting recordings was manually inspected to confirm the presence of an Australasian Bittern boom. Only true positives determined through this process were included in analyses. Altogether, 605,252 minutes of recordings were collected and investigated in this way (311,631 minutes in 2022–2023 and 293,621 minutes in 2023–2024).

Exploratory approach

As a primarily exploratory study, our focus was on generating insights and identifying patterns. To make observations more ecologically relevant, we determined the timing of each boom with respect to local sunrise/sunset, and inundation of the wetland. Firstly, we determined the number of minutes between local sunrise/sunset (Geoscience Australia 2024) and time of recording.

A boom recorded at 0904 h on 23 December 2022, for example, occurred 259 minutes after local sunrise. Then, to estimate the timing of wetland inundation across the complex, we used publicly available gauge data. Although these gauges were originally installed for flood mitigation rather than ecological monitoring, they nonetheless provide a useful indication of when water arrives at different parts of the wetland. In 2022, Hacks Lagoon largely filled by 19 September (Water Data SA 2024a, b), and had dried out by 10 January 2023. In the wetter year of 2023, Hacks Lagoon had become substantially inundated by 22 June (Water Data SA 2024a, b, c), and had dried out by 27 February 2024. Using these dates of inundation for Hacks Lagoon, we determined the number of days between date of inundation and date of booming for each recording. A boom recorded at Hacks Lagoon on 23 December 2022, for example, occurred 95 days after inundation. We used these dates for our calculations because surface water enters the complex through Mosquito Creek, first filling Hacks Lagoon before flowing into Bool Lagoon. This allowed us to examine the distribution of booms across the complex, over the survey periods. In 2022, Bool Lagoon had substantially filled by 2 October (Water Data SA 2024a, b), and had dried out by 12 January, 2023. In the wetter year of 2023, Bool Lagoon inundated similarly to Hacks Lagoon, from 22 June 2023 to 27 February 2024 (Water Data SA 2024a, b, c). We defined the annual onset of inundation as the date when water first entered Hacks Lagoon, which serves as an entry point to the entire system. Although water levels are shown alongside the distribution of booms, no formal statistical analysis was conducted to examine their relationship. As a result, the assessment of the connection between water levels and booming activity was qualitative in nature.

Observations and results

In total, 21,541 1-minute segments from the 2022–2023 (4153 minutes) and 2023–2024 (17,388 minutes) wet seasons were included in the final dataset for this study. More of these segments came from Hacks Lagoon (12,268 minutes) than Bool Lagoon (9273 minutes). Overall, more booms were detected during the midnight–noon period (12,587 minutes) than the noon–midnight period (8954 minutes).

At Bool Lagoon, >84% of booming activity occurred between 150 minutes before sunrise and 50 minutes after sunrise, and between 50 minutes before sunset and 150 minutes after sunset (Figure 2). A different and less pronounced pattern was observed at Hacks Lagoon, with ~40% of booms detected during those periods and much more calling throughout the night. Peak calling at Hacks Lagoon occurred 150–300 minutes after sunrise and 150–350 minutes after sunset (Figure 3). Very low calling rates were recorded between late morning and late afternoon at both sites. In 2022–2023, booming began 22 days after inundation at Bool Lagoon and 7 days after inundation at Hacks Lagoon, but the initial response during

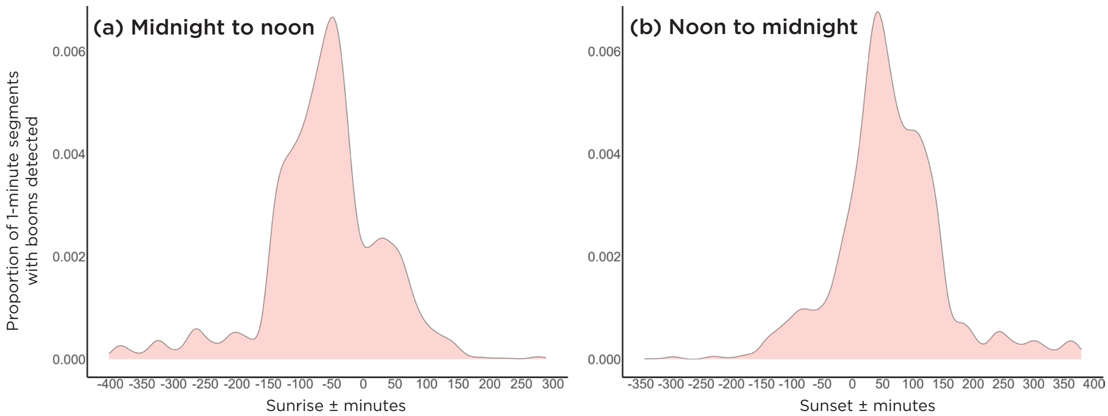

Figure 2. Distribution of Australasian Bittern booms in relation to (a) midnight to noon and (b) noon to midnight at Bool Lagoon Game Reserve. Heights of coloured ridges represent the proportion of individual 1-minute segments when a boom was detected.

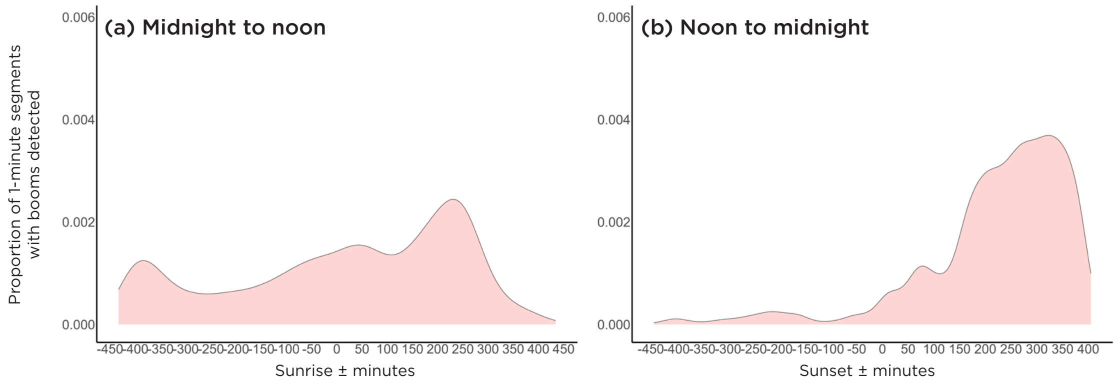

Figure 3. Distribution of Australasian Bittern booms in relation to (a) midnight to noon and (b) noon to midnight at Hacks Lagoon Conservation Park. Heights of coloured ridges represent the proportion of individual 1-minute segments when a boom was detected.

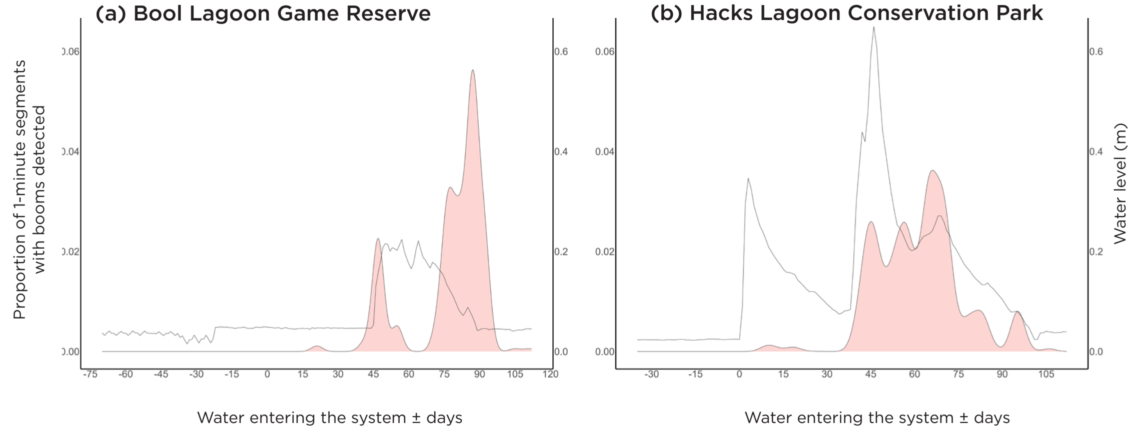

Figure 4. Distribution of Australasian Bittern booms in relation to wetland inundation for the 2022–2023 wet season at (a) Bool Lagoon Game Reserve and (b) Hacks Lagoon Conservation Park. Heights of coloured ridges represent the proportion of individual 1-minute segments when a boom was detected. The black line represents water levels across this period at each lagoon. Date zero was set as 19 September 2022 for both lagoons as that is when water entered the system (in Hacks Lagoon), with Bool Lagoon receiving water in subsequent weeks (as indicated by the black line).

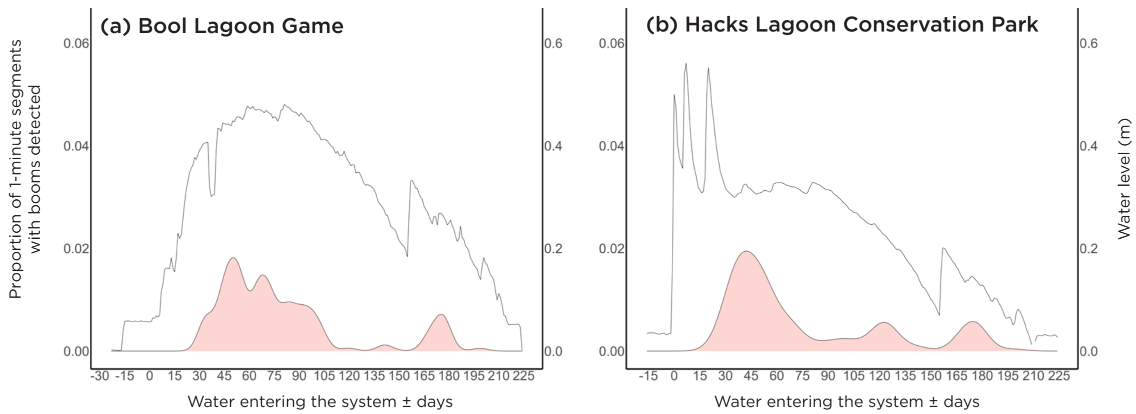

Figure 5. Distribution of Australasian Bittern booms in relation to wetland inundation for the 2023–2024 wet season at (a) Bool Lagoon Game Reserve and (b) Hacks Lagoon Conservation Park. Heights of coloured ridges represent the proportion of individual 1-minute segments when a boom was detected. The black line represents water levels across this period at each lagoon. Date zero was set as 22 June 2023 for both lagoons as that is when water entered the system (in Hacks Lagoon), with Bool Lagoon receiving water in subsequent weeks (as indicated by the black line).

the first 7–25 days post-inundation was minimal at both sites (Figure 4). Booming ceased after 109 days at Bool Lagoon and after 104 days at Hacks Lagoon. At Bool Lagoon, booming followed a distinctly bimodal pattern, with peaks at 40–50 and 75–100 days post-inundation. In contrast, at Hacks Lagoon there was a more sustained pattern between 35 and 75 days post-inundation, without clear bimodality, despite an early rise in water level that year, which did not trigger a strong calling response.

In 2023–2024, booming commenced 34 days after inundation at Bool Lagoon, and 24 days after inundation at Hacks Lagoon, with more similar calling patterns at both sites (Figure 5). Booming continued for 203 days at each site, with peaks at 30–115 days at Bool Lagoon, and 15–75 days at Hacks Lagoon. Notably, a smaller peak in calling occurred at both lagoons following a sharp rise in water levels *c*. 150 days after inundation. Although 2023–2024 was substantially wetter than the previous year, the overall duration of booming was comparable (Figure 5).

Finally, both seasons experienced sustained inundation at ≥15 cm depth: for 33 and 67 days at Bool and Hacks Lagoons, respectively, in 2022–2023, compared with 235 and 184 days in 2023–2024 (Figures 4–5).

Discussion

Effective adaptive management must be underpinned with an ecological understanding of target species (Kingsford & Norman 2002). Data illustrating relationships between species and environmental factors, especially those that constrain reproduction, are critical for conservation

(Herring *et al.* 2019). Our exploratory study offers initial insights into the timing and duration of Australasian Bittern booming with respect to sunrise, sunset, and wetland inundation over two different seasons at a large wetland complex, although more replication of sites and time would be needed for a definitive study.

Our results established that at Bool and Hacks Lagoons male Australasian Bitterns concentrated their calling in periods before or after sunrise and after sunset. These findings are consistent with other studies, which have characterised similar peak calling periods for related heron populations (Australasian Bittern: O'Donnell & Williams 2015; Least Bittern *B. exilis*: Znidersic *et al.* 2020). O'Donnell & Williams (2015), for example, advised that the peak booming time for the New Zealand population of Australasian Bitterns was 1.5 hours before sunrise and 1.5 hours after sunset. Similarly, Znidersic *et al.* (2020) demonstrated that Least Bittern calling during the breeding season peaked around sunrise and sunset. The 'absent male' hypothesis (Schlicht *et al.* 2023) provides an explanation of how such bimodal calling patterns can emerge in birds. Schlicht *et al.* (2023) proposed that females remain longer at their roosts in the morning and return to their roosts earlier than their mates, triggering males to call more frequently and at a higher rate when they are apart from the females. In the Eurasian Bittern *B. stellaris*, booming can serve as a contact call between a male and his mate (Poulin & Lefebvre 2003; White *et al.* 2006). In its close relative, the Australasian Bittern, booms likely serve a similar function (O'Donnell 2011) and may increase in frequency as a product of (1) separation of the male from the female and (2) heightened competition over the breeding season. More studies are needed, however, to confirm this in Australasian Bittern populations.

As well as complicated intraspecific interactions (e.g. potential polygyny: Kasprzykowski & Polak 2013), Australasian Bitterns have a complex relationship with wetland hydrology (Herring *et al.* 2019, 2021b; Williams *et al.* 2019). Herring *et al.* (2021b) demonstrated that inundating agricultural wetlands (rice fields to a depth of 5–25 cm) for ≥149 days can result in heightened breeding success for the species. In our study, Bool and Hacks Lagoons were inundated to a depth of ≥15 cm for 33 and 67 days, respectively, during the 2022–2023 wet season and 235 and 184 days, respectively, in the 2023–2024 wet season. Other studies note that the Australasian Bittern (and related heron species) have relatively short periods of incubation (*c.* 24 days: O'Donnell 2011) and fledging (*c.* 40–55 days: Puglisi & Bretagnolle 2005), implying that even comparatively short wet seasons may result in breeding success for the species. Despite this, successful breeding is unlikely in the first season, if allowing time for territory establishment and other reproductive milestones observed in related species (Gilbert *et al.* 2007). Nevertheless, water level, and duration and timing of inundation are important factors in Australasian Bittern reproduction (Herring *et al.* 2021b). Our data show that a sudden increase in booming activity may follow a sudden spike in water levels, even when such a spike has already occurred in that season. This may suggest that this species will make additional breeding attempts (if conditions are suitable) later in the season. More research is needed into how such factors interact in natural systems.

Implications for future surveys

Understanding patterns in booming helps design efficient monitoring efforts that support conservation (Williams *et al.* 2018). For example, those authors found that Australasian Bittern detectability was highest either in the first 30 minutes after sunset or the hour before sunrise. Our results support this in general, confirming that late morning and most of the afternoon are not suitable times to survey for this species. Our results, however, also suggest a somewhat wider window for useful field surveys either side of sunrise, and after sunset, and the possibility that the details of these times may vary between locations. Practitioners seeking to identify Australasian Bittern potential breeding habitat with acoustic monitoring could reduce the costs associated with data collection and storage by setting the recorders to focus on the same periods.

Our study detected Australasian Bittern booms as soon as 7 days after inundation during a typical wet season (September–January), and as soon as 24 days after inundation during an extended wet season (June–January). This suggests that surveys for the species, by field observers or using acoustic recorders, can be usefully conducted soon after wetlands have been inundated. Notably, however, the calling detected 7 days after inundation at Hacks Lagoon was not followed by a strong peak in booming activity. This early vocalisation might not have strictly represented calling related to breeding but could instead reflect contact calls by the males to signal their arrival at the site (as seen in other birds: see Marler 2006; Kondo & Watanabe 2009). Thus, although early detections can indicate Australasian Bittern presence, they may not reliably predict subsequent breeding activity. These distinctions are important when interpreting early-season acoustic detections and planning monitoring or conservation actions based on vocal activity alone.

Implications for local management

At the local level, our findings have clear implications for conserving and managing wetlands for the Australasian Bittern. Many of South Australia's wetlands (including Bool and Hacks Lagoons) are subject to water-allocation plans. These plans evaluate the hydrological requirements (quantity, timing, etc.) of water-dependent ecosystems, establish protective measures for them, and balance these requirements against community and industry needs (South East Natural Resources Management Board 2019; Murraylands and Riverland Landscape Board 2023). The *Water Allocation Plan for the Lower Limestone Coast Prescribed Wells Area* (South East Natural Resources Management Board 2019) outlines minimum setback distances for commercial forestry operations, for example, ensuring that adequate groundwater is available to support inundation of Bool and Hacks Lagoons (Wood 2017). Additional protective measures should be considered, such as the installation of features (e.g. snags, bunds, etc.) designed to slow the movement of water out of the wetland complex, thereby sustaining water depths conducive to a 60-day booming period and a 79-day incubation–fledging period.

The timing and duration of inundation are often identified as important for wetland-dependent species and management, and most plans would be improved by measures that explicitly accommodate the life histories of wetland species (Bino *et al.* 2021). More research is needed to improve how water allocations are managed for natural wetlands, support waterbird species (including Australasian Bittern) through their life cycles, and to assess breeding success (fledging and survivorship) as a response to water availability. Collecting and integrating such data will allow practitioners to contribute to conservation efforts for the Australasian Bittern more effectively.

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