The effects of environmental watering on frog occurrence, Hattah Lakes Icon Site

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Acknowledgement

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it. We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

We are committed to genuinely partner, and meaningfully engage, with Victoria's Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond.

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Front cover photo: Lake Konardin, Hattah-Kulkyne National Park (Geoff Brown)

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Context:

Water is a key driver of frog occurrence. Frogs are sensitive indicators of environmental change on floodplains and wetlands, particularly changes to water regimes. Therefore, it is expected that changes in environmental watering regimes will influence the occurrence of frogs throughout the watering and drying process. Little is known of the status of frogs within the Hattah Lakes Icon Site (HLIS) in relation to environmental watering. Baseline surveys of select wetlands were conducted between November 2020 and March 2021 by GHD Pty Ltd and the results of those surveys compared with those of this study.

Aim:

To determine frog species and distribution across select wetlands at the Hattah Lakes Icon Site (HLIS) following environmental water delivery during Autumn and Spring 2021 and compare to frog survey data collected as baseline data during the pre-watering phase (when four of the five study wetlands were dry).

Methods:

Survey sites were established at seven study wetlands within the HLIS: Lakes Bitterang, Bulla, Hattah, Konardin, Kramen, Mournpall and Nip Nip. Survey transects were established at each of these wetlands, providing the water-line location for two frog survey techniques (nocturnal audio-visual surveys and acoustic surveys using AudioMoth loggers) as well as habitat assessment. Habitat was assessed along and adjacent to each survey transect at the time of frog audio-visual surveys. Aquatic and wetland fringing habitat were assessed, mostly via cover estimates of various substrate types, along with measures of water quality. All survey and habitat data were consolidated into an Access database.

Results:

At least eight frog species were recorded during this study, with most study wetlands yielding records of multiple frog species. All recorded species are common and no threatened species were recorded. There was some evidence of breeding (i.e. egg masses, tadpoles or metamorphlings) at most study wetlands.

Both baseline and post-watering surveys yielded comparable numbers of species overall, although the baseline surveys yielded frogs from the only wetland that held water (Lake Kramen); no frogs were recorded at dry wetlands. However, comparisons between post-watering and baseline survey data are awkward, given (1) the different suite of wetlands targeted during each study, (2) the different survey approaches employed in each study (although approaches for each study are well established and expected to detect the existing frog assemblage), and (3) the disparity in the presence (or lack) of water between studies (and between wetlands within studies).

Conclusions and implications:

Watering resulted in the ‘arrival’ of frogs at all study wetlands. At least eight frog species were recorded overall and there was evidence of breeding at most study wetlands, albeit patchy because surveys were conducted relatively soon after the commencement of watering. All species recorded are relatively common, especially across south-eastern Australia.

Watering is essential for the persistence of frogs. No frogs were recorded at dry wetlands during both the baseline and post-watering studies.

Recommendations for the management of the HLIS to benefit the frog assemblage are provided.

1 Introduction

Frogs have a biphasic life cycle characterised by eggs being laid in water; typically, both egg and larval development occur in aquatic habitats (although eggs of some species instead develop terrestrially; Anstis 2017, Cogger 2018). One notable feature of the Australian frog fauna is its lack of dependence on permanent bodies of fresh water, and — except for those few genera that lay eggs out of water — its tendency to breed in ephemeral waterbodies (Tyler 1994). Therefore, the hydrological regime is a key determinant of frog occurrence.

Environmental water is being used across many parts of the Murray-Darling Basin to re-establish more natural water regimes and thus improve the 'health' of wetlands. Hydrology is a key component of wetland health, and frogs can be useful indicators of health because many species respond to changes in hydrology (Wassens et al. 2017). It is critical that the provision of environmental water to benefit the persistence of frogs should accommodate the species' key needs for timing, duration and frequency so that water requirements for breeding are met (Wassens 2011). Appropriate water delivery must also meet other requirements, such as provision of suitable refuges to which frogs can retreat during the day to escape predation or move to during periods of drought.

This report presents the results of frog surveys undertaken at seven lakes in the Hattah Lakes Icon Site (HLIS) in Spring-Summer 2021-22, after the commencement of water delivery to the lakes system. The overall objective of this project was to identify species of the frog assemblage that use the HLIS and their population and breeding statuses in order to evaluate the importance of environmental water delivery. It is a companion report to that delivered by GHD Pty Ltd (2021), which provided baseline information on frog occurrence at select wetlands in the HLIS.

1.1 Responses to environmental water

Water is a key driver of frog occurrence. River regulation and the requirement of water for consumption have reduced aquatic habitat in the Murray–Darling Basin, including in north-western Victoria, and mitigating these hydrological impacts is a primary focus of water management in this region. Frog monitoring is a key element of several major projects within the Basin, such as The Living Murray (https://www.mdba.gov.au/publications/brochure/living-murray-program) and the Commonwealth Environmental Water Office's FLOW-MER program (https://flow-mer.org.au/). These programs aim to inform and improve water management, leading to the maintenance or improvement of waterway and wetland health.

The responses of frogs to environmental watering are expected to vary by species and type of wetland, and be contingent on key elements of the watering regime (notably timing, duration, extent, frequency). If environmental watering is to be implemented over a suitable hydroperiod to benefit the total frog assemblage at the HLIS, it should provide variety in water depth, vegetation and structure so as to meet the habitat, life history and movement needs of all taxa. This will ultimately increase the availability of suitable habitat for refuge, feeding and breeding, and functional connectivity; more complex habitats are more likely to foster a higher diversity of species. Conversely, the provision of water may result in additional threats through increased levels of predation or disease, such as chytridiomycosis (e.g. Gervasi et al. 2017).

1.2 Frogs of the Hattah Lakes Icon Site

The DELWP Victorian Biodiversity Atlas (VBA) yields 11 frog species for the entire Mallee CMA region, nine of which have been recorded from the sixteen 10' (latitude/longitude) grids within which the HLIS is centred, including the threatened Growling Grass Frog *Litoria raniformis* (VBA accessed December 24th, 2021). This underscores the importance of the HLIS for frogs in the region.

Baseline surveys of select lakes in the HLIS were conducted between November 2020 and March 2021 using acoustic loggers to determine the frog assemblage of the study wetlands (GHD Pty Ltd 2021). Those surveys, conducted at four dry wetlands (Lakes Hattah, Bulla, Yerang and Mournpall; 1 site each) and one that held water (Lake Kramen; 6 sites), yielded seven frog species from six of the ten sites during the monitoring period, all of which were wet (i.e. at Lake Kramen). The frog species recorded were Southern Bullfrog (or Pobblebonk) *Limnodynastes dumerilii*, Barking Marsh Frog *L. fletcheri*, Spotted Marsh Frog *L. tasmaniensis*, Eastern Sign-bearing Froglet *Crinia parinsignifera*, Common Froglet *C. signifera*, Peron's Tree Frog *Litoria peronii* and Common Spadefoot Toad *Neobatrachus sudelli*.

2 Methods

2.1 Survey sites

Survey sites were established at seven study wetlands within the HLIS: Lakes Bitterang, Bulla, Hattah, Konardin, Kramen, Mournpall and Nip Nip (Fig. 1). The number of survey sites per wetland varied according to wetland size and access (Table 1). At each site a 50 m survey transect was established along the waterline, providing the location for standardised surveys and habitat assessment. Location coordinates for study transects are presented in Appendix 1.

In October 2021 all study wetlands, except Lakes Kramen and Nip Nip, held water and were filling with water from the Murray River via Chalka Creek. Filling was scheduled to continue for several months and, eventually, shortly after the commencement of this study, Lake Nip Nip would contain water. Environmental water was delivered to Lake Kramen in Spring 2019 and following natural drawdown water had receded such that in October 2021 less than half of the lake was covered. It had completely dried by late December 2021 (E. Collins pers. comm.). Lake Nip Nip had yet to receive water – it is near last to receive water during watering (E. Collins pers. comm.) – although watering was imminent since Lake Tullamook, its immediate neighbour to the west, contained water.

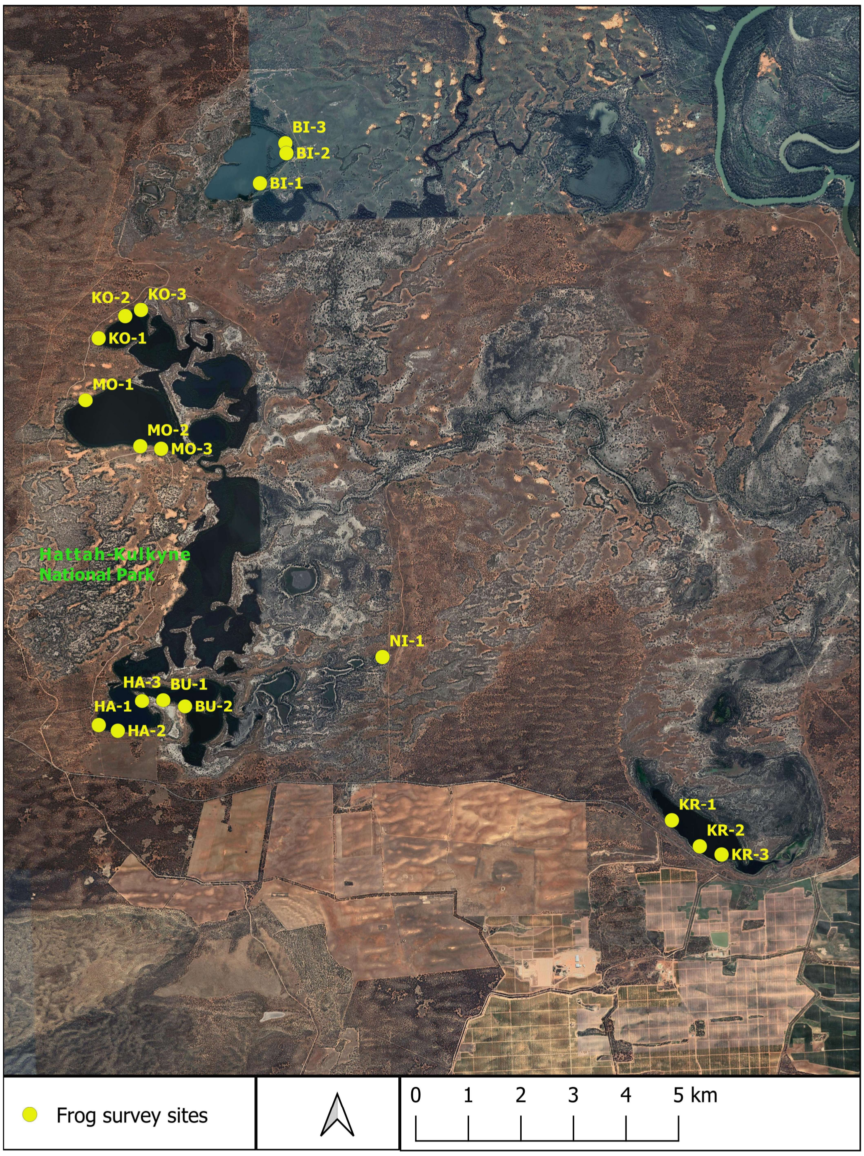

Figure 1. Location of study sites at each HLIS study wetland, Spring-Summer 2021.
Site prefix codes: BI Lake Bitterang, BU Lake Bulla, HA Lake Hattah, KO Lake Konardin, KR Lake Kramen, MO Lake Mournpall, NI Lake Nip Nip.

Table 1. Number of survey sites (transects and AudioMoth sites) at each HLIS study wetland, Spring-Summer 2021.

Wetland	Number of survey sites
Lake Bitterang	3
Lake Bulla	2
Lake Hattah	3
Lake Konardin	3
Lake Kramen	3
Lake Mournpall	3
Lake Nip Nip	1

2.2 Frog survey techniques

The methodological approach followed that employed during the recent Wetland Monitoring and Assessment Program (WetMAP) frog monitoring project across northern Victoria and targeted frog surveys at Wirra-lo Wetland Complex, north-central Victoria, both of which had the primary aim of evaluating the responses of frogs to environmental watering (Brown and Bayes 2019, Papas et al. 2020).

Two frog sampling methods were used: (i) audio-visual surveys for frogs (of all developmental stages), and (ii) acoustic monitoring using AudioMoth loggers to record calls of adult frogs. These survey techniques, described below, are complementary (Wassens et al. 2007) and designed and timed to best capture frog activity. Frog taxonomy follows Cogger (2018).

2.2.1 Audio-visual surveys

Audio-visual surveys were conducted at each site on two occasions, in late October 2021 shortly after the Spring delivery of environmental water to the HLIS, and again in early December 2021 when all wetlands held water and were still filling. Frog activity, centred on breeding, and thus frog detectability is greatest during Spring-Summer for most species known from north-western Victoria (https://frogs.org.au/frogs/ofVic/Mallee_Country).

A 50 m transect with waterline as its midline was established at each study site to accommodate both survey techniques. Audio-visual surveys, carried out by experienced observers, commenced after dark and comprised a 5-minute listening period at the approximate midpoint of each, followed by a visual search along the transect length which varied in duration according to the complexity of the site and the number of frogs observed, but always exceeded 15 minutes.

During each audio-visual survey, the following details were recorded:

- wetland name, transect number, date, weather and observer names
- start time and duration of survey
- frog species recorded by call detection and an estimate of their abundance
- number and species of individual frogs recorded by observation
- water quality (pH, electrical conductivity (mS/cm), temperature (^{o}C), turbidity (FTU))
- weather conditions (air temperature, relative humidity, wind strength, cloud cover and moon phase).

The abundance of each species was obtained either by actual count [for observed or small numbers of calling individuals (<10)] or, when listening to large choruses, by estimates (estimate categories: 10–50, 50–100 and >100). All frogs that were heard or observed on or adjacent to the transect were recorded. Simultaneous counts provided by multiple observers during a survey were averaged.

Surveys were not carried out when there were strong winds, heavy rain or when night-time temperatures fell below 10^{o}C, conditions under which frog activity is typically restricted or detectability reduced (e.g. Heard et al. 2015). Protocols to minimise the risk of transmitting pathogens between frog populations were followed (Phillott et al. 2010, Murray et al. 2011).

2.2.2 Acoustic monitoring – deployment of loggers

Acoustic monitoring was conducted using AudioMoth acoustic loggers to capture the calls of frogs over an extended period during Spring–Summer, the primary breeding season for the majority of species that inhabit (or likely inhabit) the study wetlands. AudioMoth acoustic loggers are programmable full-spectrum loggers that can record uncompressed audio (at audible to ultrasonic frequencies) to a micro SD card.

AudioMoth loggers were positioned on or close to the water's edge at the approximate mid-point of the survey transect at every study site, and programmed to record at regular intervals (for 2 minutes in every 10 minute period) between 7:30pm and 3am during each day of deployment. The recent WetMAP project revealed this time-frame to cover peak calling activity for the known frog assemblage (Papas et al. 2020). AudioMoth loggers were deployed in a zip-lock bag in a shade cloth 'pocket' and attached to a branch or tree trunk 1-2 m above ground or water-level (Fig. 2).

AudioMoth loggers were deployed on either 26th or 27th October 2021 and were left in situ until 7th December, a duration of over 40 days. Several loggers were submerged during watering – at Lakes Bitterang, Konardin and Nip Nip – so supplementary loggers were deployed at those sites on 7th December and retrieved on 3rd January 2022, a duration of 27 days.

Figure 2. AudioMoth acoustic logger attached to sapling trunk (at right), Lake Hattah, October 2021.

2.2.3 Acoustic monitoring – analysis of AudioMoth files

All AudioMoth acoustic data were downloaded and collated into a relational database using Microsoft Access. This database also contained habitat data collected at the time of the audio-visual surveys.

An extraordinary amount of effort and time are required to identify and tag acoustic data. For this reason ARI recently initiated the development of a convolutional neural network (CNN) deep learning model to automate frog species identification in large Victorian bioacoustic datasets (Howard et al. 2021). CNN models have been used successfully elsewhere to improve bird and frog species recognition from soundscape recordings (LaBien et al. 2020, Kahl et al. 2021). The CNN model outputs for this study were reviewed and manually verified to determine the occurrence of each frog species at each study site.

All AudioMoth acoustic data were provided to a pilot version (v.59) of ARI's Convolutional Neural Network (CNN) model to automate frog call recognition in large bioacoustics datasets. To date, the model has been trained using exemplar calls of 15 Victorian frog species, including all species that occur in the Mallee region with the exception of Painted Spadefoot Toad (aka Mallee Spadefoot Toad) *Neobatrachus pictus*. Up to several thousand exemplar calls per species were provided to the model as training data, in addition to many thousands of exemplars of non-frog sounds, such as environmental noises and bird calls common in the soundscapes of other Murray-Darling Basin locations, particularly the Barmah-Millewa Forest in the mid-Murray, from where much training data were gathered using AudioMoth units.

Each run of the CNN model took several hours to 'train', based on hundreds of thousands of 1.5 second-duration exemplar calls of the various species and non-frog noises it was provided with. It then used this training 'knowledge' to evaluate an unseen dataset, such as that for the current study, and provide a species prediction for each 1.5 second section of each recording file. For this analysis the model was asked not to provide a prediction for quiet periods when there were no identifiable sounds. A 'prediction' refers to a 1.5 second section of a sound file, and each prediction has an associated confidence, or probability, assigned by the model (from 0-1).

2.3 Habitat and water quality assessment

Habitat and water quality assessments were collected during surveys even though they were not required under the terms of this project. This was to ensure compatibility with existing databases (e.g. WetMAP), increase the state-wide data-set of variables associated with environmental watering and, per data analysis and modelling, to potentially aid the identification of the key environmental drivers of frog occurrence. Exploratory analysis of the relationship between frog occurrence and habitat characteristics at the HLIS, using data collected during the post-watering surveys, is presented in Appendix 2.

Habitat was assessed along and adjacent to each survey transect at the time of frog audio-visual surveys. Aquatic habitat was assessed within 10 m of the waterline (transect midline), and cover estimates were recorded for the following substrates: vegetation types (submerged, attached floating, free-floating, short emergent, tall emergent), inundated shrubs or saplings, inundated trees, bare ground, litter, open water, and logs.

Wetland fringing habitat was assessed within 5 m of the waterline, where cover estimates were recorded for short herbs/grasses, tall sedges/reeds, shrubs and saplings, trees, litter, bare ground, and logs. For the terrestrial fringing habitat, located 5–25 m away from the waterline, the estimated extent of each of the following categories was recorded: wet or dry mud, very short vegetation (grasses, sedges, salt marsh), Lignum, shrubs, tall marsh (*Typha*/*Phragmites*), Black Box, River Red Gum, other trees, bare ground, coarse litter, logs and rocky outcrops.

Measures of water quality (conductivity/salinity, pH and water temperature) were taken at the approximate midpoint of each survey transect during each audio-visual survey, using a handheld Hydrolab Quanta Portable Water Quality Testing Meter at approximately 1 m from the water's edge or, for shallow waterbodies, at a distance from the water's edge at which the meter could be properly immersed. Turbidity was also measured for each transect at the approximate midpoint, using a Hach 2100P Portable Turbidimeter.

3 Results

3.1 Audio-visual surveys

Audio-visual surveys conducted during October and December 2021 yielded frogs from three families (Hylidae, Limnodynastidae, Myobatrachidae), representing at least eight frog species, including the Eastern Sign-bearing Froglet *Crinia parinsignifera*, Common Eastern Froglet *C. signifera*, Eastern Banjo Frog *Limnodynastes dumerilii*, Spotted Grass Frog *L. tasmaniensis*, Victorian Tree Frog (Plains Brown Tree Frog) *Litoria paraewingi*, Peron's Tree Frog *L. peronii*, Painted Spadefoot Toad *Neobatrachus pictus*, and Common Spadefoot Toad *N. sudellae* (Table 2). There were also several records of unidentified Spadefoot species or unidentified frogs, typically individuals that darted quickly out of view before their species could be determined.

The frog species that occupied the most study wetlands were Eastern Sign-bearing Froglet (5 wetlands), Eastern Banjo Frog (5) and Spotted Grass Frog (6). The study wetlands that yielded the most species were Lakes Bitterang (6 species), Konardin (6) and Mournpall (5), those study lakes that received environmental water earliest.

There was evidence of frog breeding at most study wetlands. Audio-visual surveys yielded metamorphlings or sub-adults of at least three species across five wetlands, predominantly during the December surveys. Several unidentified egg-masses, most likely belonging to *Limnodynastes* species, were recorded at Lake Bitterang during the October surveys, and small numbers of unidentified tadpoles were recorded at Lakes Bulla and Mournpall during the October surveys.

3.2 Acoustic monitoring

AudioMoth loggers at most study sites remained in situ for approximately 42 days and yielded approximately 1,900 call files (.wav files) per site. Supplementary AudioMoth units were deployed on December 7th at Lakes Bitterang, Konardin and Nip Nip because units deployed in early October ultimately were submerged. Fortunately, three of four submerged AudioMoth units yielded call data for all dates up to submersion (7-17 days variously per site).

The supplementary units were collected in early January, remaining in situ for approximately 27 days. Hence, there were marginally fewer call files for analysis for some study wetlands, although these still tallied approximately 1,200 per site. Overall, 250,501 call files were available for analysis (Table 3). AudioMoth units at two study sites – Lake Bitterang 3 and Lake Bulla 2 – yielded corrupted call files which could not be used in the analysis.

3.3 Frog call analysis

ARI's Convolutional Neural Network (CNN) model generated 265,961 predictions of sounds from the Hattah Lakes 2021 dataset. However, this output is trained on single-species calls and consequently has limited capacity to identify sections with >1 frog species calling simultaneously (choruses). Thus, such predictions, along with a small number that identified species that do not occur in the Hattah Lakes study area, were screened out for further validation of the model outputs, resulting in a total of 250,501 predictions (Table 3). The predictions in Table 3 are the unvalidated outputs from the model and contain an unknown rate of false positives; Table 3 is presented to provide a sense of the CNN process, particularly the magnitude of and variation in the outputs. To generate a validated species list per site, the model outputs were addressed for manual validation as follows: for the two species with relatively few predictions, Growling Grass Frog and Peron's Tree Frog, the predictions were not subset, and were all manually validated. This was especially relevant for the threatened Growling Grass Frog as it is a species of conservation concern. For all other species, the top 50 (i.e. where the model was most confident) predictions of each species' call per site were selected for manual validation, in descending order of model confidence.

Manually validating the model's output requires custom-built software to direct the listener to each 1.5 second section of a sound file that has been predicted by the model to be a certain species, with a certain level of confidence. The listener can then agree or disagree and correct the prediction. All validations will be used as training data in further iterations, to improve further model iterations. This validation process resulted in a species list per site (Table 4), yielding a total of five species compared with eight species yielded from audio-visual surveys. Upon review, all predictions of Growling Grass Frog were found to be false positives. We did not locate any confirmed calls of this species in the acoustic dataset. While it was not feasible to manually validate all 250,000+ predictions made by the model (Table 3), examination of the model's predictions across time provided a preliminary view of calling activity at each site and AudioMoth (Fig. 1). It is apparent that the peak calling period at the HLIS, as yielded by these AudioMoth data, spanned late October-early November (Fig. 3).

Table 2. Frog species identified from each HLIS study wetland during audio-visual surveys in October and December, 2021.

Survey data for each study wetland presented as: estimate of calling frogs/tally of frogs observed. Call estimate and observational data tallied over all sites at each study wetland (number of sites per wetland in parentheses) for each survey period (number of observers in brackets).

Wetland	Lake Bitterang (3)		Lake Bulla (2)		Lake Hattah (3)		Lake Konardin (3)		Lake Kramen (3)		Lake Nip Nip (1)	Lake Mournpall (3)		Number of wetlands (18)	
Species	**Oct [3]**	**Dec [2]**	**Oct [4]**	**Dec [2]**	**Dec* [2]**	**Dec+ [2]**	**Oct [2]**	**Dec* [3]**	**Oct [2]**	**Dec [5]**	**Dec [2]**	**Oct [3]**	**Dec [2]**	**Oct**	**Dec**
Eastern Sign-bearing Froglet	68/-	10/2	18/-	-/2	7/9		5/4	24/1	-/1	24/-		14/-	-/5	6	5
Common Froglet								6/-						1	-
Eastern Banjo Frog	61/-	11/1	29/1		7/14	6/-	-/3	50/3	5/-	99/-		23/-	-/1	6	5
Spotted Marsh Frog	107/3	15/-	2/-	-/11	39/66		-/29	3/-	-/1	1090/-	120/-		-/2	5	6
Plains Brown Tree Frog	3/-													1	-
Peron's Tree Frog	22/1		20/-	-/1		3/-		18/-		13/-		20/-	2/-	5	3
Painted Spadefoot Toad					1/-									1	-
Common Spadefoot Toad	15/-							3/-						2	-
Spadefoot Toads		-/46		-/3				-/2	-/1			-/3	-/2	2	4
Frogs (unidentifiable)		-/2											-/1	-	2
Total	276/4	36/51	69/1	-/17	54/89	9/-	5/36	104/6	5/3	1226/-	120/-	57/3	2/11		
Minimum no. of species	6	4	4	4	4	2	3	6	4	4	1	4	5		

* Two audio-visual surveys were conducted at Lake Hattah in December because severe storms in October prevented surveys then

\+ Lake Nip Nip was dry in October so no audio-visual surveys were conducted then

Table 3. Unvalidated species call predictions per study site, HLIS 2021, from Convolutional Neural Network modelling.
Supp = Supplementary AudioMoth units deployed after initial units were submerged

Study site	Eastern Sign-bearing Froglet	Common Froglet	Eastern Banjo Frog	Spotted Marsh Frog	Barking Marsh Frog	Peron's Tree Frog	Growling Grass Frog	Common Spadefoot Toad	Unidentified frog spp.	Total
Bitterang 1								38	5	43
Bitterang 1 Supp	80	1	1,004	1,255	363		82	258	15,885	18,928
Bitterang 2	466	8	613	1,900	426	1	2	1,044	112	4,572
Bitterang 2 Supp	4	4	27	2,848	664		2	8	14,221	17,778
Bitterang 3	14	11	32	27	56	2	3	1,149	2	1,296
Bulla 1	7,892	120	313	2,119	133	49	14	5,076	3,233	18,949
Hattah 2	4	1	445	1,077	2	15		1,675	168	3,387
Hattah 3	438	293	621	832	781	38	42	2,632	241	5,918
Konardin 1	57,974	387	212	76	36	6		466	605	59,762
Konardin 2	158	59	98	75	108	3		3,656	200	4,357
Konardin 3	248	69	1,423	2,867	340	1	2	2,913	847	8,710
Kramen 2				42	4				220	266
Kramen 3	1,962	55	30	18,119	464	105	162	40	43,570	64,507
Mournpall 1	177	27	17	12	5	1		673	10	922
Mournpall 2	131	31	165	164	84	3		406	16	1,000
Mournpall 3	274	757	278	240	451	3	1	53	103	2,160
Nip Nip 1	1,687	2	76	592	87	3	5	2,999	171	5,622
Nip Nip 1 Supp	114	1	346	2,552	981	11	16	548	27,755	32,324
Total	**71,623**	**1,826**	**5,700**	**34,797**	**4,985**	**241**	**331**	**23,634**	**107,364**	**250,501**

Table 4. Validated occurrence of frog species at each HLIS by AudioMoth unit.
Supp = Supplementary AudioMoth units deployed after initial units were submerged

Study site	Common Spadefoot Toad	Eastern Banjo Frog	Eastern Sign-bearing Froglet	Peron's Tree Frog	Spotted Marsh Frog
Bitterang 1					
Bitterang 1 Supp	√	√	√	√	√
Bitterang 2		√			√
Bitterang 2 Supp	√	√	√	√	√
Bitterang 3		√	√	√	√
Bulla 1		√	√	√	√

Hattah 2		√	√	√	
Hattah 3		√	√	√	
Konardin 1		√	√	√	√
Konardin 2		√			√
Konardin 3		√	√		√
Kramen 2					√
Kramen 3		√	√	√	√
Mournpall 1		√	√		
Mournpall 2		√	√	√	
Mournpall 3	√	√		√	
Nip Nip 1		√		√	√
Nip Nip 1 Supp	√	√		√	√

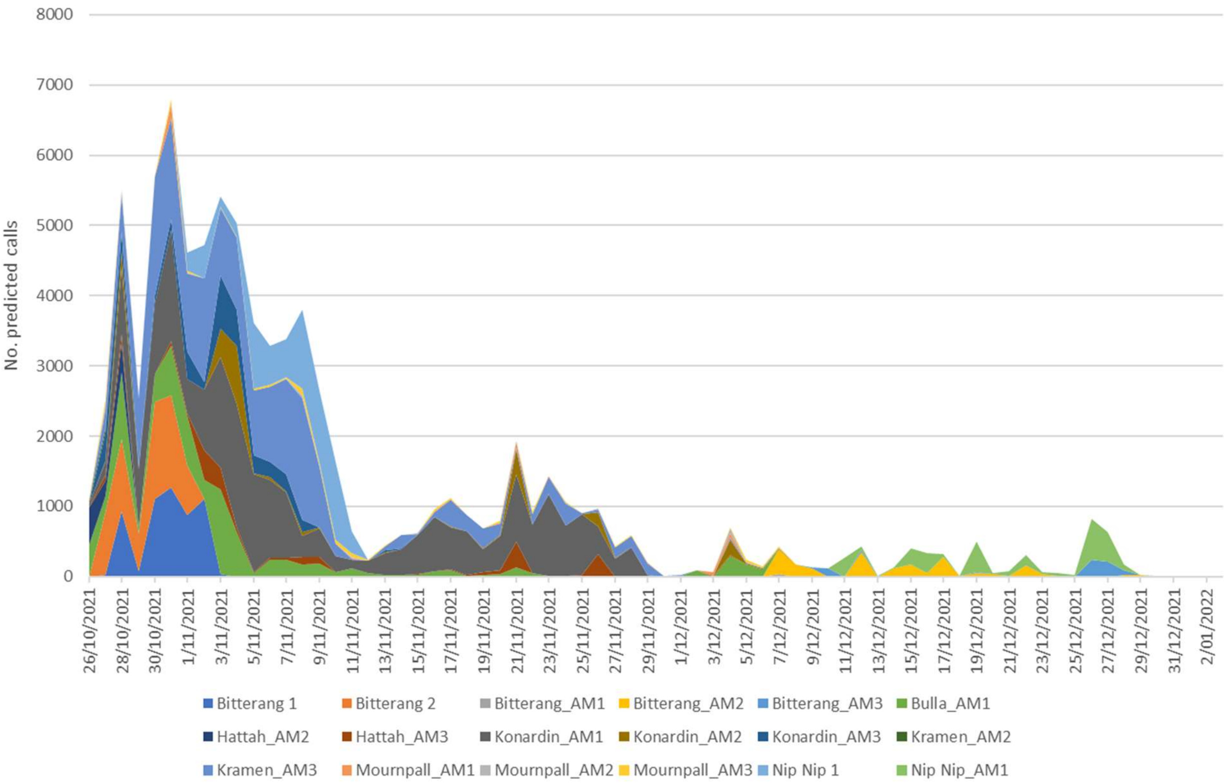

Figure 3. Number of calls (all species) predicted by the CNN model, shown by date and AudioMoth.

Nb Most AudioMoths were deployed from 26/10/2021 – 7/12/2021. Data after 7/12/2021 were only available for three AudioMoths (Bitterang_AM2, Bitterang_AM3 and Nip Nip_AM1).

3.4 Comparison with baseline (dry phase) surveys

Baseline data were collected from five wetlands using acoustic loggers (Anabat Swift) during the period 24 November 2020-17 March 2021 (GHD Pty Ltd 2021); all but Lake Kramen were dry during these surveys. Four of these lakes were also surveyed as part of the current project: Lakes Bulla, Hattah, Mournpall and Kramen; Lake Kramen was near dry with a relatively small area of surface water near the centre of the wetland. Baseline surveys used a single survey technique – acoustic monitoring — to record frogs. Therefore, there was limited overlap between projects in the study wetlands, so mostly general comparisons between baseline and post-watering survey results for the HLIS can be made.

The baseline survey focus was on fewer wetlands and more intense sampling at Lake Kramen (which held water at the time) where 6 sites were established. Notwithstanding the different survey approaches and incompletely overlapping sampling dates, the baseline and post-watering frog assemblages for the four wetlands is presented in Table 5.

Lake Kramen, the only study wetland to undergo both baseline and post-watering surveys whilst holding water, yielded seven frog species during the baseline study and four species during the current study, when little surface water remained (Table 5).

Table 5. Frog species at four HLIS wetlands recorded from acoustic monitoring during baseline and current surveys. Baseline data from GHD Pty Ltd (2021).

Wetland	Lake Bulla		Lake Hattah		Lake Kramen		Lake Mournpall	
Species	Baseline	Current	Baseline	Current	Baseline	Current	Baseline	Current
Barking Marsh Frog					√			
Common Froglet					√			
Eastern Banjo Frog		√		√	√	√		√
Eastern Sign-bearing Froglet		√		√	√	√		√
Peron’s Tree Frog		√		√	√	√		√
Spadefoot frogs *		√		X	√			√
Spotted Marsh Frog		√		X	√	√		X

X Species not recorded from acoustic monitoring yet recorded during audio-visual surveys

* Combined Painted Spadefoot Toad *Neobatrachus pictus*, Common Spadefoot Toad *N. sudelli* and unidentified Spadefoot Toads *Neobatrachus* spp.

4 Discussion and Recommendations

4.1 General

Overall, at least eight species from 3 families (Hylidae, Limnodynastidae, Myobatrachidae) were recorded during this study, and a further species, Barking Marsh Frog, was recorded during the baseline study (GHD Pty Ltd 2021), confirming that the HLIS, when it holds water for an appropriate length of time, is able to support a relatively diverse frog assemblage. The threatened Growling Grass Frog was not recorded during either survey, despite recent records in the region. This is not surprising given that this frog requires permanent or near-permanent water; occupancy by this species is strongly linked to seasonal flooding regimes and vegetation complexity (Wassens et al. 2007, Wassens et al. 2010).

Most frogs recorded during this study are common where they occur and exhibit broad distributions in southern or eastern Australia (Cogger 2018). In this study most frog species were recorded from most study wetlands, albeit in relatively low numbers. This was likely an indication of survey timing, early in the watering cycle and before most species had developed from tadpoles. There were relatively few calling frogs (adults) and most of the frogs observed during audio-visual surveys were metamorphs or sub-adults. The model outputs predict that overall frog abundance will peak early in the watering cycle — when it coincides with frog breeding activity and thus greater detectability. We expect that frogs will benefit most (i.e. breeding, feeding and refuge sites are boosted) when water levels are maximised ahead of the peak frog breeding period.

4.2 Key drivers of frog occurrence

Key drivers of frog occurrence operate at both local (wetland) and landscape scales (Papas et al. 2020). At the local scale, hydrological conditions and other environmental factors (e.g. structural vegetation, water quality) are useful predictors of site occupancy (e.g. Wassens et al. 2010). Frogs in the Murray–Darling Basin depend variously on local rainfall or flood pulses (Wassens 2011, Bino et al. 2018). For those that are dependent on flood pulses (synonymous with environmental watering in the current study), successful recruitment occurs only when the breeding window, typically Spring and Summer, and the flood pulse coincide (Wassens 2011). In addition, frog densities also respond to other environmental changes in wetlands, such as habitat alteration resulting from grazing by domestic livestock or from the introduction of exotic fish (Jansen and Healey 2003), although an assessment of these influences was not part of this study.

Biological and life-history factors, such as lags between calling and spawning, variability in tadpole development times (which can range from several weeks to 12 months, depending on species and environmental conditions) and the preference for newly-metamorphosed individuals to remain close to the natal site while gaining body condition, mean that hydroperiod is an important determinant of frog occurrence (e.g. Wassens 2011, Hamer et al. 2016, Júnior and Rocha 2017, Howell et al. 2020). Hence, recurring reductions in hydroperiod would result in the disappearance of species with longer development periods. Conversely, longer hydroperiods may lead to higher predator densities and reduced vegetation complexity, also recognised influences on frog occurrence (Wassens 2010).

Environmental watering is known to benefit many Australian frog species, the characteristics of watering (volume/duration, timing (season) and frequency) are important determinants of frog occurrence and persistence (Wassens et al. 2011, Papas et al. 2020). While wetland hydroperiod is an important influence, other wetland water characteristics are also likely to influence frog occurrence, including water depth (Queiroz et al. 2015) and water quality, the latter expressed by the degree of salinity (conductivity), pH, turbidity (Simpkins et al. 2014) and contamination (Strong et al. 2017; Sievers et al. 2019), all of which have identifiable impacts on frog larval stages.

It is difficult to determine the drivers of frog abundance at individual wetlands on the strength of data collected during the baseline and post-watering surveys, given how dynamic and changing the fringing terrestrial and shallow water zones are during the watering process. For instance, our survey data did not include the Barking Marsh Frog *Limnodynastes fletcheri*, a species that is generally common and widespread in north-western Victoria, especially along the Murray River floodplain (VBA, DELWP); it was recorded from Lake Kramen during the baseline surveys. Watering over several months results in the progressive submergence of fringing terrestrial vegetation and the eventual establishment of aquatic vegetation communities. Unsurprisingly, there are significantly more native wetland plant species in inundated and drawdown wetlands than in dry wetlands but these take time to establish (e.g. Papas et al. 2020). That said, some insight into the potential environmental drivers of frog occurrence in the HLIS is provided by the modelling for select frog species and presented in Appendix 2. It is expected that those wetlands that receive water early in the watering process and/or provide habitat for an array of frog taxa will support greater abundance and numbers of species.

The most likely threatened frog species to occur in or near the HLIS is the Growling Grass Frog; it has been recorded at several sites across the Mallee CMA region (Victorian Biodiversity Atlas, DELWP), most recently at the permanent waterbody Kings Billabong near Mildura (Papas et al. 2020). The Growling Grass Frog is an aquatic species, spending most of its life close to permanent or near-permanent water-bodies (Wassens et al. 2007, Wassens et al. 2010). It often persists as metapopulations that are relatively fluid in their spatial organisation (Wassens et al. 2008, Heard et al. 2012b, a). The most enduring water retentions within the HLIS (thus potentially providing the most likely locations for GGF and most other frog species, other environmental factors notwithstanding) are in the Chalka Creek north area at Belton's Bong, at Lake Mournpall which may hold water for up seven years, and at Lake Hattah which typically holds water for 2-3 years (P. Murdoch pers. comm.).

The only wetland to yield frog species during the baseline surveys was Lake Kramen (GHD Pty Ltd 2021). It was the only study wetland containing water during the baseline surveys, confirming the requirement for water by frogs.

This study and the baseline study have provided some insight into the value of environmental watering for frogs at the HLIS. However, further investigation is required to determine the influential environmental drivers for frogs there and thus the most appropriate watering regime.

4.3 Recommendations

Several useful recommendations regarding study site placement, sampling and future studies were provided by GHD Pty Ltd (2021) following the baseline surveys. Below, we provide additional recommendations that should inform management of the HLIS to benefit frogs. These recommendations, based on the results of the baseline and post-watering surveys, are presented because the HLIS is important for frogs in a regional context.

- Continue to monitor the population status of the frog assemblage at the HLIS, at least into the medium-term, to evaluate the effects of the watering regime
- Monitoring should align with key actions of State and National Recovery Plans for threatened frog species — the Growling Grass Frog is known from the region — as well as national and Mallee CMA management objectives for the HLIS
- Monitoring should employ appropriate standardised (i.e. repeatable) survey techniques; we advocate the combination of audio-visual surveys, preferably several times during the Spring-Summer period, in tandem with acoustic monitoring. The monitoring approach should be adaptive, assessed regularly for potential refinement, especially in light of advances in acoustic monitoring and the processing of data collected this way. Future monitoring will be more efficient in the field and provide improvements in data processing time as well as the reliability of results. The application of machine-learning to automated frog call identification is innovative (e.g. Gan et al. 2019, Gibb et al. 2019), and an analytical approach that ARI is developing with the aim of streamlining call identification with increased accuracy and one that means old data can be reprocessed in future
- Further our understanding of the mechanisms via which frogs respond to environmental watering, and factors that might modify these responses. Large-scale factors, such as the size and spatial arrangement of waterbodies, along with finer-scale parameters, such as hydrology, vegetation, predator abundance and disease, will affect frog responses. Informed decisions are required with respect to environmental watering, especially related to frequency, timing and hydroperiod. While environmental watering is known to increase frog occurrence in wetlands (Papas et al. 2020), there is still much to learn about optimal water regimes, which will vary by taxa and probably geographic location, as well as response thresholds to a single event or regime (e.g. timing and duration of a watering event, frequency of watering events). Frog species richness and abundance is typically greater in those wetlands that experience seasonal watering and drawdown than those with less frequent watering or permanent water (at reasonably consistent levels) (Papas et al. 2020)
- Develop a site-specific management plan for frogs at the HLIS (which could potentially include proximate locations); this should involve the integration of frog management into existing plans (e.g. environmental watering management plans, EWMPs) where relevant and where it does not conflict with other wetland values
- Identify and maintain drought refuges within the HLIS
- Explore the potential to utilise citizen science to report frogs (primarily from calls) to broaden or refine the monitoring program. For example, the FrogID app for mobile phones, managed by the Australian Museum Research Institute (Rowley et al. 2018, Rowley and Callaghan 2020), is a simple and efficient means to record and lodge frog calls, which are identified by expert validators.

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Appendix 1

Table A1. Locations of AudioMoth acoustic loggers (approximate mid-point of study transect) at each HLIS study wetland.

Global reference system: WGS 84.

Study wetland and site		Latitude	Longitude
Lake Bitterang			
	1	34.66076	142.38226
	2	34.66246	142.38243
	3	34.66747	142.37676
Lake Bulla			
	1	34.75566	142.35372
	2	34.75682	142.35821
Lake Hattah			
	1	34.75965	142.34017
	2	34.76071	142.3441
	3	34.7557	142.34931
Lake Konardin			
	1	34.69331	142.34239
	2	34.68965	142.34804
	3	34.68866	142.35135
Lake Kramen			
	1	34.77866	142.45872
	2	34.78323	142.46438
	3	34.78473	142.46886
Lake Mournpall			
	1	34.71255	142.35474
	2	34.71201	142.35042
	3	34.70386	142.33932
Lake Nip Nip			
	1	34.74929	142.3995

Appendix 2

While not a formal requirement of this project we conducted exploratory modelling of the frog survey data in an attempt to identify environmental characteristics that potentially influenced the occurrence of frogs at HLIS. The environmental characteristics that were measured or estimated during this study, and included in the analyses below, are described in Section 2.3 of this report. Below, we present a brief description of the analytical approach and the results of the analyses for each taxon for which there were enough data.

Methods

Given the small number of wetlands and study sites replicates, and the large number of possible explanatory variables this analysis focuses only on exploring potential relationships. Only the audio-visual surveys had covariates associated, as the covariate values were not constant over time – watering and drawdown are processes that make for a dynamic system – and there is no clear way to estimate them over time for the AudioMoth data.

To explore the associations between the abundance of particular frog species and the explanatory variables a negative binomial generalise linear model (GLM) was used. This type of model is used for count data that is overdispersed or show signs of animals clumping together (Hilbe 2011). Potential explanatory variable combinations were modelled and the information criteria (AICc) was used to calculate a model average and variable importance (Burnham and Anderson 2002). The variable importance was calculated for each variable by summing the weights of models that included that variable. The higher the importance score (between 0 and 1) the more influence that variable has on the dependent variable. The model average was calculated across the models with an AICc within 4 of the best (lowest) AICc, using their respective model weights to calculate a weighted average.

The analysis was conducted in 'R' (R Core Team 2022) using the package 'MASS' (Venables and Ripley 2002) to calculate the negative binomial regression and 'MuMIn' (Barton 2020) for calculating model weights and model averaging.

Results

Surveys were conducted at a total 18 transects across seven wetlands. There were up to three audio-visual surveys at each transect, with AudioMoths being deployed for approximately 4 weeks. Audio-visual surveys were conducted when the AudioMoths were deployed (early December) and retrieved (late December). During the audio-visual surveys some site characteristics were recorded and used in the analysis of recorded data. The approach to surveys and the collection of environmental information is described in Section 2 (Methods).

The automated system identified three unique species from the AudioMoth call files (Eastern Sign-bearing Froglet *Crinia parinsignifera*, Eastern Banjo Frog *Limnodynastes dumerilii* and Common Spadefoot Toad *Neobatrachus sudellae*) as well as some calls that could not be identified more specifically than *Limnodynastes* species (Table A1). The most commonly identified species was the Eastern Sign-bearing Froglet detected in 160 instances, while the Eastern Banjo Frog was detected at potentially every wetland, given Lake Kramen was the only one without a confirmed identification, yet *Limnodynastes* species were detected there.

The audio-visual surveys identified eight unique species as well as some individuals that could not be identified more specifically than Anura and Spadefoot Toad species (Table A2). The most commonly detected species was the Spotted Marsh Frog *Limnodynastes tasmaniensis* with around 1,500 individuals observed, while the Eastern Banjo Frog was the only species detected at every wetland. It should be noted that while the AudioMoth automated identification process only identified three unique species, it did identify 144 instances across the seven wetlands where an individual frog species could not be identified, but a chorus of frogs was detected.

Analysis of audio-visual survey data

The number of individuals detected was too small to analyse for 'unidentified frog species', Common Eastern Froglet *Crinia signifera*, Plains Brown Tree Frog *Litoria paraewingi*, Painted Spadefoot Toad *Neobatrachus pictus* and Common Spadefoot Toad. This meant that the abundance of Eastern Sign-bearing Froglet, Eastern Banjo Frog, Spotted Grass Frog, Peron's Tree Frog *Litoria peronii* and combined Spadefoot Toads *Neobatrachus* spp. were explored in the analysis.

Table A1. Species summary from the CNN analysis to identify frog calls from AudioMoth recordings.
The values represent the number of individuals assessed to belong to each species at each wetland. Species richness is the number of unique species identified at the wetland.

Location	Eastern Sign-bearing Froglet	Eastern Banjo Frog	*Limnodynastes* spp.	Common Spadefoot Toad	Species richness
Lake Bitterang	3	2	22	63	3
Lake Bulla	35	2	1	0	3
Lake Hattah	30	5	0	0	2
Lake Konardin	89	9	3	0	3
Lake Kramen	0	0	18	0	1
Lake Mournpall	3	19	0	4	3
Lake Nip Nip	0	1	2	13	3
Total	**160**	**38**	**46**	**80**	**3**
Number of transects	5	6	5	3	NA

Table A2. Species summary from the audio-visual surveys at each transect.
The values represent the number of individuals assessed to belong to each species at each wetland. Species richness is the number of unique species identified at the wetland.

Location	Eastern Sign-bearing Froglet	Common Froglet	Eastern Banjo Frog	Spotted Marsh Frog	Plains Brown Tree Frog	Peron’ s Tree Frog	Painted Spadefoot Toad	Spadefoot *spp.*	Common Spadefoot Toad	Unidentified. frogs.	Species richness
Lake Bitterang	80	0	74	125	3	23	0	46	15	2	7
Lake Bulla	20	0	30	13	0	21	0	3	0	0	5
Lake Hattah	25	0	24	134	0	0	1	0	0	0	4
Lake Konardin	26	6	58	4	0	18	0	3	3	0	6
Lake Kramen	24	0	99	1,210	0	13	0	0	0	0	4
Lake Mournpall	19	0	24	2	0	22	0	5	0	1	6
Lake Nip Nip	0	0	6	0	0	3	0	0	0	0	2
Total	**194**	**6**	**315**	**1,488**	**3**	**100**	**1**	**57**	**18**	**3**	**8**
Number of transects	6	1	7	6	1	6	1	4	2	2	NA

Eastern Sign-bearing Froglet

Data exploration for the Eastern Sign-bearing Froglet revealed the only important variables to be related to water quality: turbidity and pH (Table A3). Transects with lower turbidity or pH had a larger number of froglets, as can be seen in the model average.

Table A3. The summary of the model averaging for the Eastern Sign-bearing Froglet abundance using models with an AICc within 4 of the lowest AICc.

Parameter	Estimate	Lower bound	Upper bound
Intercept	1.363	0.877	1.849
Aquatic: inundated shrubs	0.338	-0.137	0.813
Aquatic: inundated trees	0.354	-0.119	0.827
Aquatic: short emergent	0.635	-0.059	1.329
Electro-conductivity	0.474	-0.089	1.036
pH	-0.780	-1.450	-0.109
Turbidity	-1.069	-1.938	-0.200
Water temperature	0.434	-0.069	0.937
Wet fringe: short herbs/grasses	0.691	0.069	1.313
Wet fringe: tall sedges/reeds	0.276	-0.198	0.749
Wet fringe: trees	-0.780	-1.410	-0.149

Eastern Banjo Frog

Data exploration for the Eastern Banjo Frog revealed important variables to be related to water quality (turbidity and water temperature), short emergent aquatic vegetation and wet fringe vegetation (logs and trees) (Table A4). Transects with lower turbidity or higher water temperatures had a larger number of Banjo Frogs, as can be seen in the model average (Table A4). Similarly, transects that had wet fringes with higher amounts of logs or trees had a larger number of Banjo Frogs.

Table A4. The summary of the model averaging for the Eastern Banjo Frog abundance using models with an AICc within 4 of the lowest AICc.

Parameter	Estimate	Lower bound	Upper bound
Intercept	1.626	1.330	1.923
Aquatic: short emergent	1.143	0.614	1.673
Turbidity	-0.563	-0.867	-0.258
Water temperature	0.952	0.555	1.350
Wet fringe: logs	0.409	0.140	0.679
Wet fringe: trees	0.483	0.215	0.752

Spotted Grass Frog

Data exploration for the Spotted Grass Frog revealed the important variables to be related to water turbidity and the wet fringe (trees, litter and bare ground) (Table A5). Transects with lower turbidity had a larger number of Spotted Grass Frogs, as can be seen in the model average (Table A5). Similarly, transects that had wet fringes with higher levels of litter or lower levels of bare ground or trees had larger numbers of Spotted Grass Frogs.

Table A5. The summary of the model averaging for the Spotted Grass Frog abundance using models with an AICc within 4 of the lowest AICc.

Parameter	Estimate	Lower bound	Upper bound
Intercept	1.757	1.076	2.438
Aquatic: logs	-0.608	-1.279	0.063
Aquatic: open water	0.572	-0.063	1.207
Turbidity	-1.973	-2.970	-0.976
Water temperature	0.448	-0.139	1.034
Wet fringe: bare ground	-0.615	-1.149	-0.081
Wet fringe: litter	0.637	0.009	1.264
Wet fringe: shrubs & saplings	-0.405	-1.040	0.230
Wet fringe: trees	-3.366	-4.844	-1.887

Peron's Tree Frog

Data exploration for Peron's Tree Frog revealed that the important explanatory variables were related to water quality in turbidity and water temperature (Table A6). Transects with lower turbidity or higher water temperature had a larger number of Peron's Tree Frogs, as shown in the model average (Table A6). Similarly, transects that had wet fringes with higher amounts of short herb/grasses or trees had larger numbers of Peron's Tree Frogs.

Table A6. The summary of the model averaging for Peron's Tree Frog abundance using models with an AICc within 4 of the lowest AICc.

Parameter	Estimate	Lower bound	Upper bound
Intercept	0.184	-0.421	0.789
Aquatic: inundated shrubs	0.178	-0.284	0.641
Aquatic: open water	-0.353	-0.918	0.211
Aquatic: short emergent	0.846	-0.003	1.696
Electro-conductivity	0.371	-0.173	0.915
pH	0.411	-0.556	1.377
Turbidity	-1.182	-1.786	-0.577
Water temperature	0.887	0.134	1.639
Wet fringe: short herbs/grasses	0.881	0.038	1.723
Wet fringe: trees	0.975	0.519	1.431

Spadefoot Toads

Data exploration for Spadefoot Toads showed that no variables were particularly important (Table A7). However, transects with lower pH or higher levels of inundated trees or bare ground in the wet fringe had a larger number of Spadefoot Toads, as can be seen in the model average (Table A7).

Table A7. The summary of the model averaging for Spadefoot Toads (Common Spadefoot Toad, Painted Spadefoot Toad, unidentified Spadefoot Toads combined) abundance using models with an AICc within 4 of the lowest AICc.

Parameter	Estimate	Lower bound	Upper bound
Intercept	-1.274	-2.294	-0.254
Aquatic: inundated shrubs	0.323	-0.615	1.260
Aquatic: inundated trees	1.006	0.218	1.794
Aquatic: logs	-0.258	-1.151	0.634
Aquatic: open water	0.941	-0.070	1.953
Aquatic: short emergent	0.057	-2.495	2.609
Aquatic: tall emergent	0.219	-0.456	0.893
Electro-conductivity	-1.208	-3.848	1.431
pH	-1.875	-3.466	-0.284
Turbidity	0.110	-0.808	1.027
Water temperature	0.908	-0.158	1.974
Wet fringe: bare ground	0.925	0.107	1.743
Wet fringe: litter	0.474	-0.410	1.358
Wet fringe: logs	-0.277	-1.168	0.614
Wet fringe: short herbs/grasses	0.118	-1.550	1.786
Wet fringe: shrubs & saplings	-0.096	-0.982	0.789
Wet fringe: tall sedges/reeds	0.686	-0.017	1.389
Wet fringe: trees	-0.136	-1.127	0.856
Wet fringe: water	0.015	-0.692	0.722

Table 8 presents the importance of each variable for each species or grouping (i.e. Spadefoot Toads). Note that the more information about the data that is retained in the model the lower the AICc score that model receives. Where there is a balanced set of models (each variable occurs in the same number of models, which is the case here) the AICc can be used to estimate the relative importance of each variable. That calculation (described in the methods) provides a score between 0 and 1. The closer the score is to 1 the stronger the effect of that variable, or the more important it is. Typically, relative importance should be 0.5 or greater for it to be considered important in explaining variation. A score of ~0.75 would be moderately important in explaining variation and a score of ~0.9 would be a strong explainer.

Table A8. Importance of each variable for each species or grouping. Importance is the sum of the AICc weights for each model including that variable. Scores >0.5 are presented in bold.

Variables	Eastern Sign-bearing Froglet	Eastern Banjo Frog	Spotted Marsh Frog	Peron's Tree Frog	Spadefoot Toads
Aquatic: inundated shrubs	0.130	0.003	0.026	0.103	0.101
Aquatic: inundated trees	0.161	0.002	0.030	0.063	0.393
Aquatic: logs	0.068	0.016	0.127	0.046	0.068
Aquatic: open water	0.067	0.006	0.082	0.070	0.268
Aquatic: short emergent	0.137	**0.885**	0.147	0.198	0.080
Aquatic: tall emergent	0.067	0.003	0.090	0.046	0.073
Electro-conductivity	0.093	0.066	0.050	0.060	0.115
pH	0.329	0.019	0.037	0.099	0.389
Turbidity	**0.679**	**0.502**	**0.787**	**0.833**	0.078
Water temperature	0.140	**0.977**	0.049	**0.529**	0.206
Wet fringe: bare ground	0.062	0.002	0.141	0.058	0.339
Wet fringe: litter	0.079	0.006	0.227	0.080	0.112
Wet fringe: logs	0.078	0.259	0.051	0.057	0.078
Wet fringe: short herbs/grasses	0.200	0.067	0.075	0.215	0.070
Wet fringe: shrubs & saplings	0.068	0.002	0.049	0.046	0.080
Wet fringe: tall sedges/reeds	0.117	0.002	0.030	0.048	0.215
Wet fringe: trees	0.194	0.172	**0.886**	0.201	0.072
Wet fringe: water	0.063	0.002	0.028	0.052	0.065