

Project title: Assessing Wetland Restoration Effectiveness for Frogs using Acoustic Monitoring

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Project number: TMBF 004

Project Objectives and Outcomes:

1. Advancing skills within QYAC related to bio-acoustic monitoring techniques. These skills will assist QYAC in their long-term monitoring goals beyond the life span of this project.

This study has provided QYAC rangers with an understanding of the benefits of bio-acoustic monitoring techniques and of how to conduct bio-acoustic surveys in the field. The datasets generated throughout this study have established a baseline for acid frog and competitor species' populations within the Eighteen Mile Swamp, Keyholes and Yarraman Valley wetlands.

2. Support QYAC's aspirations to manage rehabilitated land post mining by measuring the effectiveness of their restoration efforts within coastal "wallum" habitat for key frog species.

The presence-absence data for acid frogs and sibling species in the restored wetlands have been compared against reference and disturbed wetland populations. The analysis has provided evidence that the acid frog populations in restored wetlands are statistically larger than in disturbed wetlands however, cannot yet be considered analogous to populations in reference habitat. This finding indicates a positive trajectory for restoration efforts in the Yarraman Valley and may inform QYAC's future rehabilitation management plans.

3. Establishing monitoring techniques that reduces impact on the natural areas (a key QYAC goal).

This study has demonstrated that bio-acoustic monitoring is a viable surveying technique for acid frogs in the wetlands surveyed. This technique has required minimal in-field survey effort and has further reduced impacts on natural areas through easily accessible bio-acoustic recorder locations.

4. Lessons learned from Yarraman Valley will be important for future management efforts at the Keyholes and Yarram Void given ongoing recreational pressures and rehabilitation requirements.

*Water quality analysis throughout the study area has provided insight into the pressures caused by disturbances to water quality. In particular, high-pH values were observed to greatly limit the presence of *L. olongburensis*. This effect was most evident in disturbed habitat (the Keyholes), where *L. olongburensis* presence was lowest and where pH values were highest.*

5. Training opportunity for a PhD student at the interface between applied ecology and bio-acoustics and working closely with a highly dynamic group representing Indigenous Australians.

The data collected during the first breeding season has contributed to the honours thesis of an honours student and is the basis of the following research journal manuscript. Data collected during the second and third breeding seasons are currently being analysed and will

form the basis of a revised research manuscript. Data collected throughout the study will be utilised in the research of a PhD candidate.

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Evaluating habitat restoration efforts in wallum wetland environments; with a comment on the impact of water quality on *Litoria olongburensis* presence.

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Abstract

Despite the restoration of degraded ecosystems becoming increasingly commonplace, research to determine the effectiveness of such projects remains scarce. This study aimed to evaluate restoration success for wallum wetland habitat within the former Yarraman Mine on Minjerribah (North Stradbroke Island) in Queensland, Australia. Restoration success was evaluated with respect to the observed recolonisation of wallum-endemic *Litoria olongburensis* and the exclusion of competitor species *L. fallax*. Presence-absence data, derived from bioacoustic recordings obtained within restored (Yarraman), disturbed (the Keyholes) and reference (Eighteen Mile Swamp) wallum wetlands over a 16-day period, were compared between habitat treatments. Additionally, water quality variables (pH, salinity, turbidity and oxidation reduction potential) were modelled to explain variation in species presence-absence. Although *L. olongburensis* presence was found to be higher in restored wetlands than in disturbed habitat, presence was highest in the reference sites. pH was found to strongly influence *L. olongburensis* presence however, the effects of other water quality variables were inconclusive. The presence of *L. fallax*, although lower in restored habitat, could not be attributed factors assessed in this study. The results suggest that, at least for *L. olongburensis*, habitat restoration is progressing positively however, restoration efforts have not yet achieved habitat analogous to reference conditions.

Introduction

The challenge of balancing socio-economic development with environmental protection has been met with a worldwide proliferation of biodiversity offsetting policies (Maron et al. 2015). Biodiversity offsetting aims to counterbalance the ecological impacts of urban and other development activities, such as mining, primarily through habitat protection or restoration. However, the effectiveness of offsets remains poorly understood and is rarely

evaluated, even in Australia, a world leader in offset-policy development (Maron et al. 2015). Consequently, restoration outcomes for conservation-significant species in offset habitat continue to be unclear.

A case in point are the substantial populations of the threatened acid frog species *Litoria olongburensis* which occur within the ‘wallum’ wetlands on the four main sand islands of Southeast Queensland; populations considered critical for the conservation of this species (Meyer et al. 2006). Although three of these islands either largely or entirely fall under the designation of national or conservation park (Australian Department of Climate Change, Energy, the Environment and Water 2023), large portions of Minjerribah (North Stradbroke Island) have been subject to extensive sand mining between 1949 and 2019 (Burgin 2020). In the wake of its closure in 2015, the former Yarraman Mine underwent extensive restoration work with efforts being made to re-establish native vegetation and reconstruct the site’s natural topography and wallum wetland ecosystem. Once sufficiently restored, custodianship of the former mine site is due to be relinquished to the Quandamooka Yoolooburrabee Aboriginal Corporation (QYAC); QYAC is the *Registered Prescribed Body Corporate* established under the *Native Title Act 1993* to hold, protect, and manage the recognized **native title rights and interests** of the Quandamooka people over **North Stradbroke Island (Minjerribah)** and surrounding waters.

Wallum wetlands are restricted to the mainland coastal regions and dune islands of Australia’s central eastern coast, and are characterised by acidic tannin-stained, oligotrophic waters (Meyer et al. 2006). *L. olongburensis*, listed as Vulnerable under state and federal legislation (Meyer et al. 2006), is specifically adapted to develop within these waters (Ingram & Corben 1975) where species abundance has been found to be highest between pH 3.53-4.61 (Shuker, Simpkins & Hero 2016). Disturbed wallum wetlands however, may be

subject to elevated pH and turbidity due to increased surface runoff and changes to hydrology (Filer et al. 2022; Meyer et al. 2006). Both factors have been negatively correlated with *L. olongburensis* abundance (Simpkins et al. 2014; Simpkins et al. 2022), and concerns regarding pH and turbidity have been reported in the Yarraman Mine site prior to restoration (Cox & Specht 2013). Conversely, the higher pH in disturbed wallum habitat has been positively correlated with abundance of *L. fallax*, a non-acid-tolerant sibling species to *L. olongburensis* (Simpkins et al. 2022). These two species are largely allopatric due to the acidity of wallum wetlands typically exceeding the tolerances of *L. fallax* (pH <5; Hines & Meyer 2011). However, the decreased acidity in disturbed wallum habitat removes this natural barrier allowing for the colonisation of *L. fallax* (Filer et al. 2022). Sympatric populations allow for potential competition and consequently, the exclusion of *L. olongburensis* from disturbed habitat (Filer et al. 2021).

This study aimed to first, assess if the progress of restoration within the former Yarraman Mine have been conducive to the recolonisation of *L. olongburensis*; secondly, determine the influence of water quality variables on the presence-absence of *L. olongburensis* and *L. fallax*; and thirdly, identify factors which may need to be addressed to ensure the successful rehabilitation of the site and support QYAC's long-term conservation management goals. Species presence-absence within restored habitat (Yarraman) was compared to presence-absence in corresponding disturbed (The Keyholes) and reference habitat (Eighteen Mile Swamp) to determine if restoration efforts have been successful in recruiting *L. olongburensis* and excluding *L. fallax*. Additionally, a modelling approach was used to explain variation in species presence-absence due to observed water quality.

Methods

Acoustic Data

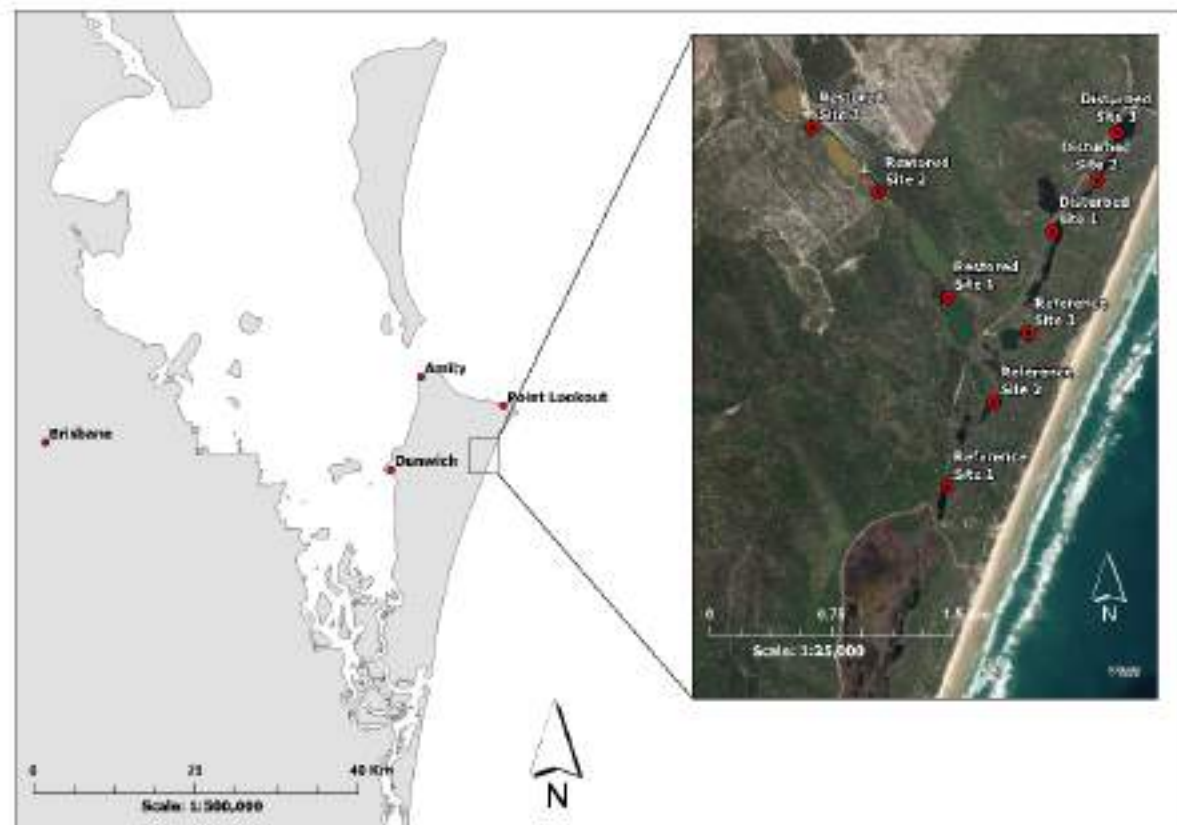
Frontier Labs BAR-LT bioacoustic recorders were installed with the assistance of QYAC rangers at survey sites within restored (n=2), disturbed (n=3), and reference (n=3) habitat treatments in Minjerribah wetlands to monitor frog call activity during the peak breeding season from 12-28 December 2022. Five-minute acoustic recordings (sample rate=44,100 Hz; gain=40 dB) were taken every hour between 8pm-3am to capture peak calling activity. Recordings were analysed manually using Audacity (Audacity Team 2021) to identify presence-absence of *L. olongburensis* and *L. fallax* vocalisations. Recording times in which wind, rain, or insect noise rendered call identification ambiguous or undeterminable were excluded. Of 128 potential recordings per site, only 99 were used in the final analysis, resulting in a total of 8.25 hours of acoustic data per site.

Water Analysis

At each site pH, salinity, and turbidity (variables known to correlate with *L. olongburensis* presence; Simpkins et al. 2014) were measured along with the oxidation reduction potential (ORP), as the concentration of heavy metals within the restoration sites remain elevated (D. Carter, pers. Comm., 4 May 2023). Three samples from each site were analysed using a Horiba U-50 series MultiParameter Water Quality Meter, from which the mean of each variable was calculated.

Statistical Analysis

All statistical analyses were conducted using R statistical software (R Core Team 2023). One-way ANOVA and Tukey's *post-hoc* analyses were performed to compare the relative species



presence between habitat treatments. Before investigating the influence of water quality variables on species presence-absence, variance inflation factor (VIF) analysis was used to detect any potential collinearity. Generalised linear mixed-effect models were then constructed for each species using the glmmTMB package (Brooks et al. 2017) with survey site, recording date, and recording time included as random variables. Due to a unimodal relationship with species presence, a quadratic term was included for ORP. Species presence models were then inspected for any significant effects of zero inflation and deviations in residual dispersion. Automated model selection was performed on the global models (including all fixed variables) to determine the best models using the MuMIn package

(Bartoń 2023). Models were ranked according to their Akaike's Information Criterion (AIC_c ; to correct for biases due to the small sample size) with the lowest AIC_c indicating the best model. As models with nearly equivalent AIC_c values may present vastly different parameters due to low parameter estimates, a model averaging approach for models with $\Delta < 4$ was used to avoid selection uncertainty (Burnham & Anderson 2002). From these models, relative variable importance was calculated using Akaike Weights (w_i). The w_i for models containing the variable of interest were summed to a maximum value of 1 indicating the highest variable importance (Burnham & Anderson 2002).

Results

Species presence ANOVAs found a significant difference in the presence of *L. olongburensis* (Df=2, F=683.3, P<0.001) and *L. fallax* (Df=2, F=147.8, P<0.001) between habitat treatments. Tukey's *post-hoc* analysis evidenced significantly higher *L. olongburensis* presence in reference (P<0.001) and restored (P<0.001) relative to disturbed habitat, however, presence was significantly lower in restored habitat than in reference conditions (P<0.001). *L. fallax* presence was lower in restored sites relative to disturbed (P<0.001) and reference habitat (P<0.001). However, no significant difference was found between reference and disturbed habitat (P=0.268).

VIF values for all variables was <5. However, due to high VIF values for salinity, it was subsequently excluded from the GLMMs. No significant effect of zero inflation nor significant deviation in residual dispersion were observed for either model. For *L. olongburensis*, automated model selection returned two models with $\Delta < 4$ (Table 1). These models contained all predictor variables with a combined weighting of 99.8% suggesting all other models compared poorly. Increasing pH had a strongly negative effect on *L.*

olongburensis presence ($P < 0.001$; Table 2) and along with ORP, had the highest relative variable importance. ORP was shown to have a significant negative curvilinear relationship with *L. olongburensis* presence. The confidence interval for turbidity included zero, suggesting this variable did not strongly influence *L. olongburensis* presence. Two models had $\Delta < 4$ for *L. fallax* presence with a combined weighting of 99.8% and containing all predictor variables. Turbidity and ORP had the highest relative variable importance with increasing turbidity having a positive effect on *L. fallax* presence ($P < 0.001$). ORP however, had a significant unimodal relationship with *L. fallax* presence, with presence highest at intermediate ORP values ($P < 0.001$). pH did not appear to strongly influence *L. fallax* presence, and the confidence interval for this variable included zero.

Discussion

Bioacoustic monitoring within the former Yarraman Mine and corresponding disturbed and reference ecosystems has offered valuable insights into the progressive recolonisation of *L. olongburensis* into previously degraded habitat. A significantly higher presence of *L. olongburensis* was found in restored sites relative to disturbed habitat. This suggests that the current condition of the restored habitat is more suitable for this species than the same habitat prior to restoration; an important indicator regarding the success of restoration efforts given the specialist nature of *L. olongburensis* (Simpkins et al. 2014). Furthermore, decreased presence of *L. fallax* in restored sites compared to other habitat treatments implies that incidences of potential competition with *L. olongburensis* would likely be reduced. However, despite the relative success of restoration efforts in comparison to disturbed habitat, *L. olongburensis* presence was still found to be significantly lower in restored sites relative to reference conditions ($P < 0.001$). This suggests that although recolonisation of this species is

occurring in the Yarraman, conditions in this wetland are not yet as suitable for *L. olongburensis* as habitat in Eighteen Mile Swamp.

Independent of habitat type, increasing pH was found to have a significant negative effect on *L. olongburensis* presence ($P < 0.001$). While wallum wetlands typically range in acidity from pH 3.6-6 (Department of Environment and Resource Management 2010), previous studies have identified that *L. olongburensis* abundance typically declines in habitats with pH > 4.6 (Shuker,

Simpkins & Hero 2016), as correlated by this study. Conversely however, pH was not found to have a significant influence on *L. fallax* ($P = 0.124$). While Eighteen Mile Swamp is amongst the best condition wallum wetland on Minjerribah (Stock 2012), *L. fallax* has nonetheless managed to colonise this habitat, which may be attributed to the relatively low acidity levels observed in this study (pH 5.13-6.82). *L. fallax* typically only occurs in wetlands exceeding pH 5 (Hines & Meyer 2011) therefore, given the lowest recorded mean pH of 5.13, pH would not be considered a limiting factor here.

It is known from the literature that changes in the pH of the wallum wetlands, either through changes in hydroperiod or via the introduction of pollutants, also serve to make conditions favourable for the colonisation of the habitat by less acid-tolerant species previously excluded due to physiological limitations (Meyer *et al.* 2006, 2010; Hines & Meyer 2011). Thus, although not tested in this study, one can expect that an increase in groundwater inflow in parts of Eighteen Mile Swamp from, for example, Karboora (Blue Lake) (as well as other groundwater inflow sites) could potentially have a significant impact on the population dynamics of *L. olongburensis* and/or previously excluded species that are less acid-tolerant. Changes in future groundwater inflow in parts of Eighteen Mile Swamp and the influence thereof on acid frog populations could make for an important future research topic.

Besides affecting the natural acidity of the wetland environment, an increase in hydroperiod may also result in more permanent water sources, allowing for more favourable conditions for the colonisation of predatory fish species (such as the mosquito fish, *Gambusia holbrooki*) (Meyer *et al.* 2006). In addition, increasing pH levels of the wallum wetlands, either through changes in hydroperiod or via the introduction of pollutants, also serve to make conditions favourable for the colonisation of the habitat by less acid-tolerant species previously excluded due to physiological limitations such as mosquito fish (Meyer *et al.* 2006, 2010; Hines & Meyer

2011). This highlights the need for future research and monitoring of acid frog-mosquito fish relationships in wetlands on Minjerribah knowing that predation by introduced species such as mosquito fish remains one of the key threatening processes to acid frogs (see *National recovery plan for the wallum sedgefrog and other wallum-dependent frog species*, Meyer *et al.* 2006).

Both species demonstrated a non-linear quadratic relationship with ORP, with species presence being lowest at low and high ORP values. While low species presences at low ORP values are consistent with previous studies demonstrating a negative correlation between anuran species richness and heavy metal concentrations (Ficken & Byrne 2013), decreasing species presence at high ORP values was unexpected. Although the influence of ORP on both *L. olongburensis* and *L. fallax* was significant (both $P < 0.001$), R^2 was relatively low ($R^2 = 0.429$ and $R^2 = 0.539$, respectively). Moreover, at some sites, both species varied between being highly present ($>95\%$) and nearly absent ($<5\%$) at similar ORP values. Therefore, the decreased species presences at high ORP values may be attributed to other influential variables not measured in the current study (e.g. sedge cover; Simpkins *et al.* 2022).

Similar to previous research regarding *L. olongburensis* abundance (Simpkins et al. 2022), turbidity was not found to significantly influence the presence-absence of this species ($P=0.820$). While an earlier study had found turbidity to have strong negative influence on *L. olongburensis* abundance, this may be attributed to the study's focus on tadpoles as opposed to adults of the species (Simpkins et al. 2014). Due to the acoustic nature of the presence-absence surveys, we are therefore unable to comment on the relationship between turbidity and tadpole abundance at the sites. However, despite Simpkins et al. (2022) finding no correlation between turbidity and *L. fallax* abundance, this study identified a significant positive relationship of *L. fallax* with turbidity ($P<0.001$), possibly due to unseen impacts on competing tadpoles or other interconnected factors such as vegetation or water depth/flow.

Although not well studied, it is fair to assume that different wetland vegetation (or wetland type – i.e. open water vs vegetated) will influence acid frog and competitor population dynamics. Beyond essential breeding habitat, not much is known about the specific habitat requirements of the wallum frogs (Meyer *et al.* 2006). However, it can be assumed that the surrounding vegetation of breeding sites most likely play a key role in the (i) dispersal of acid frog and competitor populations, (ii) availability and type of perch substrate known to influence these populations (Shuker & Hero 2012) and (iii) maintenance of the specific water chemistry and quality of the habitat (Griffith *et al.* 2003, 2008; Meyer *et al.* 2006).

This study has yielded evidence that, at least in terms of *L. olongburensis* habitat, restoration efforts in the Yarraman are showing signs of success. However, conditions in the Yarraman remain less favourable for *L. olongburensis* than conditions in reference habitat. This disparity may in part be attributed to the lower acidity observed in restored wetlands, indicating that there is still work to be done to return this habitat to a more natural state, and thereby limit the occurrence of competitive species capitalising on local disturbance. As such,

the high pH values observed in the Yarraman Valley wetlands may be the primary factor inhibiting the successful recolonisation of *L. olongburensis* in this habitat. However, acoustic monitoring, as used in this study, can aid in tracking the success and timescale of recovery efforts in the context of highly sensitive wetland habitat, and it is our hope that this record, as well as our findings here, can aid QYAC in future restoration efforts.

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Tables

Table 1. Comparison of water quality variables influencing the presence-absence of *Litoria olongburensis* and *Litoria fallax* in Minjerribah wetlands.

Model	AIC _c	Δ_i	w_i
<i>Litoria olongburensis</i>			
pH + ORP + ORP ²	308.3	0	0.714
pH + Turbidity + ORP + ORP ²	310.2	1.84	0.284
<i>Litoria fallax</i>			
pH + Turbidity + ORP + ORP ²	211.2	0	0.822
Turbidity + ORP + ORP ²	214.3	3.08	0.176

Models with Δ_i less than 4 are presented. ORP² accounts for the unimodal relationship of oxidation reduction potential with *Litoria olongburensis* and *Litoria fallax* presence-absence.

Table 2. Variable coefficients and relative variable importance of water quality variables for *Litoria olongburensis* and *Litoria fallax* in Minjerribah wetlands.

Variable	Estimate	SE [†]	Confidence interval	Z-value	P-value	Rel. Var. Imp. [‡]
<i>Litoria olongburensis</i>						
Intercept	-1.882	0.928	-3.700, -0.064	2.026	0.043*	
ORP	-98.812	23.130	-144.147, -53.478	4.265	0.001***	1
ORP ²	-79.243	24.316	-126.902, -31.584	3.254	0.001**	1
pH	-122.908	15.933	-154.137, -91.680	7.702	0.001***	1
Turbidity	1.337	5.883	-10.194, 12.868	0.227	0.820	0.28
<i>Litoria fallax</i>						
Intercept	3.738	0.727	2.314, 5.162	5.137	0.001***	
ORP	119.170	23.207	73.684, 164.657	5.127	0.001***	1
ORP ²	-101.524	26.203	-152.881, -50.166	3.871	0.001***	1
Turbidity	117.001	22.212	73.465, 160.537	5.259	0.001***	1
pH	48.258	31.364	-13.216, 109.731	1.537	0.124	0.82

[†]Standard error. [‡]Relative variable importance. Model-averaged variable coefficients and relative variable importance are derived from models where Δ_i is less than 4 for *Litoria olongburensis* and *Litoria fallax* presence-absence.