Title: A simple design feature to increase hydro-period in constructed ephemeral wetlands to avoid tadpole desiccation-induced mortality

Summary

Here we identify an easily implemented wetland design feature that can prolong the survival of the threatened Green and Golden Bell Frog (*Litoria aurea*). We observed small depressions that naturally formed within some wetlands following the construction of habitat for this species. We observed that wetlands containing depressions prolonged the survival of Green and Golden Bell Frog tadpoles during periods of rapid wetland drying whereas wetlands that did not contain depressions in the same circumstances dried, causing 100% mortality in tadpoles present. We recommend that this concept be considered as a design feature in future wetland construction for Green and Golden Bell Frog and other ephemeral wetland breeding amphibians and we provide commentary on how the benefits of this feature can be maximised. This simple design feature may be important for amphibian restoration, particularly considering climate change.

Keywords: restoration ecology; *Litoria aurea*; tadpoles

Introduction

The Green and Golden Bell Frog (*Litoria aurea*) has undergone extreme declines in Australia in the last ~45 years (White and Pyke 1996). Its distribution extended as far west as Bathurst, and covered the eastern coast from northern New South Wales (NSW) to Far East Gippsland in Victoria (White and Pyke 1999). Of this distribution, only 31 populations remain within NSW (White and Pyke 2008). Many of these populations are at risk of stochastic extinction, yet some appear stable (e.g. Goldingay*, et al.* 2017).

{Beranek, 2020 #3243}To combat this decline, extensive effort has been invested into wetland creation for this species, but these attempts have had varying success. A review of the attempts has been provided by (Beranek*, et al. in press*). However, since the ecology of Green and Golden Bell Frog is not entirely understood, wetland design for the species can be further improved (O'Meara and Darcovich 2015). Optimising the design of wetland creation for Green and Golden Bell Frog is important to increase population viability (Mahony*, et al.* 2013).

Breeding of Green and Golden Bell Frog can be enhanced by the construction of appropriate breeding habitat. It is known to breed in both ephemeral and permanent water bodies (Mahony*, et al.* 2013), and these habitat types each have their own advantages and disadvantages. For example, in a permanent wetland, there are often more tadpole predators present (O'Meara and Darcovich 2015) but ephemeral wetlands have an added risk of desiccation, which can result in 100% mortality. Instances of high mortality may become more frequent with climate change.

Here we identify a wetland feature that is relatively easy to include in amphibian wetland creation, and which may well aid in reducing desiccation induced mortality rates of Green and Golden Bell Frog tadpoles and the tadpoles of other ephemeral wetland breeding amphibians.

Methods

Study site

The study site was located on Kooragang Island (-32.852843, 151.710807), immediately north of Newcastle, Australia. It is composed of nine wetlands that were constructed specifically for the Green and Golden Bell Frog. Two thirds of the constructed wetlands were designed to be ephemeral in an average summer (i.e. would dry up during summer) and the remainder were permanent. See Beranek*, et al.* (*in press*) for a comprehensive overview of the site. Following construction, depressions formed naturally over time within a few, but not all, of the ephemeral wetlands. The depressions were around

30 – 60 cm deeper than the rest of the base of the wetlands. Depressions were present within ephemeral wetlands 1A and 2A. The dimensions of the depression in wetland 1A was about 190 x 90 cm and had a sparse coverage of Broadleaf Cumbungi (*Typha orientalis*). The dimensions of the depression in 2A was roughly 180 x 120 cm and had a dense coverage of Broadleaf Cumbungi and Marsh Club-rush (*Bolboschoenus fluviatilis*).

Frog and tadpole surveys

Diurnal and nocturnal searches for frogs were conducted weekly from September – March during the summer seasons 2016 – 2017, 2017 – 2018, and 2018 – 2019. Survey effort was scaled with wetland size and had a duration ranging from 30 – 120 minutes. During the searches, any frogs found were identified, and the occurrence and identity of tadpoles were recorded.

Dip-netting (30 cm diameter, 5 mm mesh) was used to obtain an estimate of tadpole density. Species were identified using Anstis (2013). The amount of net sweeps was stratified according to the wetland surface area; where one netting attempt was conducted per 5 m^2. Each net sweep was standardised to a 1 m stroke. The snout to vent length (SVL) of~10 tadpoles of each species present in a depression were measured with callipers.

Results

Tadpoles of four species of frogs were found in wetlands that were drying, Striped Marsh Frog (*Limnodynastes peronii*), Green and Golden Bell Frog (*Litoria aurea*), Bleating Tree Frog (*Litoria dentata*), and Peron's Tree Frog (*Litoria peronii*) (See Table 1).

By 1/05/2019 there were six instances where drying wetlands had tadpoles still present in them. Four of these instances occurred in wetlands that did not contain any depressions (4A, 4B, 4C, 2C), while two occurred in wetlands that did contain a depression (1A, 2A). In the wetlands with a depression, the water levels dropped until only the depression contained water. However by mid-March (15/03/2018) both the wetlands with depressions had almost completely dried and tadpoles were confined to one depression in each wetland (See Fig. 1). The depression in 1A contained between ~100 - 200 Green and Golden Bell Frog tadpoles, with no other species of tadpoles observed (SVL 8.2 mm ± 0.3, n = 25). The depression in 2A contained >500 Green and Golden Bell Frog tadpoles (mean SVL 7.9 mm ± 0.3 SE, *n* = 15), with some tadpoles of the Striped Marsh Frog (mean SVL 4.8 mm ± 0.2 S, *n* = 10). The day after these depressions were observed, there was ~90 mm of rainfall over four days 21-24/03/2018. The depression prolonged the hydro-period by ~6 days (i.e. the time that the overall wetland dried, but the depression remained charged). Survival of these Green and Golden Bell Frog tadpoles was later confirmed by the observation of similarly sized tadpoles following the rainfall event, and metamorphs were observed about a month later. There was a maximum metamorph count of 170 in wetland 2A; and 2 in wetland 1A.

In contrast, there appeared to be 100% mortality of tadpoles in every wetland (*n* = 3) that did not contain a depression (See Fig 2). There were ~100 Bleating Tree Frog tadpoles present within wetlands 4A and 4B in December 2017 (~10-13 mm SVL). On the second occasion drying was observed with tadpoles present in wetland 4A, in November 2018, there were ~50 large Perons' Tree Frog tadpoles observed (mean SVL 23 mm ± 0.6, n = 10). The most tadpoles observed in a drying waterbody were found in wetland 4C in November 2018, where >1000 Bleating Tree Frog tadpoles and >200 Green and Golden Bell Frog tadpoles were observed (~7-10 mm SVL for both species, see Fig. 1D). There were no metamorphs observed in the nocturnal monitoring during or after the drying of these wetlands.

Discussion

The tadpoles of Green and Golden Bell Frog can experience 100% mortality in drying ephemeral wetlands, and such instances may increase as climate change progresses, yet here we detail an easily implemented wetland design feature that may well increase tadpole survivorship. We acknowledge that our findings are not based on a replicated experiment with a sample size adequate for statistical testing and controlling for other factors such as size, location and relative depth of depressions, However, it is promising that we found that tadpoles in ephemeral wetlands that contained a depression survived to metamorphosis during times of extreme wetland drying, whereas those that were in wetlands in such circumstances that did not contain a depression did not survive. This result mirrors finding from Pechmann*, et al.* (1989) who found that the number of juveniles of common amphibians from the United States were positively associated with hydro-period.

Wetlands that contained a depression had an extended hydro-period, after the rest of the wetland basin had dried, giving tadpoles more time to reach metamorphosis. This may be due to the higher depth: surface area ratio of the depression, causing it to dry out more slowly and fill more quickly; a factor that may be influenced by the position of the depression relative to its catchment within the wetland. While teasing out the actual mechanism would benefit from controlled experimentation, it is important to observe that the depressions in our two wetlands prolonged the hydro-period of a wetland sufficiently long to allow survival of tadpoles till the next rainfall, when the depressions were completely replenished.

An issue that may arise from the inclusion of a depression in constructed wetlands is that this may increase the chance of persistence of aquatic tadpole predators in ephemeral wetlands. The main threat to Green and Golden Bell Frog would be from the Plague Minnow (*Gambusia holbrooki*), which is a hardy species and can survive in puddles (Pollard*, et al.* 2017). The only current feasible method for eliminating the Plague Minnow is by draining and drying wetlands and thus killing the fish or by natural drying (O'Meara and Darcovich 2015). Therefore, it may be important to only include depressions into the design of wetlands created for threatened species if those wetlands are free of Plague Minnow. However, depressions that are included in wetlands where threatened amphibians and Plague Minnow co-occur may provide a situation where fish are concentrated and can be easily removed through netting.

We recommend to construct depressions in concealed locations within wetlands and provide additional hides adjacent to them for predatory waterbird monitoring; if they are too visible it is likely predatory waterbirds will attend them and decimate tadpole populations. Predatory waterbirds are known to seek out drying wetlands that have high densities of prey (Gawlik 2002). To combat this, multiple depressions can be included into wetland designs for amphibians, so that there is a higher chance that one will not be visited by predatory waterbirds. Additionally, cover objects can be placed within the depression to enable refuge sites for tadpoles to escape bird predation.

The addition of small depressions at the deepest part of the wetland, which hold water after most of the ephemeral wetland dries, may provide additional temporary refuges for tadpoles which prolongs their survival. We encourage future studies to test this hypothesis and investigate the possible structural attributes of depressions may result in higher survival rates of tadpoles. This simple design feature may be an important inclusion in created or altered habitats for other threatened amphibians.

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Table 1. Summary of instances where tadpoles were present in drying wetlands. *Lim. p.* = *Limnodynastes peronii*. *Lit. a.* = *Litoria aurea*. *Lit. d.* = *Litoria dentata*. *Lit. p.* = *Litoria peronii*.

Wetland	Date	Tadpoles present				Depression presence	Metamorphs observed
		Lim. p.	*Lit. a.*	*Lit. d.*	*Lit. p.*		
1A	Summer 2017/18		Y			P	Y
2A	Summer 2017/18	Y	Y			P	Y
4A	Summer 2017/18			Y		A	N
4B	Summer 2017/18			Y		A	N
4A	Spring 2018				Y	A	N
4C	Spring 2018		Y	Y		A	N

Figure 1. Photo compilation. A: depression in 1A. B: vegetated depression in 2A. C: *Litoria aurea* tadpoles observed in depression in 1A. D: *Litoria dentata* and *Litoria aurea* tadpoles in a drying wetland (4C) that does not contain a depression.