It's a frog's life – reflections on 20 years of habitat management for the Green and Golden Bell Frog

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For 20 years Green and Golden Bell Frog habitat has been actively managed at Sydney Olympic Park through the manipulation of terrestrial and aquatic habitat elements. These require ongoing management in order to maintain their value and are supported and informed by a monitoring program that provides feedback on frog distribution, abundance and activity. The challenges presented by a diversity of landscapes, an ambiguous target species and balancing threatened species habitats in an urban park has resulted in a wide range of management techniques that have generated knowledge for other conservation programs and supported research. Since the frog's presence was confirmed in 1993, much has come to light regarding the Green and Golden Bell Frog's ecology but the species continues to challenge, delight and outright confound those committed to its conservation.

Introduction

The Green and Golden Bell Frog *Litoria aurea* (bell frog) is a charismatic species that has come to symbolise the unique and complex character of Sydney Olympic Park. By coming into prominence as a threatened species in the middle of the development for the Sydney 2000 Olympics, this species has inspired a long-term commitment to frog conservation and management at the site (Darcovich and O'Meara 2008). This commitment resulted in conservation of the frog population in the Brickpit and establishment of three new subpopulations in built habitats on remediated and restored lands at Narawang Wetland, Kronos Hill/ Wentworth Common and Blaxland Riverside Park/Wilson Park.

In the years beyond the public spotlight created by the Olympic event, the Brickpit and constructed habitats continue to be actively conserved and enhanced. The freshwater wetlands, grassland corridors and constructed ponds that constitute frog habitat are now woven into the Park's landscape character.

The bell frog population at Sydney Olympic Park is now recognised as one of the largest populations of this endangered species in New South Wales and has been classified by the State Green and Golden Bell Frog Recovery Team as a 'key population', important for the recovery of the species. The Park is a Priority Management Site under the State Government's Saving Our Species program, important for the continued conservation of the species.

During the 20 years that the Sydney Olympic Park Authority has managed frog habitat, much has been learnt about this enigmatic frog and its habitat needs.

Bell frog ecology

The bell frog's original distribution was across the eastern Australian coastal plain with a distribution of 2,275,995 square kilometres (Atlas of Living Australia) and was associated with a wide range of vegetation communities. The bell frog is described as a habitat generalist (Pyke and White 2002) and was recorded in almost all types of waterbodies; natural still waterbodies (both ephemeral and permanent) and constructed wetlands (dams, abandoned construction sites, swimming pools, small ornamental ponds, industrial ponds). The frog's diet is also that of a generalist (Bower *et al.* 2014) and the species is known to be incredibly fecund (Hamer *et al.* 2007). Based on this information, management of habitat for this species should be simple to accomplish.

However, nothing important is easy. From the 1970's the bell frog was rapidly lost from 90% of its range and there are now about 40 extant populations focussed within 1 km of the east coast of Australia (Goldingay *et al.* 2017), with the Sydney Olympic Park population among the largest. Research undertaken at the Park indicates that the age structure of the population is skewed towards first year adults and the probability of females surviving to be their second year is less than about 2% (Pickett *et al.* 2014). Females are not reproductive until they reach about 18 months of age and their second season (Pickett *et al.* 2014). This high mortality amongst adults has been attributed to chytridiomycosis caused by the fungus *Batrachochytrium dendrobatidis* (chytrid) (Murray *et al.* 2010, Stockwell *et al.* 2011). The impact of chytrid has now been the subject of extensive investigations (Stockwell and Mahony 2007, Stockwell *et al.* 2015) and the diseases source, impacts and transmission are better understood. At the time of writing, there are no practical

solutions for the disease in the field, making the understanding of habitat needs and the associated population and community ecology even more important.

The work done at Sydney Olympic Park and other bell frog sites focuses on buffering the species against the impacts of the chytrid fungus until the tools are available to mitigate this threat.

Frog habitat management at Sydney Olympic Park

For management purposes, the Authority's Biodiversity Management Plan defines frog habitat at Sydney Olympic Park by the distribution of the bell frog population since 2000. These areas have been categorised and mapped as frog habitat or potential frog habitat as shown in Figure 1. This includes precincts where habitat has been specifically constructed for the frog or where the frog has colonised and been recorded as present. In total, the Park contains 145 constructed and natural ponds of varying size and hydrological regimes and 126 hectares of terrestrial environments designed to provide habitat and movement corridors. Any of these areas, depending on the season and year, may at times be highly significant to the viability of population.

An active management program to conserve the habitat of the bell frog has been in place at Sydney Olympic Park from 2000, as the Park moved from the development phase to an operational phase. Active management within frog habitats includes vegetation management, pond hydrology management, Gambusia control, habitat enhancement works, and management of visitation activities. Because the frog is a threatened species, a regulatory licence under the New South Wales *Biodiversity Conservation Act 2016* applies to management activities within frog habitat. The licence is expressed through a Biodiversity Management Plan which contains conservation actions and key indicators for the bell frog. Standard procedures provide a management framework whereby stringent conditions are applied to maintenance works and visitor programmes within frog habitat to ensure continued conservation of the Park's population.

Habitat management aims to provide the essential requirements of bell frogs; access to water, food, breeding habitat, refuges and ability to disperse within a mosaic of habitat stages, by implementing a periodic renewal disturbance regime (including manipulation of pond wetting and drying cycles, and terrestrial and aquatic vegetation renewal).

Following is a description of the main activities undertaken to support and enhance frog habitat at Sydney Olympic Park.

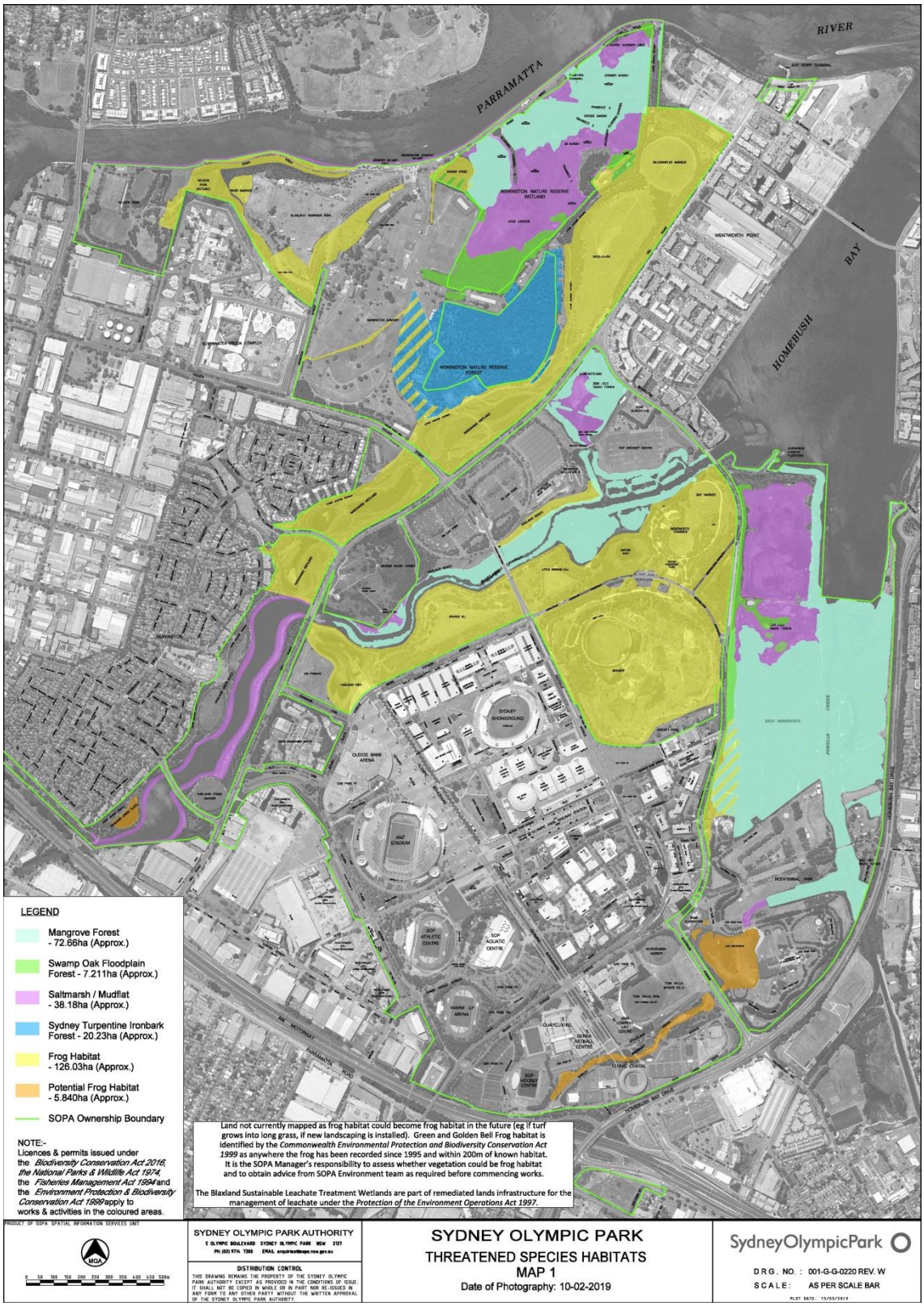

Figure 1 Frog habitat at Sydney Olympic Park. Bell Frog habitats are shown in yellow and cover 126 hectares.

Managing predation - Gambusia

Narawang Wetland is a constructed wetland covering 20 hectares and consists of 22 habitat ponds and three large water storage ponds. The wetland provides habitat for the bell frog but also functions as a floodplain for the adjacent creek. Soon after construction in 2000, *Gambusia holbrooki* invaded the wetland following flooding. Gambusia is predatory on the eggs, tadpoles and possibly juveniles of bell frogs and is listed as a key threatening process under New South Wales legislation (Hamer *et al.* 2002, NSW NPWS 2003).

An annual cyclic draining program was introduced to the 22 habitat ponds in 2003 utilising the water circulation system and associated electrical system present in the wetland. A sump within which a pump can be placed to control water levels is present in all ponds (Figure 2). Each year, one third of the ponds are drained to assist in the control of Gambusia, providing a fish-free window during the bell frog breeding season (O'Meara and Darcovich 2008).

Ponds scheduled for draining typically comprise six - eight ponds, on a three-yearly cycle. Draining and filling of ponds and supply of pumps is conducted by a contractor commencing in July/August each year. Pumping out a set of eight ponds typically takes two to three weeks, depending on rainfall and other difficulties encountered during pumping. Ponds are then ideally left for three to four weeks for the sediment to dry and crack. At that time fish-free water is returned via water points located at each pond.

Reinfestation of drained ponds with Gambusia is usually caused by flooding of the wetland after rainfall. The period of time ponds remain fish-free varies widely, with some dry years resulting in no fish for the whole breeding season and others where flooding occurred immediately after the ponds were refilled. Research on the program has found that male bell frogs preferentially selected fish-free ponds as breeding sites and concluded that pond draining to remove Gambusia is an effective strategy that can be used to greatly increase bell frog reproductive success (Pollard *et al.* 2017a).

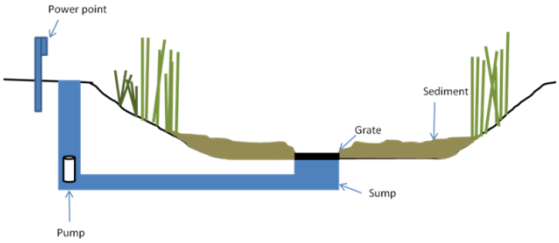

Figure 2 Typical Narawang Wetland habitat pond structure

Fish fences

As the cyclic draining program in Narawang Wetland is a temporary measure in the control of Gambusia, a trial fish fence was installed in 2016 to restrict the entry of fish to a single pond. Constructed of a sediment fence approximately 900mm high, dug 200mm into the soil and 70m long, this fence was successful at keeping the pond fish free for three years. Subsequently, a second fence was constructed in the southern part of the wetland 200m long and 600mm high (Figure 3), enabling four ponds to be fish free for two years. As the fences are a physical barrier to fauna movement, ramps made of shade cloth and rocks were installed to assist in facilitating movement.

The main challenge for these structures is flooding – the area of the second fence floods to a height of 600mm once or twice per year. The sediment fence has a pore size of 360 µm to screen out tiny fish resulting in very low transfer of water and increased risk of fence collapse under the weight of a wall of water.

Figure 3 The second Gambusia fence (600mm high) with shade cloth ramp.

Managing predation - birds

With only a small number of adult bell frogs contributing to the next generation, every tadpole becomes important. Bird netting has been added to many breeding ponds from 2016 to reduce predation by birds. Netting is also used as a response to the sighting of tadpoles in ephemeral ponds with three nets deployed in the 2019-20 season to temporarily cover ponds containing bell frog tadpoles (Figure 4).

Figure 4 Temporary netting placed over an ephemeral pond in the Brickpit in early 2020. Supplementary water was also supplied until tadpoles metamorphosed.

Pond management - age

Pond age may influence the density of vegetation, productivity, predators and competition, among other factors. In order to prevent the loss of desired habitat values, seen as a mosaic of pond types, depths, vegetation coverage and more, regular intervention is required to 're-set' a pond to the desired form.

A rolling program of pond renewal is implemented across frog habitat as early phase wetlands with limited competition are thought to play an important role in bell frog habitat selection (Pike and White 1999). This perturbation program incorporates periodic disturbance, and water level management. Works are undertaken during the frog activity season when frogs are active and visible.

Disturbance ranges from hand removal of vegetation to the drying and scraping out of whole ponds by a bobcat. There is no set formula, but an annual review of habitat condition against set parameters of the Biodiversity Management Plan identifies where intervention may be required. In each renewal activity, no other disturbance is conducted in the area until the vegetation/pond is fully restored, usually a period of 2-3 years or more.

An example of re-setting a pond can be seen in Figures 5 and 6. Over a period of 10 years, a pond became heavily vegetated and increasingly shallow. The pond was drained and hand cleared over three days during the frog activity season when frogs are able to move away from disturbance of their own accord. To ensure no fauna remains within the worksite, a hand clearance by ecologists occurs before the last vegetation is cleared.

Works then consisted of a bob-cat removing the accumulated sediment. Patches of emergent vegetation are left in situ to recolonise the pond after completion. As this pond had had bell frog breeding in the past, bird netting was placed over hoops of irrigation pipes to prevent bird access.

The two adjacent ponds were not disturbed and left as refuges.

Figure 5 This pond became totally covered in emergent vegetation with no open water.

Figure 6 The pond was cleared of excessive plant growth, scraped free of accumulated sediment and netted to prevent bird predation.

Pond management - hydrology

Frog ponds are managed to provide a wide range of depths, temperatures and vegetation and have a minimum retention of water for eight weeks. The majority of ponds at Sydney Olympic Park are connected to an irrigation system and can be filled when necessary. Ponds are required to be more than 80% full during the frog activity season (September to March). Weekly pond level checks by Authority staff and contractors ensure ponds don't dry out due to equipment failure.

During winter, water levels are allowed to drop for emergent plant health and certain ponds selected for 100% drying on a cyclic basis. These ponds are dried to mimic ephemerality, being filled at the start of the activity season or when storms are predicted. Fluctuating water levels may also improve macrophyte health. Some ephemeral ponds adjacent to breeding ponds are also opportunistically filled prior to hot and stormy weather (Box 1).

All wetlands and ponds are subject to water depth reduction due to sediment accumulation. Where possible, sediment is removed to create deeper sections to increase water holding capacity. This provides refuges for tadpoles as water levels recede during periods of low rainfall. In suitable situations, excavated sediments are retained and reformed as islands.

Pond liners are vital to maintaining good hydrology and connectivity. At Sydney Olympic Park, many types of liners have been trialled and are discussed in Box 2.

Pond management - vegetation

Pond vegetation management aims to have the majority of ponds containing 30% - 60% open water, with the perimeter macrophyte zone being at least 1.5m wide where possible. Where vegetation exceeds this parameter, vegetation is hand cut below the water level. Often, the rhizome is also removed to increase water depth.

The plant species is not as important as the structure it provides – bell frogs need something that will hold their weight, enabling them to bask. At Sydney Olympic Park, fast growing species such as Typha and Phragmites are restricted to a small number of ponds due to both aesthetics and their ability to cover a pond rapidly. Planted emergent species include *Baumea articulata, Schoenoplectus validus, Triglochin procerum* and *Eleocharis sphacelata.*

Box 1: Water manipulation in ephemeral ponds

Adult bell frogs show high wetland fidelity especially during dry periods with greater than 95% of all recaptured bell frogs being captured within 50m of the site of first capture (Hamer *et al.* 2008, Urlus and Braakhuis 2019). However, frogs are known to move opportunistically over larger distances in periods of high rainfall, inhabiting ephemeral ponds temporarily. In 2019, the irrigation system within the Brickpit was extended to allow watering of vegetation planted as part of a staged removal program for pampas grass *Cortaderia sp*. Water level manipulation within one ephemeral pond in the Brickpit to attract breeding has been ongoing successfully since 2013. The irrigation extension into more remote parts of the Brickpit opened up the opportunity to manipulate water levels in further ephemeral ponds.

In the Brickpit the permanent wetlands are less than 150 metres from a minimum of five ephemeral ponds ranging in size from 70m^2 to 630m^2. Distances between permanent wetlands and ephemeral ponds are shown in Figure 7.

Artificially filling ephemeral ponds has resulted in observations of males calling within 24 hours in a pond up to 126m from the closest permanent wetland. Bell frog tadpoles have been observed in ponds deliberately filled prior to stormy weather conditions whether the subsequent rainfall was enough to fill other ephemeral ponds or not. Only a selection of ponds is filled each year, allowing natural ephemerality to occur in the majority. Artificially filled ponds are monitored closely and only maintained with water if tadpoles are present.

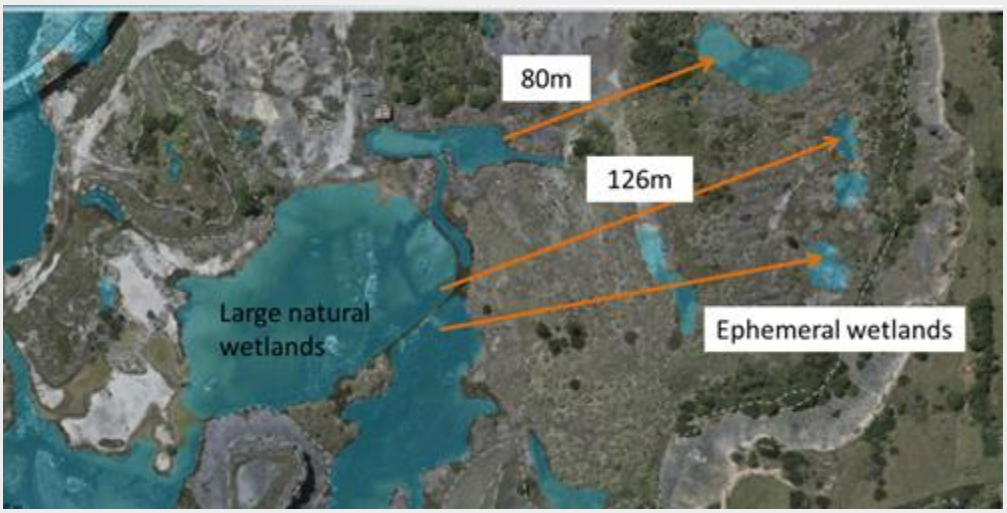

Figure 7 Example of distances between permanent wetlands to ephemeral wetlands in the Brickpit. Breeding has occurred every year in the permanent wetlands and management of water levels in the ephemeral ponds can encourage breeding in smaller ponds.

Terrestrial vegetation management

Terrestrial vegetation management includes weed management, slashing, planting, mulching, and pruning, in many cases to provide habitat perturbation and a wide variety of habitat ages and densities.

Observations of bell frogs at the Park indicate that adults stay close to ponds; primarily within 5m but range up to 50m and juveniles disperse over even larger distances (Garnham *et al.* 2015, Urlus *et al.* 2020). Some adults have a high site fidelity with the same adult observed even within the same plant over years.

Management of terrestrial vegetation aims to maintain a perimeter zone of tall dense grasses (over 30 cm high) extending a nominal 5 m from pond edges, free of invasive exotic grasses (e.g. kikuyu, water couch).

Any large scale vegetation removal must follow the procedures of the Biodiversity Management Plan. Under these conditions, any area greater than 5x5m must be cleared in stages, generally cutting the vegetation to progressively lower heights, leaving the site overnight then cutting more the next day in an attempt to encourage fauna to leave due to the disturbance and gradual removal of cover.

Most wetlands occupied by bell frogs are not strongly shaded by trees. Trees can reduce water temperature by shading and thinning of edge/emergent plants through competition for the sun. Ponds are generally managed to achieve no shading between 10am and 4pm.

Frog corridors:

Connectivity between frog ponds is vital to facilitate dispersal movement of frogs (Muir 2008, Patmore and Osborne 2008). Unshaded grassy corridors a minimum of 20m wide and dominated by tall dense grasses (over 30cm high) covering at least 70% of the nominated corridor are maintained across the site. These corridors are mapped and condition reviewed on an annual basis.

Habitat stacks

Log piles and coarse mulch assist in increasing food and shelter habitat for reptiles, amphibians and insects. 'Naturalistic' areas not requiring high presentation standards are managed to increase the density and complexity of the ground layer. Any cut tree is left onsite in log piles to increase the complexity of the mulch/ground layer.

Pest/invasive weed control

Fox and cat control programs are implemented across the site and invasive weeds targeted before they form habitat. Where invasive weeds form a large portion of the habitat, a staged removal program is utilised.

Generally invasive weeds are controlled by hand pulling as the use of herbicides in frog habitat is generally not permitted. Herbicide use can be approved on a case by case basis and involves the application of a staged frog habitat removal prior to the control of weeds.

Fauna underpasses and frog fences

In order to prevent frogs and other species from moving onto roads, 6km of purpose-designed shade cloth fencing were installed in 2000 to channel animals to underpasses under the roads to facilitate movement and genetic exchange. There are 10 underpasses in total at Sydney Olympic Park.

Shelter boards

Shelter boards in the guise of roof tiles and plywood sheets have been placed in many locations around the Brickpit. Incidental observations show that tiles are well used by juvenile frogs, particularly during cooler weather.

Box 1 Pond liners

All constructed ponds were originally lined with bentonite, and over time, some have required re-lining and new ponds added to increase water availability and connectivity. Experimentation with different pond liners has occurred throughout the Park.

Liner type	Description
Sheep trough with float valve 	The installation of a sheep trough with float valve is not expensive, allows easy management of emergent vegetation, control of predators such as reptiles and competing frog species and very easy water level control. Sheep troughs have now been used in multiple sites across the Park and have attracted dispersing juveniles, females and breeding dependant on their location within the landscape.
Rubber 	Rubber liners have been used successfully in several ponds and to date have retained water for more than 10 years. One of the most successful ponds ever constructed at the Park was a 1700m^2 rubber-lined pond located within 20m of a persistent breeding population and consisted of two large cells 200mm deep and lined with black rubber leading to high water temperatures. Bell frogs colonised and bred within the pond on a regular basis.
Reinforced plastic 	Trials of reinforced plastic liners (tarps) as pond liners have shown that these temporary liners can hold water for up to 6 years. Larger ponds up to 200m^2 were re-lined in the 2017-18 season and attracted bell frog breeding in the 2018-19 season. Reinforced plastic liners are now used in the Brickpit to extend the water holding capacity of drier areas. Observations show these ponds have been used regularly by dispersing juvenile bell frogs. The low cost of this thin liner is balanced by the high risk of breaching; foot access for vegetation and surveys must be minimised.
Fiberglass 	A fiberglass swimming pool was trialled in 2009 and while it has excellent longevity and strength, installations costs are higher than other liners. Bell frogs have been observed using the vegetation, although no breeding has been recorded in this particular pond. The same swimming pool was used successfully in the Brickpit, attracting breeding within the same year.

Observations of the same tiles show that under summer conditions, no frogs are present indicating that their use is temperature dependant and may form an important function for the dispersal of juveniles.

Pond/wetland design

Thanks to modelling by the Saving Our Species Program and others (Hamer 2008, Bower *et al.* 2013) it has been shown that large permanent wetlands closely connected to ephemeral ponds and within one kilometre of other wetlands increases occupancy rates. Based on pond occupancy at Sydney Olympic Park, bell frogs have typically demonstrated a preference for large, permanent and closely connected wetland habitats over smaller ponds (Urlus *et al.* 2020).

Management actions that create new wetlands and increase connectivity are likely to increase the proportion of sites occupied by bell frogs within management zones.

Active intervention

As part of research programs and in response to subsequent increased knowledge, active intervention activities including translocation and captive breeding of the Green and Golden Bell Frog have taken place.

1. In 2012–13, a research project by the University of Newcastle investigating water quality/pond occupancy involved the release of 11,500 captive bred tadpoles into 6 ponds. The project concluded that predation, rather than chytrid or pond quality was the limiting factor for tadpole survivorship (Pollard *et al.* 2017b).
2. In 2014–15, funding was provided by the Office of Environment and Heritage for a captive breeding project for the Brickpit population in response to findings that the population had inbreeding depression. The aim was to increase genetic diversity by translocating new alleles into the Brickpit from the Narawang Wetland population. A total of 928 late stage tadpoles were released into the Brickpit tubs in February 2015.
3. To conclude the Brickpit translocation project and test the outcomes of the 2014–15 introduction, genetic sampling of the Brickpit population was undertaken in 2019.

Monitoring

The frog population has now been intensively monitored since 1998, primarily by ecological consultants, but between 2008 and 2013 as part of a broader research program conducted by the University of Newcastle in partnership with the Authority, under an Australian Research Council grant program. This latter program included research that has greatly enhanced understanding of the Park's frog population and species biology.

The current methodology was recommended by Bower *et al.* (2014) and consists of two visual encounter surveys in December and February. This is supplemented by incidental observations by Authority staff, particularly of breeding events and pond occupation outside of the survey window and two auditory surveys by the Frog and Tadpole Study Group. The objective of the monitoring program is to gather data and information which will identify population demographics and long-term trends at the Park to assist in measuring the success of ongoing habitat maintenance and enhancements. The data is also provided to the NSW Saving Our Species program to contribute to understanding of frog habitats across all eight Priority Management Sites.

The surveys take place across 127 ponds and the morphology of each captured frog recorded, and a PIT tag inserted.

Recapture rates are extremely low - only 3% of frogs were recaptured in 2019-20 from the previous season. This supports the findings of Pickett *et al.* (2014) that the population has a very high turnover rate.

For the Sydney Olympic Park population, monitoring and research show that the key ecological issues affecting viability include:

- infection by chytrid fungus;
- low recruitment from the tadpole stage, including predation of tadpoles and metamorphs by fish, insect larvae and birds;
- loss of females prior to breeding age;
- inbreeding depression.

Reflections

Sydney Olympic Park's bell frog program continues to be one of ongoing active and adaptive management. The best available ecological advice has been applied throughout the course of the project but much still remains unknown about the ecology and habitat requirements of this threatened species. As a result, many of the management approaches described in this paper have been reached through a process of trial and error, where the negative results have been as valuable as the positives in learning more about the species. Some of the learnings from this process are described here.

Some ponds have worked better than others, sometimes for no obvious reason. Two ponds may appear the same - the same distance from a large wetland, have similar depths and vegetation but the frog perversely chooses one over the other (or neither!). This fine tuning of habitat is still done by intuition following known broad guidelines but is not evidence based and is part of providing a habitat mosaic. If in doubt, provide as many options as possible to suit the frog during different climactic conditions and life cycle stages.

It seems obvious now but constructing bell frog ponds in a flood plain was not going to end well. The introduction and continuous reintroduction of Gambusia to Narawang Wetland was unfortunate and has led to the channelling of resources to offset its impacts. In a perfect scenario, bell frog ponds would be clustered into large compartments with dykes and drainage sumps that allow the manipulation of water levels to manage possible infestations by pest fish.

For Sydney Olympic Park, constructing small ponds (<15m^2) greater than 50m apart in long corridors linking large wetlands has not been successful. These ponds were also constructed on a young landfill; the settling movement of the landform has caused some ponds to crack and leak. The landfill capping makes the retrofitting of larger ponds or clustering of more ponds very expensive.

The vegetation management protocols of the Authority's Biodiversity Management Plan are more closely aligned to bush regeneration principles and practices than traditional horticulture and urban park management. The frog habitats at Sydney Olympic Park are managed as 'natural areas' where presentation standards allow coarse mulch and vegetation complexity to support biodiversity.

Management actions aimed at disturbing ponds to encourage pond use have had variable effects. It is now becoming more evident that efforts should be concentrated adjacent to currently active ponds within reach of dispersing adults and juveniles (within 50m). If pond occupation increases, then efforts can be moved further out from the core ponds.

The bell frog never ceases to surprise. Auditory monitoring by the Frog and Tadpole Study Group in December 2019 found 4 male frogs singing hopefully in a decorative reflection pool where they have never been recorded in that pond's 20-year history. A static concrete pond with no vegetation – it was a far cry from the beautifully crafted naturalistic ponds within 100m from where they sat. Further monitoring of the pond found, of course, tadpoles.

Conclusions

The Authority has accepted the challenge to provide for on-going bell frog persistence at Sydney Olympic Park by investing in long term habitat management and monitoring. What wildlife would remain at the Park if legal drivers had not triggered this commitment to a far-reaching amphibian conservation program? The success of this project is that a sizeable population of bell frogs has been maintained throughout a period when most other populations across the Sydney region have disappeared, and this has been achieved on a restored landscape in the midst of a rapidly developing urban centre.

There have been many lessons learned along the way about creating and managing habitats where bell frogs can survive and breed, though there are no definitive easy answers and the need for ongoing innovation and adaptive management remains. Conservation of this endangered species remains a high priority and the bell frog continues to be an iconic symbol for the environmental values of Sydney Olympic Park.

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