Frogs on the hop: translocations of Green and Golden Bell Frogs *Litoria aurea* in Greater Sydney

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ABSTRACT

Translocations involving the endangered Green and Golden Bell Frog *Litoria aurea* have been under way in the Greater Sydney area since 1993. Case studies for four of these translocations are presented; the translocation sites being at Botany, Marrickville, Long Reef and Arncliffe. Bell frogs have persisted at only one of these sites since their introduction (Arncliffe).

The success or failure of each translocation has provided insights into the habitat requirements and management of bell frogs. In unsuccessful translocations, the reasons for the inability to establish a permanent population became more apparent with monitoring; at Botany, young bell frogs failed to survive the winter because of inadequate or inappropriate over-winter habitat being available; at Long Reef, foraging and breeding habitat were inadequate; at Marrickville, urban predators and disease eliminated frogs. Other factors also appear to have a significant effect on the likely outcome of the translocation. These include: the proximity of a source population, the presence or absence of predatory fish, pond water temperature and the timing of the release of tadpoles at translocation sites.

Despite the difficulties and uncertainties associated with habitat creation and the establishment of translocated frogs, translocations remain as a last resort strategy for the conservation of frog populations that may otherwise be lost.

Key words: Green and Golden Bell Frog, *Litoria aurea*, frog translocations

Introduction

Translocations of frogs may be carried out both to enhance the conservation status of a species or to protect a population from the threat of impending human development (Seigal and Dodd 2002). Individuals of a species may be introduced (or reintroduced) into an area where the species does not presently occur in order to increase its distribution (Griffiths *et al.* 1989). Individuals may be moved from one population to another in order to promote outbreeding and reduce the impacts of inbreeding (Griffiths *et al.* 1989). Individuals that are threatened by impending human development may be "rescued" and moved to another location (Oldham *et al.* 1991).

Translocation programs often include habitat enhancement, threat reduction and captive breeding. It is generally assumed, for example, that there is little point in attempting to reintroduce a species into a location where it once occurred, unless deleterious changes to the habitat are reversed and local threats to survival of the species are ameliorated (Seigal and Dodd 2002). Captive breeding is sometimes used to increase the numbers of animals available for stocking or to maintain a population while suitable habitat is found or developed.

For over 20 years translocation of frogs has been a widely and much used conservation strategy in North America and Europe. For example, during the 1980's there were over 100 translocations using crested newts (*Triturus spp.*) in the United Kingdom alone (Oldham *et al.* 1991). The success of many of these translocations was unknown as follow-up monitoring after release was rarely carried out. The failure to assess the effectiveness of these relocations did not reduce the frequency of translocation of frogs and salamanders in the northern hemisphere.

In Australia, however, translocation has only recently been adopted and so far has involved only a few species. Prior to 1995 there were no regulated programs for the relocation of frogs. Since then translocation has been used as part of programs to protect or conserve just three frog species in Australia; namely the Green and Golden Bell Frog *Litoria aurea* (Pyke and White 2001), the Spotted Tree Frog *Litoria spenceri* (Gillespie and Hero 1999) and the Corroboree Frog *Pseudophryne corroboree* (Hunter *et al.* 1999).

The Green and Golden Bell Frog has become a popular translocation species in New South Wales (NSW) because of its conservation status, its occurrence at sites where human development has been carried out, and legislation regarding the assessment and mitigation of likely impacts of proposed human developments on the environment. Since 1992 it has been considered to be under the highest risk of extinction in NSW and is presently labelled 'endangered' under the NSW *Threatened Species Conservation Act* 1995. In NSW, most of the known sites where this species occurs are on privately owned land that have been greatly disturbed by past human activities and are likely to experience further human development (Pyke and White 2001). Since many of these sites are completely artificial or human-made, it has been considered possible to create new habitat for the species (e.g. White 1999). Under recent and current environmental legislation in NSW, any adverse impacts of proposed human development on 'endangered' species must be evaluated and mitigated if possible before the proposed development receives necessary approval. In NSW, translocation of these frogs into a new site has been seen as a way of allowing development to proceed while protecting and conserving the frogs (e.g. Fanning and White 1994). In Victoria, on the other hand, the species is not considered at risk of extinction and there is less obvious overlap between the frogs and human development.

The high public profile of the Green and Golden Bell Frog (hereafter bell frog) as a consequence of its presence at Sydney Olympic Park led to interest in its fate at other locations where developments were proposed. One consequence of this notoriety is that bell frogs are often used to create media attention by opponents of particular developments where this species may be implicated (e.g. Koch 1995).

Research interest in this species has been prevalent since the species was listed as "endangered" in NSW. In 1995, a conference on the biology of the species was hosted by the Royal Zoological Society of New South Wales to provide a forum for research and discussion about bell frogs. A recent review of the biology of the species has shown that it has been the subject of more research studies and more scientific publications than any other Australian frog (Pyke and White 2001). In respect of both translocation and research, the bell frog has become a 'flagship' species.

The bell frog has also been the subject of more translocation proposals and attempts than any other Australian frog. Within the greater Sydney metropolitan area, for example, translocations have been carried out at four locations (Arncliffe, Botany, Long Reef and Marrickville). The species is also the focus of other habitat modification programs that involve the colonisation of new areas from adjoining sites (e.g. Greenacre, White 1999; Port Kembla White 2001a; Woonona; White 2001b).

Despite this high level of interest in bell frogs and their translocation there has been limited evaluation of how successful each translocation was in meeting conservation objectives and little assessment of the factors likely to have influenced this. The aim of this paper is: to provide an overview of four case histories (that we have been involved with), and to consider the possible factors that may explain the results. We consider attempted translocations that have taken place in relation to two source populations (i.e., Rosebery, Arncliffe) and the four recipient sites listed above.

Source sites, history and reasons for translocations

Rosebery population

The Rosebery site is located in eastern Sydney on an urban block bounded by Southern Cross Drive to the east, Kimberley Grove to the south, Dalmeny Ave to the west and by residential and industrial units to the north. The frog pond that was the source of founder animals for a captive-breeding colony at Taronga Zoo was located in the south-western corner of the site (334380 E, 6245724 N).

The site has been in private ownership since at least the 1950s when it was an active sand mine. Since 1993 it has been owned by Meriton Apartments Pty Ltd. In 1991, when bell frogs were first discovered at this site (Cogger 1992), the site consisted of a large, levelled rectangular block of ground. The site was almost denuded of vegetation as a consequence of 30 years of sand mining. A drainage pond was excavated in the south-western corner of the site and the land contoured so that stormwater runoff was diverted into the pond (Fig. 1). This pond was later colonised by bell frogs. The water level in the pond fluctuated markedly over time and would go dry for short periods each year. The eastern part of the Rosebery site contained mounds of bricks and concrete, which were being crushed for recycling. The remainder of the site was vacant.

Although it would probably have originally been part of a much larger and more extensive population of bell frogs, this population had become isolated from all others. Prior to 1980, the population would have been linked to the bell frog population in the Botany wetlands at Eastlakes only 1.5 km away. In 1980, the Southern Cross Drive was created which excised the Rosebery site from the Botany wetland corridor. The Botany wetlands' bell frog population was already in decline at this time and the population subsequently disappeared in 1993 (White and Pyke 1996). It is assumed that the Rosebery bell frogs are the last survivors of this much larger metapopulation.

Re-development of the site began in 1992 with further levelling of the site in preparation for the construction of a large high-rise residential complex. As part of the

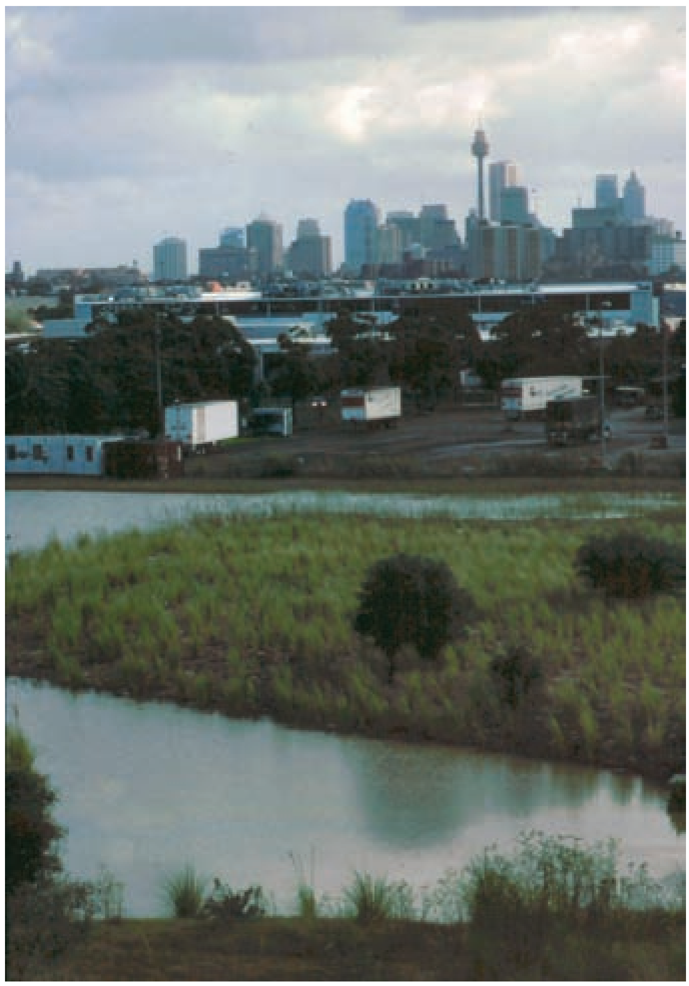

Figure 1. Rosebery bell frog site, January 1991.
Photo, A. White.

re-development, the frog pond and surrounding habitat were to be destroyed. Evaluating the impacts of these development proposals became the first test of new legislation in relation to impacts on species considered to be under risk of extinction. The *Endangered Fauna (Interim Protection) Act* 1991 had come into force in NSW and the bell frog was listed under Schedule 12 as an "endangered" species. If the proposed development was deemed to pose a significant impact on the frogs then a Section 120 licence would be required by the developer. In order to gain the licence, a Fauna Impact Statement (FIS) would need to be undertaken to assess the viability of the frog population and to propose ameliorative measures that could assist with the conservation of the Rosebery bell frog population.

This led to surveys being conducted by the Australian Museum from August of 1992 through to May 1993. The surveys located two adult bell frogs but found tadpoles to be continually present in the drainage pond. On the basis of the low number of adult frogs, it was suggested in the FIS (Cogger 1993) that the frog population may not be self-sustainable. In August 1993, the NSW National Parks and Wildlife Service (NPWS) convened a meeting with the Museum staff, the developers, and invited frog biologists. The proposition that the population was unsustainable was the main topic for discussion. It was agreed that the best outcome for the frogs would be to try to relocate the population to a safer area where the population could be increased.

A Section 120 licence was subsequently granted for the proposed development subject to several preconditions, the main one being that self-maintaining populations based on Rosebery stock be established both in captivity and in the wild. Bell frogs were collected from the Rosebery Site and a captive-breeding colony was established at Taronga Zoo in late 1993. The development consent also allowed for re-development of parts of the site away from the frog pond while the search for a suitable relocation site was under way. Searches for suitable relocation sites were carried out within the eastern suburbs of Sydney, close to previously known bell frog habitats. Several areas were assessed as potential habitat areas but finally (in 1995) one site, Sir Joseph Banks Park at Botany, was selected as the best available.

Ponds and other frog habitats were created at Botany (see below) and the translocation of captive-bred bell frogs from Taronga Zoo commenced in 1996. Subsequently, the development condition that a self-maintaining wild population derived from Rosebery stock had to be established was abandoned. Despite the loss of support by the developer and the lack of success of the initial translocation, subsequent translocations and site modifications were carried out at Botany by the authors, Taronga Zoo and Botany Council.

Arncliffe population

The Arncliffe translocation was carried out as part of the development consent for the M5 East Motorway in southern Sydney. The proposal to extend the motorway from Beverly Hills to Kyeemah meant that the transport corridor would pass through part of the Marsh Street Wetland at Arncliffe, a known site for bell frogs (White 1998). The Arncliffe bell frog population was one that was well documented and opportunistic survey records had been kept on this population since 1980 (A.W. White unpubl. data).

In 1996, a Supplementary Environmental Impact Statement (EIS) was prepared for the motorway. The EIS included a Species Impact Statement (Gunninah 1996) that concluded that the motorway would have a significant impact on the bell frogs at Arncliffe and that specific conservation measures would be required to protect the species. In 1998, a Plan of Management (White 1998) for the Arncliffe bell frogs was accepted by the NPWS. In brief, the plan detailed the creation of replacement habitat (including two frog breeding ponds) on land next to the Kogarah Golf Course, the establishment of a captive-breeding colony of Arncliffe bell frogs that would supplement the reduced number of bell frogs in the Marsh Street area, and the establishment of a Management Committee that would oversee the maintenance of the wetlands and manage frog populations.

It was decided that the location of the recreated bell frog habitat should be as close to the Marsh Street wetland and the Kogarah Golf Course (known bell frog foraging area) as possible. A suitable site was found on the northern side of the proposed M5 East Motorway corridor, next to the Kogarah Golf Course. Frog underpasses were created to link the new frog habitat area with the Marsh Street wetland.

Captive Maintenance of Threatened Populations

Captive populations based on the above two wild populations have been established at Taronga Zoo in the Sydney suburb of Mosman. Both of these programs are discussed separately below. See also McFadden *et al.* (2008).

Rosebery population

Attempts to establish a captive breeding population of bell frogs based on Rosebery stock began in late 1994 with two translocations of adult frogs from the Rosebery site to the Zoo. In October 1994, 5 pairs of bell frogs were collected and taken to the Zoo. In December 1994, an additional two adult frogs were taken to the Zoo. Only adult frogs were collected as these animals were to form the basis of a breeding colony and tadpoles were required within the next year to stock the selected relocation sites. No tadpoles or immature frogs were collected from Rosebery because of the heightened risk of undetected disease transmission

Subsequently these frogs and their progeny have been maintained at Taronga Zoo under a variety of conditions. Incoming frogs were quarantined for a period of one month before being assessed by Zoo vets. A separate holding room was established in the Serpentaria building at the Zoo. Frogs were maintained in two types of enclosures; glass aquaria kept in a controlled climate room in the Serpentaria or in a wire-meshed outside enclosure that contained four small in-ground fibreglass ponds. At least six pairs of frogs were retained in the frog room in the Serpentaria at all times. The remainder was kept in the outside enclosure.

Rosebery bell frogs are still being maintained at Taronga Zoo (at the expense of the Zoo) as a source of animals for other translocation sites. Breeding of additional bell frogs from the Rosebery founder frogs has been successful at the Zoo with tadpoles being made available each year for various projects, including Long Reef and Marrickville.

Arncliffe population

In November 1999, six bell frogs were collected from the Marsh Street wetlands (by A.W.White) and taken to Taronga Zoo. Unlike the Rosebery bell frogs, all of the Arncliffe frogs were maintained in glass aquaria in a controlled environment room in Serpentaria. The frogs were housed as pairs and when male frogs began calling, rain bars were installed in the aquaria to help stimulate breeding.

Spawning first occurred in January 2000 and the first consignment of tadpoles for release in newly created frog ponds at Arncliffe was carried out in March 2000. No additional frogs were collected from Arncliffe and the breeder population was increased using the first and second-generation progeny. A second release of captive-bred tadpoles was carried out in February 2001. No further releases were carried out as monitoring indicated that the adult bell frog population had increased from about 10 individuals in 1999, to more than 70 adult frogs in 2002.

Selection of recipient sites and individuals for release

A site was considered suitable for the attempted introduction of bell frogs if known habitat requirements of the species were apparently (or potentially) satisfied in terms of breeding, foraging and sheltering (White 1998). Ponds were considered to provide suitable breeding habitat if they contained still, open and largely unshaded water that fluctuated significantly in level, some emergent aquatic vegetation, and no Plague Minnow *Gambusia holbrooki* or other predatory fish (Pyke and White 1996, 2001). The Plague Minnow is known to feed on eggs and tadpoles of bell frogs (Morgan and Buttemer 1996; Pyke and White 1999) and is considered a significant threat to the survival of this and other frog species. Adjacent or nearby areas were considered to provide suitable shelter habitat if they contained thick, low terrestrial vegetation or rocks under which frogs could retreat. Areas of generally low vegetation were considered to provide potential foraging areas for these frogs.

At all recipient sites tadpoles were the preferred life stage for release. Growth and development of tadpoles in the ponds would verify their suitability for this stage in frog development. Individuals that have grown up in a particular pond were considered more likely to consider that pond as 'home', and hence to remain there, than individuals that had already metamorphosed into frogs when released (Cooke and Oldham 1995). Furthermore, captive maintenance of frogs after metamorphosis is much more expensive and time consuming than maintaining them as tadpoles (A.W. White & G.H. Pyke, pers. obs.). Nonetheless relatively small numbers of both immature and adult frogs have been released at the various sites (see below).

Case histories for recipient sites

Captive-bred tadpoles from the Rosebery source population maintained at Taronga Zoo have been released into sites at Botany, Long Reef and Marrickville. Captive-bred tadpoles from the Arncliffe (Marsh Street) source population have been released into an adjacent site at Arncliffe. Each of these recipient sites is discussed separately below.

a. Arncliffe

Two large ponds measuring 25 m long and 20 m wide were constructed in 1999 adjacent to the Kogarah Golf Course (Fig. 2). The ponds and the surrounding area of grassland were fenced off using cyclone wire fencing to exclude foxes and people from the site. The ponds had a maximum depth of 1 m and had a shallow area at one end of the pond only. The ponds were designed in this fashion to make them less suitable for species such as Striped Marsh Frogs *Limnodynastes peronii*. Bell frogs were still present in the Marsh Street wetlands and quickly colonised the new ponds.

Figure 2. Bell frog ponds at Arncliffe and associated boulder fields, May 2000. Photo, A. White.

The two frog ponds were completed in late November 1999 and vegetation was well established in and around the ponds by the beginning of 2000. Extensive boulder fields were created around and between the ponds (Fig. 2). The purpose of the boulder fields was to provide large areas of over-winter habitat in protected areas close to the ponds. In early 2000, construction work for the motorway portals meant that parts of the Marsh Street Wetlands would be lost. Frog searches were carried out in the affected areas and three bell frogs were captured, tagged and translocated to the new ponds on the other side of the motorway, a distance of about 150 m.

Night monitoring detected the presence of five non-translocated bell frogs in the new ponds (as well as other frog species) in January 2000. Bell frogs spawned in the new ponds in late January. Fifty bell frog tadpoles were transferred from Taronga Zoo to the Arncliffe ponds in March 2000. By this time, eight adult bell frogs were present in the ponds, previously-laid tadpoles had reached metamorphosis and 20 juvenile frogs were observed.

By late May 2000, no bell frog tadpoles remained in the ponds; many had metamorphosed but others were observed to be eaten by adult bell frogs and Striped Marsh Frogs, as well as by Eastern Water Skinks *Eulamprus quoyii*.

Juvenile bell frogs were found around the new ponds throughout winter and by spring 14 adult bell frogs were present at the site, of which 10 were first year adults.

The resident bell frog population spawned again in November 2000 and late January 2001. An additional release of 150 bell frog tadpoles occurred in February 2001. No further releases of captive-bred tadpoles occurred because the resident bell frogs appeared to be generating sufficient offspring without external assistance. Population estimates based on mark-recapture data between 2004 and the present indicates that the adult bell frog population exceeds 50 animals. This population appears to be secure.

b. Botany

The Botany Site was on reclaimed land along the northern foreshore of Botany Bay (part of Sir Joseph Banks Park; 332830 E, 6241610 N). The park was created during the 1980's when the Botany Bay Port facility and associated access roads were being created. Dredge spoils excavated to make the channels and berth areas in the shipping container dock area were used to create a new shoreline that extended from Matraville to Botany. At Botany, an area 100-150 m wide was reclaimed and this became the thoroughfare for Foreshore Drive as well as the western extension of Sir Joseph Banks Park. Although several ponds already existed within the park, none of them were particularly suitable for bell frogs because Plague Minnows was widespread in the ponds. A fish-free pond site was required that was distant from Plague Minnows-containing water bodies. The best location for the bell frog ponds was the western end of the park where there were few other ponds and public visitation was minimal.

In early 1996 excavators moved into the park to begin construction of the first specifically-made bell frog ponds in Australia. Two large and two small ponds were excavated; the two larger ponds were excavated below the water table and always contained water whereas the two smaller ponds were above the water table and only held water intermittently (Fig. 3). Bulrushes (cumbungi) *Typha orientalis* naturally established in the pond and by the end of the first year there were two large stands of bulrushes at either end of the two large ponds. The area around the ponds was replanted; all bushes and trees were removed within a 20 m radius of the ponds and native grasses (*Danthonia* sp. and *Themeda australis*) planted.

1996 – First Botany Translocation

The captive-breeding program at Taronga Zoo had proven very successful and in March 1996 the first translocation was carried out: 500 advanced bell frog tadpoles and 50 juvenile frogs were released into the two large ponds at Botany. At about this time, events had taken place that allowed the developer to be released from some of the conditions of the original licence; the translocation had become the determinant for the destruction of the frog pond at Rosebery. As no provision had been put in place for monitoring the translocated population, the only follow-up monitoring was done on an opportunistic basis and was carried out by interested biologists.

Figure 3. Ephemeral bell frog pond at Sir Joseph Banks Park, Botany, March 1997. Photo, A. White.

The two ponds proved to be suitable for tadpoles and by April all of the tadpoles had metamorphosed. Large numbers (up to 40 in a single evening) of juvenile frogs were detected around the ponds in May and early June. During winter no frogs were found and none were observed in the following spring (A.W. White, pers. obs.).

The failure of this translocation was evaluated on the basis of the limited monitoring data. The ponds and associated habitat were clearly suitable for tadpole growth and provided foraging areas for young frogs, but not for their survival beyond the winter. A possible reason for the failure of the young frogs to survive the winter may have been that they were too small and had insufficient body fat to last the non-feeding periods over winter. If the tadpoles had been introduced into the ponds before March, the young frogs would have had a longer feeding period in which to grow and may have been larger and more able to withstand the rigours of winter The simplest method to test this notion was to carry out a second translocation of tadpoles at an earlier date, in late spring or early summer. This was attempted the next season.

1997 – Second Botany Translocation

Despite intentions the second translocation could not be carried out under the same conditions as the first. During the summer of 1995/96 the new frog ponds at Sir Joseph Banks Park became infested with Plague Minnows. These exotic fish are known to kill the eggs and tadpoles of Green and Golden Bell Frogs (Morgan and Buttemer 1996; Pyke and White 1999) and are listed as a Threatening Process under Schedule 3 of the *Threatened Species Conservation Act* 1995. It is not known how the fish got into the pond although other ponds in the park contain the fish. Before the second translocation could be carried out the fish had to be reduced or eliminated. One week before the second translocation was planned to take place the pond was hand-netted daily. Over 500 fish were removed but some (less that 50) remained.

In February 1997 a second translocation of tadpoles and young frogs was carried out. The result was an immediate disaster. The remaining Plague Minnows quickly killed the tadpoles (A.W. White, pers. obs.) and within a month of the release no tadpoles or juvenile frogs (if metamorphosis had occurred) could be found.

1999 – Third Botany translocation

By the time it was apparent that the Botany pond had failed, the Rosebery source pond had been destroyed and the population was now only represented by the captive colony at Taronga Zoo. The Sir Joseph Banks Site was no longer useable as a potential translocation site while Plague Minnows were present. Meanwhile, pilot studies (A.W. White, unpubl. data) had suggested that tadpoles of the Striped Marsh Frog could reduce the survival of bell frog tadpoles in ponds that they cohabit. A system was needed that could exclude or reduce the number of Striped Marsh frogs from the bell Frog pond while bell frogs were becoming established.

In June 1999, Taronga Zoo undertook a series of habitat alterations at Sir Joseph Banks Park. Rotenone and chlorine, both potent fish poison were used to eradicate Plague Minnows from the ponds and frog barrier fences were constructed around the pond area. A monitoring program using local school children was devised and in November the third translocation occurred with 1,500 tadpoles and 50 juvenile frogs released. Tadpole metamorphosis took place rapidly and the juvenile frogs were well developed and approached adult proportions by the onset of winter (T. Russell, unpubl. data). However, the frog exclusion fencing was not successful in keeping out competing frogs and other species became established alongside the bell frogs. No adult bell frogs survived through the next spring.

The loss of frogs over the winter period strongly suggested that shelter habitat may have been inadequate around the ponds. In late 1999, large sandstone boulders were placed around the banks of the largest pond. In January 2000, 1,000 tadpoles were released into this pond and the other large pond. Sixty juvenile bell frogs were present around the two ponds in April of 2000. Unlike previous translocation attempts, several adult bell frogs survived the winter (which was cold but wet) and emerged the next spring. Adult frogs remained at the site until the next summer when they were no longer detected.

c. Long Reef

The site at Long Reef consisted of Long Reef Golf Course and some adjacent areas. It is located on a headland that lies between the Pacific Ocean and a residential area in the Sydney suburb of Collaroy (343130 E, 6265240 N). The bell frog translocation and monitoring program and release sites are discussed in more detail in Pyke *et al.* (2008).

This site was chosen as a release site for bell frogs in 1997 when suitable breeding habitat for this species seemed to have been inadvertently created through the creation a series of new ponds through the golf course. These ponds were developed in such a way that they would receive runoff from the adjacent road and urban area with the goals of providing freshwater aquatic habitat for plants and animals, providing a source of irrigation water for use on the golf course and improving the quality of the water before it flowed out to the ocean. Originally there was a natural wetland in about the same area as where these ponds were being developed but this was apparently destroyed when the golf course expanded from nine to 18 holes in about 1930.

In 1997, two further ponds were developed specifically to provide further habitat for the bell frog. The two ponds, though smaller than those previously created, contained apparently suitable breeding habitat and were surrounded by low vegetation. In 2003, another two ponds were developed in response to the discovery that existing ponds were too cold to support growth and development of bell frog tadpoles. These ponds were subsequently found to contain suitably warm water.

The translocation program for bell frogs at Long Reef began in January 1998 with the first release of captive-bred tadpoles at the site and the commencement of regular monitoring of the population and factors that might affect it. This first release consisted of about 2400 tadpoles which were introduced into each of seven ponds on the golf course, including the two newest frog ponds, the one oldest golf pond and four of the ponds created during the wetland development. There have been further releases since then. Between January 1998 and March 2004, total releases of bell frogs at Long Reef have amounted to about 9,300 tadpoles, 70 immatures and 5 adults (Table 1). Because of limited numbers of tadpoles available for release and the effects of Plague Minnows in many of the ponds, most of the releases following the first have been restricted to the initial two frog ponds (see Pyke *et al.* 2008 for details).

A monitoring program was carried out every 1-2 weeks during the warmer months of the year and about every 4 weeks during the remainder of the year. The monitoring initially included tadpoles and later life-stages of frogs, but subsequently also included fish when they were discovered to be present soon after monitoring began. Tadpoles and fish were monitored with daytime sweeps of a net at fixed points around each pond and through visual counts of animals visible at night from the pond

Table 1. Summary of circumstance and results of translocation projects.

Recipient site	Mean no. tadpoles released per year	Total no. of tadpoles released	Mean no. metamorphs observed	Mean no. of immatures observed	Mean no. of adults observed	On-site breeding	Bell frogs present nearby	Chytrid detected	Foxes present	Rock shelter available
Arncliffe	100	230	>50	>25	>20	Yes	Yes	No	No	Yes
Botany	500	2,500	>100	>25	<10	No	No	No	Yes	Yes
Long Reef	1300	9,300	8	44	11	No	No	No	Yes	Yes
Marrickville	22	162	14	13	12	Yes	No	Yes	No	No

edges with a strong spotlight. Frogs were monitored through night-time searches within and adjacent to each pond and looking under artificial shelter boards positioned around each pond. Captured frogs were individually 'marked'.

Conditions in and around the ponds changed through the course of the project. As a consequence of growth of vegetation within the ponds, there was an increase in the amount of emergent aquatic vegetation in some of the ponds, especially in the two frog ponds. This necessitated some removal of aquatic vegetation from one of the frog ponds in order that some open water remain. Rock piles were added to the areas adjacent to the two frog ponds to provide more potential shelter for frogs. The two frog ponds, which have been stocked with bell frogs, were also colonised by the Striped Marsh Frog.

Some habitat areas at Long Reef were initially adequate for the development of bell frog tadpoles into young frogs, although tadpole releases in autumn were unsuccessful. Foraging and shelter habitat were sufficient to permit these frogs to develop to maturity. Male bell frogs were heard calling in 1999 and 2000, but breeding did not taken place. With increases in aquatic vegetation, water temperature became too low to support tadpole growth and development. Insufficient tadpoles were available from the Taronga Zoo breeding program for release into additional warmer ponds and the population has died out.

d. Marrickville

This site was located in the densely settled residential suburb of Marrickville, in the grounds of the Marrickville Community Nursery in the Addison Road Community Centre (329805 E, 6246950 N; Fig. 4). This site was chosen as tightly controlled habitat could be created on the site, whereby all other frogs and fish could be excluded from the area. In addition, the site was amenable to regular monitoring as it was small in area and had no inaccessible areas where frogs could avoid detection.

Unlike other translocation projects, the Marrickville project was not aimed at creating a long-term habitat area for the species. This project was a short-term experiment designed to investigate factors that may impact on urban bell frog communities (White 2006).

It appeared likely that the conservation of non-captive, translocated bell frogs would depend on the preservation or creation of a range of secure habitats. One way of achieving this outcome could be through "back-yard" conservation where frog ponds and frog habitat are created in urban residences. At the time of the development of this project, it was not known how much space would be required to create viable frog habitat and what additional impacts may exist in urban settings.

In 1997, Marrickville City Council made available a small portion of land in the community nursery in the Addison Road Community Centre for the creation of a "back-yard" frog pond (Caiwood 1997). The Georges River Catchment Management Committee provided the funds to prepare the site. A 4.5 m diameter pond was constructed which had a maximum depth of 50 cm. The base of the pond was lined with a waterproof mat. Sandstone blocks were use to surround the pond. Pots containing the emergent rushes *Typha sp.* and *Eleocharis sp.* were submerged in the pond. Frog-exclusion fencing was set up around the outer perimeter of the nursery to exclude other frog species from entering the site and to prevent Bell frogs from escaping the site; an area of 600 m^2 was enclosed. Half of the nursery site was allocated to seedling propagation, pots containing young plants were set out on prepared gravel beds and were regularly watered by timed sprinklers; the remainder of the site was vegetated and consisted of a mixture of native plants and exotic grasses.

Figure 4. Bell frog pond at Marrickville, March 1998. Photo, A. White.

Local residents were enlisted to help with the monitoring of the bell frog population that was to be established in the pond. Training and information days were held at the site to prepare the monitoring team and to establish the monitoring routine. A "Friends of the Bell Frogs" group (Marrickville Chapter) was formed.

In February 1998, 22 captive-bred bell frog tadpoles (derived from Rosebery stock) were taken from Taronga Zoo and released in the new pond. At weekly intervals, the tadpoles were caught and measured. Once the tadpoles had metamorphosed, monitoring sessions were reduced to fortnightly. When the juvenile frogs reached snout-vent lengths greater than 40 mm they were micro-chipped with a passive induction transponder tag (Christy 1996). In this way growth records and movement around the site could be recorded for each frog.

Of the 22 tadpoles released 14 became adult frogs. Eight tadpoles were observed being attacked and eaten by Kookaburras *Dacelo novaeguineae* and Sacred Kingfishers *Todirhampus sancta*. Once it was realised that these birds were preying on the tadpoles, bird-scaring flutter tapes were strung across the pond and predation by birds ceased.

The 14 young adult frogs survived the 1998 winter and by mid-August the first calling by male frogs was heard. During the summer of 1998/99, calling occurred regularly but no matings took place. An examination of the female frogs revealed that none became gravid during this first year.

In early 1999, two adult bell frogs were killed and one was seriously wounded by Black Rats *Rattus rattus* (Fig. 5). Black Rats were observed attacking adult frogs and rat traps were set out and the rodents were quickly

Figure 5. Injured bell frog rescued from Black Rat, Marrickville, January 1999.

eliminated. No further deaths resulted from predation. One adult frog managed to escape the confines of the nursery and was found dead (run-over) the next day about 350 m from the frog pond

In February 1999, 100 new tadpoles were added to the pond. Again, the tadpoles were caught and measured weekly until metamorphosis, when monitoring sessions became less frequent. Eighty-four of these tadpoles reached metamorphosis but few survived more than a few days on land. Cannabalism by the adult bell frogs was high and a number of juvenile frogs were observed being eaten. Adult frogs were also observed to feed on large tadpoles. By May 1999, there were 24 adult bell frogs present (11 from the initial release and 13 from the second release). In August calling was heard from males from both age classes. No breeding had taken place by the end of September.

Calling continued through spring and the first breeding event occurred in November 1999. Female bell frogs from the first tadpole release were gravid whereas female frogs from the second tadpole release were not. Over 3000 tadpoles were present in the pond by late November but by the end of December, this number had fallen to about 200. Cannibalism of the tadpoles and emerging froglets was observed at each monitoring night. Only two froglets survived to become adult frogs. These froglets did not remain around the central frog pond but inhabited dense patches of grass and *Lomandra*, about 10 m away from the pond.

In April 2000, maintenance work at the nursery site required that the frog-exclusion fence be removed for a period of about 5 weeks. Within a week of the removal of the fence, two Striped Marsh Frogs were found in the pond. Shortly afterwards, more Striped Marsh Frogs were found in the pond. In early May an adult bell frog was found dead. Over the next three weeks five other corpses were found and these were forwarded to Taronga Zoo for autopsy. The autopsies revealed that the bell frogs were infected with chytrid (*Batrachochytrium dendrobatoides*), a highly infectious micro-fungal disease of frogs (Berger *et al.* 1998). A Striped Marsh Frog was caught and killed and forwarded to the Zoo for autopsy. It also contained the skin vesicles that characterise this disease (K. Rose pers. comm.). By the end of June only one bell frog remained alive. Other Striped Marsh Frogs invaded the pond and began breeding there.

As exposure to diseased frogs was likely to be a problem for any "back-yard" frog population a simple test was carried out to try to protect it. Dr Michael Mahony at Newcastle University, in undertaking tadpole growth experiments with varying salinity levels, had a Chytrid outbreak that wiped out individuals except those exposed to higher NaCl concentrations (M. Mahony pers. comm.). Also a number of field-workers have noted that most remaining bell frog populations are close to the coast and perhaps within the reach of a saline influence. Consequently this has led to a perception that perhaps Chytrid spores are sensitive to certain levels of salinity. During the spring of 2000, the frog-exclusion fence was reinstalled and the frog pond was salted using commercial NaCl. The salt concentration was brought to the equivalent of 3% sea-water and this was tested regularly and adjusted as required (White 2006). Bell frog tadpoles are known to be able to survive salinity levels of up to 10% and at least 5% sea-water without any obvious ill effect (Mahony unpublished; Christy and Dickman 2002). Attempts to collect and remove all of the Striped Marsh Frogs from the nursery area were unsuccessful.

In December 2000, 40 bell frog tadpoles were released into the pond (which also contained tadpoles of the Striped Marsh Frog). By late January 2001, the first juvenile bell frogs emerged. Only 7 bell frog tadpoles survived to metamorphosis (the others died in the pond). None of the frogs developed symptoms of chytridiomycosis. These young bell frogs were subsequently preyed upon by the adult Striped Marsh Frogs and the population perished. In March 2001, the Marrickville translocation experiment was terminated.

Discussion

Criteria for success

Each of the translocation projects that we have described had distinct goals for habitat creation and population establishment: habitat components that were assessed included the establishment of foraging, shelter, over-winter and breeding habitat; while the population goal was to establish a self-sustaining, viable population of bell frogs at each site. Using these criteria, only the Arncliffe site achieved all of the habitat requirements and also achieved the population goal. The other three sites failed in one or more of these criteria (Table 2).

Factors affecting the success of translocated Green and Golden Bell Frogs

The bell frog should be an ideal candidate species for translocations because it appears to be "pre-adapted" to colonising artificial habitats (Pyke and White 2001). The failure of translocated frogs to become established at recipient sites is a strong indicator of the failure to provide suitable habitat. Factors such as predation, disease and inadequate over-winter habitat had a major influence on the outcomes of the four projects described above.

Table 2. Outcome of four translocations of Green and Golden Bell Frogs in Sydney

Recipient Site	Duration of project (years)	Tadpoles reach metamorphosis	On-site breeding occurred	Likelihood of population survival
Arncliffe	1999-2008	Yes	Yes	High
Botany	1996-2001	Yes	No	Extinct
Long Reef	1998-2004	Yes	No	Extinct
Marrickville	1997-1999	Yes	No	Extinct

The range of outcomes from the four translocations demonstrates quite dramatically how population survival and occupation of habitat areas are influenced by a variety of environmental and ontogenic factors. The Marrickville translocation is an example of a heavily controlled translocation where potential predators and competitors were excluded. Under these circumstances, very high survival rates were achieved for tadpoles reaching metamorphosis and for juvenile frogs reaching adulthood. This is in stark contrast with most other sites where there were significant losses of bell frogs at the time of metamorphosis and subsequent losses of adults.

Predators of Green and Golden Bell Frogs in the wild have been described (Pyke and White 2001). These generally range from snakes, to wading birds and fish. However, for translocated populations in urban or near-urban areas the predators were quite different. At Marrickville, most predation was caused by adult bell frogs or Striped Marsh Frogs eating juvenile frogs or tadpoles. Black Rats were the main exotic predator of adult bell frogs while native birds were the main predator of tadpoles. At Arncliffe (A.W. White unpub. obs.) foxes and eels appear to be the main predators of adult bell frogs.

Plague Minnows were present at Botany and Long Reef. In both cases their presence had a marked influence on the survival of bell frogs. At Botany, the second translocation attempt failed completely due to the presence of these fish while at Long Reef, tadpoles metamorphosed to produce frogs only at ponds where Plague Minnows were absent. Plague Minnow predation on bell frog eggs and tadpoles has been previously noted (Morgan and Buttemer 1996; Pyke and White 2000).

Fox predation stands out as a factor that could limit the success of translocation projects involving bell frogs but further examination of this possibility is required. If significant over-winter frog mortality arises from fox predation, then it should be possible to find some evidence of this through analyses of fox scats or stomach contents. Unfortunately, however, it is possible for such predation to be highly significant in terms of a relatively small frog population and yet represent only a very small component of fox diet in the area.

The impact of competition from other frog species has not been adequately demonstrated for Green and Golden Bell Frogs. The reasons for the inability of bell frogs to be successfully reintroduced into the Marrickville Site after the arrival of Striped Marsh Frogs are unclear. In a study of natural frog colonisation of ponds, Pyke and White (1999) found that bell frogs could be lost from stable ponds when other frog species had become established. The apparent inability of bell frogs to compete with some frog species may account for the regular, long-range dispersal events observed for this species (Pyke and White 2001). Dispersal is particularly high in recently metamorphosed frogs and it appears that mortality rates are also high during dispersal. At Marrickville, where juvenile frogs were unable to disperse, juvenile survivorship was high when adult frogs were absent. Interactions between frogs may also be determined by susceptibility to disease.

The advent of new diseases is also a compounding factor in the success of translocated populations. The Marrickville population was the only population studied where exotic disease (chytrid) definitively affected the population, in this case it almost completely exterminated the population. Chytrid was not detected in the other, less-confined populations and the chances of finding dead or dying frogs was lower. Unconfined populations also have an advantage in that the spread of a disease through a population may be less comprehensive as some individuals may not encounter infected individuals or infected habitats.

The addition of a weak salt solution to a chytrid-infected pond suggested that this treatment is not harmful to tadpoles or frogs and may confer some degree of protection against Chytridiomycosis (White 2006). The use of weak salt as a preventative measure needs to be fully investigated but appears to have the potential to become a standard treatment for all bell frog ponds.

Behavioral traits of bell frogs may also play a role in the outcome of the translocations. The early translocations of bell frogs at Botany were deemed unsuccessful because juvenile frogs were not found after winter. This was interpreted as a failure to provide sufficient over-winter habitat for the young frogs. However, the construction of a frog-exclusion fence in 1998 resulted in the retention of juvenile frogs at the release pond. In hindsight, it appears that bell frog translocation areas require more than one functional pond and dispersal areas for juvenile frogs to survive in until they are large enough to safely return to the breeding ponds (where there is usually a high density of attending male frogs). Goldingay and Lewis (1999) recommend the establishment of multiple ponds as a safeguard against fish invasion and other adverse impacts.

The colonization of frogs, such as occurred at Arncliffe, suggests that translocation methods may be able to exploit the juvenile dispersal trait to advantage. At Arncliffe, juvenile frogs rarely stayed near the initial breeding ponds but quickly colonised nearby sites. Regular recaptures of juvenile frogs at these sites suggests that once the frogs have found a suitable new habitat they are likely to remain there as adults. On this basis, if a new bell frog pond is created near the source population, it is likely to be passively colonized (Goldingay 1996) and the frogs that take up residence appear more likely to remain at this site as adults. A frog pond constructed at Boilermakers Point, near Port Kembla was 200 m from a known bell frog site. The pond was colonized by adult bell frogs within months and bred there over several years (Goldingay and Lewis 1999). Lack of maintenance of *Typha* subsequently let it become largely unsuitable (Goldingay and Newell 2005).

Further understanding of the relative roles of various factors in determining the degree of success of bell frog translocation projects may also arise through an extension of the present review to include some of the other similar translocation attempts that have been made. Since these projects have all involved habitat creation or enhancement, their consideration should include these processes as well as the translocation itself.

Design of bell frog ponds

The bell frog ponds used in the Marrickville and Arncliffe translocation were based on breeding habitat requirements detailed in Pyke and White (1996). In particular, breeding ponds needed to have a deep and a shallow area, needed to have fluctuating water levels and the capacity to be drained, had surrounding rock piles, emergent water plants at one end and areas of open water.

Several structural factors appear to be important in determining the success of a bell frog pond. One structural factor that appears to be important is the provision of large rock fields (shelter and over-winter habitat) around the frog ponds. By providing these shelter areas close to the ponds, there is less potential for predation of frogs moving between the ponds and shelter sites. Rock piles were created next to the ponds at Arncliffe and at Botany. In both cases, adult and juvenile bell frogs have been observed under the rocks. Rock fields may provide a high density of refuge sites within a short distance of a pond. If shelter sites are provided further from the pond, the chances of predation (by foxes and rats) of moving bell frogs may increase. Dense vegetation cover can also be used (such as at Marrickville) but this type of shelter has a drawback, the soil underneath can dry out much faster than the soil under large rocks. Similarly, predators cannot move rocks in search of frogs.

Another structural feature is the provision of drains and external water supplies (such as at Arncliffe). These features allow the level of the pond to be raised and lowered at will. The raising of the water level of a pond in early spring after a period of low water during winter was believed to trigger the early colonisation of a pond by male bell frogs. The pond could then be kept relatively full during spring and summer, making the pond available for opportunistic breeding over a long period.

The provision of drains in bell frog ponds is useful for other reasons. In the event of the ponds becoming infested with unwanted fish or disease-carrying amphibians, the pond can be quickly drained and the contaminated water discarded. Pond draining is a more acceptable method of fish control than using fish poisons or electro-fishing and it has the extra advantage of simulating a major fluctuation in water level. If salt is to be added to ponds as a preventative measure against micro-fungal diseases, the ability to drain the ponds is a great aid in regulating salt levels. Finally, when ponds become too overgrown with emergent plants, ponds can be quickly and cheaply drained, and the vegetation allowed to die back to preferred levels.

Important issues in translocation

Translocations should never be accepted lightly as a means to achieve species conservation. Translocations are risky and there is a high risk of failure. Even for species like the Green and Golden Bell Frog whose gross habitat requirements have been well studied and documented (Pyke and White 2001), success in translocation cannot be guaranteed.

In addition, there are conservation concerns about the possible impacts on species that are translocated. Greer (1996) lists several major concerns that are predicated on the presumed knowledge of those undertaking the translocation. The translocation of a species in space may have serious implications in terms of genetic and disease exchange with resident frog populations, and because of this change of circumstance, the evolutionary path of the population (species) may be diverted into a different direction. Such dramatic genetic impacts are only likely if bell frogs are relocated to areas distant from the source populations (Burns and Ferraria 2004). On a more pragmatic note, translocations are an expensive undertaking. Significant costs are associated with the creation of alternative habitat areas, ongoing monitoring and reporting, habitat management and maintenance. In the case of translocations undertaken because of a commercial development, there is often a considerable time lag between the translocation of frogs and the approval to destroy existing habitat. In NSW, the NPWS requires that recreated habitat must be demonstrated to be successful before original habitat is destroyed. The ultimate proof of the suitability of the new habitat is the successful breeding of the frogs in both the parental and F1 generations. As female bell frogs take 18 months to sexually mature, this requirement means that a time delay of between 3 and 4 years must elapse before it is possible to meet the breeding requirement.

One of the most important requirements for translocation is the need for regular long-term monitoring of the translocated population. Only through long-term monitoring will it be possible to determine population response to the new habitat and to assess population fluctuations. Once these baseline data are established, any subsequent fluctuations can be reviewed in terms of natural cycles. Changes in the frog population should be used as the guide to direct modifications of frog habitat and to ensure the effectiveness of breeding ponds. Monitoring must be long-term as bell frog populations are not stable and population numbers vary greatly between and within seasons. Ideally, monitoring should occur throughout the spring and summer months and should include measures of reproduction as well as population estimation.

Translocation outcomes

Despite the bell frog being such a good candidate for successful translocation to new or enhanced habitat, such translocation attempts have so far been generally unsuccessful. Three out of the four translocation projects described above have failed to achieve the desired result of establishment of self-maintaining populations. Arncliffe, the only successful project, appears to have succeeded primarily because bell frogs were already present nearby and quickly colonised and bred in newly-created habitat. The translocations described above provide useful information about the habitat needs of bell frogs and may pave the way for increasingly successful translocation ventures in the future. These results also suggest, amongst other things, that a relatively circumspect view should be taken of translocations that are proposed to allow development to proceed while protecting and conserving frog populations.

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