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Evaluation of Impacts of Bushfire on the Spotted Tree Frog *Litoria spenceri* in the Taponga River Catchment, Northeast Victoria

Black Saturday Victoria 2009 – Natural values fire recovery program

Graeme Gillespie, Matt West

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Evaluation of Impacts of Bushfire on the Spotted Tree Frog *Litoria spenceri* in the Taponga River, Catchment Northeast Victoria

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Front cover photo: Spotted Tree Frog (© Graeme Gillespie). All photographs in this report are by Graeme Gillespie unless otherwise credited

Contents

List of figures

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Summary

The Spotted Tree Frog, *Litoria spenceri*, is listed as Endangered nationally. It occurs along a small number of mountain streams in north-eastern Victoria and southern New South Wales.

The species has suffered significant declines in recent decades. Since 2003 all the catchments supporting populations of the Spotted Tree Frog have suffered severe disturbance from bushfire, culminating in the 2009 fires, which burnt the Taponga River catchment in the Central Highlands of Victoria. We present a review of the potential impacts of bushfire on the Spotted Tree Frog and its management, and a preliminary evaluation of the impact of the 2009 bushfire on the Taponga River Spotted Tree Frog population. A population monitoring program had been undertaken for Spotted Tree Frogs in the Taponga catchment for 17 years prior to the 2009 fire, providing an opportunity to evaluate impacts of the fire on the population by comparing the demography of the population before and after the 2009 fire event. Using the two 200 m stream transects monitored in previous years, and the same sampling techniques, repeated surveys were undertaken during both the day and night, for Spotted Tree Frogs between October and March in 2009/2010 and 2010/2011. All captured frogs were measured, sexed, checked for previous toe-clip numbers, or if new, given a new unique toe-clip number, then released at point of capture. Juvenile recruitment immediately post-fire was lower than ever previously recorded, but improved in the subsequent year. In contrast, adult survivorship increased compared with pre-fire survivorship estimates. These life history differences possibly reflect differences in microhabitat use or differences in ability of adults and juveniles to evade fire events. It does not appear that the fire has had a significant adverse impact on Spotted Tree Frogs, however the absence of control sites or adequate replication limits interpretation of these observations.

1 Introduction

Fire is a natural part of the Australian environment and fire regimes have played a significant role in influencing patterns of biodiversity across the continent. Amphibians are a significant component of Australian vertebrate diversity and biomass, occurring in virtually all terrestrial and freshwater habitats. Whilst many frog species are restricted to environments that don't experience fire or are rarely burnt, such as rainforests and wet schlerophyll forests, most species occur in habitats, such as wet and dry schlerophyll forests, woodlands and heathlands, which do experience bushfires with varying frequencies and intensities and are strongly influenced by them. However, despite the ecological significance of fire in the Australian context and its importance as a management tool, little is known about the impact of fire on amphibians. The few studies that have been conducted suggest that responses vary amongst species, habitats and regions (Pilliod 2003). Populations of some species may increase after fire events (Roberts *et al.* 1999), some remain stable (Bamford 1992; Lemckert *et al.* 2004), while others may decline (Bamford 1992; Driscoll and Roberts 1997). Presumably frog species have evolved strategies to deal with fire in the Australian environment; either by seeking refugia (e.g. Penman *et al.* 2006), or through life history strategies that enable their populations to recover after specific fire events and deal with certain fire regimes.

Over the past 30 years, many Australian amphibian species have experienced severe population declines and range contractions (Hero *et al.* 2006). Nearly 20% of Australian species are currently threatened with extinction (Hero *et al.* 2006; http://www.environment.gov.au/cgi-bin/sprat/public/publicthreatenedlist.pl). Of the 38 frog taxa occurring in Victoria, nine are currently considered threatened at a national level (DSE 2007). A range of factors have been implicated in these declines, such as habitat loss, invasive species and the emergent amphibian pathogen *Batrachochytrium dendrobatidis* (Bd) (Berger *et al.* 1998; Hero *et al.* 2006; Gillespie *et al.* 2011). More recently evidence is mounting that climate change is also playing a role in some declines (Pounds *et al.* 2006; Laurance 2008; Bickford *et al.* 2010). For many threatened species it is likely that various factors are operating in concert with complex interactions (Stuart *et al.* 2004). Bushfire or inappropriate fire regimes have been identified as potential threats for many threatened frog species in southeastern Australia (e.g. Corroboree Frogs (Hunter 2010a), Spotted Tree Frog (Gillespie *et al.* 1999), and Southern Barred Frog (Hunter and Gillespie in review)). However, there are almost no empirical data on the impacts of fire on any threatened frog species in Australia, nor a clear understanding of how fire should be dealt with in areas where they occur.

The Spotted Tree Frog *Litoria spenceri* is restricted to mountain streams in the southern highlands of Australia, mostly in the Goulburn and upper Murray River basins of north-east Victoria (Gillespie and Hollis 1996). The species has suffered local extinctions and population declines over the past 30 years; currently five populations survive in Victoria and one in New South Wales (Gillespie and Clemann in review). The Spotted Tree Frog is listed as Endangered Nationally under the *Environment Protection and Biodiversity Conservation Act* 1999 and in Victoria (DSE 2007), and is listed as a threatened taxon under the Victorian *Flora and Fauna Guarantee Act* 1988 (FFG). Several factors have apparently contributed to the observed declines of the Spotted Tree Frog including predation by introduced trout (Gillespie 2001, 2010); habitat disturbance and alteration from historic gold mining, roads, and recreation activities (Gillespie and Hollis 1996); and Bd (Gillespie and Marranteli 2001, Berger *et al.* 2004). Bushfire and excessive fuel reduction burning have been identified as potential threats to populations of the Spotted Tree Frog and a precautionary approach to fire management in Spotted Tree Frog catchments has been advocated (Gillespie and Robertson 1998; Gillespie *et al.* 2004). The revised draft FFG Action Statement recommends that fire should be excluded from Spotted Tree Frog Special Protection Zones. These zones extend 1km either side and upstream of all mapped potential Spotted Tree Frog habitat in catchments containing extant populations. However, the advantages and disadvantages of excluding fire from these areas for Spotted Tree Frog conservation are unknown.

Spotted Tree Frogs occur along swift-flowing rocky streams between 200 and 1100 m above sea level, flowing through Dry and Montane Forests (Gillespie and Hollis 1996). They breed in late spring, laying their eggs in rock crevices in the stream, their tadpoles develop in slow-flowing and shallow sections of streams over summer, metamorphosing between January and April (Gillespie 2002b, Gillespie 2011). Juvenile and adult frogs are highly sedentary (G. Gillespie unpublished data); not only do they appear not to venture far from the riparian environment, but they rarely move more than 100 m along watercourses in their lifetimes, which may span 14 years (Gillespie 2011). Fire may potentially adversely affect Spotted Tree Frogs in several ways:

- Directly killing adults and juvenile frogs foraging or sheltering in terrestrial habitats.
- Reducing availability of terrestrial shelter sites, exposing frogs to increased predation.
- Increasing sediment loads and ash entering streams, filling rock crevices and reducing availability of oviposition sites.
- Increased sediment loads in streams can reduce tadpole growth and development rates resulting in delayed metamorphosis or reduced size at metamorphosis, which in turn reduce fitness and survival (Gillespie 2002a).
- Changing stream hydrology, such as higher catchment runoff and more intense flushing flows during heavy rain events (Durnham *et al.* 2007), may potentially flush eggs and tadpoles down stream, damaging and killing them.

Fire fighting responses may also have adverse effects:

- Disturbance of streams and riparian zones from construction of fire lines in places where roads would normally be excluded, resulting in increased erosion and siltation of streams.
- The fire retardant Phos-Chek® is widely applied aerially during fire fighting in Victoria, and was used in the Taponga catchment during the 2009 fire (S. Smith, DSE pers. comm.). Phoscheck® retardant is considered practically non toxic to *Daphnia magna*, Rainbow Trout and Flathead Minnow (PC Australasia Pty Ltd (2010a). Phos-Chek® Class A foam is used during some ground-based fire fighting operations, but is not likely to have been applied near streams containing Spotted Tree Frogs (S. Smith, DSE pers. comm.). It is harmful to Rainbow Trout and similar products are toxic to *Daphnia* and algae (PC Australasia Pty Ltd 2010b). Toxicity tests on amphibians are not available for these products.

Fire may also have positive effects on Spotted Tree Frogs:

- Stream nutrient levels are expected to increase after fires due to ash and increased run-off (see Durnham *et al.* 2007), which may benefit tadpole growth and survival.
- Increased sediment loads and reduced water quality may adversely affect introduced trout by increasing mortality from reduced water quality and lower oxygen concentrations, and reducing recruitment from loss of spawning sites, in turn reducing predation upon Spotted Tree Frogs.
- Spotted Tree Frogs appear to prefer stream sections with limited riparian forest development and open canopies with high sunlight penetration. The species basks for thermoregulation and sunlight penetration is also important for raising stream water temperatures for tadpole development. In the absence of fire, many riparian zones will develop increased density of mesic vegetation, with increased shading from broad-leaved species. In the longer-term, fires may therefore be important in maintaining relatively sparse and open riparian habitats suitable for the Spotted Tree Frog.

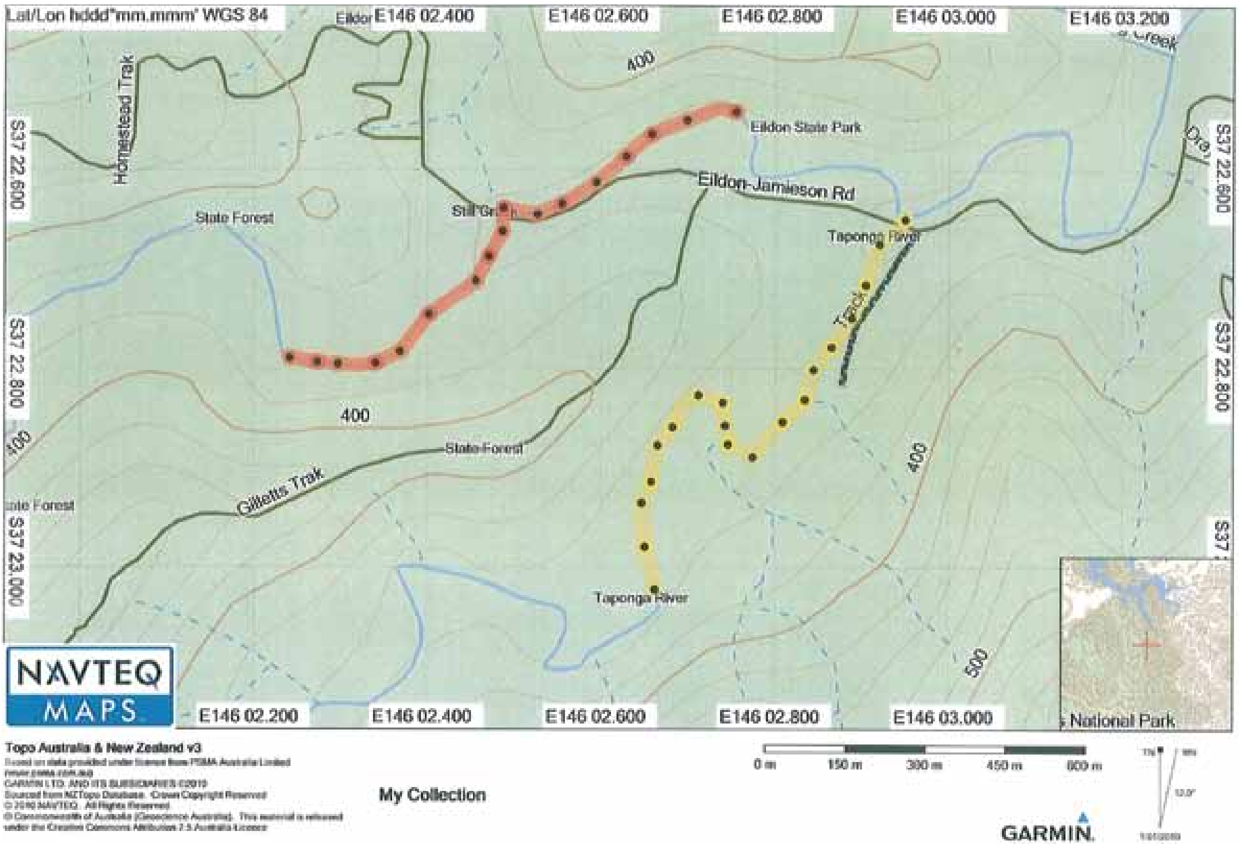
Since 2003, all Spotted Tree Frog catchments in Victoria have been burnt by major bushfires. In 2009 the Kilmore-Murrindindi North fire complex burnt entirely the last unburnt Spotted Tree Frog catchment, the Taponga River, a tributary of the Big River (Eildon). Unlike other Spotted Tree Frog populations (indeed most other threatened species) detailed population monitoring had been undertaken on the Taponga River population for 17 years prior to the fire. This pre-fire data provided an opportunity to evaluate, to a limited extent, the impacts of bushfire on this species. Such an evaluation might inform future fire-related management actions to help ensure the survival of this species. The specific objectives of this study were to evaluate impacts of the 2009 fire on Spotted Tree Frog survival and juvenile recruitment. A qualitative assessment of impacts on habitat and habitat recovery are also provided.

2 Methods

2.1 Pre-fire population monitoring

A transect 200 m in length was first established along Still Creek, a tributary of Taponga River (146°2’25”E; 37°22’51”S), in November 1992. A second 200 m transect was subsequently established along the main branch of the Taponga River (146°2’20”E; 37°22’50”S) in February 1995. Transect censuses were conducted every one to three weeks between October and April each year since. Transects were sampled during the middle of the day and after dusk during each visit. Whenever possible, censuses were undertaken during high pressure weather systems: no rain, sunny days and nights with mild temperatures above 10°C. Times of high stream flows after heavy rains were avoided, for operator safety. Meteorological information such as cloud cover, precipitation and wind strength was recorded at the commencement and completion of each census. Qualitative observations of stream condition (flow rates etc.) were also recorded. Censuses were conducted with two people walking up-stream, searching for frogs perching or sheltering within the stream margins and adjacent riparian habitats. Every frog encountered was measured (snout to urostyle length), sexed if possible (see Gillespie and Hollis 1996; Gillespie 2011) and, if not a recapture, given a unique toe-clip number using the method described by Hero (1989) with the following modifications: thumbs were not clipped to minimise interference with clasping ability; recently metamorphosed individuals encountered in late summer and autumn (February–April) were given a single toe-clip number unique to their cohort. When encountered in subsequent seasons, these individuals were then given a unique number by clipping an additional toe. All digits were removed at the base of the penultimate phalange. Prior to the year 2000, digits were stored in vials containing 10 % neutral-buffered formalin and subsequently used for determining frog age by skeletochronology (see Gillespie 2010, 2011). From the year 2000, digits have been stored in vials containing 75% ethanol to enable future genetic analyses. In 2005 sampling for the amphibian pathogen Bd also commenced; prior to release, each frog was swabbed for Bd by rubbing a sterile swab (Medical Wire and Equipment, MW-100) along the ventral surfaces of the frog, in the groin area, and in the palm of the hand and foot as the frog gripped the swab. Bd pathology will be analysed as part of a broader post graduate research project investigating the epidemiology of Bd in Spotted Tree Frogs. Frogs were released as soon as possible at site of capture.

Figure 1. Locations of the 1 km transects sampled for Spotted Tree Frogs. Red – Still Creek; yellow – Taponga River.



2.2 Post-fire population monitoring

In November 2009, following the Black Saturday bushfire in February 2009, both transects were extended to 1 km in length (Fig. 1). This was not done in response to the fire specifically but to increase sampling power for monitoring trends in the population. These transects incorporated the original 200 m transects and were sampled in the same way as previously, except that they were only sampled between November and March, which has been found to be the optimum season to find Spotted Tree Frogs (Gillespie 2002b). Day and night censuses were undertaken on each transect on seven occasions in 2009/10 and eight occasions in 2010/11.

Quantitative assessment of fire impacts on frog habitat was not possible because no pre-fire data were available. Photos were taken of sections of transects immediately after the fire, which enabled qualitative comparison with pre-fire photos taken in December 2008. Photos were also taken of transects in December 2010 for qualitative assessment of habitat recovery.

2.3 Analysis of fire impacts

Numbers of adults and juveniles detected on each transect since the Black Saturday fire were compared to the seasons before the fire. Post-fire survivorship of frogs was assessed as follows for each sampling year; the proportion of frogs known to be alive the subsequent year on each transect was calculated by examining recapture data over the subsequent two year interval. Recaptures outside of the original 200 m transect section were not included. This time interval was chosen because: (i) we currently have only two years of post-fire data; and (ii) frog recaptures beyond three year intervals are rare. This calculation was done for each sampling season on each transect except 2006/7 and 2007/8 because the fire was in February 2009 (prior to the end of the frog sampling season), which meant that survivorship data for these sampling seasons was only partially affected by the fire event. Survivorship data for the 2008/9 season was all post-fire, so these data for Still Creek and Taponga River were compared to the pre-fire samples using a Mann-Whitney test.

No control sites were available for this study because: (i) adequate monitoring had not been undertaken on any other Spotted Tree Frog populations; and (ii) all other populations had also been affected by previous large bushfires in 2003 and 2007.

3 Results

An inspection of the Taponga River catchment in the vicinity of the Spotted Tree Frog population in late February 2009 indicated that the fire had comprehensively burnt the valley and riparian areas of the catchment. Apart from some very small patches of un-burnt ferns (*Blechnum* spp.) remaining along a few sections of stream bank, and a few un-burnt heads of some riparian understory trees (*Acacia melanoxylon* and *Leptospermum grandifolium*), the fire burnt to the water's edge. Photographs of the Taponga River and Still Creek transects prior to and immediately after the 2009 fire, and two years post fire, are shown in Figures 2–4.

In the summer of 2010/11, the Taponga River catchment experienced well above-average spring and summer rainfall. Stream levels remained high, above those typically experienced at the end of October, throughout the season. Stream water temperatures were also significantly lower than average (G. Gillespie unpubl. data). Severe rainfall events over the summer also caused repeated flushing flows in the Taponga River and Still Creek (Fig. 4), which scoured stream banks in many areas, moved gravel and sand bars, and mobilised large volumes of coarse woody debris. We observed the formation of numerous large log jams along transects, many of which were later washed away by subsequent high flow events, further mobilising woody debris and built-up sediment deposited behind the jams. Bank scouring appeared to be worst in the most severely burnt sections of stream. As of March 2011, many of these areas remain completely bare of any understory riparian vegetation.

The total numbers of adult males and female frogs detected in each of the two seasons sampled since the fire were not significantly different from those in years prior to the fire (Fig. 5). In contrast, in the season immediately after the fire, no juveniles were detected on either transect (juveniles refer to the progeny of breeding in the previous summer, so are approximately one year-old at time of sampling). Furthermore, numbers of juveniles along the entire one kilometre transects were also very low that season (Fig. 6), suggesting that the reduction was not restricted to the old transect areas. However, juveniles were located in the 2010/11 season (Fig. 5 and 6), with a big increase on the Still Creek transect, indicating that reproductive success and juvenile survival improved again during the 2009/10 breeding season.

Frog survivorship, as measured by the proportion of all frogs known to have survived two years after first capture, increased significantly after the fire for all frogs combined (Mann-Whitney U = 3.0, Wilcoxon W = 328.0, $p = 0.034$) (Fig. 7). No significant differences were found in survivorship for adults or juveniles separately (Fig. 7).

Figure 2. Sections of the Taponga River catchment before and immediately after the 2009 fire. A – White Creek, just upstream from the Still Creek monitoring transect photographed in December 2008; B – same site in March 2009. Note: The netted area is an experimental setup as part of ongoing research into the ecology the Spotted Tree Frog and C – Upper Taponga River site showing how fire has burnt vegetation to the waters edge.

A.

B.

C.

Figure 3. One of the few relatively un-burnt sections of Spotted Tree Frog habitat in the Taponga River catchment.

Figure 4. Sections of the Taponga River catchment in December 2010, nearly two years after the fire. Note level of riparian vegetation recovery and bank scouring from high stream flows. A – Still/White Creek confluence (Michael Williams, IT'S A WILDLIFE); B – Taponga River transect.

Figure 5. Means and standard errors of numbers of frogs in each demographic category detected on the original two 200 m transects on Taponga River and Still Creek for each season sampled. Note: no standard errors on first three years as sampling only occurred along Still Creek.

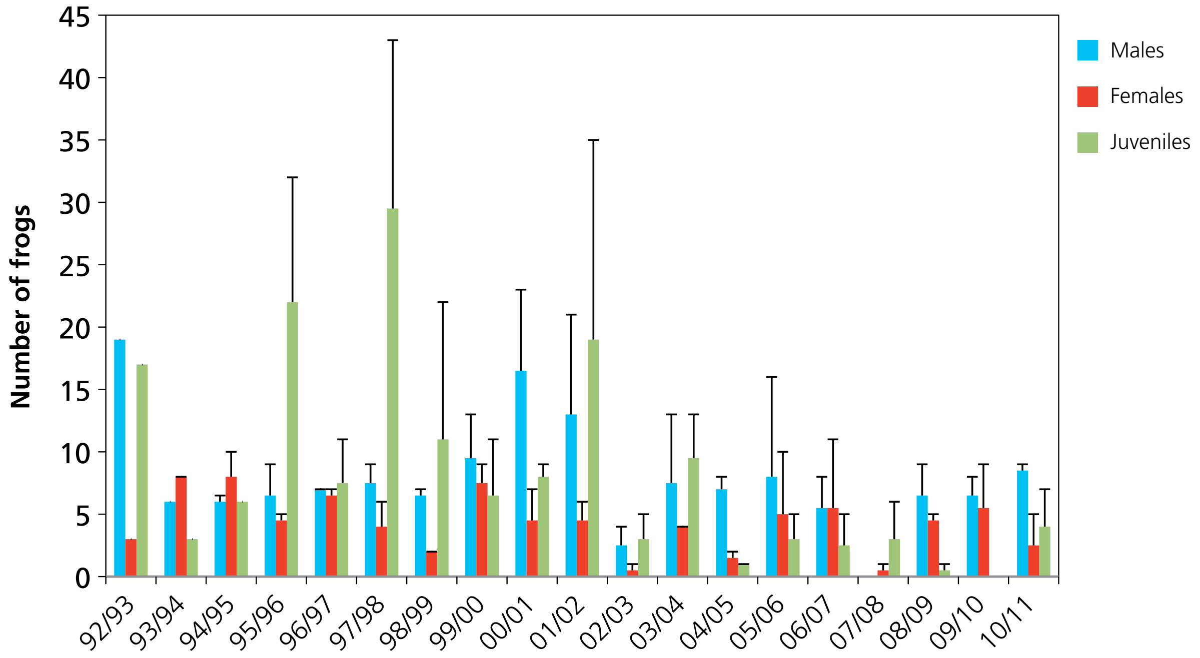


Figure 6. Comparison of means and standard errors of annual total numbers of frogs encountered on the original 200 m transects and numbers per 200 m of the extended 1 km transects for the past two seasons. A – 200 m transects; B – 1 km transects averaged over 200 m.

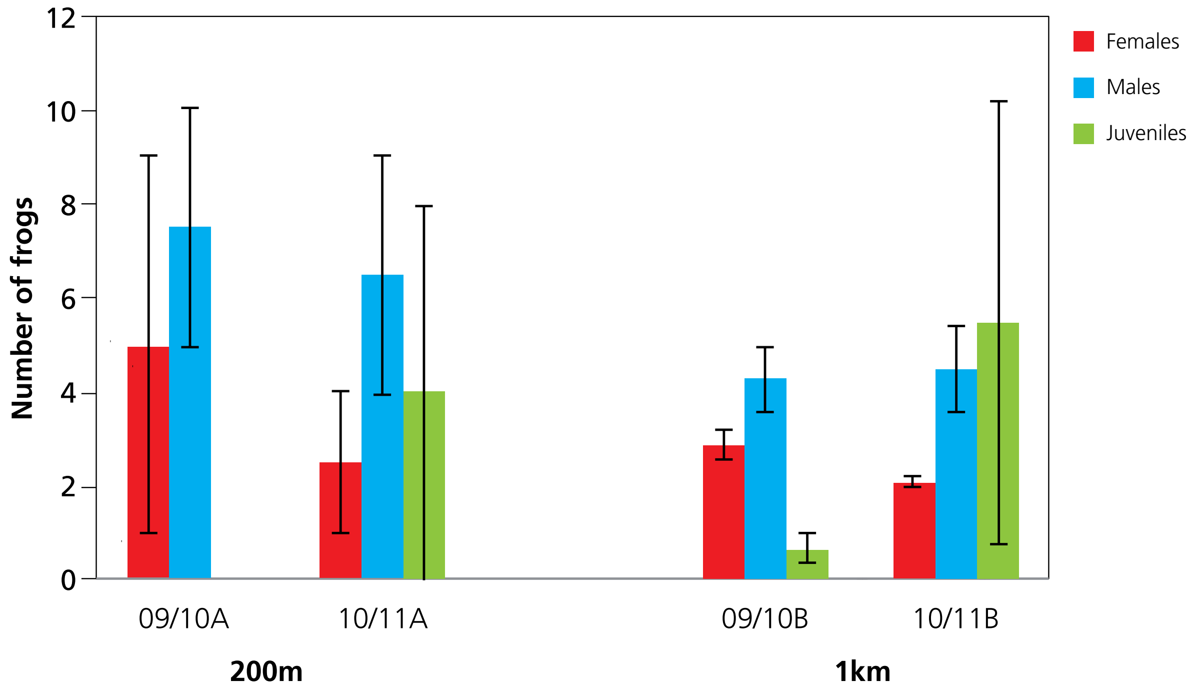
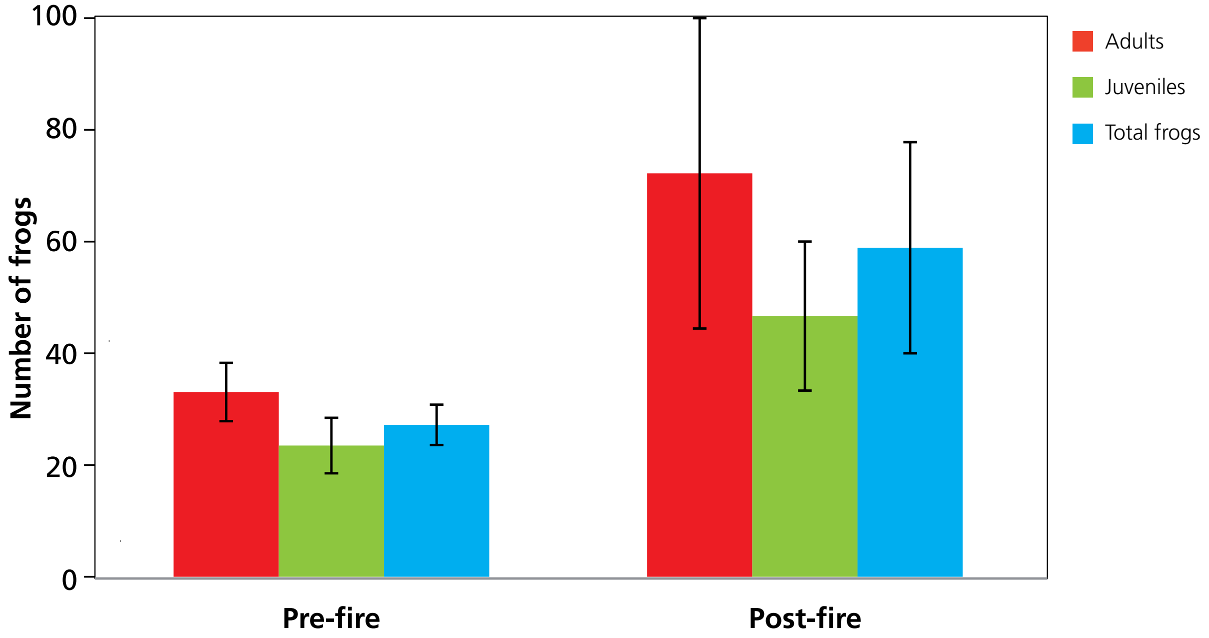


Figure 7. Means and standard errors of proportions of all frogs (adults and juveniles combined) known to have survived 2 years after first capture across all sampling seasons on both transects, pre- and post- the 2009 fire.



4 Discussion

We observed the lowest level of recruitment in 19 years in the summer season immediately after the 2009 fire. In the absence of control sites, it is not possible to be certain as to whether or not the fire was the cause of this result. The adult population density was low along both transects relative to historic levels at the time of the fire and during the preceding season, and this undoubtedly contributed to reduced recruitment as there would have been relatively low egg numbers laid at the time. However, higher recruitment has been seen in previous seasons when adult density has been very low (Fig. 5). Therefore it is likely that the fire did adversely impact recruitment. At the time of the 2009 fire, most tadpoles would have recently metamorphosed and would have been sheltering amongst litter and under small cobble stones along the banks of the stream. As illustrated in Figure 2, the fire burnt vegetation and litter right to the water's edge in many places. Small recently metamorphosed frogs have limited ability to move quickly and seek shelter in water, so it is likely that many of them would have perished in the fire.

In contrast there was a large increase in recruitment during the 2009/10 season, as reflected in the large number of juveniles detected along the Still Creek transect in the 2010/11 season. The reason why this only occurred along the Still Creek transect and not the Taponga River transect is unclear. One possibility is that blackberry spraying undertaken along the main Taponga River tributary and transect area and not the White/Still Creek catchment during 2010 may have killed a lot of recently metamorphosed frogs. This age group is likely to be the most vulnerable due to its reduced physiological tolerance. Recently metamorphosed individuals would have been more likely than adults to be perched on, or sheltering in, bank and riparian vegetation at the time of spraying and therefore be more exposed to herbicide drift.

No adverse impact from the fire on adults or juveniles was discernable. Adults and juveniles are more agile than recently metamorphosed individuals, and typically use the stream to escape from predators. It is reasonable to assume that they sought shelter in the water or under bank crevices well protected from the fire.

Our estimate of increased frog survivorship since fire does not take into account variation in detection probabilities. Frogs may have become easier to detect after the fire, due to simplification of riparian habitat structure, reduced camouflage or changes in frog behaviour (e.g. increased time spent foraging). If this were so, we would have also encountered individuals more frequently within each season, but this was not the case. The absence of control sites means that it is not possible to definitively attribute the observed increase in survivorship to the fire. Other possibilities include the breaking of the drought in southeastern Australia since the fires; however, previous data suggests that Spotted Tree Frogs may be adversely affected by *La Ninia* events, such as experienced since 2010 (Gillespie and Marantelli 2001). However, bushfire could result in increased survivorship of Spotted Tree Frogs in the following ways:

- We think that the main natural predators of Spotted Tree Frogs are Highland Copperhead snakes (*Austrelaps superbus*) and Wolf Spiders (Lycosidae); the latter are extremely abundant along the streams in similar microhabitats to the frogs (G. Gillespie pers. obs.). No data are available on the impact of the fire on these species but we saw very few wolf spiders along either transect after the fires. These predators may have been reduced in abundance, thus reducing predation pressure on Spotted Tree Frogs.
- Increases in juvenile recruitment such as that observed on the Still Creek transect, may be attributed to adverse impacts of the fire on trout survival and recruitment, resulting in increased tadpole survival. Trout are likely to be adversely affected by increased water temperatures and suspended sediment loads associated with fires. Their reproductive success may also be reduced due to blanketing of gravel beds with sedimentation.
- There is increasing evidence that frog species that can raise or maintain high body temperatures may have greater resistance to Bd, or greater ability to cope with Bd infection (see Griggs et al. in press). Many frog species, including the Spotted Tree Frog, are able to raise their body temperatures by basking or perching on warm surfaces, such as rocks that have been exposed to sunlight (Gillespie and Hollis 1996). The fire opened up the riparian canopy of the Taponga River, allowing increased sunlight penetration to Spotted Tree Frog microhabitats. It is possible that this may have augmented Spotted Tree Frog microhabitat temperatures and facilitated reduced infection and mortality from Bd. However no data are available to support this hypothesis at this stage.

There have been very few previous studies on the impacts of fire on frogs. In an investigation of the responses and adaptations of three frog species to fire and their relationship to vegetation structure, litter density and potential food supply in Western Australia, Bamford (1992) found no relationship between time since fire and number of species or total abundance of frogs. However, the abundance of two species was greater in long unburnt areas. The differences were proposed to be the result of nett movement away from burnt areas after fire. Arnold *et al.* (1993) found little impact of fire on frogs immediately after fire, but found lower densities on plots three years since fire. Investigations of fire impacts on *Geocrinia* spp. in Western Australian forests found 30% declines in populations two years after fire, but no differences between burnt and control plots seven years after fire (Driscoll and Roberts 1997; Conroy 2001). Friend (1993) speculated that most frog species are probably indirectly affected by fire due to their utilisation of pools, ponds and subterranean shelter sites, which are essentially protected from the direct effects of fire. However, there are many indirect ways in which fire could profoundly impact frog populations. For stream-breeding species, such as the Spotted Tree Frog, the effects are further compounded by down-stream impacts of fires on hydrology, water chemistry, nutrient levels and temperature (Durnham *et al.* 2007). Fires *per se* may not be the most important factor, but rather the consequential changes in habitat and microclimate that impact on frog habitat, such as hydrology, quality or openness of vegetation and patchiness of fire (Bamford and Roberts 2003). Thus although many frogs can survive the immediate fire impact, there may be declines some time after fire, followed by recovery.

A range of factors are known to influence Spotted Tree Frog population dynamics, including trout predation, Bd, climatic variation and anthropogenic disturbance. These factors have potentially complex interactions that are poorly understood (Gillespie 2011). Evaluating the impacts of the 2009 fire on Spotted Tree Frogs is further limited by indirect interactions between some of these other factors (e.g., trout). Furthermore, the high flows experienced in the most recent 2010/11 season are also likely to affect Spotted Tree Frog demography. For instance, these flows have dislodged a lot of riparian coarse woody debris, scoured riparian vegetation, and in some cases, eroded stream banks. It is possible that the effects of the high flows on Spotted Tree Frog habitat have been exacerbated by the 2009 bushfire. The absence of control (unburnt pre and post-fire monitoring) sites, along with other confounding factors such as the aforementioned blackberry spraying, mean that the patterns observed here need to be interpreted cautiously. It does appear that, to date, population densities of Spotted Tree Frogs on Still Creek and Taponga River have not changed appreciably since the fire. The population has fluctuated considerably on the transects over the years of sampling, due to the complex interactions discussed above. Consequently the impact of the fire on Spotted Tree Frog populations would need to be considerable for it to be detected, especially in the absence of control sites. By contrast, in 2007 we observed a significant increase in mortality subsequent to an increase in prevalence of the amphibian disease Bd (see Fig. 5; C. Todd, G. Gillespie and M. Scroggie unpublished data). In comparison no such effect was observed from the fire, except perhaps on recently metamorphosed individuals. Therefore in the recent history of the population (last five years), Bd appears to have had a bigger impact upon the population.

Population densities of Spotted Tree Frogs are inherently too low to enable statistically robust estimates of annual population sizes along the transects, or actual changes in population size on a year to year basis. In the longer term, further monitoring data will enable estimation of changes in population trends associated with particular events of interest (such as the 2009 fire), but this will require several more years of population monitoring data. This study not only highlights the value of long term monitoring of biodiversity assets, but also the need to sustain such monitoring in order to enable robust evaluation of impacts of unplanned events, such as bushfire, along with planned management actions.

We recommend that annual demographic monitoring be continued in the Taponga River catchment. We also recommend, as a precautionary principle, that herbicides not be used to treat weeds in riparian zones in this catchment.

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