The Minister approved this conservation advice and retained this species in the Endangered category, effective from 19/10/2021

Conservation Advice

Litoria booroolongensis

Booroolong Frog

Taxonomy

Conventionally accepted as *Litoria booroolongensis* Moore, 1961.

Studies indicate that there is significant genetic divergence between populations distributed in the Northern Tablelands from those in the Central and Southern Tablelands (from the Turon River and south) (Donnellan pers comm, cited in OEH 2012). These lineages are considered to be separate evolutionarily significant units. Research is currently being undertaken to determine whether the level of divergence warrants the description of multiple taxa. However, the available genetic, morphological, and bioacoustics data are consistent with the Booroolong Frog being a single species (S Donnellan et al. unpub. data; J Rowley et al. unpub. data).

Summary of assessment

Conservation status

Endangered: Criterion 2 B2(a)(b)(i,ii,iii,iv,v)(c)(ii,iv)

The highest category for which *Litoria booroolongensis* is eligible to be listed is Endangered.

Litoria booroolongensis has been found to be eligible for listing under the following categories:

Criterion 2: B2(a)(b)(i,ii,iii,iv,v)(c)(ii,iv): Endangered
Criterion 3: C1: Vulnerable

Species can be listed as threatened under state and territory legislation. For information on the listing status of this species under relevant state or territory legislation, see http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl

Reason for conservation assessment by the Threatened Species Scientific Committee

This advice follows assessment of new information provided to the Committee to list *Litoria booroolongensis*.

Public consultation

Notice of the proposed amendment and a consultation document was made available for public comment for 45 business days between 18 November 2020 and 22 January 2021. Comments received that were relevant to the survival of the species were considered by the Committee as part of the assessment process.

Species/sub-species information

Description

Litoria booroolongensis (Booroolong Frog) is a medium-sized frog from the Family Hylidae ("tree frogs"). Females are larger than males, reaching a maximum snout-to-vent length (SVL) of 55 mm, while males reach 40 mm SVL. The dorsal surface is smooth or with scattered low tubercles and may be grey, olive, or reddish-brown, with faint black reticulations and scattered salmon-coloured flecks. The ventral surface is finely granular and a white or cream colour. The

backs of the thighs may be dark brown or covered in a yellow and black reticulated pattern. The head is slightly broader than it is long, and the snout is rounded. A faint, thin, black stripe begins at the snout, passes through the eye, then widens to enclose a small distinct tympanum before terminating at the shoulder. The eyes are prominent and golden, with the upper half of the iris often brighter than the lower half. Males have small dark flecks on their throats and lack a distinct vocal sac. Disks on the fingers and toes are well developed. On the hands, the second finger is longer than the first, and on the feet, a small but prominent inner metatarsal tubercle and tiny outer metatarsal tubercle are present. Fingers are free from webbing, while the toes are nearly fully webbed with webbing reaching the disc of the fifth toe. The species can be further identified from the male's breeding call, which is a soft "qrk, qrk, qrk" purring sound lasting two or three seconds. The description of the adult is drawn from Cogger (2014) and Anstis (2017).

The tadpole is streamlined (elongated and flattened) and reaches a total length of 50 mm prior to metamorphosis. On the rounded head, the eyes are golden (with darker sides and a small V-shaped umbraculum), the nares are moderately spaced, and the mouth is ventral. The dorsal surface of the body is rusty-brown with some darker mottling, which continues along the tail muscle. A conspicuous dark brown band is present across the lower back region. The sides of the body are rusty-brown with a copper sheen. The ventral surface has an almost uniform gold sheen with some darker patches. The tail muscle is thick and tapers to a narrow point. The dorsal fin arches gradually to the midpoint of the tail and then tapers to a rounded tip. The ventral fin is not arched. A dense network of darker pigment is present on the dorsal fin and posterior half of the ventral fin. The description of the tadpole is drawn from Anstis (2017).

Distribution

Prior to the mid-1980s, the Booroolong Frog was considered to be extensively distributed and secure. The species was found on the tablelands and slopes of New South Wales (NSW), with a small distribution in north-eastern Victoria (Heatwole et al. 1995; Hunter & Gillespie 1999; Gillespie & Hunter 1999; Tyler & Knight 2011). The species was predominantly found along western-flowing streams and their headwaters at elevations from 200–1300 m (P Spark pers comm cited in OEH 2012). However, following a dramatic reduction in numbers in the 1980s and 1990s, only a small part of the distribution range is now occupied, and the species is found in low abundance at most remaining sites (Gillespie & Hines 1999; Gillespie & Hunter 1999; Gillespie 1999, 2000; Clemann 2003; Hunter 2007; Hunter et al. 2011; OEH 2012; Spark 2020a, 2020b). In particular, except for a small subpopulation near Glenn Innes in north-eastern NSW, the Booroolong Frog has disappeared from all high elevation streams (Rowley & Cutajar 2018; Spark 2020a). All subpopulations are separated by large areas of highly modified and unsuitable habitat (OEH 2012).

In 2012, *the National Recovery Plan for the Booroolong Frog - Litoria booroolongensis* (the recovery plan) identified 28 subpopulations of the Booroolong Frog inhabiting 55 streams across seven catchments (Namoi, Hunter, Manning, Central West, Lachlan, Murrumbidgee, and Murray) (OEH 2012). These subpopulations can be broadly grouped into three regions: Northern Tablelands, Central Tablelands, and Southern Tablelands (including two subpopulations in Victoria (Burrowye Creek and Koetong Creek) (Gillespie & Hunter 1999; OEH 2012).

Declines have been particularly severe in the Northern Tablelands, resulting in extirpation of most subpopulations. Those that remain are largely restricted to the southern end of the Northern Tablelands (Namoi, Hunter, and Manning catchments) (Gillespie 1999, 2000; Hunter 2007; OEH 2012) apart from a recently rediscovered subpopulation in the north, near Glen Innes (Rowley & Cutajar 2018). Recent drought (2017-20) has compounded these losses, with surveys revealing that the species is close to regional extinction in the Northern Tablelands (Spark 2020a, 2020b). In addition, surveys throughout the Central Tablelands (Central West and Lachlan catchments) have failed to locate the Booroolong Frog along many streams, suggesting numbers have declined and it is rare in the region (Gillespie & Hines 1999; Hunter 2007; Spark 2020a), and the species has not been recorded in the adjacent Hawkesbury-Nepean catchment since 1985 (OEH 2012). The majority of subpopulations are now found in the Southern Tablelands (Murrumbidgee and Murray catchments), occupying 27 streams (OEH 2012; Hunter & Smith 2013). However, the species is infrequently observed

(Hunter & Gillespie 1999), and a number of subpopulations are under threat of local extinction due to their small size and the risk of stream drying (Hunter & Smith 2006).

Relevant biology/ecology

Habitat

The Booroolong Frog lives exclusively along rocky sections of permanent streams in wet and dry forest, woodland, and cleared grazed land. The species is reliant on permanent running water and does not occupy ephemeral streams, or streams that have dried during severe drought (Hunter & Smith 2006; Hunter 2007; D Hunter unpub data cited in OEH 2012; Hunter & Smith 2013).

The Booroolong Frog has a strong preference for headwater streams in the 350–700 m elevation range that have gravel and rock rapids, riffles, and pools. Most records are from shallow sections of streams (10–20 cm depth) that are dominated by a range of rock sizes (from softball to football size) with exposed rock islands, and the species is positively associated with increasing abundance of aquatic rock crevices (Gillespie & Hunter 1999; Hunter 2007; Hunter & Smith 2013; Spark 2020a). Sites with high sunlight exposure, through the absence or limited number of riparian trees, are also favoured (Gillespie & Hunter 1999; Hunter 2007; Hunter & Smith 2013; Spark 2020a).

Breeding

The Booroolong Frog has a generalised reproductive strategy, which, together with a relatively long breeding period (October to early January) and high fecundity, allows the species to persist in less predictable environments (Gillespie 2011). During the breeding season, individuals move from their daytime sheltering sites to cobble banks and exposed rocks in or beside flowing water to call and mate but will often return to the same sheltering sites during the day. Females ovipost in rock crevices, laying around 1300 eggs in one or two rigid gelatinous clumps in shallow, slow-flowing sections of stream or isolated rock pools along the stream margins. Embryos hatch about seven or eight days later and metamorphosis occurs in 75 days in captivity (Gillespie 2011; Anstis 2017).

Behaviour

The Booroolong Frog is relatively sedentary and does not venture away from streams to the adjoining landscape outside of the breeding season (Spark 2020a). The majority of individuals move less than 50 m within a season, with maximum movements of 250 m having been recorded (Hunter 2001). However, radiotracking has revealed that individuals may undertake large movements of approximately 100 m in a day (G Liu unpub. data). During summer, the Booroolong Frog basks in the sun on exposed rocks near flowing water or shelters in crevices under rocks and logs or within grass in the riparian zone. Individuals are also found uphill from rivers in exposed rocky sections. During winter, juveniles and adults shelter together under rocks within the riparian zone (Heatwole et al. 1995; Hunter and Smith 2006; Hunter 2007; Cogger 2014; Anstis 2017, G Liu unpub. data).

Tadpoles are adapted to the riverine environment and are strong swimmers, able to withstand faster flowing water (Anstis 2017). They are generalist benthic grazers and feed on algae and other organic detritus (Inger 1986, cited in Hunter 2013). Tadpoles are able to tolerate variable water quality, being found in streams and streamside pools close to agricultural land. However, it is unknown whether subpopulations exposed to agricultural run-off are viable in the medium or long-term (Hunter 2007).

The Booroolong Frog population exhibits large annual fluctuations in abundance. This is likely related to a high annual adult mortality (over 90 percent) and variable recruitment through to sexual maturity. Hunter (2007) found that fluctuations in abundance are synchronised across different catchments, suggesting the species is strongly influenced by factors operating across the broader landscape, such as drought.

Threats

Table 1: Threats impacting the Booroolong Frog in approximate order of severity of risk, based on available evidence.

Threat factor	Threat type and status	Evidence base
Climate change		
Stream drying (drought)	Known current	Climate change is expected to cause a pronounced increase in extinction risk for frogs over the coming century (Hagger et al. 2013; Pearson et al. 2014). Climate projections for eastern Australia include reduced rainfall, increased average temperatures, and more frequent droughts (CSIRO 2007; CSIRO & Bureau of Meteorology 2015). The Booroolong Frog is particularly vulnerable to drought, being reliant on permanent flowing streams for breeding (Hunter & Smith 2006; Hunter 2007; Hunter & Smith 2013). During recent severe droughts, streams previously inhabited by the Booroolong Frog dried, with surveys revealing dramatic declines or absence of the species (Hunter & Smith 2006; Hunter et al. 2017; Spark 2020a, 2020b). In part, this vulnerability is a consequence of the species short generation length and high annual mortality (Hunter 2007), with failed recruitment over a one–two year period having the potential to result in subpopulation extirpation (D Hunter unpub. data cited in Hunter & Smith 2006 and OEH 2012). The length of stream occupied at a site serves as a useful measure of subpopulation resilience to drought. It reflects the extent of suitable habitat, with more habitat available the less susceptible the subpopulation is to local perturbations (Hunter & Smith 2006; OEH 2012). A length of 3 km or under is considered relatively short (Hunter 2007). Of the 55 streams occupied by the Booroolong Frog recorded in the 2012 recovery plan, 7 (13 %) are 1 km or shorter and 13 (24 %) are 3 km or shorter (OEH 2012). The limited availability of habitat for these subpopulations is compounded by the sedentary nature of the Booroolong Frog, with the species unable to relocate to more favourable habitat or for individuals to recolonise recently extirpated areas. In addition, the Booroolong Frog's resilience to drought is compromised by disease-driven population declines (see disease section, below) and the loss of refugia, brought about by agricultural practices (particularly water extraction and pastoralism) that have severely modified riparian habitat (Hunter & Smith 2006; Scheele et al. 2016; Hunter et al. 2018; Spark 2020a, 2020b).

Increased intensity/frequency of bushfire	Known current	The Booroolong Frog lives exclusively along permanent streams and is able to take refuge from fire, reducing the threat from direct contact. However, fire can adversely affect stream breeding habitat, increasing water temperature, altering water chemistry (Lyon & O'Connor 2008), and creating sediment/ash runoff "slugs" that can form in waterways following rainfall (Lyon & O'Connor 2008; Alexandra & Finlayson 2020). These slugs can fill in crevices in stream substrates, reducing the availability of refugia (Welsh & Ollivier 1998), and promote toxic algal blooms (Alexandra & Finlayson 2020) that can deoxygenate the water and cause egg and tadpole death. Sediment slugs can impact aquatic ecosystems up to 80 km downstream of burnt areas (Lyon & O'Connor 2008), greatly increasing the impact to stream dependent species outside of the immediate burnt area. In 2019-20, following years of drought (DPI 2020), catastrophic wildfire conditions culminated in fires that covered an unusually large area of eastern and southern Australia. The full impact of these bushfires has yet to be fully determined. However, an analysis by a team from the National Environmental Science Program (NESP) Threatened Species Recovery (TSR) Hub showed that a significant proportion of the range of the Booroolong Frog was affected, with 5 % burnt in high to very high severity fire, and a further 9 % burnt in low to moderate severity fire (Legge et al. 2021). Surveys immediately after the fire event indicate that some subpopulations have been severely impacted by a combination of fire, flood, and disease (West & Johnson 2020).
Disease		
Chytridiomycosis caused by the chytrid fungus	Known current	Chytridiomycosis is an infectious disease caused by the amphibian chytrid fungal pathogen *Batrachochytrium dendrobatidis* (*Bd)*. Infected populations exhibit diverse susceptibility to *Bd*. Some species do not exhibit any apparent symptoms while others are extremely vulnerable, resulting in mass die-off and extinction (DOEE 2016). Sick and dead Booroolong Frogs infected with *Bd* have been found in the wild on several occasions (D Hunter pers obs cited in OEH 2012), and the observed rapid decline of the species from the mid-1980s to the 1990s coincided with the disappearance of several other frog species along eastern NSW attributed to *Bd* (Berger et al. 1998; Berger et al. 2016), suggesting that *Bd* was primarily responsible (Hunter et al. 2018; Lemckert & Mahony 2018). This is supported by the near total loss of Booroolong Frogs at higher elevation sites, where cool, moist conditions are optimal for *Bd* growth (Ron 2005; Skerratt et al. 2007; Puschendorf

		et al. 2011; Sapsford et al. 2013; Berger et al. 2016; Lemckert & Mahony 2018). An experiment by Cashins et al (2013) demonstrated that prior exposure to *Bd* does not stimulate a protective adaptive immune response in the Booroolong Frog, with individuals being reinfected throughout the experiment. However, the survival of the majority of frogs in the experiment indicated existence of protective innate immunity, with 50 % of all frogs clearing infection (with 38 % never developing a detectable infection), 25 % maintaining a sublethal infection until the end of the experiment, and 25 % dying. *Bd* impacts have been observed to be most severe following metamorphosis (Berger et al. 1998, 1999, 2016; Garner et al. 2009), with mortality of adults and juveniles eroding the capacity of subpopulations to sustain recruitment losses associated with drought (see climate change section, above) and from predation of eggs and tadpoles by introduced fish (see invasive species section, below).
Habitat loss and fragmentation		
Loss of rocky habitat/habitat fragmentation	Known current	Widespread loss and degradation of rocky sections of permanent streams in the tablelands, slopes, and lowland regions of NSW and Victoria has been a major factor in the decline of the Booroolong Frog (Gillespie & Hines 1999, Hunter & Smith 2013; Hunter et al. 2018). The majority of the population occurs outside of reserves (National Parks and Wildlife Service estates) (OEH 2012; Hunter & Smith 2013) and is subject to disturbance. Since 2003, smothering of rocky crevices (through increased sedimentation and encroachment of woody weeds) has contributed to the loss of over 50 % of available breeding habitat along many streams occupied by the Booroolong Frog (Smith & Hunter 2008, cited in OEH 2012). Soil erosion, caused by primary industries (agriculture, mining, and forestry) and urban development (road construction and maintenance), as well as in-stream sediment disturbance by European carp (*Cyprinus carpio*) (Hunter & Smith 2006; Hunter 2007; OEH 2012), can blanket streambeds and fill the crevices in the rocky substrates used by the Booroolong Frog (Welsh & Ollivier 1998; Hunter 2007, Spark 2020a). The Booroolong Frog has been recorded alongside modified stream banks and tadpoles appear able to withstand a range of water quality. However, disturbance along many streams is an ongoing process. Change to water quality and the habitat may reach a threshold where the Booroolong Frog can no longer persist. In addition, subpopulations along modified sections of stream may be reduced in

		density, more fragmented, and hence more susceptible to stochastic events (Hunter & Smith 2006; Hunter 2007; OEH 2012).
Changes in hydrology	Known current	Stream structure, flow, and water quality are all reduced through river regulation (dams) and water extraction. Any reduction in stream-flow can increase the likelihood of stream drying during periods of drought and can increase sedimentation. In addition, the high degree of shading from dams and cold water releases can alter water temperatures downstream. Spark (2020a) recorded water temperature 5 °C colder downstream of Chaffey dam (Peel River) than at sites upstream. Colder water can inhibit the growth and development of tadpoles and native aquatic invertebrates (which form the base of the food chain), can favour exotic fish such as carp and trout, which predate egg and larval stages of the Booroolong Frog, and can enhance the growth of *Bd* (Hunter & Gillespie 1999; Hunter 2003, 2007; Hunter & Pietsch 2008; Hunter et al. 2011; Hunter et al. 2018). In addition, the sudden release of a large volume of dam water can flush eggs and tadpoles downstream (Gillespie & Hines 1999; Hunter 2007) to less favourable habitat.
Invasive species		
Predation by introduced fish	Known current	Fish are a major influence on amphibian assemblages, with the introduction of predatory fish having the potential to eliminate frog species (Gillespie & Hero 1999). Nearly all streams occupied by the Booroolong Frog are inhabited by a range of introduced fish species, including brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), European carp, goldfish (*Carassius auratus*), redfin perch (*Perca fluviatilis*), and mosquito fish (*Gambusia holbrooki*). Mosquito fish and carp are continuing to expand their range in areas occupied by the Booroolong Frog (D Hunter pers obs cited in OEH 2012). Experimental work has demonstrated that these species will eat Booroolong Frog eggs and tadpoles (Hunter 2003, 2007; Hunter & Pietsch 2008; Hunter et al. 2011; Hunter et al. 2018). The threat of predation is heightened as these fish species share a habitat preference with the Booroolong Frog for shallow, relatively slow-flowing sections of streams, and their occurrence in high densities in summer coincides with the hatching of tadpoles. In addition, the tadpoles have not evolved avoidance behaviour, as they are not consumed by native fish species (likely due to their unpalatability) (Hunter et al. 2011).

		Even low levels of predation of eggs and tadpoles by introduced fish could restrict the ability of the Booroolong Frog to compensate for *Bd*-induced mortality of adults and juveniles (Hunter 2007) (see disease section, above) and trout migration may spread novel strains of *Bd* (Hunter & Pietsch 2008).
Invasive weeds	Known current	The colonisation of the riparian zone by woody weeds, including willow (*Salix spp*.) and blackberry (*Rubus fruticosus*), has the potential to smother loose rocky habitat (see habitat loss section above) that is critical for Booroolong Frog reproduction and shelter (Hunter & Gillespie 1999; Hunter 2007; Hunter & Smith 2013). Encroachment of these weeds can also modify flow-regimes (Hunter & Gillespie 1999), create excessive shading of riparian areas used by basking frogs for thermoregulation, and reduce stream temperatures (Hunter and Smith 2013).
Habitat damage by domestic stock	Known current	The majority of the Booroolong Frog population is outside of reserves and occurs along streams flowing through freehold land (OEH 2012; Hunter & Smith 2013). These streams are susceptible to bank erosion from domestic cattle feeding and drinking at the streams edge, resulting in increased sedimentation (see habitat loss section, above).
Predation by feral cats (*Felis catus*).	Suspected Current	The extent of predation by the feral cat on the Booroolong Frog is unknown. However, a study by Woinarski et al. (2020) estimated that nearly 100 million native frogs are killed annually in Australia by the feral cat. Compounding this predation rate, the number of predators attracted to the area (Hradsky et al. 2017) and predator activity (Leahy et al. 2015) increase where habitat has been modified through frequent or intense burning (see climate change section, above).

How judged by the Committee in relation to the EPBC Act criteria and regulations

Criterion 1. Population size reduction (reduction in total numbers)
Population reduction (measured over the longer of 10 years or 3 generations) based on any of A1 to A4

	Critically Endangered Very severe reduction	Endangered Severe reduction	Vulnerable Substantial reduction
A1	**≥ 90%**	**≥ 70%**	**≥ 50%**
A2, A3, A4	**≥ 80%**	**≥ 50%**	**≥ 30%**

A1 Population reduction observed, estimated, inferred or suspected in the past and the causes of the reduction are clearly reversible AND understood AND ceased.

A2 Population reduction observed, estimated, inferred or suspected in the past where the causes of the reduction may not have ceased OR may not be understood OR may not be reversible.

A3 Population reduction, projected or suspected to be met in the future (up to a maximum of 100 years) [(*a) cannot be used for A3*]

A4 An observed, estimated, inferred, projected or suspected population reduction where the time period must include both the past and the future (up to a max. of 100 years in future), and where the causes of reduction may not have ceased OR may not be understood OR may not be reversible.

based on any of the following:

(a) direct observation [*except A3*]

(b) an index of abundance appropriate to the taxon

(c) a decline in area of occupancy, extent of occurrence and/or quality of habitat

(d) actual or potential levels of exploitation

(e) the effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites

Insufficient data to determine eligibility

Female Booroolong Frogs take two–three years to reach maturity (Gillespie 2000; Hunter 2001; G Gillespie unpub data cited in OEH 2012) and have a maximum age of four years (G Gillespie pers comm cited in OEH 2012; D Hunter unpub. data cited in OEH 2012).Therefore, the generation length is estimated to be three years. As three generations gives a nine year time scale, the default is a 10-year period for this criterion.

The Booroolong Frog population has severely declined since the mid-1980s (Gillespie & Hines 1999; Hunter & Smith 2006; Hansen & Crosby 2016; Hunter et al. 2018; Lemckert & Mahony 2018) and the species is estimated to have disappeared from half of its known range (Gillespie 1999, 2000). This decline began outside of the 10-year timeframe for evaluating a change in population size, but the decline appears to be ongoing, and the viability of many extant subpopulations is thought to be precarious due to their small size (Hunter & Smith 2006; Hunter 2007; OEH 2012). The timing of the early declines suggests that *Bd* was the primary cause (Hunter et al. 2018; Lemckert & Mahony 2018), but since 2003, the majority of the population decline is a result of drought and stream drying (Gillespie & Hines 1999; Hunter & Smith 2006; Hunter 2007; McFadden et al. 2010; OEH 2012; Hunter et al. 2020; Spark 2020a, 2020b). Monitoring programs have documented rapid declines and extirpation from streams that dried during the Millennium drought (2003-09) (Hunter & Smith 2006; Hunter et al. 2017) and the most recent drought (2017-20) (Spark 2020a, 2020b), which is the worst on record in many regions across NSW (Water NSW 2020).

Declines have been most severe on the Northern Tablelands, where the Booroolong Frog is found in five small subpopulations: two in the Namoi catchment (Cockburn River and Peel River), one in the Manning catchment (Barnard River), one in the Hunter Catchment (Isis River), and one recently rediscovered near Glen Innes. Surveys (2017-19) identified that the subpopulations in the Naomi and Manning catchments are close to local extinction, with the Peel River and Barnard River recorded as dry and the Cockburn River more than 90 percent dry with only a few large waterholes left (Spark 2020b). Intensive management (a captive breeding program and protection of the few small spring-fed sites where the frog has persisted) has been proposed to preserve the Booroolong Frog in the region (Spark 2020a).

The full impact of the 2019-20 bushfires on the Booroolong Frog has yet to be determined, but the population is very likely reduced. The fires may have accelerated any population decline, particularly in streams that dried during the drought and where shelter was restricted to a few waterholes. An analysis by a team from the NESP TSR Hub shows that a significant proportion of the range of the Booroolong Frog was affected by these fires: five percent was burnt in high to very high severity fire, and a further nine percent was burnt in low to moderate severity fire. A structured expert elicitation process was used to estimate the proportional population change for this species from pre-fire levels to immediately after the fire and then out to three generations after the fire, when exposed to fires of varying severity. These results, combined with the spatial analyses of fire overlap, suggest that one year after the fire, the species has experienced an overall decline of seven percent from pre-fire levels, but that the decline could be as large as 27 percent (bound of 80 percent confidence limits). After three generations, the estimate for the overall population decline relative to the pre-fire population is predicted to be 16 percent, but potentially as much as 44 percent (bound of 80 percent confidence limit). For comparison, experts also estimated the population change over time in the absence of fire, finding that by three generations the overall population of Booroolong Frogs after the fire to be one percent lower than it would have been had the 2019-20 fires not occurred (Legge et al. 2021).

Fire impact surveys for the species have yet to be conducted in NSW, but in Victoria, surveys have revealed the fires affected the Burrowye Creek subpopulation (distributed over Burrowye and Guy Forest creeks). At these sites, post-fire flooding buried the best breeding habitat in ash, mud, and other debris. Only three frogs were found during the surveys at Guy Forest Creek and none at Burrowye Creek. However, the timing of the surveys was after the peak of the breeding season and during tadpole development and metamorphling emergence. Therefore, further surveys are required to quantify the impact of the fires in both NSW and Victoria (West & Johnson 2020).

Despite these recent major disturbances, the size of the likely population reduction is uncertain. The Booroolong Frog has a reasonable capacity to recover from major population declines due to individuals rapidly reaching maturity and the high fecundity of adult females (Gillespie 2000; Hunter 2001; G Gillespie unpub data cited in OEH 2012; Hunter 2013). Due to this capacity, together with a lack of baseline data on the extent of the population decline over the last 10 year period (post the Millennium drought), and the relatively small overlap of the distribution range with 2019-20 fire affected areas (particularly by high to very high severity fire), the Committee considers that there is insufficient information to determine the eligibility of the species for listing in any category under this criterion.

Criterion 2.	**Geographic distribution as indicators for either extent of occurrence AND/OR area of occupancy**		
	Critically Endangered Very restricted	**Endangered Restricted**	**Vulnerable Limited**
B1. Extent of occurrence (EOO)	**< 100 km²**	**< 5,000 km²**	**< 20,000 km²**
B2. Area of occupancy (AOO)	**< 10 km²**	**< 500 km²**	**< 2,000 km²**
AND at least 2 of the following 3 conditions:			
(a) Severely fragmented OR Number of locations	**= 1**	**≤ 5**	**≤ 10**
(b) Continuing decline observed, estimated, inferred or projected in any of: (i) extent of occurrence; (ii) area of occupancy; (iii) area, extent and/or quality of habitat; (iv) number of locations or subpopulations; (v) number of mature individuals			
(c) Extreme fluctuations in any of: (i) extent of occurrence; (ii) area of occupancy; (iii) number of locations or subpopulations; (iv) number of mature individuals			

Eligible under Criterion 2 B2(a)(b)(i,ii,iii,iv,v)(c)(ii,iv) for listing as Endangered.

The Booroolong Frog is found on the ranges of eastern NSW and north-eastern Victoria (Gillespie & Hines 1999; Gillespie & Hunter 1999; Gillespie 1999, 2000; Clemann 2003; Hunter 2007; Hunter et al. 2011; OEH 2012), with the population broadly grouped into three regions: Northern Tablelands, Central Tablelands, and Southern Tablelands (Gillespie & Hunter 1999; OEH 2012).

Upper and lower plausible values for the geographic distribution of the Booroolong Frog are provided, which are estimated by mapping point records obtained from state governments, museums, and CSIRO. A plausible range for the geographic distribution is required as there is uncertainty over the extent of occurrence (EOO) and area of occupancy (AOO) of the species, resulting from the lack of a long-term systematic monitoring program, with parts of the former range (particularly the Northern Tablelands and eastern flowing streams) having had limited targeted surveys (OEH 2012). The EOO was calculated using a minimum convex hull, and the AOO calculated using a 2x2 km grid cell method, based on the IUCN Red List Guidelines 2014.

The upper plausible value reflects point records over an extended 40-year period (1979-2019). This crudely compensates for the lack of a systematic monitoring program by allowing additional records to be included in the estimates, particularly records prior to the *Bd*-induced population decline. However, only some of this habitat may now be occupied. The upper plausible value provides an EOO estimate of 234 956 km^2, and an AOO of 708 km^2.

The lower plausible value reflects point records over a 10-year period (2009-19). This is required as some aspects of the Booroolong Frog's biology and ecology make it particularly vulnerable to stochastic events, which can quickly reduce the species' geographic distribution. Over the last 10-years, the species has been impacted by severe drought (2017-20) across its entire distribution and the 2019-20 bushfires, with burnt areas overlapping with 14 percent of the distribution (see Criterion 1). The lower plausible value provides an EOO estimate of 50 104 km^2 and an AOO of 368 km^2.

The resulting plausible AOO range (368–708 km^2) is narrow and straddles the threshold for the Endangered and Vulnerable categories (500 km^2). Subsequently, a precautionary approach has been taken, and the AOO is determined to be restricted (< 500 km^2), meeting the threshold for listing as Endangered under subcriterion B2.

The case for being precautionary, and listing in the Endangered category, is strengthened by the lower plausible value including sites that have been extirpated by the recent drought (2017-20) (see Criterion 1) and other sites that are likely significantly impacted by the 2019-20 bushfires (both of these events occurred towards the end of the 10-year period that point records were taken). Further, the species' short generation length and high annual mortality contribute to the population rapidly responding to disturbance (IUCN Standards and Petitions Committee 2019), and, if the disturbance occurs over an extended period of time, can result in the extirpation of the species. Other aspects of the species population demographics also reduce the probability of the Booroolong Frog's continued occupancy at many sites following disturbance (Alford & Richards 1999). These include the isolation and small size of some subpopulations (increasing their susceptibility to local perturbations), and the location of most breeding sites, which are degrading as a consequence of occurring alongside streams flowing through freehold land in the agricultural landscape (Gillespie & Hines 1999; Gillespie & Hunter 1999; Gillespie 1999, 2000; Clemann 2003; Hunter 2007; Hunter et al. 2011; OEH 2012; Hunter & Smith 2013; Spark 2020a).

A location is defined by the IUCN Standards and Petitions Committee (2019) as a "geographically or ecologically distinct area in which a single threatening event can rapidly affect [in one generation or 3 years] all individuals of the taxon present [to the point that the population cannot recover in that location]". Under this definition, the proximity of sites is an important consideration. Sites that are close to each other experience more similar (more correlated) conditions over time than sites that are far away from each other. This is demonstrated by the patchy nature of bushfires across the landscape and the varying *Bd*-induced mortality rate along altitudinal gradients for many frog species. As the Booroolong Frog population is dispersed over

a relatively large area across the landscape, with AOO found in patches that are geographically separated from each other by wide expanses of either unoccupied or unsuitable habitat (OEH 2012), the entire population is unlikely to be impacted by the same threat, at the same level of severity, at the same time, such that it would decline to a level that recovery is unlikely.

However, the extent and severity of the recent drought (2017-20) and the 2019-20 bushfires has recalibrated the size of an area that can potentially be considered one location, particularly for species that have a biology and ecology that makes them more susceptible to these threats, such as the Booroolong Frog (see above). Recent surveys have revealed the extent of the impact of drought on the species, particularly in the Northern Tablelands where many subpopulations are close to extirpation (see Criterion 1), and analysis of the impact from the 2019-20 bushfires estimates an overall population decline of up to 27 percent from pre-fire levels one year after the bushfires (see Criterion 1).

Subsequently, the number of locations is assessed to be five, in line with the roughly grouped areas (detailed below) where records of the Booroolong Frog sites are found to be relatively contiguous, are of a size that could realistically be entirely burnt by high severity fire or impacted by a severe drought, and have little chance of recolonisation given their isolation from each other. This meets the threshold for listing as Endangered under subcriterion (a).

The five locations are:

1. Glenn Innes, NSW
2. Naomi catchment (Cockburn River and Peel River), Hunter catchment (Isis River), and Manning catchment (Barnard River)
3. Central West catchment (Sewell's Creek, Upper and lower Fish River, and Turon River) and Lachlan catchment (Abercrombie River)
4. Murrumbidgee catchment (Goobragandra River, Yarrangobilly River, Macpherson Swamp, and Mountain, Brungle, Bombowlee, Gilmore, Adelong, Yaven Yaven, Umbango, and Jounama creeks)
5. Murray catchment (Tooma River and Jingelic, Horse, Mannus, McCabe, Maragle, Burrowye, and Koetong creeks).

A continuing decline in EOO, AOO, extent and/or quality of habitat (and therefore number of locations or subpopulations), and number of mature individuals may be inferred based on the ongoing threats to the Booroolong Frog, primarily through habitat loss from drought (see Criterion 1) and changes to riparian zone structure (either directly or indirectly) from primary industries. Any action or event that reduces stream permanency (e.g. water extraction or climate change) or results in loss of rock crevices (e.g. smothering by weeds, sediment, or post-fire ash slugs), threatens the persistence of subpopulations of this species (OEH 2012). This supports an Endangered listing under subcriterion (b)(i,ii,iii,iv,v).

In addition, extreme fluctuations in frog abundance and AOO have been recorded at several sites that meet the threshold for listing as Endangered under subcriterion (c)(ii,iv). An extreme fluctuation is defined as occurring where "population size or distribution area varies widely, rapidly, and frequently, typically with a variation greater than one order of magnitude (a tenfold increase or decrease)" (IUCN Standards and Petitions Committee 2019). The Booroolong Frog population exhibits large annual fluctuations in abundance, which have trended downwards since the 1980s (see Criterion 1). This is likely related to this species high annual adult mortality and variable recruitment through to sexual maturity. Hunter (2007) observed that fluctuations in Booroolong Frog abundance appear to be synchronised across different catchments, suggesting the species is strongly influenced by factors operating across the broader landscape, such as drought. This is borne out by recent surveys in the Northern Tablelands (Spark 2020b) and Southern Tablelands (Hunter et al. 2020). In these surveys, frog abundance fluctuated widely (over several sites and across different catchments), rapidly (in the space of one or two generations), frequently (more than once at Coppabella Creek (lower) over a 12-year period), and at a greater than one order magnitude (at several sites). Recorded fluctuations in abundance mirrored the measured length of available rocky habitat (following drought) at

surveyed sites, which is a good approximation for likely AOO (see biology/ecology section, above).

In the Northern Tablelands, surveys on frog abundance in 2017 recorded 768 frogs across 30 sites. In 2019, surveys at the same sites recorded 17 frogs at three sites (27 sites were re-surveyed, with the other three sites recorded as dry and unsuitable habitat for Booroolong Frogs) (Spark 2020b). This represents a 10-fold (or greater) decrease in both number of mature individuals (768 to 17 individuals) and AOO (30 to three sites occupied). In the Southern Tablelands, surveys of frog abundance at four sites in the Murray catchment over a 14-year period (2005-2019) also demonstrated large and rapid fluctuations in numbers. At Coppabella Creek (lower), a low of under five individuals was recorded in 2008 (raw data not available), through to high of approximately 150 in 2011, before falling to approximately 10 individuals in 2019. This represents a fluctuation at over a 10-fold increase followed by a similar decrease over an 11-year period. Similar fluctuations (in magnitude) were recorded at Lankeys Creek, while at Jingellic Creek and Copabella Creek (upper), the order of magnitude was approximately six-fold (Jingellic Creek recorded 60 individuals in 2005, falling to 10 in 2019; Copabella Creek (upper) recorded 62 individuals in 2014, falling to 10 in 2019). The AOO (length of available rocky habitat) was also recorded at these sites. Coppabella Creek (lower) had a recorded minimum AOO of approximately 20 m in 2008 and a maximum of approximately 660 m in 2011, before falling to approximately 175 m in 2019. This represents a 33-fold increase in AOO followed by a nearly four-fold decrease over an 11-year period. Similar fluctuations were recorded at Lankeys Creek, while at Jingellic Creek, a three-fold decrease was recorded (360 m falling to 120 m from 2011 to 2019). Surveys at Coppabella Creek (upper) were over too short a time-period (2014-2019) to demonstrate a fluctuation in AOO (Hunter et al. 2020).

The Committee considers that the species' area of occupancy is restricted, and the geographic distribution is precarious for the survival of the species because the number of locations is restricted, and continuing decline in extent of occurrence, area of occupancy, habitat, number of locations and number of individuals may be inferred or projected, together with an extreme fluctuation in AOO and number of individuals. Therefore, the species has met the relevant elements of Criterion 2 to make it eligible for listing as Endangered.

Criterion 3. Population size and decline				
		Critically Endangered Very low	**Endangered Low**	**Vulnerable Limited**
Estimated number of mature individuals		**< 250**	**< 2,500**	**< 10,000**
AND either (C1) or (C2) is true				
C1	An observed, estimated or projected continuing decline of at least (up to a max. of 100 years in future)	**Very high rate 25% in 3 years or 1 generation (whichever is longer)**	**High rate 20% in 5 years or 2 generation (whichever is longer)**	**Substantial rate 10% in 10 years or 3 generations (whichever is longer)**
C2	An observed, estimated, projected or inferred continuing decline AND its geographic distribution is precarious for its survival based on at least 1 of the following 3 conditions:			
(a)	(i) Number of mature individuals in each subpopulation	**≤ 50**	**≤ 250**	**≤ 1,000**
	(ii) % of mature individuals in one subpopulation =	**90 – 100%**	**95 – 100%**	**100%**
(b)	Extreme fluctuations in the number of mature individuals			

Eligible under Criterion 3 C1 for listing as Vulnerable

The population size of the Booroolong Frog is estimated to be less than 5000 adults (DAWE 2020b), meeting the threshold for listing as Vulnerable.

Across the distribution range of the Booroolong Frog, a number of subpopulations are under threat of local extinction due to their small size and the risk of stream drying (see Criterion 1). Declines have been most severe on the Northern Tablelands, with subpopulations in the Naomi and Manning catchments close to the point of local extinction through stream drying during drought (2017-20) (P. Spark 2020b). Impacts from the drought have been exacerbated by the 2019-20 bushfires. Surveys conducted in Victoria have revealed post-fire flooding burying the best breeding habitat in ash, mud, and other debris at some sites (West & Johnson 2020), and analysis of the impact estimates an overall population decline of 16–44 percent from pre-fire levels over the next 10 years (see Criterion 1).

A precautionary approach on the extent of the population reduction has been taken as on-ground surveys following the 2019-20 bushfires have not been conducted in NSW and those in Victoria have not quantified the impact to the Booroolong Frog. Therefore, the Committee has inferred a significant cumulative decline of minimally 10 percent over the next 10 years, in-line with the NESP TSR Hub analysis, together with the threat posed by further stream drying through more frequent drought events, and the additive impacts from fish predation and *Bd*-infection on different life-stages (see Criterion 1). This meets the threshold for sub-criterion C1.

The Committee considers that the estimated total number of mature individuals of this species is limited with a projected continuing decline at a substantial rate. Therefore, the species has met the relevant elements of Criterion 3 to make it eligible for listing as Vulnerable.

Criterion 4. Number of mature individuals			
	Critically Endangered Extremely low	**Endangered Very Low**	**Vulnerable Low (Medium-term future)[1]**
Number of mature individuals	**< 50**	**< 250**	**< 1,000**
D2[1] Only applies to the Vulnerable category Restricted area of occupancy or number of locations with a plausible future threat that could drive the species to critically endangered or Extinct in a very short time	-	-	**D2.** Typically: area of occupancy < 20 km2 or number of locations ≤ 5

[1] The IUCN Red List Criterion D allows for species to be listed as Vulnerable under Criterion D2. The corresponding Criterion 4 in the EPBC Regulations does not currently include the provision for listing a species under D2. As such, a species cannot currently be listed under the EPBC Act under Criterion D2 only. However, assessments that demonstrate eligibility for listing under other criteria may include information relevant to D2. This information will not be considered by the Committee in making its assessment of the species' eligibility for listing under the EPBC Act, but may assist other jurisdictions to adopt the assessment outcome under the common assessment method.

Not eligible.

The population size of the Booroolong Frog is estimated to be less than 5000 adults (DAWE 2020b), which is not considered low. Therefore, the species has not met this required element of the criterion.

Criterion 5. Quantitative Analysis			
	Critically Endangered Immediate future	**Endangered Near future**	**Vulnerable Medium-term future**
Indicating the probability of extinction in the wild to be:	**≥ 50% in 10 years or 3 generations, whichever is longer (100 years max.)**	**≥ 20% in 20 years or 5 generations, whichever is longer (100 years max.)**	**≥ 10% in 100 years**

Insufficient data to determine eligibility.

Population viability analysis has not been undertaken and there are insufficient data to demonstrate the probability of extinction in the wild and whether the species is eligible for listing under this criterion.

Conservation actions

Recovery plan

The National *recovery plan for Booroolong Frog Litoria booroolongensis* (OEH 2012) was developed by the NSW state government and adopted under the EPBC Act in 2012. It is due to expire in 2022.

The Committee recommends that following expiry of the existing recovery plan, a new national recovery plan for *Litoria booroolongensis* is not required as it would not have a significant conservation benefit above existing mechanisms. An approved conservation advice provides sufficient direction to implement priority actions and mitigate against key threats.

Primary conservation actions

1. Habitat loss, disturbance, and modifications

    - Use species distribution and habitat modelling to identify habitat critical to survival (high probability/high quality for the species) and key population areas. Ensure this habitat is protected from disturbances that undermine its suitability for the species.
    - Protect environmental flow regimes to enhance breeding opportunities for the Booroolong Frog, by
        - liaising with water management authorities in each catchment to ensure that any potential stream works (diversions and impoundments) and maintenance works (de-silting of water storages) do not affect Booroolong Frog habitat, do not degrade water quality, and do not substantially affect current flow regimes.
        - limiting direct pumping of water from streams during drought periods.
        - limiting the proportion of catchment converted to forestry plantations to ensure persistence of surface water flows.
    - Minimise sediment load from entering waterways due to poor road construction and maintenance, inappropriate use of heavy machinery in the riparian zone, and soil ripping over a large area.
    - Remove weeds and undertake habitat restoration works to support the regeneration of streambank habitat. Note: this should be undertaken by cutting and pasting/painting methods, as herbicide formulations can be toxic to frogs and tadpoles, particularly if they contain glyphosate and surfactants (Mann et al. 2003).

- Designate protection zones around all known breeding sites to ensure habitat is not further fragmented by timber harvesting or clearing of freehold land.
- Monitor all compliance with relevant prescriptions relating to roading and timber harvesting in Booroolong Frog catchments.
- Investigate options for enhancing the resilience of the species' current habitat to climate change and options for providing new habitat that would be suitable for the species under climate change scenarios.

2. 2019-20 bushfire response

- Conduct on-ground surveys to establish the extent of population response to the 2019-20 bushfires and to provide a baseline for ongoing monitoring. The design of the monitoring program should reflect considerations in Southwell (2020).
- In the aftermath of the bushfires, protect unburnt areas within or adjacent to recently burnt areas from further fire, in order to provide refuge sites, as well as protecting (from fire) unburnt areas that are not adjacent to burnt areas.
- Control introduced predators to support the recovery of populations affected by fires or populations near areas that have been affected by fire.
- Control introduced herbivores and remove weeds to support the regeneration of streambank habitat at some localised sites.
- Establish the impact of fire retardants, used to fight bushfires, on frog populations.

Conservation and management priorities

Invasive species (including threats from grazing, trampling, predation)

- In areas burnt by the 2019-20 bushfires, control introduced species (including predators, herbivores, and weeds) to support population recovery.
- Prevent the introduction and reduce populations of invasive and native predators (including introduced and native fish outside of their natural range) in streams where these species occur.
    - Restrict trout stocking in streams supporting self-sustaining trout populations and restrict the release of trout into streams that currently do not support self-sustaining trout populations. As the Booroolong Frog is compromised by trout predation, eradication programs should be considered.
- Undertake removal and control of willow and blackberry along sections of stream supporting Booroolong Frog populations.

Impacts of domestic species

- Use fencing, or other measures where applicable, to reduce the access of domestic stock, where required.

Disease

- Investigate measures for minimising the impact of *Bd* on Booroolong Frog subpopulations. In particular:
    - Conduct research into mechanisms of frogs' resistance to *Bd*, with any identified mechanisms considered to be used in selective breeding methods to produce resistant frogs for release.

- Investigate availability of *Bd* refuge sites, either within or outside of the natural known range of the species.
- Investigate the role of co-occurring species, acting as reservoir species for *Bd*, in driving Booroolong Frog declines.

- Minimise the spread of *Bd*.
  - implement suitable hygiene protocols (Murray et al. 2011) to protect priority populations as described in the threat abatement plan for infection of amphibians with chytrid fungus resulting in chytridiomycosis (DOEE 2016).
  - Provide disease identification and prevention protocols (methods of handling, diagnostic keys, etc.) to researchers and land managers for use in the field.

Stakeholder Engagement

- Educate landowners and managers of the importance of maintaining riparian habitat and the integration of habitat protection into land management regulations.
- Provide input into the various impact assessment and planning processes on measures to protect the Booroolong Frog and its habitat. These include water resource plans, park management plans, and environmental impact assessments.
- Engage interested nature conservation, land management, and land holder groups in conservation management activities and citizen science projects, such as non-invasive monitoring through the FrogID project. Carefully managed activities to prevent disturbance to frogs (particularly in breeding season) and participants should be made aware of the need to follow correct field practices and hygiene protocols to mitigate the risks of trampling and disease transmission. If necessary, use workshops to aid stakeholders in developing the skills and knowledge required to manage threats to this species while undertaking these activities.
- Increase community awareness about the status, threatening processes, and conservation of the Booroolong Frog, particularly in areas where this species occurs along streams flowing through privately owned or managed properties.

Survey and Monitoring priorities

- Monitor the species to detect any change in populations and understand how different subpopulations are responding in different environmental and management settings and in response to various threats or ecological loads. As detailed in Hunter (2007), monitoring should be a combination of raw counts by spotlighting (to monitor shifts in the abundance of the Booroolong Frog) and mark-recapture (to identify which life-history stages and external factors are contributing to change in abundance).
- Regularly review the monitoring program to ensure that the number of sites being monitored is adequate.
- Assess the population size, distribution, and long-term trends using the established modelling and analytical methods. Develop models to evaluate critical life history stages and the roles of key threatening processes.
- Survey sites within the known distribution range of the species where the environment is considered likely to be suitable for the species to identify whether populations exist that are previously unknown. Ensure that surveys are conducted when detection is most likely (peak calling period occurs between October and early January).

Information and research priorities

- Determine genetic variability and structure within and amongst Booroolong Frog subpopulations to inform management and recovery priorities.
- Identify all potential threatening processes that may have affected the species distribution and abundance, then evaluate their relative contribution to the decline and impediment to recovery. In particular:
    - Understand the influence of climate change on the long-term survival prospects of the species due to altered rainfall patterns, temperatures, bushfires, and diseases, through maintaining robust population and environmental monitoring.
    - Understand the influence of disturbance on the long-term survival prospects of the species due to increased sedimentation, pollutants (including agricultural run-off), and change to riparian vegetation, through maintaining robust population and environmental monitoring.
    - Monitor fish populations at sites to determine the influence of invasive fish population dynamics on frog population dynamics, including the increased risk of *Bd*-infection.
    - Improve understanding of the extent and impact of infection by *Bd* on the Booroolong Frog to better inform how to apply existing or new management actions relevant to the recovery.
- Investigate options for linking, enhancing, or establishing additional subpopulations.

Captive breeding/re-establish populations

- Develop, undertake, and support captive management, where required. Lessons learnt from previous captive breeding efforts should inform future actions. Where not deemed a threat to survival, monitor the dispersal and movements of individuals via mark-recapture methods, radio tracking, or genetic methods.

Recommendations

(i) The Committee recommends that *Litoria booroolongensis* be retained in its current listing status of Endangered in the list referred to in section 178 of the EPBC Act as there is insufficient evidence to support transferring it to a different category and inclusion of the species in that category is having a beneficial impact on the continued survival of the species.

(ii) The Committee recommends that there not be a recovery plan for this species.

Threatened Species Scientific Committee

25/02/2021

References cited in the advice

Alexandra J & Finlayson M (2020). Floods after bushfires: rapid responses for reducing impacts of sediment, ash, and nutrient slugs. *Australasian Journal of Water Resources*. DOI: 10.1080/13241583.2020.1717694

Alford RA & Richards SJ (1999). Global amphibian declines: A problem in applied ecology. *Annual Review of Ecology and Systematics 30*, 133-165

Anstis M (2017). *Litoria booroolongensis* in *Tadpoles and frogs of Australia*, 2nd edition. New Holland Publishers, Australia. pp 159-161.

Berger L, Speare R, Dasak P, Green DE, Cunningham AA, Goggin CL, Slocombe R, Ragan MA, Hyatt AD, McDonald KR, Hines HB, Lips KR, Marantelli G, & Parkes H (1998). Chytridiomycosis causes amphibian mortality associated with population declines in the rainforests of Australia and Central America. *Proceedings of the National Academy of Science USA* 95, 9031-9036.

Berger L, Spear R, & Hyatt AD (1999) Chytrid Fungi and Amphibian declines: overview, implications and future directions in *Declines and disappearances of Australian frogs*. Environment Australia. pp 23-33.

Berger L, Roberts AA, Voyles J, Longcore JE, Murray KA, & Skerratt LF (2016). History and recent progress on chytridiomycosis in amphibians. *Fungal Ecology* 19, 89-99.

Clemann N (2003). Action Statement 118 - Booroolong Frog *Litoria borroolongensis*. Victorian Department of Sustainability and Environment.

Cogger HG (2014). *Litoria booroolongensis* in *Reptiles and Amphibians of Australia, 7th edition*. CSIRO Publishing, Collingwood, Victoria. pp 152.

Cashins SD, Grogan LF, McFadden M, Hunter D, Harlow PS, Berger L, & Skerratt LF (2013). Prior infection does not improve survival against the amphibian disease chytridiomycosis. *PLoS ONE* 8(2): e56747. doi:10.1371/journal.pone.0056747. Available at: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0056747

Garner T, Walker S, Bosch J, Leech, S, Rowcliffe J, Cunningham A, & Fisher M (2009). Life history tradeoffs influence mortality associated with amphibian pathogen *Batrachochytrium dendrobatidis*. *Oikos* 118, 783-791.

Gillespie, G. R. (1999). Survey of the distribution and habitat of the Booroolong frog *Litoria Booroolongensis* on the south-western slopes of the Great Dividing Range in New South Wales. Report to the NSW National Parks and Wildlife Service, Queanbeyan. Arthur Rylah Institute, Department of Natural Resources and Environment, Victoria.

Gillespie, G. R. (2000). Survey, monitoring and management of the Booroolong Frog and Spotted Tree Frog in New South Wales. Report to the NSW National Parks and Wildlife Service, Queanbeyan. Arthur Rylah Institute, Department of Natural Resources and Environment, Victoria.

Gillespie GR & Hunter DA (1999). The Booroolong Frog *Litoria booroolongensis* Moore 1961 (Anura: Hylidae): an addition to the frog fauna of Victoria. *Victorian Naturalist* 116(3), 112-

114. Available at: https://www.biodiversitylibrary.org/item/123989#page/116/mode/1up viewed: 12 August 2020

Gillespie GR (2011). Egg compliment variation amongst temperate stream-breeding Hylid frogs in south-eastern Australia. *Proceedings of the Royal Society of Victoria* 123, 153-160.

Gillespie GR & Hero JM (1999). Potential impacts of introduced fish and fish translocations on Australian amphibians in A Campbell (ed) D*eclines and disappearance of Australian frogs.* Environment Australia, Canberra. pp 131-144. Viewed: 21 May 2020 Available at: https://www.environment.gov.au/system/files/resources/7de68015-f93b-4064-bed6-b2e21d16b5bd/files/frogs.pdf#page=131

Gillespie GR & Hines H (1999). Status of temperate riverine frogs in southeastern Australia in A Campbell (ed) D*eclines and disappearance of Australian frogs.* Environment Australia, Canberra. pp 109-130.

Hagger V, Fisher D, Schmidt S & Blomberg S (2013). Assessing the vulnerability of an assemblage of subtropical rainforest vertebrate species to climate change in south-east Queensland. *Austral Ecology* 38, 464-475.

Hansen N & Crosby K (2016). Habitat used of the threatened Booroolong Frog (*Litoria booroolongensis*) in the Central West Catchment Management Area. *Australian Zoologist* 38(2), 161-170

Hradsky BA, Mildwaters C, Ritchie EG, Christie F & Di Stefano J (2017) Responses of invasive predators and native prey to a prescribed forest fire. *Journal of Mammalogy* 98, 835-847.

Heatwole H, De Bavay J, Webber P, & Webb G (1995). Faunal survey of New England. IV. The frogs. *Memoirs of the Queensland Museum* 38, 229-249. Viewed: 20 May 2020 Available at: https://www.biodiversitylibrary.org/item/123808#page/1/mode/1up

Hunter D (2001). Surveys and monitoring of threatened frog species in south-eastern New South Wales between October, 2000 and March, 2001. Unpublished report to the NSW National Parks and Wildlife Service.

Hunter D (2003). Potential impact of introduced trout on the Booroolong Frog (*Litoria booroolongensis* Moore 1961): results from experiments testing palatability and predation in artificial encolsures. Unpublished report to the NSW Fisheries.

Hunter D (2007). Conservation management of two threatened frog species in south-eastern New South Wales, Australia. PhD thesis, University of Canberra.

Hunter D (2013). Booroolong Frog - Species Information Sheet. Provided to the Department of Sustainability, Environment, Water, Population and Communities.

Hunter D, Clemann N, Coote D, Gillespie G, Hollis G, Scheele B, Philips & West M (2018). Frog declines and associated management response in south-eastern mainland Australia and

Tasmania in H Heatwole & JJL Rowley (eds) Status of conservation and decline of amphibians Austr*alia, New Zealand, and Pacific Islands*. CSIRO publishing, Clayton South. pp 39-58.

Hunter D & Gillespie GR (1999). The distribution, abundance and conservation status of riverine frogs in Kosciuszko National Park. *Australian Zoologist* 31, 198-209.

Hunter D & Pietsch R (2008). Assessing the population status of the endangered Booroolong Frog (*Litoria booroolongensis*) in area subject to non-native trout stocking. Unpublished report to the NSW Department of Primary Industries.

Hunter DA & Smith M (2006). Survey, habitat assessment and management recommendations for the endangered Booroolong Frog (*Litoria booroolongensis*) in the Murray Catchment Management Area of NSW. Murray Catchment and Management Authority.

Hunter DA, Smith MJ (2013). Multiscale habitat assessment for the endangered Booroolong frog (*Litoria booroolongensis*): implications for threatened species management in the rural landscape of siutheastern Australia. *Herpetological Conservation and Biology* 8(1), 122-130.

Hunter DA, Smith MJ, Scroggie MP, & Gilligan D (2011). Experimental examination of the potential for three introduced fish species to prey on tadpoles of the endangered Booroolong Frog, *Litoria booroolongensis*. *Journal of Herpetology* 45(2), 181-185.

Leahy L, Legge SM, Tuft K, McGregor HW, Barmuta LA, Jones ME, & Johnson CN (2015). Amplified predation after fire suppresses rodent populations in Australia's tropical savannas. *Wildlife Research* 42, 705-716.

Lemckert FL & Mahony M (2018). The status of decline and conservation of frogs in temperate coastal south-eastern Australia in H Heatwole & JJL Rowley (eds) *Status of conservation and decline of amphibians Australia, New Zealand, and Pacific Islands*. CSIRO publishing, Clayton South. pp 59-72.

Lemckert FL & Penman TD (2012). Climate change and Australia's frogs: how much do we need to worry? in D Lunney & P Hutchings (eds) *Wildlife and climate change: towards robust conservation strategies for Australian fauna*. Mosman, New South Wales. pp 92-98.

Lyon JP & O'Connor JP (2008). Smoke on the water: Can riverine fish populations recover following a catastrophic fire-related sediment slug? *Austral Ecology* 33, 794–806.

Mahony, M. (1999). Review of the declines and disappearances within the bell frog species group (*Litoria aurea* species group) in Australia. In: A. Campbell (ed). *Declines and disappearances of Australian frogs*. Canberra: Environment Australia. pp 81-93.

Mann RM, Bidwell JR & Tyler MJ (2003). Toxicity of herbicide formulations to frogs and the implications for product registration: a case study from Western Australia. *Applied Herpetology* 1, 13-22.

McFadden M, Hunter D, Harlow P, Pietsch R, & Scheele B (2010). Captive management and experimental re-introduction of the Booroolong Frog on the South Western Slopes region, New South Wales, Australia in P Soorae (ed) Global re-introduction perspectives: 2010. IUCN. pp 77–80.

McGregor H, Legge S, Jones ME, & Johnson CN (2015) feral cats are better killers in open habitats, revealed by animal-borne video. *PLoS ONE* 10, e0133915.

Pearson RG, Stanton JC, Shoemaker KT, Aiello-Lammens ME, Ersts PJ, Horning N, Fordham DA, Raxworthy CJ, Ryu HY, McNees J & Akçakaya HR (2014). Life history and spatial traits predict extinction risk due to climate change. *Nature Climate Change* 4. pp 217–221.

Penman TD, Lemckert FL & Mahony MJ (2006). A preliminary investigation into the potential impacts of fire on a forest dependent burrowing frog species. *Pacific Conservation Biology* 12(1), 78-83.

Puschendorf R, Hoskins CJ, Cashins SD, McDonald K, Skerratt LF, Vanderwal J, & Alford RA (2011). Environmental refuge from disease-driven amphibian extinction. *Conservation Biology* 25, 956-964.

Ron S (2005). Predicting the distribution of the amphibian pathogen *Batrachochytrium dendrobatidis* in the New World. *Biotropica* 37, 209-221.

Rowley JJL & Cutajar TP (2018) Rediscovery of the Booroolong Frog *Litoria booroolongensis* on the Australian New England Tablelands after more than 40 years. *Herpetological Review* 49, 620-621.

Sapsford SJ, Alford RA, Schwarzkopf L (2013). Elevation, temperature, and aquatic connectivity all influence the infection dynamics of the amphibian chytrid fungus in adult frogs. *PLoS ONE* 8(12), 1-12.

Scheele BC, Hunter DA, Banks SC, Pierson JC, Skerratt LF, Webb R, & Driscoll DA(2016). High adult mortality in disease-challenged frog populations increases vulnerability to drought. *J Anim Ecol* 85, 1453-1460.

Skerratt LF, Berger L, Speare R, Cahsins SD, McDonald KR, Phillott AD, Hines HB, Kenyon N (2007). Spread of Chytridiomycosis has caused the rapid global decline and extinction of frogs. *EcoHealth* 4, 125-134.

Skerratt LF, Berger L, Clemann N, Hunter DA, Marantelli G, Newell DA, Philips A, McFadden M, Hines H, Scheele BC, Brannelly LA, Speare R, Versteegen S, Cahsins SD, & West M (2016). Priorities for management of chytridiomycosis in Australia: saving frogs from extinction. *Wildlife Research* 43, 105-120.

Tyler MJ & Knight F (2011). A field guide to the frogs of Australia. CSIRO, Collingwood, Victoria. pp 54-55.

Welsh HHJ & Ollivier LM (1998). Stream amphibians as indicators of ecosystem stress: a case study from California's redwoods. *Ecological Applications* 8, 1118-1132.

Woinarski JCZ, Legge SM, Woolley LA, Palmer R, Dickman CR, Augusteyn J, Doherty TS, Edwards G, Geyle H, McGregor H, Riley J, Turpin J, Murphy BP (2020). Predation by introduced cats *Felis catus* on Australian frogs: compilation of species records and estimation of numbers killed. *Wildlife Research*

Other sources cited in the advice

CSIRO (2007). Climate Change in Australia. Viewed: 26 February 2020 Available at: http://www.climatechangeinaustralia.gov.au/

CSIRO and Bureau of Meteorology (2015). Climate Change in Australia Information for Australia's Natural Resource Management Regions: Technical Report, CSIRO and Bureau of Meteorology, Australia.

DAWE (Department of Agriculture, Water and the Environment) (2020b). *Litoria booroolongensis* in Species Profile and Threats Database, Department of the Environment, Canberra. Viewed 21 May 2020 Available at: http://www.environment.gov.au/sprat.

DOEE (Department of the Environment and Energy) (2016). Threat abatement plan for infection of amphibians with chytrid fungus resulting in chytridiomycosis, Commonwealth of Australia 2016.

DPI (NSW Department of Primary Industries) (2020). Drought in NSW. Viewed: 13 February 2020 Available at: https://www.dpi.nsw.gov.au/climate-and-emergencies/droughthub/drought-in-nsw

Hunter D, Coote D, & Briggs J (2020). Fish, frogs, and fresh flowing water (MERI Plan). Saving Our Species program, NSW Office of Environment & Heritage. pp 1–68

IUCN Standards and Petitions Committee (2019). Guidelines for Using the IUCN Red List Categories and Criteria. Version 14. Prepared by the Standards and Petitions Committee. Available from http://www.iucnredlist.org/documents/RedListGuidelines.pdf

Legge S, Geyle H, Garnett S, Rumpff L, Whiterod N, Nimmo D, Woinarski J, Scheele B, Southwell D, & Ward M (2021). Effects of fire severity on the response of populations of priority wildlife species. National Environmental Science Programme (NESP) Threatened Species Recovery (TSR) Hub project 8.3.2. Australian Government Department of Agriculture, Water and the Environment, Canberra. Manuscript in preparation.

OEH (NSW Office of Environment & Heritage) (2012). National Recovery Plan for Booroolong Frog (*Litoria booroolongensis*) Office of Environment and Heritage (NSW), Hurstville. Viewed: 19 May 2020 Available at:

http://www.environment.gov.au/system/files/resources/bb38ec60-bdea-43db-8fbd-4b28a0af6fca/files/litoria-booroolongensis.pdf

Southwell D (2020). Design considerations for post natural disaster (fire) on-ground assessment of status of species, ecological communities, habitats and threats. Threatened Species Recovery Hub. Viewed: 28 May 2020 Available at: http://www.environment.gov.au/system/files/pages/a8d10ce5-6a49-4fc2-b94d-575d6d11c547/files/draft-post-fire-rapid-assessment-guide.pdf

Spark P (2020a). Expert review of the likely impact to the Booroolong Frog resulting from the Peel River Drought Protection Works Project, Tamworth in *GHD report for WaterNSW – WaterNSW Peel River Drought Project*.

Spark P (2020b). Incomplete summary of 2019 Booroolong Frog surveys to determine the impact of the severe drought on the frog population. In possession of author, Queensland.

Water NSW (2020). Regional Drought Report (June 2020). Viewed: 6 August 2020 Available at: https://www.waternsw.com.au/__data/assets/pdf_file/0019/159400/Regional-Drought-Report-June-2020.pdf

West M & Johnson G (2020). BBRER Theme 1: Immediate reconnaissance - Activity 2: Threatened reptiles and frogs. Post-fire assessment report: Spotted Tree Frog & Booroolong Frog. Bushfire Biodiversity Response and Early Recovery Program. Department of Environment, Land, Water and Planning, Hume Region, NE Victoria & University of Melbourne.