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Predation by introduced cats *Felis catus* on Australian frogs: compilation of species' records and estimation of numbers killed.

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Running head: Predation by cats on frogs

Key words: amphibian; diet; feral cats; invasive predator

Abstract

Context

We recently estimated the numbers of reptiles, birds and mammals killed by cats (*Felis catus*) in Australia, with these assessments providing further evidence that cats have significant impacts on Australian wildlife. No previous studies have estimated the numbers of frogs killed by cats in Australia and there is limited comparable information from elsewhere in the world.

Aims

We sought to: (i) estimate the numbers of frogs killed by cats in Australia and (ii) compile a list of Australian frog species known to be killed by cats.

Methods

For feral cats, we estimated the number of frogs killed from information on their frequency of occurrence in 53 cat dietary studies (that examined stomach contents), the mean number of frogs in dietary samples that contained frogs, and the numbers of cats in Australia. We collated comparable information for take of frogs by pet cats, but the information base was far sparser.

Key results

Frogs were far more likely to be reported in studies that sampled cat stomachs than cat scats. The mean frequency of occurrence of frogs in cat stomachs was 1.5%. The estimated annual *per capita* consumption by feral cats in Australia's natural environments is 44 frogs, and hence the annual total take is estimated at 92 million frogs. The estimated annual *per capita* consumption by pet cats is 0.26 frogs, for a total annual kill of one million frogs by pet cats. Thirty native frog species (13% of the Australian frog fauna) are known to be killed by cats: this tally does not include any of the 51 threatened frog species, but this may simply be because no cat dietary studies have occurred within the small ranges typical of threatened frog species.

Conclusions

This study indicates that cats in Australia kill nearly 100 million frogs annually, but further research is required to understand the conservation significance of such predation rates.

Implications

This study completes a set of reviews of the impacts of cats on Australian terrestrial vertebrates. Cat predation on Australian frogs is substantial but is likely to be markedly less than that on Australian reptiles, birds and mammals.

Short summary

Cats have a significant detrimental impact on the Australian reptile, bird and mammal faunas, but no previous studies have examined the extent of cat predation on Australian frogs. We estimate that cats in Australia kill about 93 million frogs per year, and compile records of cat predation on 30 Australian frog species. However, this extent of predation is notably less than that by cats on reptiles, birds and mammals.

Introduction

Domestic cats *Felis catus* were introduced to Australia in 1788 (Abbott 2008). With many further introductions and natural spread (Abbott 2008; Abbott *et al.* 2014), feral cats now occupy the entire Australian mainland and about 100 islands, including most of the largest islands (Legge *et al.* 2017). Feral cats have been implicated in the extinction and decline of many Australian mammals (Woinarski *et al.* 2015; Radford *et al.* 2018) and some birds (Garnett *et al.* 2011; Woinarski *et al.* 2017a) and the decline of some reptiles (Woinarski *et al.* 2018; Chapple *et al.* 2019). Partly because of such concern about their impacts on Australian wildlife, there are now many studies that have examined the diet of feral cats across Australia, and many local estimates of cat density, allowing for reasonably robust continental scale assessment of the total number of individual animals killed per year by cats: in a series of linked analyses, we have estimated that cats in Australia kill about 1,144 million mammals (Murphy *et al.* 2019), 377 million birds (Woinarski *et al.* 2017a) and 649 million reptiles (Woinarski *et al.* 2018) per year. The large series of cat dietary studies has also allowed for the compilation of inventories of the species killed by cats, with these demonstrating that cats are known to consume at least 170 Australian native mammal species (59% of the extant fauna), 338 bird species (46%) and 258 reptile species (26%) (Woinarski *et al.* 2017b; Woinarski *et al.* 2018; Woolley *et al.* 2019).

There has been notably less concern about the impacts of cats on Australia's frog fauna, and cat predation is not generally held to be a major threat to this fauna, at least relative to widely recognised and more acute threats, such as chytrid fungus and habitat degradation (Scheele *et al.* 2019). Furthermore, although introduced animal species are considered a major cause of the decline of many threatened amphibian species (Chanson *et al*. 2008), cats are not widely recognised as a major threat to frogs at global scale. For example, a representative global review of predation on frogs collated records of 137 anuran species reported as prey of 136 vertebrate species, but none of these predation records were by cats (Toledo *et al*. 2006). Likewise, a global review of cats as a threat to threatened island vertebrates concluded that detrimental impacts of introduced cats had been reported for 25 reptile, 123 bird and 27 mammal species, but no frog species, and that feral cats on islands were responsible for at least 14% of global reptile, bird and mammal extinctions, but no frog extinctions (Medina *et al*. 2011). Another global review reported records of cats on islands consuming 179 vertebrate species, of which only three were amphibian species, and that mammals and birds contributed most of the food reported for cats (Bonnaud *et al*. 2011).

However, frogs form a large part of the diet of some small felid species (e.g., the Iriomote cat *Prionailurus bengalensis iriomotensis*) (Nakanishi and Izawa 2016), and cats in Australia are known to consume frogs, sometimes in large numbers. For example, McGregor *et al.* (2017) reported 70 individual frogs in the stomach of a single feral cat in north-eastern Queensland. Furthermore, studies applying recent developments in animal-borne video cameras suggest cat predation of frogs may have been overlooked or under-estimated in previous dietary sampling (McGregor *et al.* 2015; Hernandez *et al.* 2018).

One potential problem with estimating the extent of predation on frogs, relative to other vertebrates, is that frogs that are consumed may not be readily detectable in predator stomach or scat sampling. This is because frogs do not possess hard keratinised material (Egeter *et al*. 2015a), whereas the fur, scales or feathers of other vertebrate groups may be far more persistent and detectable in such samples. Egeter *et al*. (2015a, 2019) used DNA based diet analyses to demonstrate that conventional (morphological) assessment of the incidence of frogs in predator stomachs and scats severely under-estimated the extent of predation on frogs in New Zealand, with laboratory studies using frogs fed to predators concluding that only about 2% of consumed frogs were detected in morphological inspection of predator stomach samples. However, the predators used in those studies were rats (*Rattus norvegicus* and *R. rattus*), house mice *Mus musculus* and hedgehogs *Erinaceus europaeus*, all of which masticate their prey intensely before it enters the digestive tract, leaving few physical traces evident in stomach or scat analyses (Egeter *et al*. 2019).

However, such under-estimation of frogs in dietary samples is far less likely for predation by cats. As described by Hetherington *et al*. (2007), the dentition of cats is notably different to these other predators, and hence consumed prey items are far more detectable and identifiable in stomach samples: "In cats the canines are long and the carnassial teeth are highly specialised and adapted to cutting and shearing, as are the molars. Therefore, none of the teeth are suitable for chewing. The loss of grinding premolars in cats has reduced their chewing efficiency and led to their propensity to swallow relatively larger portions of food and inert material such as bone. The tendency to swallow large portions of food has been confirmed in dietary studies of feral cats" (Hetherington *et al*. 2007, p. 468, citations omitted). Many prey items, especially those of the size of most frogs, are swallowed whole by cats (Brooker 1977), or in large enough chunks to allow ready detection in stomach sampling.

Here we use the large existing set of cat dietary studies in Australia, previously compiled to consider the predation rates on birds, reptiles and mammals, to provide an assessment of the extent of predation by cats on Australian frogs, and the possible impacts of such predation. We consider that it would be neglectful to not also include consideration of frog tallies within this set of studies. Specifically, we: (i) estimate the number of frogs killed per year in Australia by cats, and spatial variation in this extent of killing; and (ii) compile a list of frog species known to be killed by cats, with particular reference to those species recognised as threatened. As context, we compare these tallies with (i) those we have previously reported for mammals, birds and reptiles, and (ii) comparable figures reported for cat predation on frogs elsewhere in the world.

Methods

The number of frogs killed by feral cats in largely natural environments

Our analytical pathway follows that used in parallel estimates of the numbers of birds, reptiles and mammals killed by cats in Australia (Woinarski *et al.* 2017a; Woinarski *et al.* 2018; Murphy *et al.* 2019). To estimate the number of frogs killed by cats per km^2 per day, we took the product of: (i) modelled cat density, projected across Australia; (ii) the predicted frequency of occurrence of frogs in cat stomach samples; and (iii) the predicted number of individual frogs in those stomach samples that contained frogs.

We used the estimates of spatially variable density and total population size of feral cats given by Legge *et al.* (2017). They collated and modelled 91 site-based estimates of feral cat density to derive an estimate of 2.1 million feral cats in largely natural environments of Australia (varying between 1.4 million in drought and average years to 5.6 million after prolonged and extensive wet periods).

For the frequency of occurrence of frogs in feral cat diet samples (i.e., the proportion of samples that contained frogs), we collated information from 86 studies (Table S1). Of these, 53 examined cat stomach contents, 29 examined cat scats, and four examined a combination of both. These sample sizes are slightly less than those used in our parallel analyses of the representation of reptiles, birds and mammals in cat diet, mostly because frogs were lumped with diverse minor food items in a 'miscellaneous' or 'other' category in some studies (e.g., Cahill 2005).

All of the studies considered included a quantitative assessment of the frequency of frogs in cat stomachs or scats (4,230 stomachs, 3,265 scats, and 675 combined stomach/scat samples). Based on the results of other studies (e.g., Nakanishi and Izawa 2016), we considered it likely that frogs would be difficult to detect in cat scats (compared to stomachs), so – after testing for such difference – we excluded scat samples (and mixed scat/stomach samples) from the formal analysis of cat diet.

The studies were widely spread (Fig. 1) and included a broad representation of Australia's natural environments, with sampling taking place both in times of drought and in high rainfall years. Although the incidence of frogs in cat diet may well be influenced by seasonality and rainfall events, we do not consider temporal variation in cat diet as part of this analysis, because many of the studies collated here spanned several seasons, and/or the time of year covered by the sampling was not specified. Furthermore, we do not include year because a consistent directional trend in diet over decadal scales is implausible.

As with our parallel analyses of the occurrence of reptiles, birds and mammals in cat dietary studies, we used a small set of five climatic and environmental attributes of each study site to assess and model the extent of variation in the frequency of frogs in cat stomachs. One attribute was whether the study was from an island or the mainlands of Australia and Tasmania (64 519 km^2) and, if on an island, the size of the island. We derived a composite variable expressing whether the site was an island, and the size of the island:

$$island\ size\ index = \log_{10}\left(\text{minimum}\left\{1, \frac{area}{10000}\right\}\right),$$

where *area* is island area in km^2. Hence, any land mass or island with an area ≥10 000 km^2 (i.e., the Tasmanian and Australian mainlands) has an index of zero. All other Australian islands are <10 000 km^2 and hence have negative values, which become increasingly negative with decreasing island area. From the location of each study, we also determined mean annual temperature (Australian Bureau of Meteorology 2016a), mean annual rainfall (Australian Bureau of Meteorology 2016b), mean tree cover within a 5-km radius (Hansen *et al.* 2003) and topographic ruggedness (standard deviation of elevation within a 5-km radius) (Jarvis *et al.* 2008).

We used generalized linear models (GLMs), in the statistical package R (ver. 3.4.2; R Core Team 2017) to examine variation in the frequency of frogs in the stomachs of feral cats. The response variable was the proportion of stomach samples containing frogs, and hence was analysed using the binomial error family. By using this error family, the GLMs accounted for the lower precision of the studies that had smaller numbers of cat stomach samples.

As candidate models, we examined all combinations of the five explanatory variables described above (island size index, temperature, rainfall, tree cover, ruggedness), plus an interaction between temperature and rainfall (to account for a possible negative effect of temperature on water availability). We compared models using $QAIC_c$, a second-order form of Akaike's Information Criterion (Burnham and Anderson 2003). $QAIC_c$, rather than simply AIC_c, was necessary because the data were over-dispersed. The model with the lowest value of $QAIC_c$ was used for inference about the relationships between frequency of frogs in cat stomachs and the explanatory variables, and to predict the frequency of frogs in cat stomachs across Australia's largely natural environments (i.e. excluding areas of highly modified environments).

Most of the collated studies report only frequency of occurrence rather than the number of individual frogs in those samples. However, in a subset of 11 studies of cat stomach samples, tallies were given for the number of individual frogs in those samples that contained frogs. Previous studies on reptiles (Woinarski *et al.* 2018) and mammals (Murphy *et al.* 2019) in cat diets identified a relationship between the number of individual reptiles or mammals in stomach samples containing reptiles or mammals, and the frequency of occurrence of reptiles or mammals in stomach samples. In the case of frogs, we found no such relationship. Hence, we described the number of individual frogs in each stomach sample containing frogs as a simple mean.

We assume that one stomach sample represents the prey eaten by an individual cat in a 24-h period (Liberg 1982; Krauze-Gryz *et al.* 2012). Hence, to estimate the number of frogs killed by a feral cat per day, we multiplied the predicted frequency of frogs in cat diet samples across Australia by the mean number of individual frogs in those diet samples with frogs. We multiplied this by the modelled density of cats in largely natural environments across Australia (Legge *et al.* 2017), and then by 365.25 (days in a year), to derive estimated number of frogs killed by feral cats per km^2 per year. We summed this rate across the extent of largely natural environments of Australia (ca. 7.7 million km^2) to derive the total number of frogs killed by feral cats each year.

We characterised the uncertainty of the estimated total number of frogs killed by feral cats using bootstrapping. Bootstrapping is an appropriate approach because we needed to propagate errors through a number of analytical steps. Hence, we simultaneously bootstrapped (10 000 times) the three underlying datasets: (i) mean cat density; (ii) mean frequency of frogs in cat diet samples; and (iii) mean number of individual frogs in cat diet samples containing frogs. For each random selection of these underlying data, we recalculated the total number of frogs killed. We report the 2.5% and 97.5% quantiles for the 10 000 values of the total number of frogs killed.

The number of frogs killed by feral cats in highly modified environments

Legge *et al.* (2017) provided separate estimates for the total population size of feral cats in Australia's largely natural environments (and spatial variation in density of these cats) and of the total population size of feral cats in Australia's highly modified environments (0.72 million, without consideration of spatial variation in density). This distinction is relevant for assessment of their consumption of wildlife, as feral cats in modified environments (such as urban areas) may derive much of their diet from foods provided deliberately or inadvertently by humans, and hence may have a lower *per capita* take of wildlife than feral cats in largely natural environments that are not food supplemented. However, whereas we compiled 86 datasets of the diet of feral cats in largely natural environments, we could locate only six such datasets (that included information on frog presence or absence) for the diet of feral cats in modified environments. Only one of these studies was based solely on stomach contents, with this small sample size precluding meaningful estimation of the numbers of frogs killed by feral cats in highly modified environments.

The number of frogs killed by pet cats

From national surveys of pet ownership, the population of pet cats in Australia is estimated at 3.88 million (Animal Medicines Australia 2016). There are few Australian studies that report on the take of wildlife by randomly or representatively selected pet cats. Our previous assessments of the numbers of reptiles, birds and mammals killed by cats in Australia included information from three sets of studies of the take of wildlife by pet cats (Paton 1990; Paton 1991; Trueman 1991; Paton 1993; Barratt 1995; Barratt 1997, 1998). However, Paton's studies did not provide explicit information on take of frogs by cats, so we include information here from only two studies. These report on the numbers of prey items brought back to the cats' homes over a specified time period. However, pet cats return to their homes only a proportion of the animals that they actually kill. Several recent studies (none from Australia) have estimated this proportion: reported values are 8.8% (Krauze-Gryz *et al.* 2012), 12.5% (Maclean 2007), 23% (Loyd *et al.* 2013), and 30% (Kays and DeWan 2004). Here, we average across Australian studies the number of individual frogs reported by pet owners to be killed by their pet cats per year, and scale this up to account for the number of frogs killed but not returned to the cats' homes, using the mean (19%) from these four studies of pet cats that provide robust estimates of the proportion of cat-killed animals returned to the cat's home. We note that some other Australian studies (e.g., Calver *et al.* 2007; Roetman *et al.* 2018) report frogs being killed by pet cats, but that the cats in these studies are not random samples of the pet cat population and/or their catch data cannot readily be recalibrated to numbers of frogs killed by cats per unit time.

Inventory of frog species killed

We used the list of Australian frog species given in Cogger (2014), with some subsequent taxonomic updates. For every species, we noted the conservation status assigned nationally (under the *Environment Protection and Biodiversity Conservation Act 1999*: EPBC Act) or globally (the IUCN Red List), as at September 2019. We derived an inventory of frog species killed by cats from the cat dietary studies described above. Many of the studies included in this collation recorded frogs in the dietary samples but did not identify those frogs to species level, at least in part because key identification features were not necessarily still present in semi-digested frogs. We also used information reported on injured wildlife brought to veterinarians (Dowling *et al.* 1994), although we note that that source had limited information on frogs.

Results

The number of frogs killed by feral cats in largely natural environments

Across 53 studies in largely natural environments in Australia, the frequency of occurrence of frogs in cat stomach samples was 1.5% (95% confidence interval [CI]: 1.0–2.5%). Frogs were much less frequently reported in cat scat samples, with a frequency of 0.06% (95% CI: 0.00–0.91%), and hence further analysis was restricted to data from the set of studies sampling cat stomachs.

Generalised linear modelling indicated that none of the five environmental variables examined were clearly correlated with the frequency of frogs in feral cat stomach samples: i.e., frogs were no more or less likely to occur in cat dietary samples in wetter or drier areas. The best model of frequency included no environmental variables (i.e. the null model): i.e., spatial variation in the number of frogs killed by cats in Australia was best explained simply by spatial variation in the numbers of cats in Australia.

Across those studies that counted the number of individual frogs in cat stomachs, the mean number of individual frogs present in stomachs with frogs was 9.1 (95% CI: 2.2–22.2). However, this average was appreciably influenced by a single cat with 70 individual frogs in its stomach, and the correspondingly large confidence intervals carry forward to large confidence intervals around estimates of the total take of frogs by cats.

Taking the product of: (i) the number of feral cats; (ii) the frequency of frogs in feral cat stomach samples; (iii) the number of individuals present in each feral cat stomach sample containing frogs; and (iv) 365.25 days in a year, yields an estimate of the number of frogs killed by feral cats across largely natural environments in Australia in a typical year: 92 million (95% CI: 19–302 million). On average, a feral cat kills 44.4 frogs per year (95% CI: 9.8–126.9). The number of frogs killed by feral cats averages 12.0 km^{-2} yr^{-1} in largely natural environments.

The number of frogs killed by feral cats in highly modified environments

All six studies (that included 423 cat dietary samples) of the diet of feral cats in highly modified environments reported no frogs in their samples. However, only one of these studies (with a sample size of only 13 cats) was based exclusively on stomach samples. Accordingly, we could derive no estimate of the numbers of frogs killed by feral cats living in highly modified environments.

The number of frogs killed by pet cats

Barratt (1997) reported 22 frogs killed by 214 pet cats over a 12-month period in Canberra, but not all cats were monitored over the duration of this study. Of 138 pet cats whose diet was monitored consistently over 12 months, the mean number of frogs caught was 0.1 per cat (Barratt 1998). Scaling up by the average proportion of prey individuals killed relative to those brought home by pet cats (ca. 19%), this represents 0.53 frogs killed per pet cat per year. Trueman (1991) monitored diet in 166 pet cats over a ca. 3-month period in Hobart, with these cats reported as bringing home a total of 364 animal prey: none of these were frogs.

With the caveat of very small sample size (N=2 studies, with an average of 0.26 frogs killed per pet cat per year), the total Australian pet cat population of 3.88 million cats is estimated to kill 1.01 million frogs per year.

Inventory of frog species killed

We collated records of 30 Australian frog species known to be killed by cats (Table S2), 13% of Australia's ca. 236 described frog species. This tally extends from the 21 frog species previously reported in cat dietary studies collated by Doherty *et al.* (2015). All frog species reported killed by cats are native, with no records in our compilation of cat predation on the sole established introduced amphibian species in Australia, the cane toad *Rhinella marina*. For the 51 Australian frog species considered threatened at national or global level (excluding four recognised as extinct), we could find no records of predation by cats in Australia. However, there are records of predation by cats on one Australian threatened frog species, *Litoria raniformis*, for its introduced population in New Zealand (Egeter *et al*. 2015b). Presumably if cats eat that frog species in New Zealand, then they are also likely to eat it in Australia.

Discussion

Our previous parallel studies concluded that cats in Australia kill ca. 650 million reptiles, ca. 380 million birds and > 1 million mammals per year (Woinarski *et al.* 2017a; Woinarski *et al.* 2018; Murphy *et al.* 2019), reinforcing concerns that this introduced predator may have significant impacts on components of Australian biodiversity (Department of the Environment 2015; Woinarski *et al.* 2019). Our assessment here is that the kill rate on Australian frogs, although substantial (ca. 90 million frogs per year), is appreciably less than for other terrestrial vertebrate groups. Furthermore, no threatened Australian frog species is known to be killed by cats, and the proportion of frog species known to be killed by cats is much smaller than for reptiles, birds and mammals.

However, we acknowledge caveats in this assessment, most notably that detectability of consumed frogs in cat dietary samples may be less than for other vertebrate groups, resulting in a bias towards under-reporting of frogs in such samples (Egeter *et al*. 2015a, 2015b, 2019). This under-representation may be especially evident in cat scat samples: in our collation of studies, frogs were 25-times more likely to be reported in cat stomachs than cat scats, such that the latter samples are especially likely to be uninformative and under-record the incidence of frogs in cat diet: consequently we did not include scat samples in our estimates.

Beyond exclusion of cat scat samples, there are two approaches that may help resolve the extent of bias associated with putative detectability constraints. One is to use DNA meta-barcoding (de Sousa *et al.* 2019) as has been done to examine the incidence and conservation significance of predation by introduced mammals on New Zealand frogs (Egeter *et al*. 2015a, 2019).

The other approach to help resolve the extent to which detectability of frogs in dietary samples may constrain the interpretation of frequency of occurrence of frogs in predator dietary samples is to assess predation events before the prey is digested. Three studies using collar-mounted cameras suggest that cats may take appreciably more frogs than is evident from cat stomach analyses. Such self-filming recorded that frogs comprised 44% of 32 vertebrate kills by feral cats in an Australian study that happened to occur in and around a mainly wetland area (McGregor *et al.* 2015). In two comparable American studies, Loyd *et al*. (2013) reported that frogs comprised 6% of 31 vertebrate individuals killed by pet cats, and Hernandez *et al.* (2018) found that frogs comprised 56% of 90 vertebrate individuals killed by unowned cats. McGregor *et al*. (2015) also reported that half of the frogs shown (by cameras) to be killed by cats were then not eaten by the cat, suggesting a further possibility that stomach sampling may under-estimate the numbers of frogs killed.

The observations of owners of pet cats can also provide information on prey before they are digested. In the few relevant Australian studies of pet cats, frogs are rarely reported, in contrast to the results from the three studies that used collar-mounted cameras. For example, owners of pet cats in Canberra reported that their pet cats brought home 22 frogs, compared with 131 reptiles, 529 birds and 1273 mammals (i.e. frogs comprised only 1.1% of the total number of vertebrate animals brought home by pet cats) (Barratt 1997). In a similar study in Hobart, cat-owners reported that their pet cats brought home no frogs, but 164 mammals, 161 birds and 39 reptiles. Although the relative abundance of difference taxonomic groups may well be different to Australia, comparable results were also reported in New Zealand, where Morgan *et al*. (2009) reported pet cats brought home five introduced frogs among 981 prey animals (i.e., 0.5% of all prey items; and 0.7% of vertebrate prey items) reported in an urban setting bordering a wetland; Flux (2007) reported only one (introduced) frog among 558 (0.2%) animals brought home; and Gillies and Clout (2003) reported only two (introduced) frogs among 1674 (0.1%) animals returned home by pet cats. These figures suggest frogs comprise only a small proportion of the prey taken by pet cats, but we note the further caveats that it is possible that frogs are much less abundant in urban settings than in less modified environments, and that pet cats may have taxonomic biases in how they treat animals they have taken, for example possibly being more likely to eat or discard frogs (than other vertebrate groups) at the point of killing, rather than carry them home (Loyd *et al*. 2013). Notwithstanding these potential caveats, and the limited number of studies, this low proportional take of frogs by pet cats provides some support for the estimated take by Australian feral cats reported here. In our previous studies, we reported that feral cats in natural environments Australia take about 815 million mammals, 272 million birds and 466 million reptiles per year (Woinarski *et al.* 2017a; Woinarski *et al.* 2018; Murphy *et al.* 2019). The comparable estimate of 92 million frogs reported here from stomach samples thus represents about 5.6% of the total take of vertebrates by feral cats, substantially higher than the equivalent proportion for frogs seen to be taken by pet cats, but appreciably less than two of the three studies based on collar-mounted cameras.

Furthermore, our estimate of the tally of frogs killed by cats in Australia does not include (because of data insufficiency) the number of frogs killed by feral cats in highly modified environments, with such cats comprising about 25% of the Australian feral cat population. Plausibly, feral cats in highly modified environments kill frogs at the same rate as feral cats in largely natural environments. If that is the case, then the tally of frogs killed by feral cats per year in Australia would be about 123 million.

We also note that the lack of records of cats consuming Australian threatened frog species should not imply that cats may not be a threat to these species. For 19 of the 35 frog species listed as threatened under the EPBCA, the relevant listing advice (see http://www.environment.gov.au/biodiversity/threatened/species/pubs/1815-conservation-advice-04072019.pdf for example) estimates the extent of occurrence and area of occupancy. For these species, the mean and median of extent of occurrence is 1163 km^2 and 60 km^2, and the mean and median area of occupancy is 34 km^2 and 20 km^2, with these areas comprising far less than 0.02% of the Australian land mass: these areas are smaller than those typical for threatened Australian bird and mammal species (Garnett *et al*. 2011; Woinarski *et al*. 2014). Hence, the absence of records of cat predation upon Australia's threatened frog species may be simply because no cat dietary studies have been conducted in their range. The number and proportion of Australian frog species recorded as consumed by cats is also smaller than the equivalent numbers and proportions of Australian reptile, bird and mammal species. There are interpretational constraints on this comparison too, for even many non-threatened frog species have very small distributions, and many frog species are challenging to identify live in the hand, let alone as digested material in stomach samples: consequently many of the studies collated here simply recorded 'frogs' as dietary items rather than distinguishing these to species level.

Largely because samples based on cat scats are unreliable for estimates of predation on frogs – and hence we excluded them from our analyses – the sample size underlying our study is appreciably smaller than for our parallel assessments of the numbers of reptiles, birds and mammals killed by cats in Australia. This was so across all three segments of the cat population, but especially so for pet cats and feral cats in highly modified environments. As a further caveat, in much of Australia, frog populations are also notably seasonal or episodic, often appearing in large numbers only after rain events (Morton *et al.* 1993), such that there is likely to be a high degree of temporal variability in consumption rates of frogs by cats, with such variability not readily accountable in our modelling across the collated studies. Indeed, such high temporal variability may partly explain why our modelling failed to detect any influence of environmental and geographic factors in variation among studies in the frequency of frogs in cat diet. In addition, the availability of frogs as prey may depend on fine-sale habitat features (e.g., rivers, swamps) that are not well-represented by the broad-scale geographic variables used in our analysis.

Notwithstanding such caveats, our smaller estimates of predation by cats on frogs than on other terrestrial vertebrates is likely to be real. The lower tallies of frogs may in part be because cats prefer to hunt and kill reptiles, birds and mammals ahead of frogs (Fitzgerald 1988; Bradshaw *et al.* 1996), or because frogs typically occur in wetland habitats that are generally less preferred by cats.

There are no previous reviews of predation by cats on frogs. In a review of 31 global studies reporting the diet of cats, Pearre and Maass (1998) reported amphibians as a main prey item in three of five Australian studies (all also included within our compilation) but in none of the 26 cat diet studies included from elsewhere. The most substantial inter-continental comparison available for contextualising our study is that of Loss *et al.* (2013) for the USA (excluding Alaska and Hawaii) (Table 1), with the USA estimates informed not only by north American studies but also by results from studies in temperate areas elsewhere in the world. The estimated *per capita* take of frogs by pet cats is similar for both continental areas, although we note that our estimate for Australian pet cats is based on limited evidence, as is that of Loss *et al.* (2013) (five studies globally, of which two were Australian). In contrast, our estimate of the *per capita* take of frogs by feral (unowned) cats is at least an order of magnitude greater than for the USA. Given that the total population sizes for both pet and unowned cats in the USA are at least an order of magnitude greater than those for Australia, this indicates that more frogs are killed by cats in the USA than in Australia. Note that this comparison excludes the Australian component of feral cats in modified environments, for which our data were too sparse to estimate take of frogs. The USA estimate includes such cats in the tallies for unowned cats. However, we also note that the tally reported by Loss *et al.* (2013) for frogs killed by unowned cats in the USA is based on only three global estimates, quixotically all from Australian studies (with these three studies all included in our compilation).

Based on the same datasets and comparable analytical pathway to our previous assessments of the take by Australian cats of other vertebrate groups, we estimate that nearly 100 million frogs are taken by feral cats per year in Australia. The extent to which this figure is an under-estimation because of constrained detectability of frogs in cat stomachs remains unresolved, and we recommend further studies are needed to examine this potential bias. The tally is also difficult to translate to conservation impact, because there are no reliable estimates of frog population size in Australia or the capability of the frog fauna to withstand such predation rates. We also note that further targeted research is warranted on the incidence and impact of predation by cats on threatened frog species.

Conflicts of interest

Sarah Legge is an associate editor for *Wildlife Research* and was the guest Editor-in-Chief for this special edition. Other co-authors of this paper (John Woinarski, Chris Dickman, Tim Doherty, Hugh McGregor and Brett Murphy) are also guest Associate Editors of this edition. Notwithstanding this relationship, none of the co-authors, at any stage, had editor-level access to this manuscript while in peer review. Such exclusion is the standard practice when handling manuscripts submitted by an editor to this journal. *Wildlife Research* encourages its editors to publish in the journal and they are kept totally separate from the decision-making process for their manuscripts. The authors have no further conflicts of interest to declare.

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Table 1. Comparison between Australia (the current study) and the contiguous USA (Loss *et al.* 2013) in cat population size and consumption of frogs. Note that we were unable to derive an estimate of the consumption of frogs by the 0.7 million feral cats in modified Australian environments, and that component is not included here.

Parameter	Contiguous USA (Loss *et al.* 2013)	Australia (this study)
Land area	8.08 million km^2	7.69 million km^2
Pet cats		
Cat population size	84 million	3.9 million
Frogs killed cat^{-1} yr^{-1}	0.05–0.5	0.26
Frogs killed by cats yr^{-1}	16.5 million (95% CI: 3.4–45.0 million)	1.01 million
Feral (unowned) cats		
Cat population size	30–80 million	2.1 million
Cat density	3.7–9.9 cats km^{-2}	0.27 cats km^{-2}
Frogs killed cat^{-1} yr^{-1}	1.9–4.7	44.4 (95% CI: 9.8–126.9)
Frogs killed yr^{-1}	154 million (95% CI: 69–296 million)	92 million (95% CI: 19–302 million)
Total frogs killed by cats yr^{-1}	173 million (95% CI: 86–320 million)	93 million

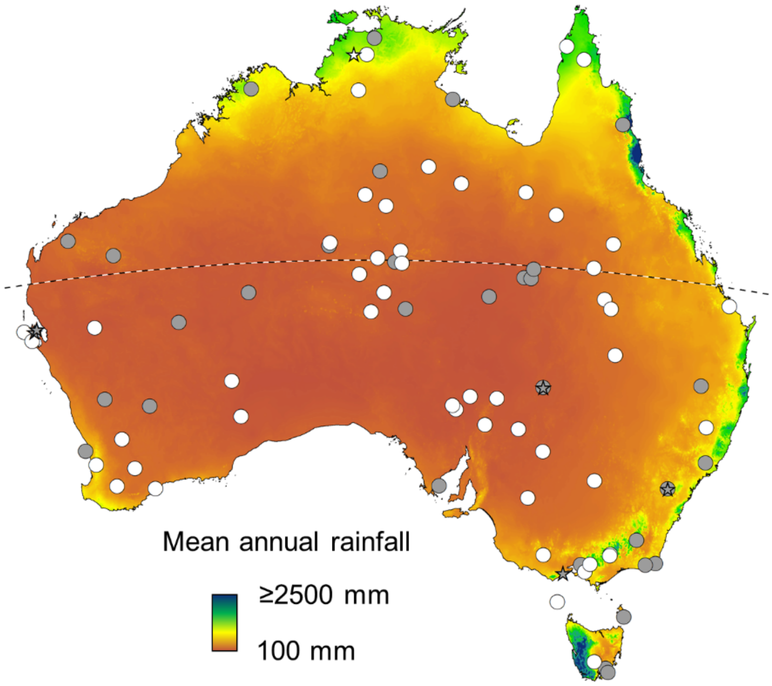

Fig. 1. The occurrence of cat dietary studies examined, 86 of which occurred in largely natural environments, indicated by circles. Of these, 53 were based on stomach samples (indicated by white circles) and 34 were based on either scat samples, or a combination of scat and stomach samples (indicated by grey circles). There were an additional six studies at rubbish dumps or other highly modified environments, indicated by stars (white stars are those based on stomach samples alone, grey stars those based on scat/mixed samples). Coloured shading indicates mean annual rainfall (Australian Bureau of Meteorology 2016b). The dashed line indicates the Tropic of Capricorn.

Table S1: Data sources used in compilation of cat predation on frogs.

site	source	lat	long	mainland	modified envt (1), such as tip	sample.type	N cat dietary samples	%FOO frog
Anglesea_tip_Vic_	Hutchings 2003	-38.433	144.15	mainland	1	both	171	0
APYlands Warru	Read et al. 2019	-26.08	132.214	mainland	0	stomach	103	0
Armidale_NSW	van Herk 1980	-30.467	151.567	mainland	0	stomach	26	11.6
Astrebla_Downs_Qld	Palmer (unpubl.)	-24.167	140.533	mainland	0	both	217	0
Barkly_Tablelands_NT	Paltridge et al. 1997	-19.733	136.917	mainland	0	stomach	130	0
Barrington_Tops_NSW	Glen et al. 2011	-32.167	151.833	mainland	0	scat	49	0
Blackall_Qld	Palmer (unpubl.)	-24.9	145	mainland	0	stomach	30	0
Burt_Plain_bioregion_NT	Edwards (unpubl.)	-23.1	133.8	mainland	0	stomach	39	0
Charles_Darwin_reserve_WA	Doherty 2015	-29.61	117	mainland	0	scat	123	0
Christmas_Island	Corbett et al. 2005	-10.5	105.667	island	0	scat	92	0
Christmas_Island	Tidemann et al. 1994	-10.5	105.667	island	0	stomach	93	0
Croajingalong_Vic	Triggs et al. 1984	-37.417	149.75	mainland	0	scat	48	0
Daly_Basin_bioregion_NT	Edwards (unpubl.)	-13.4	131.32	mainland	1	stomach	13	0
Dandenong_Valley_Metropolitan_Park_Vic	Brunner et al. 1991	-37.917	145.2	mainland	0	scat	85	0
Davenport_Downs_Qld_1994_96_	Palmer (unpubl.)	-24.183	140.917	mainland	0	both	184	1.1
Denham_Dump_WA	Palmer (unpubl.)	-25.917	113.567	mainland	1	scat	53	0
Diamantina_Lakes_Qld	Palmer (unpubl.)	-23.717	141.017	mainland	0	both	257	0.8
Dirk_Hartog_Island	Deller et al. 2015	-25.833	113.017	island	0	stomach	14	0
Dwellingup_WA	Dickman (unpubl.)	-32.73	116.05	mainland	0	stomach	14	0
East_Gippsland_Vic	Buckmaster 2011	-37.567	149.15	mainland	0	scat	22	0
Eastern_Highlands_Vic	Jones & Coman 1981	-37.267	146.933	mainland	0	stomach	117	0.85
Farina_SA	Bayly 1978	-30.117	139.433	mainland	0	stomach	21	0
Finke_bioregion_NT	Edwards (unpubl.)	-25.15	132.92	mainland	0	stomach	23	4.3
Fitzgerald_NP_WA	O'Cconnell 2010	-34.2	119.367	mainland	0	stomach	41	2.7
Flinders_Ranges_SA	Johnston et al. 2012	-31.44183	138.8305	mainland	0	stomach	24	0
Flinders_Ranges_SA	Hart 1994	-31.44183	138.8305	mainland	0	stomach	46	0
Gibson_Desert_WA	Burrows et al. 2003	-25	125.5	mainland	0	scat	19	0
Great_Dog_Island_Tas	Hayde 1992	-40.267	148.25	island	0	scat	91	0
Great_Sandy_Desert_NT	Edwards (unpubl.)	-22.7	130	mainland	0	stomach	18	0
Great_Western_Woodlands_WA	Palmer (unpubl.)	-30.17	119.5	mainland	0	scat	11	0
Hamilton_Downs_NT	Edwards (unpubl.)	-23.65	133.5	mainland	0	scat	187	0

Heirisson_Prong_WA	Risbey et al. 1999	-26.333	113.383	mainland	0	stomach	109	0
Inglewood, QLD	Palmer (unpubl.)	-28.50	150.92	mainland	0	scat	22	0
Inland_NE_Qld	Kutt 2011	-22.167	145.167	mainland	0	stomach	169	9
Kakadu_NT	Stockeld et al. 2016	-12.6	132.35	mainland	0	scat	84	0
Kanandah, Nullarbor, WA	Algar & Friend 1995	-31.01	124.71	mainland	0	stomach	76	0
Karijini_NP_WA	Johnston et al. 2013	-22.683	118.35	mainland	0	scat	77	0
Katherine_VRD_NT	Dickman (unpubl.)	-15.2	131.567	mainland	0	stomach	29	6.9
Kellerberrin_Durokoppin_WA	Dickman (unpubl.)	-31.63	117.72	mainland	0	stomach	48	0
Kinchega_NP_NSW	Jones & Coman 1981	-32.55	142.3	mainland	0	stomach	65	0
King Island, Tas	Whisson 2009	-39.88389	143.98407	island	0	stomach	73	0
Kintore_Tanami_Desert_	Paltridge 2002	-19.2	132.667	mainland	0	scat	70	0
Kosciusczko_NSW	Watson 2006	-36.4	148.417	mainland	0	both	17	0
Lambert_station_SW_Qld	Lapidge & Henshall 2001	-25.33	145.4	mainland	0	stomach	23	6.1
MacDonnell_Ranges_bioregion_NT	Edwards (unpubl.)	-23.47	132.57	mainland	0	stomach	144	0.9
Macquarie_I_Tas	Jones 1977	-54.5	158.95	island	0	scat	756	0
Mallee_Vic	Jones & Coman 1981	-34.883	141.633	mainland	0	stomach	131	2.3
Matuwa (Lorna Glen)	Wysong 2016	-26.23	121.56	mainland	0	scat	337	0
Mitchell_Grass_Downs_bioregion_NT	Edwards (unpubl.)	-18.95	135.19	mainland	0	stomach	207	0
Mitchell_grass_downs_Qld	Mifsud & Woolley_2012	-21	142	mainland	0	stomach	199	0
Monkey_Mia_WA	Palmer (unpubl.)	-25.794	113.717	mainland	1	scat	19	0
Mt_Field_Tas	Lazenby 2012	-42.683	146.717	mainland	0	stomach	27	0
Mt_Isa_Cloncurry_Qld	Dickman (unpubl.)	-20	140.33	mainland	0	stomach	26	3.8
Mulyungarie_SA	Palmer (unpubl.)	-31.55	140.79	mainland	0	stomach	40	0
Muncoonie_Lakes_Birdsville_QLD	Palmer (unpubl.)	-25.2	138.68	mainland	0	scat	27	0
North Kimberley, WA	Palmer (unpubl.)	-15.00	126.15	mainland	0	scat	23	4.3
Oberon_NSW_natural_	Denny 2005	-33.7	149.85	mainland	0	scat	33	0
Oberon_NSW_tip_	Denny 2005	-33.7	149.85	mainland	1	scat	48	0
Offham_Cunnamulla_SW_Qld	Palmer (unpubl.)	-27.55	145.91	mainland	0	stomach	23	13
Pannawonica, WA	Palmer (unpubl.)	-21.72	116.03	mainland	0	scat	78	0
pastoral_mostly_Pilbara_and_Murchison_WA	Martin et al. 1996	-26.083	116.9	mainland	0	stomach	50	5.7
Phillip_I_Vic	Kirkwood et al. 2005	-38.25	145.5	island	0	stomach	277	0.7
Piccaninny Plains, Qld	McGregor et al. 2017	-13.22	142.77	mainland	0	stomach	18	5.6
Pine_Creek_bioregion_NT	Edwards (unpubl.)	-13.42	131.98	mainland	0	stomach	14	0
Powelltown, Vic	McComb et al. 2019	-37.8611	145.76741	mainland	0	stomach	7	0
Purple_Downs_SA	Bayly 1976	-30.767	137.117	mainland	0	stomach	14	0
Reevesby_I_SA	Copley 1991	-34.517	136.283	island	0	scat	20	0
Rottnest_Island_WA	Dickman (unpubl.)	-32.005	115.53	island	0	scat	32	3.1
Roxby_Downs_SA	Read & Bowen 2001	-30.567	136.9	mainland	0	stomach	360	0.9
rural_mostly_wheatbelt_WA	Martin et al. 1996	-33.117	118.283	mainland	0	stomach	40	12.5
Sandford_Tas	Schwartz 1995	-42.94	147.498	mainland	0	scat	47	0

Simpson_Desert_NT	Pavey et al. 2008	-25.933	134.117	mainland	0	scat	44	0
Southern_NT	Strong & Low 1983	-23.7	133.88	mainland	0	stomach	22	0
SW Wheat-belt WA	Crawford 2010	-33.89	117.11	mainland	0	stomach	39	0
Tanami_bioregion_NT	Edwards (unpubl.)	-20.91	133	mainland	0	stomach	70	0
Tanami_NT	Paltridge et al. 1997	-20.367	131.9	mainland	0	stomach	130	0
Taunton_Qld	Augusteyn (unpubl.)	-24.45845	151.79815	mainland	0	stomach	101	3
Tennant_Creek_Tanami_Desert_	Paltridge 2002	-22.85	129.95	mainland	0	scat	76	0
Tibooburra_NSW_natural_	Denny 2005	-29.433	142.017	mainland	0	scat	144	0
Tibooburra_NSW_tip_	Denny 2005	-29.433	142.017	mainland	1	scat	119	0
Victoria - modified environments	Coman & Brunner_1972	-37.62	142.85	mainland	0	stomach	27	7.4
Victoria - native vegetation	Coman & Brunner_1972	-37.33	146.92	mainland	0	stomach	53	0
Watarrka_NT	Paltridge et al. 1997	-24.25	131.567	mainland	0	stomach	130	1.5
Wedge_Island_Tas	Beh 1995	-43.133	147.68	island	0	scat	527	0
West_Pellew_Island_NT	Paltridge et al. 2016	-15.583	136.33	island	0	scat	18	0
Western_Qld	Yip et al. 2015 boom years	-23.433	144.25	mainland	0	stomach	152	3.3
Western_Qld	Yip et al. 2015 bust years	-23.433	144.25	mainland	0	stomach	35	5.7
Wet_Tropics_Qld	Burnett 2001	-16.267	145.033	mainland	0	scat	123	0
Witchelina_SA	Woinarski et al. 2017	-30.1	137.9	mainland	0	stomach	404	1.2
Yathong_NSW	Catling 1988	-33.75	145.5	mainland	0	stomach	112	0
Great Victoria Desert	Turpin & Riley (unpubl.)	-29.2608	124.2856	mainland	0	stomach	17	0
Weipa_QLD	Trewella (unpubl.)	-12.63	141.88	mainland	0	stomach	30	0

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Table S2. List of Australian frog species, and records of their consumption by cats. Conservation status (*Environment Protection and Biodiversity Conservation Act* and/or IUCN Red List) codes: EX Extinct; CR Critically Endangered; EN Endangered; VU Vulnerable; DD Data Deficient.

Scientific name	**Common name**	**EBPCA_Status**	**IUCN_Status**	**Cat-eaten source**
Adelotus brevis	Tusked Frog			
Arenophryne rotunda	Sandhill Frog			
Assa darlingtoni	Pouched Frog			
Austrochaperina adelphe	Northern Territory Nursery-Frog			
Austrochaperina fryi	Fry's Nursery-frog			
Austrochaperina gracilipes	Slender Nursery-frog			
Austrochaperina pluvialis	Rain Nursery-frog			
Austrochaperina robusta	Robust Nursery-frog			
Cophixalus aenigma	Tapping Nursery-frog	EN	VU	
Cophixalus australis	Southern Ornate Nursery-frog			
Cophixalus bombiens	Buzzing Nursery-frog			
Cophixalus concinnus	Beautiful Nursery-frog, Elegant Frog	CR	CR	
Cophixalus crepitans	Rattling Nursery-frog			
Cophixalus exiguus	Scanty Nursery-frog			
Cophixalus hinchinbrookensis	Hinchinbrook Island Nursery-frog			
Cophixalus hosmeri	Hosmer's Nursery-frog, Rattling Nursery-frog	CR		
Cophixalus infacetus	Inelegant Nursery-frog			
Cophixalus kulakula	Kutini Boulder-frog			
Cophixalus macdonaldi	McDonald's Nursery-frog, Mount Elliot Nursery Frog	CR	EN	
Cophixalus monticola	Mountain Top Nursery-frog	CR	EN	
Cophixalus neglectus	Neglected Nursery-frog, Bellenden Ker Nursery-frog	CR	EN	
Cophixalus ornatus	Ornate Nursery-frog			
Cophixalus pakayakulangun	Golden-capped Boulder-frog			
Cophixalus peninsularis	Cape York Nursery-frog			
Cophixalus petrophilus	Blotched Boulder Frog			
Cophixalus saxatilis	Rock Nursery-frog		VU	

Cophixalus zweifeli	Cape Melville Nursery-frog, Zweifel's Frog			
Crinia bilingua	Bilingual Froglet			
Crinia deserticola	Desert Froglet			
Crinia fimbriata	Kimberley Froglet			
Crinia flindersensis	Northern Flinders Ranges Froglet			
Crinia georgiana	Tschudi's Froglet			
Crinia glauerti	Glauert's Froglet			
Crinia insignifera	Sign-bearing Frog			
Crinia nimba	Moss Froglet			
Crinia parainsignifera	Eastern Sign-bearing Froglet			
Crinia pseudinsignifera	False Western Froglet			
Crinia remota	Remote Froglet			
Crinia riparia	Streambank Froglet			
Crinia signifera	Common Eastern Froglet			Doherty *et al*. (2015); Kirkwood et al. (2005)
Crinia sloanei	Sloane's Froglet	EN	DD	
Crinia subinsignifera	Small Western Froglet			
Crinia tasmaniensis	Tasmanian Froglet			
Crinia tinnula	Wallum Froglet		VU	
Cyclorana alboguttata	Striped Burrowing Frog			Doherty *et al*. (2015); Kutt (2011)
Cyclorana australis	Giant Frog			McGregor et al. (2015)
Cyclorana brevipes	Short-footed Frog			
Cyclorana cryptotis	Hidden-ear Frog			
Cyclorana cultripes	Knife-footed Frog			
Cyclorana longipes	Long-footed Frog			
Cyclorana maculosa	Daly Waters Frog			
Cyclorana maini	Main's Frog			
Cyclorana manya	Small Frog			
Cyclorana novaehollandiae	New Holland Frog			Doherty *et al*. (2015); Kutt (2011)
Cyclorana platycephala	Water-holding Frog			
Cyclorana vagita	Wailing Frog			
Cyclorana verrucosa	Rough Frog			
Geocrinea rosea	Karri Frog			
Geocrinia alba	White-bellied Frog, Creek Frog	CR	CR	
Geocrinia laevis	Smooth Frog			
Geocrinia leai	Lea's Frog			
Geocrinia lutea	Walpole Frog			

Geocrinia victoriana	Eastern Smooth Frog			
Geocrinia vitellina	Orange-bellied Frog	VU	VU	
Heleioporus albopunctatus	Western Spotted Frog			
Heleioporus australiacus	Giant Burrowing Frog	VU	VU	
Heleioporus barycragus	Western Marsh Frog			
Heleioporus eyrei	Moaning Frog			Doherty *et al*. (2015); Dickman (unpubl.) [Rottnest I]
Heleioporus inornatus	Plains Frog			
Heleioporus psammophilus	Sand Frog			Doherty *et al*. (2015); O'Connell (2010)
Lechriodus fletcheri	Fletcher's Frog			
Limnodynastes convexiusculus	Marbled Frog			
Limnodynastes depressus	Flat-headed Frog			
Limnodynastes dorsalis	Western Banjo Frog, Pobblebonk			Doherty *et al*. (2015)
Limnodynastes dumerilii	Eastern Banjo Frog			Doherty *et al*. (2015); Kirkwood et al. (2005); Barratt (1997)
Limnodynastes fletcheri	Long-thumbed Frog			Doherty *et al*. (2015); Palmer (unpubl.) [Offham]
Limnodynastes interioris	Giant Banjo Frog			Doherty *et al*. (2015); Paton (1990)
Limnodynastes lignarius	Woodworker Frog			
Limnodynastes peronii	Brown-striped Frog			Paton (1990)
Limnodynastes salmini	Salmon-striped Frog			
Limnodynastes tasmaniensis	Spotted Grass Frog			Doherty *et al*. (2015); Holden & Mutze (2002)
Limnodynastes terraereginae	Northern Banjo Frog			Doherty *et al*. (2015); Kutt (2011)
Litoria adelaidensis	Slender Tree Frog			Calvert *et al*. (2007)
Litoria andirrmalin	Cape Melville Tree Frog		VU	
Litoria aurea	Green and Golden Bell Frog	VU	VU	
Litoria aurifera	Kimberley Rockhole Frog			
Litoria axillaris	Kimberley Rocket Frog			
Litoria bicolor	Northern Dwarf Tree Frog			
Litoria booroolongensis	Booroolong Frog	EN	CR	
Litoria brevipalmata	Green-thighed Frog		EN	
Litoria burrowsae	Tasmanian Tree Frog			
Litoria caerulea	Green Tree Frog			Doherty *et al*. (2015); Kutt (2011); Dowling et al. (1994); Paton (1990); McGregor et al. (2015)
Litoria castanea	Yellow-spotted Tree Frog, Yellow-spotted Bell Frog	CR	CR	

Litoria cavernicola	Cave-dwelling Frog			
Litoria chloris	Red-eyed Tree Frog			
Litoria citropa	Blue Mountains Tree Frog			
Litoria cooloolensis	Cooloola Tree Frog		EN	
Litoria coplandi	Copland's Rock Frog			
Litoria cyclorhyncha	Spotted -thighed Frog			Doherty *et al*. (2015)
Litoria dahlii	Dahl's Aquatic Frog			
Litoria daviesae	Davies's Tree Frog		VU	
Litoria dayi	Australian Lace-lid, Lace-eyed Tree Frog	VU	EN	
Litoria dentata	Bleating Tree Frog			
Litoria electrica	Buzzing Tree Frog			
Litoria eucnemis	Growling Tree Frog			
Litoria ewingii	Brown Tree Frog			Doherty *et al*. (2015); Kirkwood et al. (2005); Egeter *et al*. (2015) [NZ, introduced]
Litoria fallax	Eastern Dwarf Tree Frog			Dowling et al. (1994)
Litoria freycineti	Freycinet's Frog		VU	
Litoria gilleni	Centralian Tree Frog			
Litoria gracilenta	Dainty Gree Tree Frog			
Litoria inermis	Peters's Tree Frog			
Litoria infrafrenata	Giant Tree Frog			
Litoria jervisiensis	Jervis Bay Tree Frog			
Litoria jungguy	Jungguy Tree Frog			
Litoria kroombitensis	Kroombit Tree Frog	CR		
Litoria latopalmata	Broad-palmed Frog			Doherty *et al*. (2015); Molsher *et al*. (1999); van Herk (1980); Kutt (2011); Yip et al. (2015)
Litoria lesueri	Lesuer's Frog			van Herk (1980)
Litoria littlejohni	Littlejohn's Tree Frog, Heath Frog	VU		
Litoria longirostris	Long-snouted Frog			
Litoria lorica	Armoured Mistfrog	CR	CR	
Litoria meiriana	Rockhole Frog			
Litoria microbelos	Javelin Frog			
Litoria moorei	Western Green and Golden Bell Frog, Motorbike Frog			Doherty *et al*. (2015); Calvert et al. (2007)
Litoria myola	Kuranda Tree Frog	CR	CR	
Litoria nannotis	Waterfall Frog, Torrent Tree Frog	EN	EN	
Litoria nasuta	Rocket Frog			McGregor et al. (2015); QM

Litoria nigrofrenata	Bridle Frog			
Litoria nudidigita	Leaf Gree River Tree Frog			
Litoria nyakalensis	Mountain Mistfrog, Nyakala Frog	CR	CR	
Litoria olongburensis	Wallum Sedge Frog, Olongburra Frog	VU	VU	
Litoria pallida	Pale Frog			
Litoria paraewingi	Victorian Frog			
Litoria pearsoniana	Pearson's Tree Frog			
Litoria peronii	Peron's Tree Frog			Doherty *et al*. (2015); Molsher et al. (1999); Barratt (1997)
Litoria personata	Masked Frog			
Litoria phyllochroa	Leaf Gree Tree Frog			Dowling et al. (1994)
Litoria piperata	Peppered Tree Frog	VU	CR	
Litoria raniformis	Growling Grass Frog, Southern Bell Frog, Green and Golden Frog, Warty Swamp Frog	VU	EN	Egeter *et al*. (2015) [NZ, introduced]
Litoria revelata	Revealed Frog			
Litoria rheocola	Common Mistfrog, Creek Frog	EN	EN	
Litoria rothii	Roth's Tree Frog			
Litoria rubella	Desert Tree Frog			Doherty *et al*. (2015); Woinarski *et al*. (2018); Dickman (unpubl.) [Katherine - VRD]; Kutt (2011); Lapidge & Henshall (2001); Yip et al. (2015); QM
Litoria serrata	Serrated-armed Tree Frog			
Litoria spenceri	Spotted Tree Frog	EN	CR	
Litoria spendida	Magnificent Tree Frog			
Litoria staccato	Chattering Rock Frog			
Litoria subglandulosa	Glandular Frog		VU	
Litoria tornieri	Tornier's Frog			
Litoria tyleri	Tyler's Tree Frog			
Litoria verreauxii	Verreaux's Tree Frog	VU (for *L. v. alpina*)		
Litoria wilcoxi	Wilcox's Frog			
Litoria wotjulumensis	Wotjulum Frog			
Litoria xanthomera	Orange-thighed Tree Frog			
Metacrinia nichollsi	Nicholl's Toadlet			
Mixophyes balbus	Stuttering Frog, Southern Barred Frog (in Victoria)	VU	VU	
Mixophyes carbinensis	Carbine Tableland Barred Frog			

Mixophyes coggeri	Cogger's Barred Frog			
Mixophyes fasciolatus	Great Barred Frog			H. Hines (*pers. comm.*)
Mixophyes fleayi	Fleay's Frog	EN	EN	
Mixophyes iteratus	Giant Barred Frog, Southern Barred Frog	EN	EN	
Mixophyes schevilli	Northern Barred Frog			
Myobatrachus gouldii	Turtle Frog			
Neobatrachus albipes	White-footed Frog			
Neobatrachus aquilonis	Northern Burrowing Frog			
Neobatrachus fulvus	Tawny Frog			
Neobatrachus kunapalari	Kunapalari Frog			
Neobatrachus pelobatoides	Humming Frog			
Neobatrachus pictus	Painted Frog			Doherty *et al*. (2015); Paton (1994)
Neobatrachus sudelli	Sudell's Frog			Doherty *et al*. (2015) [as *N. centralis*]; Read & Bowen (2001) [as *N. centralis*]; Woinarski et al. (2018); Paltridge *et al*. (1997); Edwards (unpubl.) [Finke]
Neobatrachus sutor	Shoemaker Frog			
Neobatrachus wilsmorei	Goldfields Bullfrog			
Notaden bennettii	Crucifix Toad			
Notaden melanoscaphus	Northern Spadefoot Toad			
Notaden nichollsi	Desert Spadefoot Toad			
Notaden weigeli	Weigel's Toad			
Paracrinia haswelli	Haswell's Frog			
Philoria frosti	Baw Baw Frog	CR	CR	
Philoria kundagungan	Mountain Frog		EN	
Philoria loveridgei	Loveridge's Frog		EN	
Philoria pughi	Pugh's Sphagnum Frog		EN	
Philoria richmondensis	Richmond Range Spagnum Frog		EN	
Philoria spagnicola	Spagnum Frog		EN	
Platyplectrum ornatum	Ornate Burrowing Frog			Doherty *et al*. (2015); Dickman (unpubl.) [Katherine - VRD]; Kutt (2011)
Platyplectrum spenceri	Spencer's Burrowing Frog			Doherty *et al*. (2015); Paltridge *et al*. (1997); Edwards (unpubl.) [MacDonnell ranges]
Pseudophryne australis	Red-crowned Toadlet		VU	
Pseudophryne bibronii	Brown Toadlet			
Pseudophryne coriacea	Red-backed Toadlet			

Pseudophryne corroboree	Southern Corroboree Frog	CR	CR	
Pseudophryne covacevichae	Magnificent Brood Frog	VU	EN	
Pseudophryne dendyi	Dendy's Toadlet			
Pseudophryne douglasi	Douglas's Toadlet			
Pseudophryne guentheri	Gunther's Toadlet			
Pseudophryne major	Large Toadlet			
Pseudophryne occidentalis	Orange-crowned Toadlet			
Pseudophryne pengilleyi	Northern Corroboree Frog	CR	EN	
Pseudophryne raveni	Copper-backed Broodfrog			
Pseudophryne robinsoni	Central Ranges Toadlet			
Pseudophryne semimarmorata	Southern Toadlet			
Rana daemeli	Wood Frog			
Rheobatrachus silus	Southern Gastric-brooding Frog	EX	EX	
Rheobatrachus vitellinus	Northern Gastric-brooding Frog, Eungella Gastric-brooding Frog	EX	EX	
Rhinella marina	Cane Toad			
Spicospina flammocaerulea	Sunset Frog	VU	VU	
Taudactylus acutirostris	Sharp-snouted Day Frog, Sharp-snouted Torrent Frog	EX	CR	
Taudactylus diurnus	Southern Day Frog, Mt Glorious Torrent Frog	EX	EX	
Taudactylus eungellensis	Eungella Day Frog	EN	CR	
Taudactylus leimi	Liem's Torrent Frog			
Taudactylus pleione	Kroombit Tinker Frog, Pleione's Torrent Frog	CR	CR	
Taudactylus rheophilus	Tinkling Frog, Tinkling Torrent Frog	EN	CR	
Uperoleia altissima	Montane Toadlet			
Uperoleia arenicola	Jabiru Toadlet			
Uperoleia aspera	Derby Toadlet			
Uperoleia borealis	Northern Toadlet			
Uperoleia capitulata	Small-headed Toadlet			
Uperoleia crassa	Fat Toadlet			
Uperoleia daviesae	Davies's Toadlet			
Uperoleia fusca	Dusky Toadlet			
Uperoleia glandulosa	Glandular Toadlet			
Uperoleia inundata	Floodplain Toadlet			
Uperoleia laevigata	Smooth Toadlet			
Uperoleia lithomoda	Stonemason Toadlet			

Uperoleia littlejohni	Littlejohn's Toadlet			
Uperoleia marmorata	Marbled Toadlet			
Uperoleia martini	Martin's Toadlet			
Uperoleia micra	Tiny Toadlet			
Uperoleia micromeles	Tanami Toadlet			
Uperoleia mimula	Mimic Toadlet			
Uperoleia minima	Small Toadlet			
Uperoleia mjobergii	Mjoberg;s Toadlet			
Uperoleia orientalis	Alexandria Toadlet			
Uperoleia rugosa	Wrinkled Toadlet			
Uperoleia russelli	Russell's Toadlet			
Uperoleia saxatilis	Pilbara Toadlet			
Uperoleia talpa	Mole Toadlet			
Uperoleia trachyderma	Blacksoil Toadlet			
Uperoleia tyleri	Tyler's Toadlet			

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