Drying microclimates threaten the persistence of Critically Endangered white-bellied frogs

In brief

The Critically Endangered white-bellied frog and its close relative the Vulnerable orange-bellied frog are both restricted to a few square kilometres of habitat in south-west Western Australia. Over half of the known white-bellied frog populations have become extinct in recent decades, surviving populations continue to decline, and past translocation efforts have had mixed success.

We examined the micro-habitat requirements of these terrestrial-breeding species as well as their physiological thresholds for water balance and temperature.

We found that soil moisture and temperature during the warmer dry season were the most important predictors of the abundance of white- and orange-bellied frogs, and also explained why the species have become locally extinct in some areas and the variation in outcomes of previous translocation efforts.

We recommend: management actions at key sites that preserve moisture and maintain lower soil temperatures, such as adding and protecting logs; and monitoring and protecting two sites that remain suitable year-round and between years, as critical habitat for the species.

Translocations remain an important conservation tool for the species and we have defined a range of site habitat attributes that will increase the likelihood of success of new translocations.


The white-bellied frog is restricted to a few square kilometres of habitat in south-west Western Australia. Image: Emily Hoffmann

Background

Defining the habitat requirements of threatened species is essential to conserve them effectively. The process can reveal why populations have declined, as well as identify critical habitat for conservation actions such as translocations.

Over 40% of amphibian species worldwide are threatened. Amphibians determine their body temperature largely by selection of their microenvironment, and their permeable skin and unshelled eggs make them especially sensitive to water loss and pollutants. As a consequence, amphibians are highly sensitive to changes in habitat and more vulnerable to changes in climate than other vertebrates.

The white-bellied frog *Geocrinia alba* is a Critically Endangered terrestrial-breeding frog. It is currently restricted to a few square kilometres of viable habitat in the Margaret River region of south-west Western Australia.

The species occurs in distinct corridors along the edges of drainage lines. Frogs use these habitats to breed and lay eggs in shallow depressions in areas of moist soil next to temporary streams. Adult males show an extreme tendency to stay in the one site. Individuals will generally move less than a few metres between years, which means

The University of Western Australia; Department of Biodiversity, Conservation and Attractions; Parks and Wildlife Service; Perth Zoo Saving Wildlife; Forrest Research Foundation

LEFT: We sampled habitats at 60 sites across the ranges of the white-bellied and orange-bellied frogs. Image: Bruno Buzatto

Background (continued)

there is almost no dispersal between sub-populations. It also means that if a habitat becomes unsuitable, the frogs have very limited ability to disperse to suitable habitat elsewhere.

Over half of the known white-bellied frog sub-populations have become extinct in recent decades. The surviving sub-populations are also continuing to decline. Considerable habitat clearance and land-use change in the region contributed to earlier extinctions, but localised extinctions are continuing to occur throughout the entire range of the species, including in areas that seem undisturbed, such as those in conservation estates.

Conservation translocations of white-bellied frogs began in the early 2000s, with the first use of captive reared individuals in 2010 as well as of a closely related neighbouring species, the orange-bellied frog *Geocrinia vitellina*, which is listed as Vulnerable and has a similarly restricted distribution. The translocations aimed to increase the number of sub-populations of both species but have had varied outcomes.

It was not clear why both species have patchy distributions, nor why some *G. alba* populations are declining in areas with apparently intact habitat. Likewise, it was unknown why translocation efforts to new sites have had only limited success.

The region where white-bellied frogs occur is experiencing a significant warming and drying trend. This may pose a threat to species close to their physiological limits as well as to those with limited ability to move.

Main aim of the research

This research project aimed to improve conservation outcomes for white-bellied frogs through investigating their micro-habitat requirements, as well as their eco-physiology.

Understanding habitat associations

In particular, the research investigated whether fine-scale differences in habitat features could explain:

1) why sub-populations of white-bellied and orange-bellied frogs occur only in isolated patches along stretches of seemingly suitable riparian habitat;

2) why white-bellied frogs are declining and have become locally extinct at some sites; and

3) why translocation efforts for both species have had mixed outcomes.

Frog physiology and habitat microclimates

We sought to estimate the thresholds for temperature tolerance and moisture loss of both the white- and orange-bellied frogs to assess their sensitivity to warmer and/or drier conditions.

We then looked for where suitable microclimates exist in habitats in and around persisting sub-populations of white-bellied frogs.

Finally, we evaluated the sensitivity of white-bellied frogs to climatic changes, based on whether the frogs are experiencing conditions that are near or exceeding their physiological limits.

What we did

The research was a collaboration between researchers from the University of Western Australia and the Western Australian Department of Biodiversity, Conservation and Attractions *Geocrinia* Recovery Team, and was conducted from 2017 to 2020.

Habitat surveys

We looked at which variables were most important in determining the presence of white-bellied and orange-bellied frogs. We did this by comparing habitat attributes at sites where frogs are present with adjacent sites where frogs are absent (around 50 m from frog populations) and sites where white-bellied frogs have become locally extinct.

We also examined habitat variables at six translocation sites (two white-bellied frog sites; four orange-bellied frog sites) to assess whether differences across sites could explain why some translocations have been more successful than others.

We sampled habitats at 60 sites across the ranges of the two frog species. At each site, we sampled attributes relating to the site's hydrology (moisture levels and ability to hold moisture), microclimate, habitat structure and soil properties such as salinity.

Frog physiology experiments

We estimated the temperature tolerance of each species by collecting data on development rates of the frogs in a captive rearing program at a range of constant and fluctuating temperatures. To determine

RIGHT: Agar frogs mimic the water-loss properties of live frogs, making them useful to investigations of microclimatic conditions at frog sites. Image: Emily Hoffmann

What we did (continued)

the moisture thresholds for both species, we assessed whether frogs gain or lose water from a range of moistened substrates.

Habitat microclimates across space and time

We used models of frogs made of agar (which mimic the water-loss properties of live frogs) to investigate the risk of desiccation and microclimate conditions in and around frog sites (in areas where frogs are found, nearby riparian habitats, and nearby terrestrial (woodland) habitats).

Finally, we analysed soil microclimates at a range of habitats occupied by white-bellied frogs over a two-year period. We did this to find out when and where frogs are experiencing potentially stressful conditions, based on our new understanding of their physiological tolerances.

Key findings

Soil moisture during the drier months a key habitat feature

Our key finding was that soil moisture during the warmer dry season (summer to autumn) was the most important predictor of the abundance of white- and orange-bellied frogs. This factor explained not only the patchy distribution of the species but also why white-bellied frogs were now absent from some areas; and, further, it explained in large part the variation in outcomes of previous translocation efforts.

White- and orange-bellied frogs appear to share the same environmental niche, although they showed no overlap in their distributions. It is not surprising that they share adaption to such similar habitat, as they are the most closely related of the four *Geocrinia* species in south-western Western Australia.

We showed specifically that natural and translocated populations of white-bellied and orange-bellied frogs preferred habitat patches that stayed wetter and cooler during the summer to autumn months, and frogs were absent or locally extinct at sites that experienced drier (and consequently hotter) conditions during this time.

White-bellied frogs were also more likely to be found in areas with higher moss cover, and areas with less bare ground and lower soil conductivity (i.e., lower salinity).

Frogs have low tolerances to hotter, drier conditions

We found that white-bellied frogs, as well as orange-bellied frogs, have narrow physiological tolerances compared to other amphibians. They had relatively low thresholds for the upper temperatures they can tolerate and were extremely sensitive to water loss. This indicates that they need sites with cool, moist microclimates year-round to survive.

Constrained to a rare (and potentially disappearing) niche

Using frog models made of agar, we showed that the risk of the frogs losing water was lowest in the habitat patches where frogs presently occur in the landscape, even compared to similar habitat only tens of metres away.

We found that microclimate conditions within frog sites varied considerably across sites and between years. In 2018–19, soils dried out more over the warmer summer to autumn months, but conditions at most (five of six) sites remained within the frogs' physiological tolerances year-round.

However, 2019–20 was an extremely dry year, and most (six of eight) white-bellied frog sites recorded soil moisture levels that were drier than the frog's absorption threshold (the soil water potential that allows them to gain water), and half of the sites experienced temperatures that exceeded white-bellied frogs' thermal optimum.

We found that the number of days that soil moisture was drier than the frog's absorption threshold was associated with smaller estimated population size.

Even if adults can find microhabitats to survive unsuitably dry or warm conditions, their egg clutches may not survive. Dry conditions during the breeding season a few years in a row could have dramatic impact on recruitment, with adults not being replaced.

Cited material

Hoffmann EP, Williams K, Hipsey MR, Mitchell NJ (2021) Drying microclimates threaten persistence of natural and translocated populations of threatened frogs. *Biodiversity and Conservation*, 30 (1), 15-34.

Hoffmann EP, Cavanough KL, Mitchell NJ (2021) Low desiccation and thermal tolerance constrains a terrestrial amphibian to a rare and disappearing microclimate niche. *Conservation Physiology*. 9 (1), doi:10.1093/conphys/coab027

Implications

We detected critical habitat differences on an extremely fine scale, just tens of metres along drainage lines. These distances are far finer in scale than the focus of much climate and species distribution modelling, which emphasises the need to consider modelling habitat variables at the scale most relevant to that species.

Drying, warming conditions pose a significant threat

Our study revealed that the current conditions experienced within some white-bellied frog habitats will be stressful to the frogs. The extreme warming and drying conditions expected under climate change pose a critical immediate threat across the species' range as well as explaining their recent declines.

South-western Western Australia has experienced a 15–20% decline in rainfall and a consequent 35–50% reduction in streamflow since the 1970s, with the biggest rainfall changes taking place at the start of the wetter winter period in May and June.

Without intervention, both white- and orange-bellied frogs are at risk of further habitat and range contraction due to projected regional declines in levels of rainfall and groundwater.

Future management options?

Conservation areas may not adequately buffer a species from wider regional threats, such as drying brought about by climate change or increased groundwater extraction.

Novel management actions could be explored to mitigate drying at key sites, such as environmental watering/sprinkler systems, groundwater injection wells, upland vegetation thinning, or assisted colonisation to moister areas that provide the microclimates that the threatened *Geocrinia* species need.

Preserving fallen logs (protecting them from being collected for firewood and from being destroyed in hot fires) could be crucial in providing emergency refuge to the frogs if fire destroys their other damp microhabitats. We showed that logs provided one of the best microclimates for preventing water loss and maintaining low soil temperatures, and we observed frogs in the field occupying this under-log microhabitat. Adding more logs could be considered as a strategy to mitigate some aspects of climate change.

We identified two sites that remained suitable year-round and between years, and that never breached the species' heat and moisture thresholds. These two sites currently support two of the largest white-bellied frog sub-populations, and therefore should be monitored and protected as critical habitat for the species.

A priority for future work should be to monitor microclimate conditions at these sites as well as exploring whether other suitable, climatically resilient habitats exist in the region.

Translocation site selection

Our findings suggest that the conditions that led to the loss of many white-bellied frog populations have not improved, and that sites where the species became locally extinct are not suitable for recolonisation. Therefore, translocations of captively-reared juvenile frogs remain an important conservation tool for the species.

Our study highlights the need to consider fine-scale habitat features for translocations, as well as year-round conditions at sites, to increase the likelihood of success of new translocations. Translocation sites for white- and orange-bellied frogs should ideally possess the following attributes:

- Soils that maintain a water potential of at least –50 kPa throughout the year, which equates to soil moisture of more than 10.5% VWC (volumetric water content) in sandy soil to 27.6% VWC in clayey soils
- Soil temperatures that remain below 23.3°C throughout the year
- Substantial ground cover, with <10 % bare ground and the presence of moss and logs
- Low soil conductivity (< 0.8 dS m^{-1})

Further Information

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