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Two new frog species (Microhylidae: *Cophixalus*) from boulder habitats on Cape York Peninsula, north-east Australia

CONRAD J. HOSKIN[1,2,4] & KIERAN ALAND[3]

[1]*Division of Evolution, Ecology & Genetics, Research School of Biology, The Australian National University, Canberra ACT 0200, Australia*

[2]*New address: School of Marine & Tropical Biology, James Cook University, Townsville, Queensland 4811, Australia*

[3]*Queensland Museum, PO Box 3300, South Bank, Brisbane, Queensland 4101, Australia. E-mail: kieran.aland@qm.qld.gov.au*

[4]*Corresponding author. E-mail: conrad.hoskin@gmail.com*

Abstract

Australia has a highly localised but diverse radiation of microhylid frogs. 18 species are described from north-east Queensland (14 *Cophixalus* and 4 *Austrochaperina*), most with highly localised montane distributions. While most species are small (10-25 mm) rainforest species, two differ dramatically in ecology and morphology. *Cophixalus saxatilis* and *C. zweifeli* inhabit isolated areas of jumbled boulder-pile habitat and are considerably larger than all other species (30-45 mm). Here we describe two new species of large, boulder dwelling *Cophixalus* from the Pascoe River region of Cape York Peninsula. *Cophixalus kulakula* **sp. nov.** occurs in piled boulder habitat amongst rainforest in the Tozer Range area, while *Cophixalus pakayakulangun* **sp. nov.** occurs in similar habitat in the Kennedy Hills region north of the Pascoe River. These are the most northerly sites for *Cophixalus* in Australia and both occur in rainforest areas not occupied by other species of *Cophixalus*. Both species are large (snout-vent length > 40 mm) and of similar morphology to the other two boulder-dwelling species. *Cophixalus kulakula* **sp. nov.** and *C. pakayakulangun* **sp. nov.** differ from each other and from all other described *Cophixalus* genetically and in aspects of colour pattern and morphology. The call of *C. kulakula* **sp. nov.** is also unique, but the call of *C. pakayakulangun* **sp. nov.** remains unknown. The two new species are each others closest relatives (albeit with approximately 8% genetic divergence for 12S and 16S mtDNA) and are allied to *C. ornatus.* The diet of both species consists primarily of ants. Both species have highly localised distributions but are abundant within these and are probably secure.

Key words: *Cophixalus kulakula*, *Cophixalus pakayakulangun*, boulder, granite

Introduction

Two genera of frogs of the family Microhylidae are found in Australia, *Cophixalus* Boettger, 1892 (14 species) and *Austrochaperina* Fry, 1912 (5 species) (Zweifel 1985, 2000; Hoskin 2004). All but one of these species are restricted to north-east Queensland, and most have very small distributions (Hoskin 2004). The remaining species, *Austrochaperina adelphe* (Zweifel 1985), is restricted to the far north of the Northern Territory (Zweifel 1985, 2000; Hoskin 2004). Only one Australian microhylid species is shared with the diverse microhylid radiation of New Guinea — *Austrochaperina gracilipes* Fry, 1912, which occurs on northern Cape York and southern New Guinea and is unusual amongst Australian microhylids in occurring primarily in open forest and savanna habitats (Zweifel 1985). Most Australian microhylid species are restricted to rainforest. The majority of the species occur in montane rainforests of the Wet Tropics region, where they account for approximately 50% of the rainforest frog diversity (Hoskin 2004; Hoskin & Hero 2008). The rainforest species generally occupy leaf-litter, ground debris and low vegetation, and are of small body size (SVL 10–30 mm) (Zweifel 1985; Hoskin 2004, 2008).

Two species (*C. saxatilis* Zweifel & Parker, 1977 and *C. zweifeli* Davies & McDonald, 1998, Fig. 1) differ obviously in ecology and morphology, being found in boulder-pile habitat with little or no vegetation and being larger (SVL 30–47 mm). *Cophixalus saxatilis* is found in granite boulder piles of the Black Trevethan Range

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(Black Mountain) on the northern periphery of the Wet Tropics rainforests (Zweifel & Parker 1977), while *C. zweifeli* is restricted to similar granite boulder habitat 175 km to the north in the Melville Range (Cape Melville) (Davies & McDonald 1998). Other vertebrate and invertebrate species have also evolved to utilise these discrete areas of boulder-pile habitat, including a skink (*Carlia scirtetis* Ingram & Covacevich, 1980) and a gecko (*Nactus galgajuga* (Ingram, 1978)) at Black Mountain, and a skink (*Cryptoblepharus fuhni* Covacevich & Ingram, 1978) and a hylid frog (*Litoria andiirrmalin* McDonald, 1997) at Cape Melville (Couper & Hoskin 2008). In eastern Queensland, extensive areas of boulder-pile habitat with at least some associated rainforest have generally been considered to be restricted to Black Mountain and Cape Melville (Davies & McDonald 1998). However, there are also smaller and more scattered areas of similar habitat further north on Cape York and these have received little attention. This is largely due to the inaccessibility of these remote regions, particularly during the summer wet (monsoon) season when the activity of some groups (e.g. frogs) is greatest.

Here we describe two new species of *Cophixalus* frogs that we discovered during exploration of boulder habitats in the Pascoe River region of Cape York Peninsula.

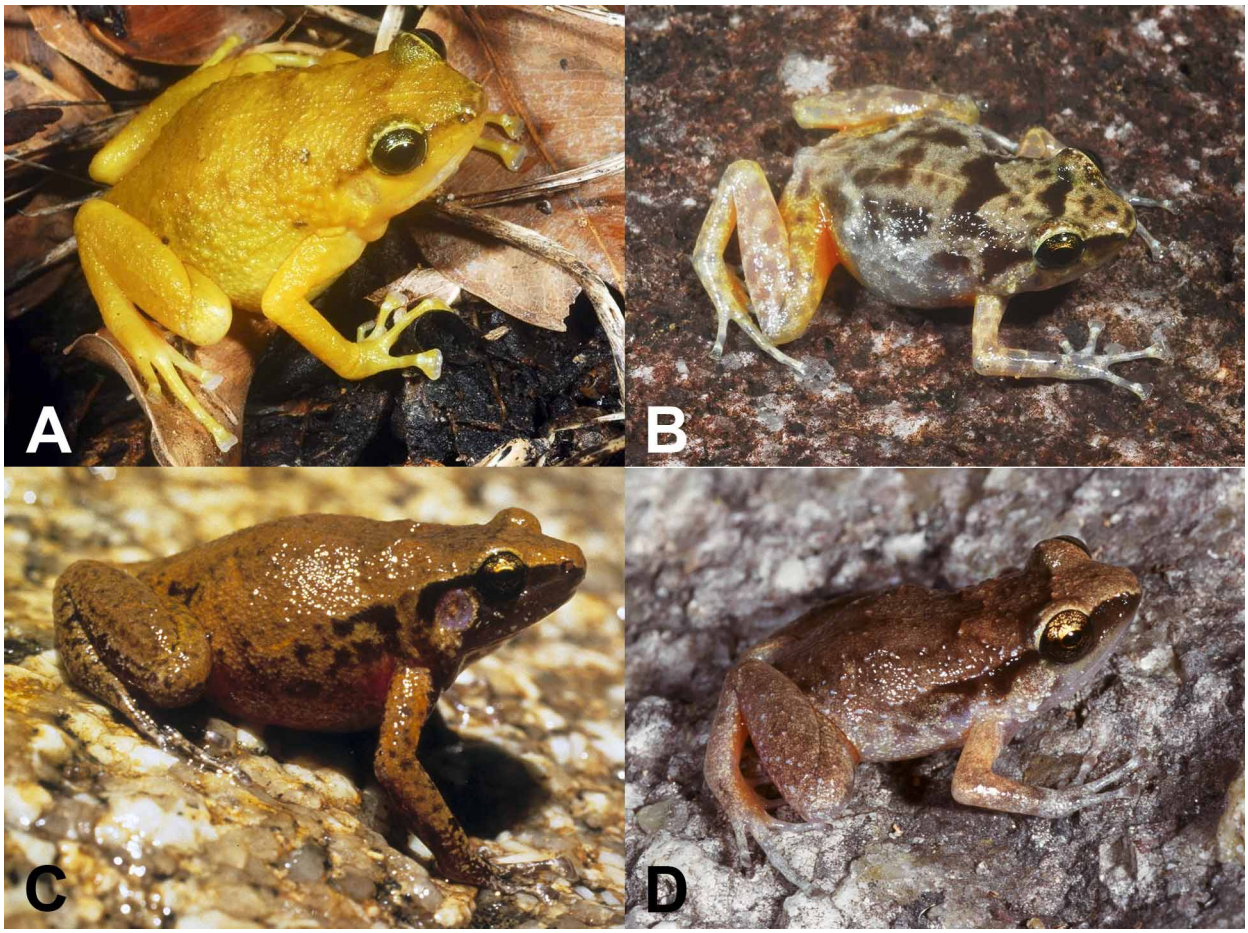

FIGURE 1. *Cophixalus saxatilis* female (A) and male (B), Black Mountain (photos: Eric Vanderduys); *C. zweifeli* female (C) (photo: Keith McDonald) and probable sub-adult male (D) (photo: Harry Hines), Cape Melville.

Methods

Morphometrics. Specimens examined are held in the Queensland Museum (QMJ codes). The following characters were measured: snout to vent length (SVL), from snout to urostyle; tibia length (TL), from knee to heel; forearm length (FL), from elbow to 'heel' of the palm; head width (HW), measured at the tympana (i.e. at widest point of the head); head length (HL), from anterior edge of tympanum to snout; head depth (HD), at the crown between the eyes; eye diameter (ED); eye to naris distance (EN); distance between the nares (IN); third finger disc width (3DW); third finger length (3FL), from split with second finger to tip of disc; fourth toe length (4TL), from split

with third toe to tip of disc. All measurements were taken using Mitutoyo electronic callipers and rounded to the nearest 0.1 mm. Field measurements of SVL and weight (WT) were taken using Mitutoyo vernier callipers and a spring-loaded Pezola, respectively.

Genetics. All genetic techniques follow those outlined in Hoskin (2004). Liver samples from multiple individuals from each population within each species were sequenced for portions of the mitochondrial 16S rRNA and 12S rRNA genes (944 base pairs in total). The sequences were analysed against sequences from all Australian species of *Cophixalus* (except *C. peninsularis* Zweifel, 1985) and *Austrochaperina* (Hoskin 2004; Hoskin *et al.* unpublished). All genetic divergences presented are Kimura two-parameter distance estimates calculated in Paup* version 4.0b10 (Swofford 2003).

Call recording and analysis. Recordings were made in the field using a Canon G11 camera with an in-built microphone. Call traits were measured using the software Raven Pro version 1.3. The following call traits were measured: dominant frequency (the frequency at which the call is of greatest intensity), duration (beginning of the first pulse to the end of the last pulse of a call), number of pulses, and pulse rate (number of pulses divided by call duration). The time between calls (call rate) was also measured. Trait averages were derived from five consecutive calls for an individual.

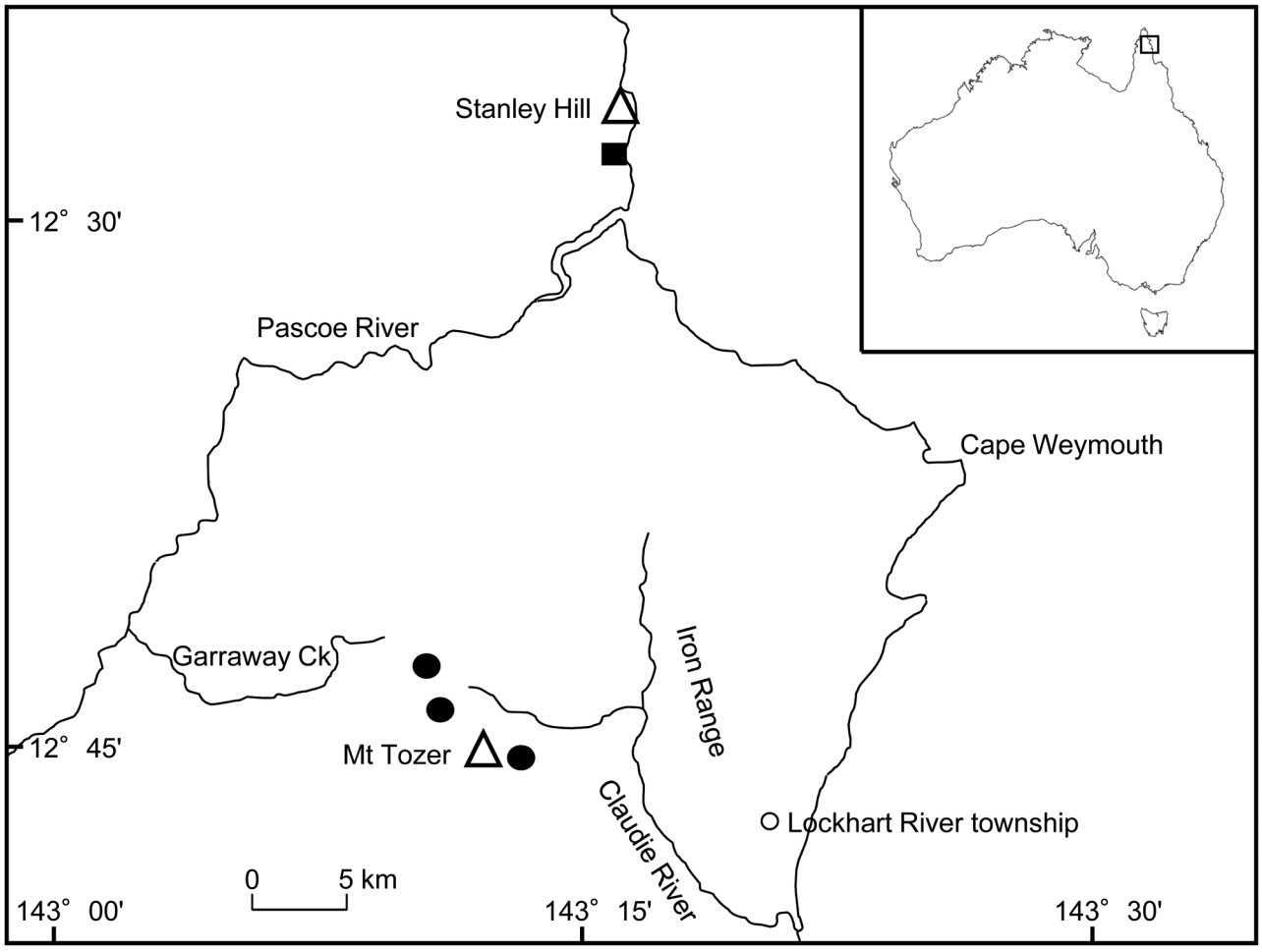

FIGURE 2. Map of the Iron Range region showing the localities for *C. kulakula* **sp. nov.** (filled circles) and *C. pakayakulangun* **sp. nov.** (filled square). Other localities mentioned in the text are shown. The inset shows Australia.

Systematics

The two new species are clearly assignable to *Cophixalus* based on genetic data (Hoskin *et al*. unpublished). Morphological diagnosis of Australo-Papuan microhylid genera is based on characters of internal morphology (Zweifel 1985, 2000). This was not conducted here due to the limited number of specimens.

***Cophixalus kulakula* sp. nov.**
Kutini Boulder-frog
(Fig. 3)

Material examined. Holotype: QMJ88540, female, boulder field hill approx. 5 km NW of Mt Tozer summit (12°42′37S, 143°10′22″E, elevation 180 m), Cape York Peninsula, north-east Queensland, C. J. Hoskin and K. Aland, 13 April 2010. **Paratypes:** QMJ88536 (male), QMJ88537 (male), QMJ88538 (juvenile), QMJ88539 (female), collection details as for holotype; QMJ88503 (female), QMJ88504 (male), gully on eastern side of Mt Tozer (12°45′46S, 143°13′26″E, elevation 231 m), K. Aland, 20 February 2009; QMJ88541 (female), QMJ88542 (female), QMJ88543 (male), QMJ88544 (male), boulder field on western slopes of Mt Tozer uplands (12°43′46S, 143°11′07″E, elevation 170 m), K. Aland and C. J. Hoskin, 13 April 2010. **Additional material:** An additional two individuals from this latter site were measured in the field.

Diagnosis. A medium sized frog with long, slender fingers and large, obviously truncated finger pads. *Cophixalus kulakula* **sp. nov.** can be distinguished from its congeners by a combination of the following characters: large size (SVL: 40–48 mm, average 43 mm), red/orange in groin and on posterior thigh (but not in axilla), fairly uniform pale or brown dorsum and flanks. The mating call is also distinct from all *Cophixalus* for which the call is known, in being a short, wavering 'bleat'.

Etymology. From *kul'a kul'a*, meaning 'rocky place' in Kuuku Ya'u, a language of the Sandbeach People of Eastern Cape York. This epithet was suggested by Mr Ronald Giblet, custodian of the Kutini clan estate in which the first specimens were discovered. The species epithet is used as a noun in apposition.

Measurements of holotype. QMJ88540, female; SVL 43.0 mm; TL 21.5 mm; FL 10.5; HW 15.8 mm; HL 11.7 mm; ED 3.7 mm; EN 3.4 mm; IN 3.6 mm; 3DW 2.9 mm; 3FL 8.1 mm; 4TL 11.3 mm.

Description of type series. Data presented as range followed by mean in brackets. **Adult measurements** (mm): SVL 39.8–48.0 (43.1); TL 19.5–22.8 (20.7); FL 9.8–11.8 (10.6); HW 14.5–17.5 (15.9); HL 10.1–11.7 (11.0); ED 3.7–4.7 (4.2); EN 3.2–3.8 (3.5); IN 3.2–4.2 (3.6); 3DW 2.3–3.1 (2.7); 3FL 7.0–8.1 (7.4); 4TL 9.3–11.9 (10.5). **Adult proportions**: TL/SVL 0.45–0.52 (0.48); FL/SVL 0.23–0.27 (0.25); FL/TL 0.48–0.58 (0.51); HW/SVL 0.34–0.41 (0.37); HL/SVL 0.24–0.27 (0.25); HW/HL 1.34–1.55 (1.45); ED/SVL 0.08–0.11 (0.10); EN/IN 0.86–1.11 (0.99); EN/ED 0.71–0.93 (0.84); 3DW/SVL 0.054–0.068 (0.062); 3FL/SVL 0.16–0.19 (0.17); 4TL/SVL 0.22–0.27 (0.24). **Comparison of sexes:** Females are on average larger than males (SVL 43.7 *vs.* 42.5) but the ranges overlap substantially (females: 39.8–48.0 mm, males 40.5–44.8 mm). No differences in proportions were detected between the sexes. **Juvenile measurements** (mm): SVL 24.2; TL 12.2; FL 5.5; HW 9.1; HL 7.0; ED 2.5; EN 2.2; IN 2.0; 3DW 1.5; 3FL 4.2; 4TL 5.8. **Juvenile proportions**: TL/SVL 0.50; FL/SVL 0.23; FL/TL 0.45; HW/SVL 0.38; HL/SVL 0.29; HW/HL 1.31; ED/SVL 0.10; EN/IN 1.14; EN/ED 0.88; 3DW/SVL 0.060; 3FL/SVL 0.18; 4TL/SVL 0.24. Compared to adults, the juvenile has a proportionally longer head and shorter forearms. ***Head:*** Narrower than body, triangular in dorsal view; snout truncated at the nares, noticeably projecting in profile; canthus rostralis angular, loreal region steep; nares much closer to tip of snout than to eye, nares anterolateral on tip of snout; eyes large; eye diameter greater than eye to naris distance; internarial distance about equal to distance from eye to naris; tympanum large (approximately half to greater than half diameter of eye) but indistinct beneath overlying skin, bordered dorsally by supra-tympanic fold. ***Body:*** Rotund. ***Limbs:*** Hindlimbs and forearms relatively long; fingers and toes unwebbed; relative finger length 3>4>2>1; fingers 2, 3 and 4 long and slender with very large and obviously truncated discs, first finger short with disc expanded but small and rounded; low, ovoid inner and larger, rounded outer palmar tubercles; subarticular tubercles low, moderately prominent; relative length of toes 4>3>5>2>1, toe 4 very long and slender; large, truncated discs on toes 2, 3 and 4, discs smaller and more rounded on toes 1 and 5; low, rounded inner metatarsal tubercle, no outer metatarsal tubercle; subarticular tubercles low and rounded, moderately prominent; discs on longest fingers larger than discs on longest toes. ***Skin:*** Ventral surface smooth; dorsal surface of head and limbs covered in very fine tubercles, back covered with scattered low tubercles; distinct supra-tympanic fold. ***Colour pattern in preservative:*** All dorsal surfaces uniformly dark brown. Tympanum tawny brown with darker centre. White patches at the base of the finger and toe discs. Dark brown dorsal colouration merges to lighter brown on flanks. Ventral surface of head and body light grey-brown. Ventral surfaces of limbs brown; discs and tubercles grey. The orange seen in life in the groin, posterior thigh and on the calf appears as white patches in preserved specimens.

Measurements of live individuals. Two adults were measured in the field: female, SVL 44.3 mm, WT 8.1 g; male 42.4 mm, 6.1 g.

Colour pattern in life (Fig. 3)**.** ***Adults***. No sexual dimorphism in colour pattern evident. Dorsal colour variable. Some individuals emerging from rock crevices were dark brown (Fig. 3B) and most individuals changed to this colouration in bags following capture. Individuals active on the surface of the rocks or in associated vegetation were even light brown, uneven grey-brown (Fig. 3C) or a fairly uniform pale putty colour (Fig. 3A). Diffuse, pale lumbar ocelli are present on some individuals. There is a dark canthal band from the nare to the eye, through the iris, and along the supra-tympanic fold. The upper iris is heavily speckled with gold or copper; speckling is present but less intense in the lower iris. Most individuals have a paler brown or yellowish forehead triangle and similar colouration on the eyelids. The darker dorsal colouration merges with the paler ventral colouration on the flanks. The ventral surfaces are uniformly white on some individuals, while on others they are pale with heavy grey mottling on the chin, throat, chest and forearms (Fig. 3D). The palms are dark. Reddish orange markings are present in the hidden parts of the hindlimbs (in the groin and on the posterior thigh and inner calf) (Figs 3C, 3D). The brightness and extent of these markings varies between individuals, from very bright and discrete to more diffuse. ***Juveniles***. Greyish brown to yellowish colour with darker mottling on the back, arms and legs. There is a yellowish brown forehead triangle, a dark canthal streak and dark markings on the loreal region, above the tympanum and on the anterior flank. Yellow lumbar ocelli are evident. The flanks and ventral surfaces are mottled grey, and the groin, posterior thigh and calf are orange.

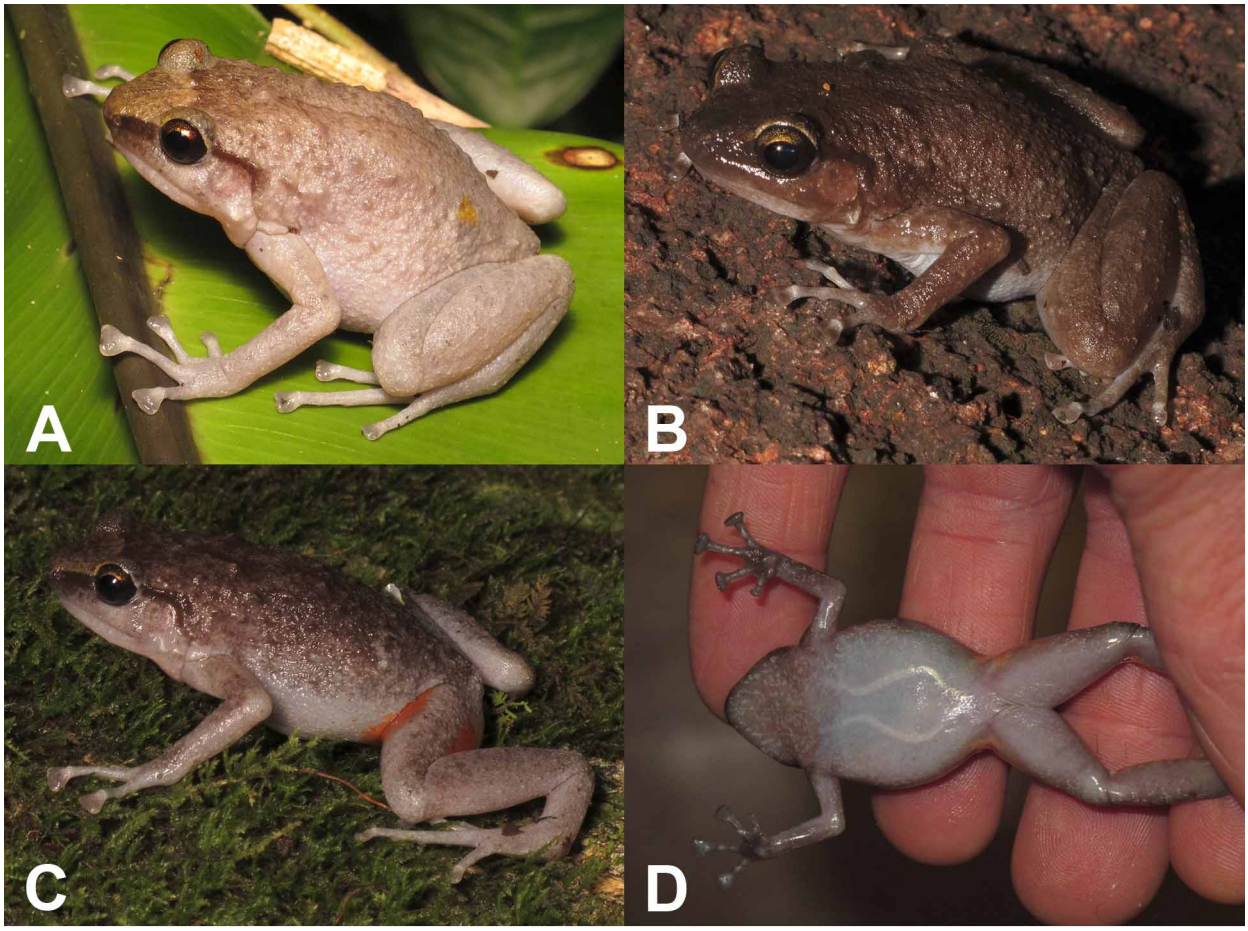

FIGURE 3. *Cophixalus kulakula* **sp. nov.** in life: (A) female foraging on fern leaf, (B) female emerging from boulders, (C) male, (D) male ventral surface (photos: Kieran Aland).

Call. Calls were only obtained for a single individual, which was not collected. No obvious differences were heard between the calls of this individual and those calling around it. The mating call of *C. kulakula* **sp. nov.** is a short, wavering 'bleat' of the following mean characteristics: dominant frequency 1.97 kHz (1.95–1.99), duration 0.38 s (0.35–0.41), pulses per call 155 (140–167), and pulse rate 411 pulses/s (381–448). Calls are uttered at an interval of approximately 8 seconds. Air temperature at the time of recording was approximately 28 ºC. Figure 4 displays a single representative call.

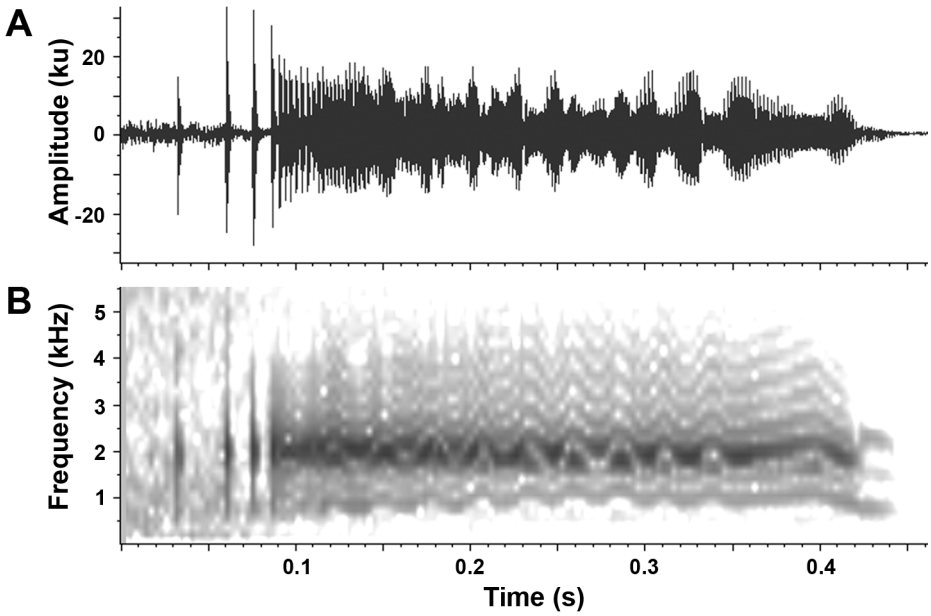

FIGURE 4. A single call of *Cophixalus kulakula* **sp. nov.** (A) Waveform, displaying amplitude (*y*-axis) against time (*x*-axis, seconds). (B) Spectrogram, displaying call frequency (*y*-axis) and intensity (degree of shading) against time (*x*-axis, seconds).

The call is distinct from that of other Australian *Cophixalus* (although the calls of *C. pakayakulangun* **sp. nov.** and *C. zweifeli* are not known). It is obviously different to the tapping calls of most Australian *Cophixalus* (including *C. saxatilis*) and is most similar to the 'bleat' of *C. ornatus*. The call of *C. ornatus* is a loud, 'clean', high-pitched 'beep', whereas that of *C. kulakula* **sp. nov.** is relatively soft, deeper in pitch and has a wavering, 'scratchy' quality to it. The call is of higher dominant frequency than would be expected for body size, compared to the relationship seen across other *Cophixalus* and Australian frogs in general (Hoskin *et al.* 2009).

Comparison. *Cophixalus kulakula* **sp. nov.** does not co-occur with any other *Cophixalus*. It could only be confused with the other three boulder-adapted *Cophixalus*: *C. pakayakulangun* **sp. nov.** (Stanley Hill region, 30 km to the north), *C. zweifeli* (Cape Melville, 210 km south-east) and *C. saxatilis* (Black Mountain, 390 km south-east). These four species can be distinguished as follows. *Cophixalus saxatilis* differs from the other species in that females are bright yellow (Fig. 1A) and males are heavily mottled and relatively small (29–35 mm) (Fig. 1B). *Cophixalus zweifeli* (Figs 1C, 1D) and *C. kulakula* **sp. nov.** have red/orange in the groin and on the posterior thigh, whereas this is at most a faint wash on adult *C. pakayakulangun* **sp. nov.**. *Cophixalus zweifeli* differs from *C. kulakula* **sp. nov.** in that it also has red/orange in the axilla (absent in *C. kulakula* **sp. nov.**) and dark blotching on the anterior half of the flanks (i.e. above the axilla) (Figs 1C, 1D), whereas the flanks of *C. kulakula* **sp. nov.** are generally unmarked (Fig. 3). Additional differences between *C. pakayakulangun* **sp. nov.** and *C. kulakula* **sp. nov.** are that *C. pakayakulangun* **sp. nov.** females are larger (SVL 49–53 mm *vs.* 40–48 mm), there is generally an obvious gold tinge to the eyelids and forehead of *C. pakayakulangun* **sp. nov.** (Figs 6A, 5B) whereas this is faint or absent on *C. kulakula* **sp. nov.** (Figs 3A–C), and the juveniles of *C. pakayakulangun* **sp. nov.** are blotched with dark markings (Fig. 6D) whereas those of *C. kulakula* **sp. nov.** are mottled with darker markings but not obviously blotched.

Genetics. There is substantial sequence divergence (for 944 bp 12S and 16S rRNA) between *C. kulakula* **sp. nov.** and all other Australian *Cophixalus* (average = 12.1%, range = 8.3–14.7%) (Hoskin *et al.* unpublished). Phylogenetic analyses suggest that *Cophixalus kulakula* **sp. nov.** is most closely related to *C. pakayakulangun* **sp. nov.**, and these two species are allied to *C. ornatus* (Hoskin *et al.* unpublished). Sequence divergence between *C. kulakula* **sp. nov.** and *C. pakayakulangun* **sp. nov.** is high (8.3%) compared to that between some sister-species of north Queensland *Cophixalus* (e.g., 4.2% between *C. concinnus* Tyler, 1979 and *C. monticola* Richards, Dennis, Trenerry & Werren, 1994; 5.1% between *C. aenigma* Hoskin, 2004 and *C. exiguus* Zweifel & Parker, 1969). A 16S sequence for *C. kulakula* **sp. nov.** was deposited in GenBank (accession number JN208371).

Distribution. *Cophixalus kulakula* **sp. nov.** is known from three sites in the vicinity of Mt Tozer in north-east Queensland (Fig. 2). One of the sites is on the eastern side of Mt Tozer, another is on the north-western slopes of

the Mt Tozer uplands, and the third is a hill to the north of 'Tozer's Gap', approximately 5 km NW of Mt Tozer. There are other patches of boulder habitat in the Mt Tozer area and in the adjacent rocky hills to the north known as "The Paps", and *C. kulakula* **sp. nov.** probably inhabits many of these. A fourth known site, provisionally assigned to *C. kulakula* **sp. nov.** (see Discussion), is Tor Hill, approximately 25 km SW of Mt Tozer.

Habitat and habits. *Cophixalus kulakula* **sp. nov.** inhabits deeply piled granite boulder habitats and its morphology is similar to that of the other three boulder-adapted Australian *Cophixalus*. These species are all relatively large and have long fingers and greatly enlarged finger discs. As for the other species, *C. kulakula* **sp. nov.** is restricted to boulder habitats. These are either boulder fields or deeply piled rock in rainforest gullies (Fig. 5). At most sites the boulders are festooned with vegetation such as ferns, vines (*Scindapsus altissimus* and others) and umbrella trees (*Schefflera*). The frogs emerge from deep crevices on dusk to forage at night on the surface of rocks and on associated vegetation (particularly *Schefflera*) (Fig. 5). Some individuals were observed in the crowns of umbrella trees up to 2.4 metres above the rocks below. No other frogs were observed in boulder habitats at these sites. Analysis of *C. kulakula* **sp. nov.** scats (removed from holding bags in the field) revealed that they feed primarily on ants; as has been found for other Australian *Cophixalus* (Hoskin 2004; Williams *et al.* 2006). An adult *C. kulakula* **sp. nov.** was observed feeding on *Oecophylla smaragdina* ants by picking individual ants from an ant trail. Other invertebrate groups represented in the scats were Coleoptera and Blattodea.

FIGURE 5. Habitat of *Cophixalus kulakula* **sp. nov.**, Mt Tozer region (photo: Kieran Aland).

Cophixalus kulakula **sp. nov.** were abundant at sites in February 2009, April 2010 and December 2010, with males and females being observed in approximately equal numbers. Males were calling in December but not in February and April, despite wet weather during all visits. This suggests that breeding occurs earlier in the wet season. Juveniles (approx. 25 mm) were observed at one site in April. Males were observed calling from the tops and sides of boulders. Males were calling in small groups, with males spaced several metres from each other, and such groups were widely separated despite apparently suitable boulder habitat in between. A calling male was observed

to lead a female from his calling site in piled boulders to a crevice below an isolated small boulder approximately 40 metres away on the rainforest floor. The male uttered a call shorter than the mating call (described above) while leading the female. This behaviour is similar to that reported for *C. ornatus*, in which males lead females some distance from a calling site to a nest site (Zweifel 1985; Hoskin 2004; Felton *et al.* 2006). As for other Australian microhylids (Hoskin 2004), *C. kulakula* **sp. nov.** is almost certainly a terrestrial breeder. A female preserved in January contained 47 unpigmented ova of an average diameter of 2.8 mm (2.7–2.9). These eggs were all of similar size and appeared to represent one clutch. If this were the case, then this represents a substantially larger clutch size than recorded for other Australian microhylids (6–22 eggs, average 12), including that recorded for another large boulder-dwelling species, *C. saxatilis* (13 eggs) (Hoskin 2004).

***Cophixalus pakayakulangun* sp. nov.**
Golden-capped Boulder-frog
(Fig. 6)

Material examined. Holotype: QMJ88547, female, boulder field just south of Stanley Hill (12°27′50S, 143°16′14″E, elevation 40 m), Cape York Peninsula, north-east Queensland, C. J. Hoskin and K. Aland, 18 April 2010. **Paratypes:** QMJ88548 (female), QMJ88545 (male), QMJ88546 (male), QMJ88534 (juvenile), QMJ88535 (juvenile), collection details as for holotype. **Additional material:** An additional three individuals from the type locality were measured in the field.

Diagnosis. A medium sized frog with long, slender fingers and large, obviously truncated finger pads. *Cophixalus pakayakulangun* **sp. nov.** can be distinguished from its congeners by a combination of the following characters: large size (SVL: 42–53 mm, average 47 mm); no red/orange in groin or axilla or on posterior thigh; golden tinge to eyelids and forehead; dorsum and flanks fairly uniform pale, grey or brown.

Etymology. From the Kuuku Ya'u words *pakaya* – down/inside/under, *kul'a* – rocks/boulders, *ngun* – belonging to. The name translates approximately to 'belonging among the boulders'. The specific epithet was suggested by Mrs Suzie Pascoe and Mrs Lucy Hobson in liaison with Rev. David Thompson. Mrs S. Pascoe and L. Hobson are recognised among the custodians of Kuuku Ya'u country. The species epithet is used as a noun in apposition.

Measurements of holotype. QMJ88547, female; SVL 51.7 mm; TL 23.7 mm; FL 11.8; HW 18.6 mm; HL 12.7 mm; ED 4.5 mm; EN 3.8 mm; IN 4.4 mm; 3DW 3.7 mm; 3FL 8.7 mm; 4TL 11.0 mm.

Description of type series. Data presented as range followed by mean in brackets. **Adult measurements** (mm): SVL 42.2–51.7 (46.8); TL 19.4–24.8 (22.3); FL 10.2–12.9 (11.6); HW 15.7–18.6 (17.2); HL 10.8–12.7 (11.8); ED 4.1–4.5 (4.3); EN 3.6–3.9 (3.7); IN 3.2–4.4 (3.8); 3DW 2.6–3.7 (3.2); 3FL 6.8–8.7 (7.9); 4TL 9.3–11.1 (10.4). **Adult proportions**: TL/SVL 0.46–0.49 (0.48); FL/SVL 0.23–0.27 (0.25); FL/TL 0.50–0.54 (0.52); HW/SVL 0.36–0.39 (0.37); HL/SVL 0.25–0.26 (0.25); HW/HL 1.41–1.51 (1.45); ED/SVL 0.09–0.10 (0.09); EN/IN 0.86–1.15 (1.00); EN/ED 0.83–0.90 (0.87); 3DW/SVL 0.062–0.071 (0.068); 3FL/SVL 0.16–0.17 (0.17); 4TL/SVL 0.21–0.23 (0.22). **Comparison of sexes:** Females (average SVL = 51.3 mm, range = 49.0–52.9) are larger than males (average SVL = 43.8 mm, range = 42.2–46.7). No differences in proportions were detected between the sexes. **Juvenile measurements** (mm): SVL 24.0–24.6 (24.3); TL 12.2–12.7 (12.4); FL 5.4–6.0 (5.7); HW 8.4–8.8 (8.6); HL 6.7–6.7 (6.7); ED 2.7–2.9 (2.8); EN 1.8–2.0 (1.9); IN 1.9–2.2 (2.0); 3DW 1.3–1.4 (1.4); 3FL 4.0–4.0 (4.0); 4TL 5.6–5.9 (5.8). **Juvenile proportions**: TL/SVL 0.51–0.52 (0.51); FL/SVL 0.22–0.25 (0.23); FL/TL 0.44–0.47 (0.46); HW/SVL 0.35–0.36 (0.35); HL/SVL 0.27–0.28 (0.28); HW/HL 1.26–1.31 (1.28); ED/SVL 0.11–0.12 (0.12); EN/IN 0.90–0.95 (0.93); EN/ED 0.63–0.72 (0.68); 3DW/SVL 0.056–0.058 (0.057); 3FL/SVL 0.16–0.17 (0.16); 4TL/SVL 0.23–0.24 (0.24). Compared to adults, juveniles have a proportionally longer head, larger eyes, longer hindlegs, shorter forearms and smaller finger discs. ***Head:*** Narrower than body, triangular in dorsal view; snout truncated at the nares, noticeably projecting in profile; canthus rostralis angular, loreal region steep; nares much closer to tip of snout than to eye, nares anterolateral on tip of snout; eyes large; eye diameter greater than eye to naris distance; internarial distance about equal to distance from eye to naris; tympanum large (approximately half diameter of eye) but indistinct beneath overlying skin, bordered dorsally by supra-tympanic fold. ***Body:*** Rotund. ***Limbs:*** Hindlimbs and forearms relatively long; fingers and toes unwebbed; relative finger length 3>4>2>1; fingers 2, 3 and 4 long and slender with very large and obviously truncated discs, first finger short with disc expanded but small and only slightly truncated; rounded outer palmar tubercle and smaller, ovoid inner palmar

tubercle; subarticular tubercles low, moderately prominent; relative length of toes 4>3>5>2>1, toe 4 very long and slender; large, obviously truncated discs on toes 2, 3 and 4, discs smaller and more rounded on toes 1 and 5; low, rounded inner metatarsal tubercle, no outer metatarsal tubercle; subarticular tubercles low and rounded, moderately prominent; discs on longest fingers larger than discs on longest toes. ***Skin:*** Ventral surface smooth; dorsal surfaces covered in fine tubercles; distinct supra-tympanic fold. ***Colour pattern in preservative:*** Even brown dorsally; tympanum paler; forehead triangle and eyelids heavily flecked with grey. White patches at the base of the finger and toe discs. Brown merges to paler ventral colour on the lower flanks. Ventral surfaces of chest, belly and hindlimbs pale; throat, forearms and feet brown. Tubercles and discs pale.

Measurements of live individuals. Seven adults and two juveniles were measured in the field: adults SVL 43.0–52.9 mm (average = 47.4), WT 6.9–12.6 g (average = 9.4); juveniles SVL 24.8–26.4 mm (average = 25.6), WT 1.3–1.6 g (average = 1.45).

Colour pattern in life (Fig. 6)**.** ***Adults***. No sexual dimorphism in colour pattern evident. Dorsal colour most often even brown (Fig. 6A), but sometimes uneven or diffusely mottled brown or grey (Fig. 6B). Forehead and eyelids usually gold or yellowish (Fig. 6A, 6B), but silver or grey in some individuals. Gold or silver flecking particularly conspicuous on eyelids. Sometimes also yellowish colouration to tympanum (Fig. 6B). Loreal region dark; in pale individuals this appears as a dark canthal streak (Fig. 6B). Dark supratympanic fold and sometimes also dark marking below the tympanum. Tympanum pale. Pale lumbar ocelli indistinctly visible in some individuals. Ventral surfaces pale with grey wash to throat, armpits and forelimbs, and darker palms and soles of feet (Fig. 6C). Generally no orange colouration to groin, posterior thigh and inner calf; where this is present it is at most a pale salmon wash. ***Juveniles.*** Sandy yellow dorsal surfaces with dark blotches on the back, flanks and limbs (Fig. 6D). There is a yellow forehead triangle and yellow lumbar ocelli. A dark canthal streak extends behind the eye above and below the tympanum. The groin, posterior thigh, calf and top of foot have a salmon orange wash. The ventral surfaces are grey, flecked with white.

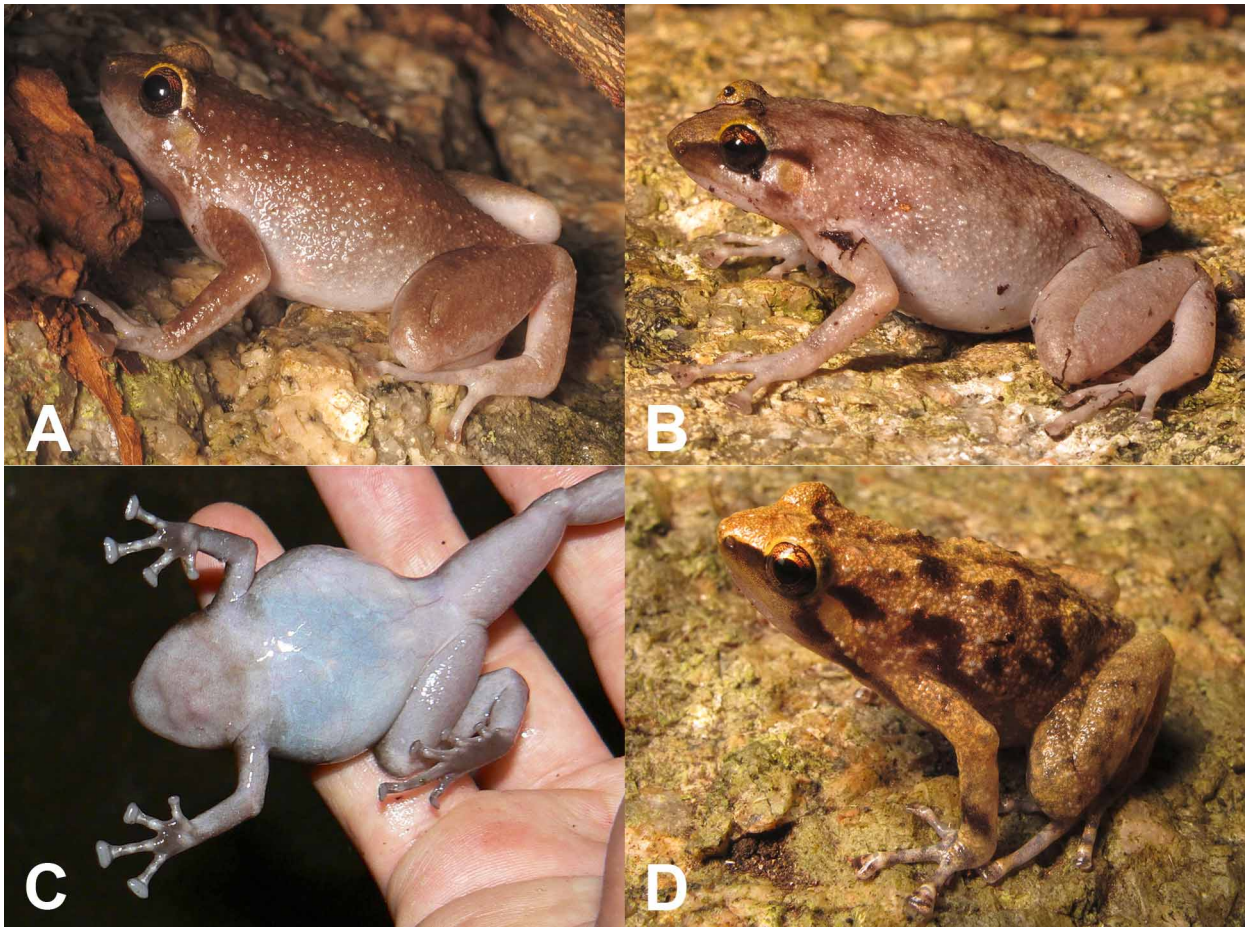

FIGURE 6. *Cophixalus pakayakulangun* **sp. nov.** in life: (A) female, (B) male, (C) female ventral surface, (D) sub-adult (photos: A, B, D, Kieran Aland; C, Conrad Hoskin).

Call. The call of *C. pakayakulangun* **sp. nov.** is not known.

Comparison. *Cophixalus pakayakulangun* **sp. nov.** does not co-occur with any other *Cophixalus*. It could only be confused with the other three boulder-adapted *Cophixalus*: *C. kulakula* **sp. nov.** (Fig. 3), *C. zweifeli* (Figs 1C, 1D) and *C. saxatilis* (Figs 1A, 1B). See the *C. kulakula* **sp. nov.** 'Comparison' section for a comparison of these four species.

Genetics. Average sequence divergence (for 944 bp 12S and 16S rRNA) between *C. pakayakulangun* **sp. nov.** and all other Australian *Cophixalus* is 12.9% (range = 8.3–17.1%) (Hoskin *et al.* unpublished). Phylogenetic analyses suggest that *Cophixalus pakayakulangun* **sp. nov.** is most closely related to *C. kulakula* **sp. nov.**, and that both are allied to *C. ornatus* (Hoskin *et al.* unpublished). A 16S sequence for *C. pakayakulangun* **sp. nov.** was deposited in GenBank (accession number JN208372).

Distribution. *Cophixalus pakayakulangun* **sp. nov.** is known only from the type locality, just south of Stanley Hill in north-east Queensland (Fig. 2). This is north of the Pascoe River and approximately 30 km north of the *C. kulakula* **sp. nov.** sites.

Habitat and habits. *Cophixalus pakayakulangun* **sp. nov.** inhabits deeply piled granite boulder field habitat that is festooned with vegetation such as vines, creepers, ferns and umbrella trees (*Schefflera*) (Fig. 7). As for *C. kulakula* **sp. nov.**, this species appears to be restricted to boulder habitat and no individuals were found away from rocks. The frogs emerge from the jumbled boulders on dusk to forage at night on the rocks and associated vegetation. No other frog species were observed utilizing boulder habitat at this site. As for *C. kulakula* **sp. nov.**, analysis of scats of *C. pakayakulangun* **sp. nov.** revealed that they feed primarily on ants (including *Polyrachis*, *Camponotus* and *Odontomachus*), as well as Coleoptera and Blattodea. This diet conforms broadly to that recorded for other Australian *Cophixalus* (Williams *et al.* 2006).

FIGURE 7. Habitat of *Cophixalus pakayakulangun* **sp. nov.**, Stanley Hill area (photo: Conrad Hoskin).

Cophixalus pakayakulangun **sp. nov.** was abundant at the site during wet weather towards the end of the wet season (April 2010), with males and females being observed in approximately equal abundance. However, no calling was heard and this suggests that breeding occurs earlier in the wet season. This is supported by the abundance of juveniles (approx. 25 mm) at the site in April. *Cophixalus pakayakulangun* **sp. nov.** almost certainly lays a clutch of terrestrial eggs, as seen in other Australian microhylid frogs (Hoskin 2004).

Two tubular structures are visible under the skin on the ventral surface of adult male *C. pakayakulangun* **sp. nov.** and *C. kulakula* **sp. nov.** (visible in Fig. 3D). These structures lie on either side of the midline, are easy to observe and allow for immediate determination of sex of live individuals (but are less obvious in preservative). We have subsequently observed these on males of other Australian frogs (e.g. *Uperoleia*). On dissection, these structures appear to lie within the muscular layers of the abdominal wall. We do not know what these structures are but we hypothesize that they might be involved in calling.

Discussion

The description of *C. kulakula* **sp. nov.** and *C. pakayakulangun* **sp. nov.** brings to 16 the number of Australian *Cophixalus* species. Eleven of these species are found in the Wet Tropics region (between Townsville and Cooktown) and five are found further north on Cape York. Three of these Cape York species are restricted to boulder habitats (*C. kulakula* **sp. nov.**, *C. pakayakulangun* **sp. nov.**, *C. zweifeli*) and the other two are found in the rainforests of the McIlwraith Ra. The two new species bring the number of boulder-dwelling species of *Cophixalus* to four. These boulder habitats acted as litho-refugia when rainforest contracted during historically dry periods, thus enabling the persistence of rainforest lineages (Couper & Hoskin 2008). The habitat occupied by *C. kulakula* **sp. nov.** and *C. pakayakulangun* **sp. nov.** is similar to that of *C. saxatilis* (Black Mountain) and *C. zweifeli* (Cape Melville) in being deeply piled granite rocks, but differs in generally being covered by more vegetation (apart from Tor Hill, discussed below). The boulder habitat at most of the *C. kulakula* **sp. nov.** and *C. pakayakulangun* **sp. nov.** sites is festooned with creepers, umbrella trees, ferns and other lush vegetation. Rather than a discrete boulder pile (like Black Mountain), the habitat is more scattered and dispersed in the form of boulder piles, boulder slopes and piled boulders along gully lines. Both species are probably distributed throughout suitable boulder habitat in the vicinity of the known sites. The species were both found in abundance at sites and their habitat is largely protected by its inaccessibility.

A population of *C. kulakula* **sp. nov.** was discovered by Ray Lloyd and Simon Kennedy (February 2010) at Tor Hill (12°54′52″S, 143°03′51″E, elevation 200 m), a large granite boulder pile approximately 25 km south-west of the populations in the Mt Tozer region. As for the other sites, the frogs were abundant on the surface during warm, wet weather (Ray Lloyd, pers. comm.). The boulder habitat at Tor Hill is similar to that at the sites near Mt Tozer but has less rainforest vegetation covering and surrounding it. This population is isolated from the other sites by unsuitable habitat. The Tor Hill population is approximately 3% divergent (12S/16S mtDNA) from the *C. kulakula* **sp. nov.** populations in the vicinity of Mt Tozer. Using a coarse mtDNA clock rate of 1%/My for rRNA sequence divergence (Moritz *et al.* 2000), it is estimated that these populations have been isolated from each other for over one million years. The general appearance, pattern and morphology of the Tor Hill frogs is similar to that of the Tozer populations. However, from a limited sample of measurements, Tor Hill males appear to be smaller (SVLs: 29 mm, 35 mm, N = 2) than those from the Mt Tozer region (40–45 mm, N = 7). Females from Tor Hill and Tozer populations are of similar size. Other aspects of the morphology of Tor Hill frogs may also differ (Hoskin, unpub. data). Based on a faint call recording made by Ray Lloyd the call is similar, but this needs to be assessed in more detail. Confirmation that the Tor Hill population is indeed *C. kulakula* **sp. nov.** requires detailed comparison of morphology and calls.

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APPENDIX 1. Photograph of the preserved holotypes: (A) *Cophixalus kulakula* **sp. nov.** (QMJ88540), (B) *Cophixalus pakayakulangun* **sp. nov.** (QMJ88547).