

A new species of rock-dwelling hylid frog (Anura:Hylidae) from the eastern Kimberley region of Western Australia

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Abstract – Australia's documented frog diversity slowly continues to grow owing to genetic tests for cryptic species and ongoing exploration of remote regions. Recent collecting trips in Western Australia's east Kimberley region resulted in the discovery of a new rock-dwelling hylid frog, *Litoria staccato* sp. nov. The new species is closely related to the much more widely distributed *L. coplandi*, which also breeds in the same rocky creeks. *Litoria staccato* sp. nov. is a small to moderate-sized frog characterised from co-occurring species by a combination of a moderately pointed snout, expanded terminal discs, half-webbed toes and a mottled appearance with variable colouration (reddish brown, grey or beige). The advertisement call consists of a rapid burst of irregularly-spaced notes, followed by groups of softer calls comprised of single or complex notes. Compared to *L. coplandi*, *L. staccato* sp. nov. is slightly smaller, has reduced webbing between the toes, different colouration and pattern (including diffuse vertebral and dorsolateral stripes), reduced glandular tissue at the angle of the jaw and a highly divergent call. Tadpoles show some adaptations to stream-living but also have body shape affinities associated with ground hylid pond-dwelling types such as *L. inermis*. The new species has only been found near Wyndham in the far north of Western Australia, and no specimens have been detected in existing museum collections indicating a restricted distribution. Owing to its remoteness and complex geology, the Kimberley region may hold other undiscovered rock-dwelling species with small natural ranges.

Key words: frog, Kimberley, *Litoria*, rock-dwelling, tadpole

INTRODUCTION

Frogs of the genus *Litoria* are prominent among northern Australian vertebrate fauna. Here they have radiated into a diversity of forms specialized for different lifestyles, including species that are strongly associated with rocky streams and pools along escarpments. There are currently three small rock-dwelling hylids from the humid Kimberley to Arnhem Land region of northern Australia: *L. coplandi*, *L. personata* and *L. meiriana*. All three species have expanded terminal discs on their fingers and toes and are encountered along rocky creeks, water holes and escarpments. Tyler and Davies (1978) initially placed *L. coplandi* in its own monotypic species group. Barker *et al.* (1995) placed the rock-dwelling forms either directly in a "*L. latopalmata*" group (*L. personata*) or in "other *Litoria*" (*L. coplandi* and *L. meiriana*). Before being formally described, specimens of *L. coplandi* were placed in "*L. latopalmata watjulumensis*" but later described as a separate taxon by Tyler (1968a). Tyler *et al.* (1978) compared the new taxon *L. personata*

to various *L. latopalmata* group members, but not to *L. coplandi*. Recent molecular work indicates that all three rock-adapted hylids may be only distantly related (S. Donnellan *personal communication*), suggesting that they evolved an association with flowing water and pools on rocks independently. *Litoria meiriana* is likely to be only distantly related to the other two species based on morphological (adults and tadpoles), behavioural and genetic differences (Tyler and Davies 1978; Tyler *et al.* 1983; S. Donnellan *personal communication*).

Potential threats to the native frogs of the tropical Kimberley region in Western Australia from introduced species such as the cane toad (*Bufo marinus*: Bufonidae) and chytrid fungus have generated concern about the future status of frogs there. As a result, new surveys are being conducted to estimate the true diversity of the region. Initial surveys conducted in the wet season of 2005–2006 in the east Kimberley have revealed a previously unknown taxon closely allied to, and syntopic with, the rock frog, *L. coplandi*. Here we describe this

taxon as a new species and present information on the male advertisement call, embryonic and tadpole development and the breeding habitat.

MATERIALS AND METHODS

We examined 12 adult specimens of the new taxon and compared them with its suspected close allies *L. coplandi* and *L. personata*. Morphological measurements generally follow Tyler (1968b) with some modifications (see Table 1). Measurements that could be made on either side of the body (e.g., tarsus length) were measured on the right side of the animal, unless this was damaged or misshapen. Measurements were made under a Leica MZ6 dissecting scope with digital vernier callipers to the nearest 0.01 mm. We also calculated the following

ratios (see Table 1A for abbreviations): HL/HW, IN/IO, EN/IN, TL/SVL, TarL/SVL and TarL/TL.

We compared the calls of two males of the new species with the call of one *L. coplandi* and one *L. meiriana*. Calls were recorded on a Marantz PMD670 digital recorder with a BeyerDynamic M88N microphone. Sound analysis was carried out on Cool Edit Pro and Raven 1.3b (Charif *et al.* 2004).

We collected a sample of embryos just prior to hatching close to where calling males and a gravid female had been collected the previous night. Six hatchlings and a small sample of capsules from the same clutch were also preserved. A sample of live hatchlings was collected and reared to metamorphosis to confirm identity. In addition, another sample of small tadpoles at stages 26–27 (Gosner 1960) found in the same pool and

Table 1 Characters measured with abbreviations and explanations.

Character	Abbrev.	Explanation of Measurement
A. Adults		
Snout-vent length	SVL	From tip of snout to posterior tip of urostyle
Inter-limb length	ILL	From axilla to groin
Head length	HL	From tip of snout to posterior edge of tympanum
Head width	HW	Width of head at centre of tympani
Eye-naris distance	EN	From anterior corner of eye to posterior edge of naris
Interorbital span	IO	Distance between anterior corners of eyes
Internarial span	IN	Distance between inner edges of nares
Naris-mouth distance	NM	Posterior edge of naris to upper edge of jaw
Eye diameter	EL	Anterior to posterior corners
Tympanum length	TymL	Anterior to posterior edges
Forearm length	FL	Elbow to proximal edge of palmar tubercle
Hand length	HandL	Tip of 3 rd finger to proximal edge of palmar tubercle
Third finger disc width	3 rd FDW	Maximum transverse width of 3 rd finger disc
Tibia length	TL	Measured with leg in natural resting position, from knee to tarsus
Tarsus length	TarL	Measured with leg in natural resting position, from proximal end of tarsus to proximal edge of inner metatarsal tubercle
Foot length	FootL	From tip of 4 th toe to proximal end of inner metatarsal tubercle
Fourth toe disc width	4 th TDW	Maximum transverse width of 4 th finger disc
B. Tadpoles		
Total length	TL	From tip of snout to tail tip
Body length	BL	From tip of snout to end of body
Body depth	BD	Maximum height of body
Body width	BW	Widest point of body in dorsal view
Body width at eyes	EBW	Body width at level of eyes in dorsal view
Tail muscle depth	BTM	Depth of tail muscle at base
Tail muscle width	BTMW	Width across tail muscle at base in dorsal view
Tail depth	TD	Measured at midpoint of tail
Dorsal fin depth	DF	Measured at tail depth
Tail muscle depth	TM	Measured at tail depth
Ventral fin depth	VF	Measured at tail depth
Inter-orbital span	IO	Measured in dorsal view
Inter-narial span	IN	Measured in dorsal view
Eye to naris	EN	Measured in dorsal view
Narial diameter	N	Measured in dorsal view
Snout to spiracle	SS	
Snout to naris	SN	
Snout to eye	SE	
Eye diameter	ED	
Oral disc width	ODW	Measured at maximum in ventral view

considered likely to be this species, was collected and reared to metamorphosis. Tadpoles were reared in 50 cm diameter containers of stream water to a depth of 14 cm, rocks and leaf litter from the stream where they were collected. Water was aerated and temperatures ranged from about 16–36°C during development.

Tadpole descriptions follow Anstis (2002). Abbreviations for tadpole morphometric characters follow Anstis and Tyler (2005) and are given in Table 1B. Measurements were made with an ocular micrometer attached to a microscope and vernier callipers. Embryos and tadpoles were drawn with the aid of a camera lucida, and photographs of live tadpoles taken using a Nikon D70 and 60 mm macro lens.

SYSTEMATICS

Family HYLIDAE Rafinesque 1815

Genus *Litoria* Tschudi 1838

Litoria staccato sp. nov.

Chattering Rock Frog

Figures 1–5

Holotype

WAM R162611. Adult male collected near “The Grotto”, 30 km south of Wyndham, Western Australia (15.72540°S, 128.27953°E), by P. Doughty and C. Mills on 30 January 2006. Liver sample stored at -75°C at the Western Australian Museum, Welshpool.

Paratypes

WAM R162512, R162514 (males) and WAM R162513 (female) collected 8 January 2006 by P. Doughty, J. Francis and M. Anstis (15.71466°S, 128.27288°E); WAM R162537-8 (males) collected on 15 January 2006 by P. Doughty, J. Francis and C. Mills (15.72506°S, 128.27951°E); WAM R162612-6 (males) and WAM R162620 (female) collected on 30 January 2006 by P. Doughty and C. Mills (15.72540°S, 128.27953°E). Liver samples stored at -75°C at the Western Australian Museum, Welshpool.

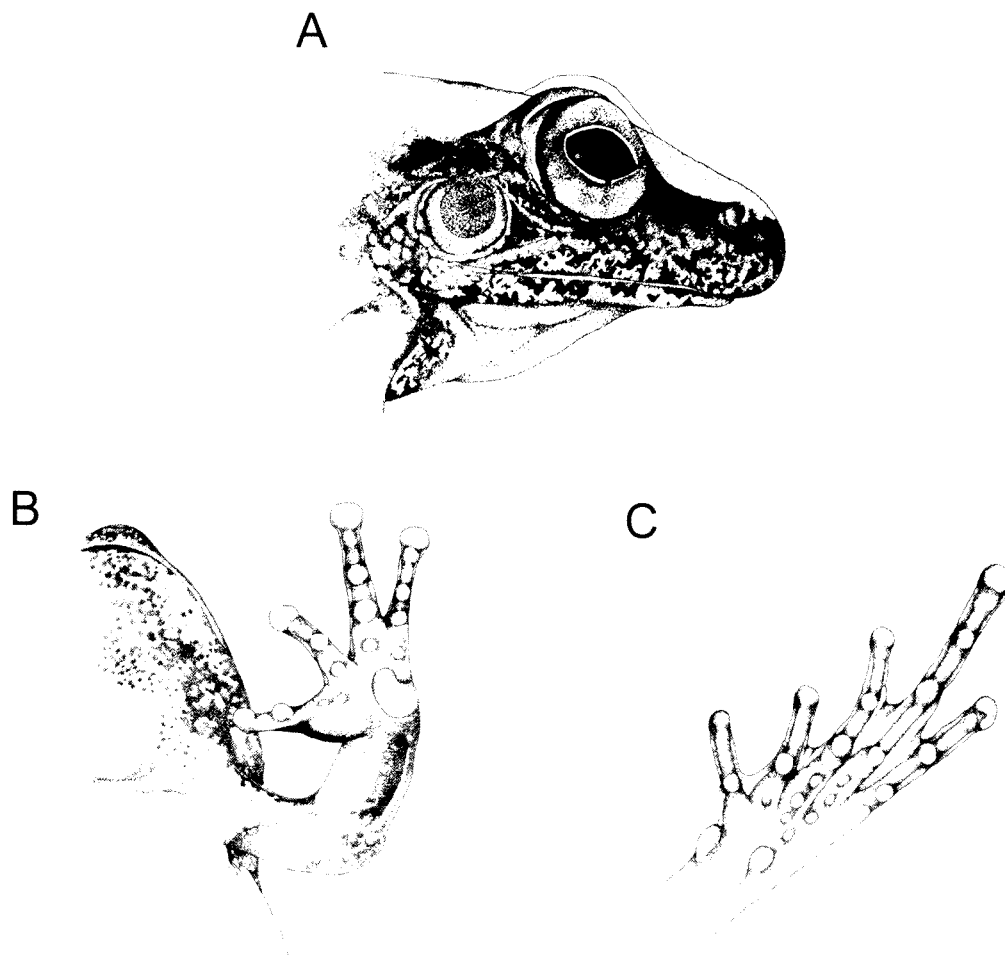


Figure 1 Head (A), chin and hand (B) and foot (C) of the male holotype of *Litoria staccato* (WAM R162611).

Embryos and Tadpoles

WAM R162946-7 (embryos), WAM R162948-57 (tadpoles) collected 9 January 2006 by M. Anstis and P. Doughty (15.71466°S, 128.27288°E).

Diagnosis

A small to moderate-sized rock-dwelling hylid with moderately pointed snout, medium build and slender limbs. Tips of fingers widely expanded and toes half-webbed. Dark lateral head stripe present but not clearly defined; pale triangular patch usually discernible on snout. Lateral head stripe continues beyond tympanum and fades posteriorly into broader mottled lateral stripe that demarcates lateral and ventral zones. Dorsal colour of males variable, ranges from reddish brown to slate grey to beige; females reddish brown. There are variably expressed diffuse darker vertebral, dorsolateral and lateral stripes.

Distinguishable from similar-sized ground hylid frogs of the Kimberley-Arnhem Land region by possession of broadly expanded discs on tips of fingers and toes (not *L. inermis*, *L. latopalmata*, *L. nasuta* or *L. pallida* which lack expanded terminal discs), toes half-webbed (not *L. coplandi*, *L. meiriana* or *L. wotjulumensis* which have fully webbed toes) and mottled dorsal colouration with diffuse lateral head stripe, vertebral and dorsolateral stripes (not *L. personata* which has strong lateral head stripe and uniform-coloured dorsum) (see also *Comparison with other species*, below). The male call consists of a series of rapid, high-pitched irregularly spaced notes, interspersed with short and complex softer calls (Figure 3C).

Description of holotype

Head narrow and triangular with moderately pointed snout and prominent eyes (Figure 1A). In profile, snout gradually narrows to oblique tip. Nares positioned on tip of snout under canthus rostralis, slightly oval, opening dorsolaterally and slightly forwards. Canthus rostralis straight with moderately sharp edge; loreal region steep-sided and concave. Tympanum prominent and circular, distinct annulus present except for dorsal edge. Small cluster of 5–6 glandular nodules between lower posterior edge of tympanum and insertion of forearm. Vomerine teeth a pair of smooth ridges anterior to medium-large oblique choanae. Tongue oval, tapers posteriorly, free edge blunt and unnotched.

Arms short and slender. Fingers long, slender and unwebbed but with weak lateral fringes (Figure 1B). Palmar tubercles at base of outer portion of wrist prominent and paisley-shaped (narrow end pointing towards fingers). Large tubercles present on finger joints with smaller tubercles on palm. Nuptial pad comprised of fine layer of small dark rugose tubercles on inner margin of 1st finger.

Fingers in order of length: 3>4>1>2. Tips of fingers with broad discs: 1st and 2nd fingers approximately 2x wider, and 3rd and 4th fingers approximately 1.5x wider than distal phalanx in life (in preservative, discs 1.5x and 1x wider, respectively).

Legs long and slender. Distinct fold of skin above knee. A fringe runs along inner tarsus and connects to inner metatarsal tubercle. Moderate sized inner metatarsal tubercle narrow, projects distally (Figure 1C). Outer metatarsal tubercle small and oval, projects towards toes. Feet narrow. Toes in order of length: 4>5>3>2>1. Webbing between 1st and 2nd and between 2nd and 3rd toes to proximal end of distal phalanges on each toe. Webbing between 3rd and 4th toes to just beyond proximal joint of distal phalanx on 3rd toe, and to base of proximal end of penultimate phalanx on 4th toe. Webbing between 4th and 5th toes to base of proximal end of penultimate phalanx on 4th toe and to just above proximal end of distal phalanx on 5th toe. Lateral fringes on all toes beyond webbing. Toe discs only slightly wider than penultimate phalanx in life (in preservative, approximately the same width). Medium conical subarticular tubercles on joints of toes with minute tubercles on plantar surface.

Skin on dorsum and limbs smooth. Belly granular with slight transverse crease between arms, towards anterior edge of arm insertion. Underside of posterior edge of thighs with larger flattened granulation. Coccyx forms prominent ridge that protrudes slightly beyond end of body. Cloaca positioned just below coccyx, projects dorso-posteriorly.

Dimensions of holotype (mm)

SVL 30.5; ILL 13.15; HL 11.66; HW 10.83; EN 2.76; IO 5.3; IN 3.21; NM 1.64; EL 3.21; TymL 2.30; FL 6.15; HandL 7.60; 3rdFDW 0.72; TL 15.72; TarL 8.40; FootL 11.69; 4thTDW 0.56; HL/SVL 0.38; HL/HW 1.08; EN/IN 0.86; EN/IE 0.52; TL/SVL 0.52; TarL/SVL 0.28; TarL/TL 0.53.

Colour in life

Dorsum light reddish brown (Figure 2A). Faint, darker, narrow vertebral and wider dorsolateral stripes present, the latter forming a diffuse border between dorsal and lateral zones. Lateral head stripes dark grey, not sharply defined along snout, with diffuse dorsal and ventral edges. Lateral head stripe begins narrowly at rostrum passing through nostril and lower half of eye; continues posteriorly from eye through tympanum, extending just above dorsal edge of tympanum; angles downwards towards ventral surface, fading diffusely just over half-way between insertion of arms and legs; continues as diffuse mottled border between lateral and ventral zones. A subtle, yet distinct, paler triangular patch on snout is defined dorsally by border of lateral head stripes and posteriorly by

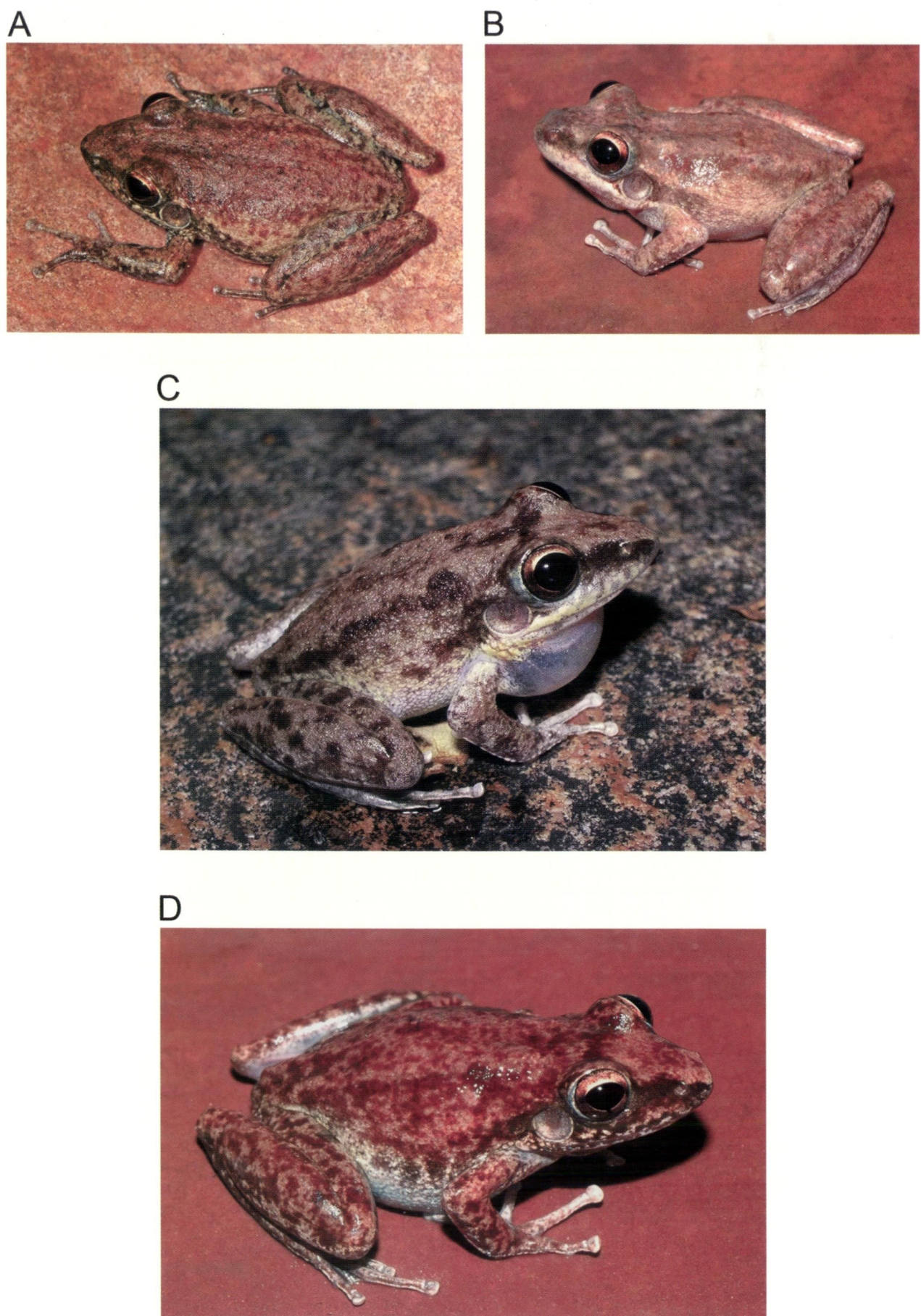


Figure 2 Adult frogs in life of *Litoria staccato* showing colour variation. A) holotype male (WAM R162611) with reddish brown colour; B) beige male (WAM R162514); C) calling slate grey male (uncollected); D) reddish brown female (WAM R162513).

diffuse darker bar between eyes. As triangular patch narrows towards tip of snout, it broadens slightly and contacts nares before terminating just anterior to nares. Lateral head stripes continue forward to join at rostrum tip. Upper lip mottled with diffuse black. Lower lip pale with dark mottling not extending to chin. Chin darkly stippled anterior to vocal sac, and less stippled towards margin of jaw. Lower two-thirds of iris brown, upper third bright copper gold, pale gold border above pupil, less distinct below pupil.

Tympanum unpigmented except for darker patch extending from dorsal edge to centre. Annulus of tympanum pale. Pale lemon yellow wash over upper lip (below stripe), sides and posterior surface of thighs. Bright lemon yellow wash over groin, fades anteriorly. Flanks and posterior surfaces of thighs diffusely mottled with reddish brown colour of dorsum. Dorsal surface of limbs reddish brown (same as dorsum) with diffuse darker mottling. Dorsal surfaces of arms mottled, fingers paler, especially 2nd and 3rd. Outer edge of forearms with darker mottling. Dorsal surface of legs dark with some mottling, especially on posterior edge of thighs where blotches form an uninterrupted line. Belly and ventral surface of limbs pale white, undersurfaces of feet dark brown.

Colour in preservative

Dorsal surfaces much darker than in life – dark slate to chocolate brown – with vertebral and dorsolateral stripes much less apparent. Dark lateral head stripe poorly defined with ground colour discernible beneath; continues past tympanum and fades on side near arms. Yellow wash in groin barely discernible. Undersurfaces pale yellow, hands and feet dark.

Variation

Male body sizes varied only slightly – the smallest was 29 mm and the largest 33 mm (Table 2). The build, proportions and general appearance of male specimens generally agreed with the holotype except for the following (WAM prefixes excluded below). Shape of rostrum varied from sharp and angular (R162614, R162616) to more broadly rounded (R162612). Glandular tissue at angle of jaw similar to holotype for most males, but in R162616, nodules were higher and more prominent, and in R162512, skin was nearly smooth. Nuptial pads ranged from less developed (lighter and less extensive; R162512) to very heavy and extensive (R162537). R162515 possessed slightly rougher pads than other males.

The two female specimens had lengths of 35.5 and 36.5 mm – larger than any of the 10 males. Both females were collected near calling males and were heavily gravid. Other than overall body size there were no obvious differences between males and

Table 2 Summaries of characters and ratios measured for *Litoria staccato*, *L. coplandi* and *L. personata*. Mean±S.D. (range). Sample sizes are for species unless noted. See Table 1A for abbreviations.

Character	<i>L. staccato</i> N = 12	<i>L. coplandi</i> N = 56	<i>L. personata</i> N = 12
SVL	31.4±2.4 (29–36.5)	33.4±4.0 (24.5–43.0)	30.8±2.4 (26.5–33.5)
ILL	13.0±2.1 (10.4–18.4)	13.8±2.1 (8.8–18.0)	12.3±1.9 (9.5–15.3)
HL	11.3±0.7 (10.4–13.1)	12.4±1.3 (8.6–15.2)	11.2±0.8 (9.7–12.4)
HW	10.7±0.8 (9.8–12.6)	11.8±1.4 (8.9–14.6)	9.9±0.7 (8.6–11.0)
EN	2.8±0.2 (2.6–3.1)	3.2±0.4 (2.6–4.1)	3.0±0.3 (2.4–3.2)
IO	5.4±0.3 (4.8–6.0)	6.6±0.7 (5.0–8.2)	5.9±0.5 (5.0–6.5)
IN	3.2±0.2 (2.8–3.6)	3.2±0.4 (2.4–4.1)	3.2±0.2 (2.9–3.4)
NM	1.8±0.2 (1.5–2.1)	2.1±0.3 (1.6–2.7)	1.7±0.2 (1.5–1.9)
EL	3.2±0.3 (2.8–4.0)	3.7±0.4 (2.9–4.5)	3.3±0.4 (2.6–4.0)
TymL	2.3±0.1 (2.0–2.5)	2.6±0.3 (2.1–3.8)	2.5±0.6 (1.9–3.3)
FL	6.4±0.7 (5.7–7.9)	6.9±0.7 (5.5–8.6)	6.6±0.6 (5.7–8.0)
HandL	7.6±1.2 (6.0–9.6)	8.4±1.3 (5.8–10.3)	7.7±0.6 (6.6–8.5)
3 rd FDW	0.98±0.15 (0.77–1.23)	1.14±0.23 (0.63–1.81)	0.93±0.22 (0.60–1.13)
TL	16.0±1.3 (14.3–18.4)	18.7±2.2 (14.8–24.1)	17.4±1.6 (14.7–20.0)
TarL	8.4±0.6 (7.4–9.7)	9.1±1.1 (7.4–11.4)	9.2±1.0 (7.2–10.6)
FootL	11.9±1.2 (10.8–14.4)	13.3±1.8 (10.4–18.2)	12.1±1.3 (10.1–13.9)
4 th TDW	0.73±0.10 (0.63–0.94)	0.98±0.25 (0.58–1.68)	0.72±0.21 (0.48–1.04)
HW/SVL	0.34±0.01 (0.31–0.36)	0.36±0.01 (0.32–0.36)	0.32±0.01 (0.32–0.36)
HL/HW	1.05±0.03 (1.02–1.10)	1.04±0.05 (0.82–1.16)	1.13±0.04 (1.07–1.21)
EN/IN	0.89±0.04 (0.81–0.95)	0.98±0.08 (0.81–1.16)	0.93±0.06 (0.82–1.04)
EN/IO	0.52±0.02 (0.47–0.56)	0.48±0.04 (0.41–0.57)	0.50±0.04 (0.45–0.57)
TL/SVL	0.51±0.02 (0.46–0.55)	0.56±0.04 (0.45–0.65)	0.57±0.03 (0.49–0.60)
TarL/SVL	0.27±0.01 (0.25–0.29)	0.27±0.02 (0.22–0.33)	0.30±0.02 (0.24–0.33)
TarL/TL	0.52±0.02 (0.49–0.55)	0.49±0.02 (0.44–0.53)	0.53±0.03 (0.48–0.58)

females in morphological characters, but the small number of females prevented further evaluation.

Colouration of males was variable. In addition to the reddish brown of the holotype and paratypes R162537-8, R162612 and R162616, other individuals were bright beige while active in life (R162514 and other uncollected males – Figure 2B). Still others were slate grey (R162512, R162613-5 – Figure 2C). Mottling on the dorsum was also variable – some individuals had darker mottling (e.g., R162612) while others had only faint variegations (e.g., R162514). Collected individuals changed colour from generally vivid while active to more dull and/or mottled the following day, obscuring the diffuse vertebral, dorsolateral and lateral streaks.

The lateral head stripe ranged from relatively demarcated (e.g., R162613) to diffuse grey (e.g., R162514) with borders never sharply defined. In most males, the lateral head stripes did not meet at the tip of the snout, but in one other individual (R162537) they joined, as in the holotype. The paler snout patch outlined by the lateral head stripes and the diffuse posterior bar between the eyes varied in definition from very clear (e.g., R162537) to poorly defined (R162612). Presence of the thin vertebral and wider dorsolateral streaks was highly variable. In some specimens, stripes were relatively solid and dark (e.g., R162613, R162615), in others there was only a slight stripe (R162514), or heavy mottling that obscured stripes (R162612). The border between lateral and ventral regions varied from a smooth transition with little marking (R162514), to a mottled transition zone (R162612, R162614), to a darker stripe (R162613, R162614). Mottling on posterior edge of thighs ranged from diffuse (e.g., R162614-5; as for holotype), to faint uniform stippling (R162612-3), or very faint stippling (R162514).

The two female specimens were similar in colouration – both had the dull reddish brown background colouration seen in several males, with moderate to heavy dark mottling on dorsal surface. Snout patches were less prominent and vertebral, dorsolateral and transverse bars weakly defined. Female R162513 was lighter overall, including paler sides, no stippling on chin and only faint stippling on back of thighs (Figure 2D). Female R162620 was darker, with mottled sides, light stippling on chin and mottling on back of thighs similar to some males.

Advertisement call

The calls of the holotype male (R162611) and a paratype (R162612) were recorded on 30 January 2006 between 7 and 9 pm. The air temperature 1 cm above the males was 28.7°C (R162611) and 26.6°C (R162612), and the temperature of the flowing water about 5 cm below the surface was ~ 29°C for both.

The call of the holotype of *L. staccato* is presented in Figure 3C. It consists of a sequence of rapid, high-pitched, irregularly spaced, short (staccato) notes, followed by a series of softer and more widely spaced notes with occasionally more complex notes (Figure 3C–F). The holotype male called 3.8 times per minute with call duration averaging 6.5 s (maximum – 15 s). Notes in the main call are irregularly spaced, sounding similar to a Morse code signal. There were an average of 25 notes/call and 4.3 notes/s. The notes increased slightly in amplitude during the call (Figure 3C). Each note consisted of a series of 14–19 pulses that increased in amplitude gradually with a sharper decrease, and with dominant frequencies of 2–3 and 4–6 kHz (Figure 3D). Between the main calls, the much less frequent softer calls were delivered in small clusters of typically 3–4 notes (up to six). These notes were made up of 5–8 pulses with dominant frequencies at 2, 3.5 and 5 kHz (Figure 3E). A third type of call was occasionally given among the softer calls that consisted of a rapid, trill-like series of modulated pulses with several peaks (Figure 3F). During the 10 minute recording, the male only began to give these more complex calls in the middle third of the calling sequence. These complex notes were made up of 34–48 pulses, had 4 or 5 peaks in amplitude during the brief (0.15 s) call and had dominant frequencies at 1.5 and 3.5 kHz.

The paratype male (R162612) had very similar call characteristics for the main call, but did not give the soft or complex calls between the main calls. These two individuals were calling on either side of a stream > 5 m apart. In both recordings, other males called simultaneously in response to each other. A gravid female (R162120) was captured within 2 m of R162612.

Breeding choruses

Litoria staccato males called in choruses of 2–6 males in slow-flowing sections of a rocky creek at one site, and around shallow water in crevices or under boulders at another site located on an escarpment. Calling sites included exposed rocks, within crevices and under overhanging vegetation. One male (R162612) was observed calling ~ 10 cm above the water (head facing down and towards the stream) while clinging vertically to a ~ 50 cm boulder at the creek's edge. No males were observed to be within 5 m of each other and males often called from positions on opposite sides of the water body. Calls of males in breeding choruses occurred synchronously.

Embryos

A single clutch of embryos was collected that were either just prior to hatching or just hatched at stages 20–21 with capsules partly decomposed. The clutch was collected from a very small and shallow

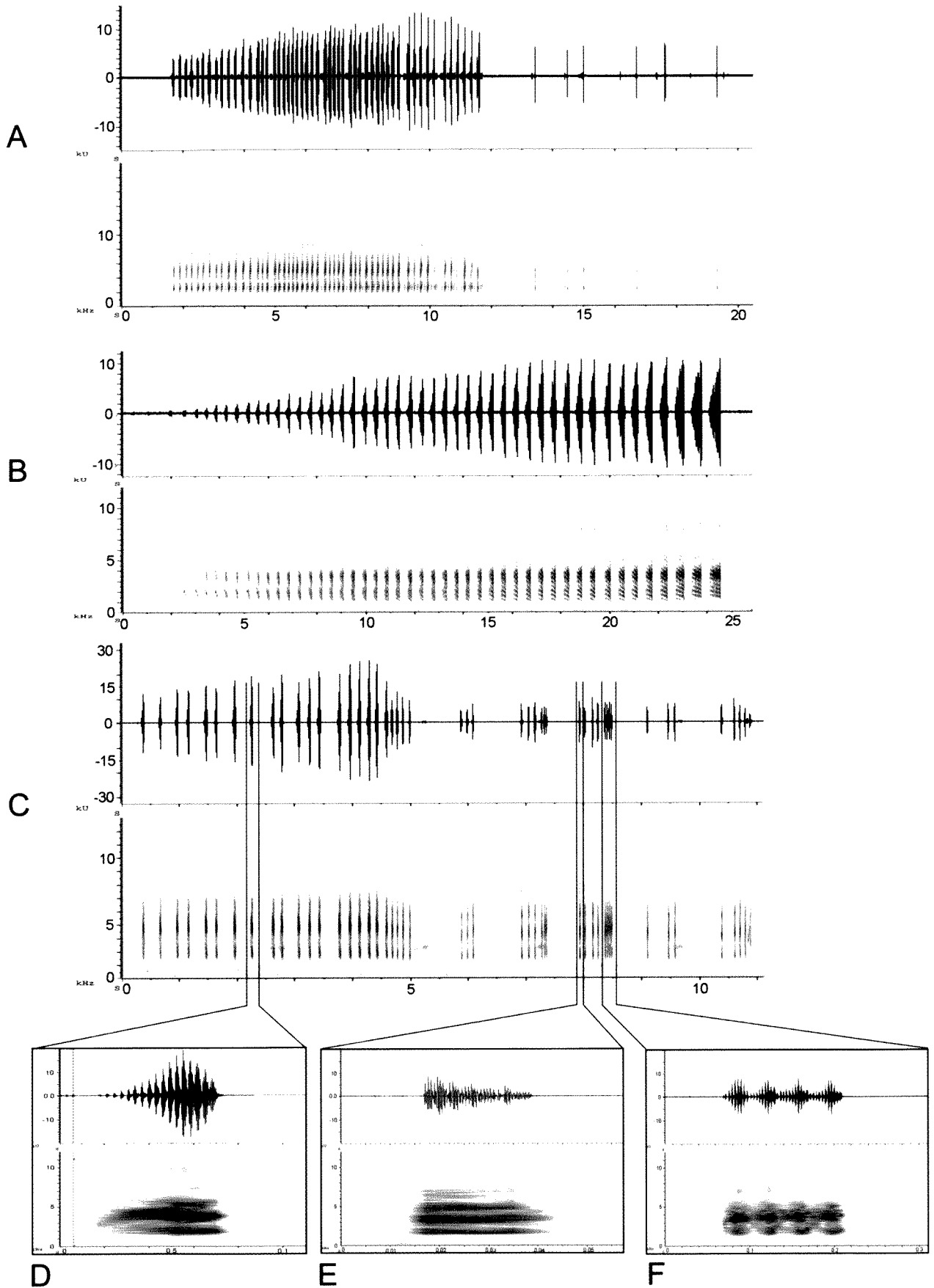


Figure 3 Oscillograms (upper) and sonograms (lower) of male advertisement calls. A) *Litoria meiriana* (WAM R162521); B) *L. coplandi* (uncollected); C) *L. staccato* holotype (WAM R162611); D) *L. staccato* main call; E) *L. staccato* soft call; F) *L. staccato* complex call.

rock pool (70 x 30 cm and 2–3 cm deep) segregated by about two metres from the main creek, most of which was flowing at a reduced water level beneath large boulders. The pool contained leaf litter and tannin-stained water and was on a rock shelf where several calling males and a gravid female were found the previous night. The sample of small tadpoles collected at stages 26–27 was taken from the same pool. The remaining jelly capsules were covered with silt and most were decomposing, but those of six embryos which had died earlier at about stages 13–14 were still intact, and these had a mean external capsule diameter of 3.83 mm (3.54–3.86 mm).

Measurements of embryos are shown in Table 3. Two embryos at stage 20 had shorter gills, darker fins and a less arched dorsal fin than those at stage 21.

Stage 21 (Figure 4A). – Dorsum and tail muscle appear black macroscopically; area above head (lateral view) translucent grey; tail fins dusky grey; snout angular in lateral view; abdomen broad in dorsal view, yolk white; optic bulge discernable but barely pigmented; two pairs well developed external gills with 3–4 upper and 5–6 lower filaments; adhesive organs black and prominent; deep triangular stomodaeum bordered by labial ridges; narial pits visible.

Stage 23 (Figure 4B). – Reached on 10 January; dorsum very dark brown with scattered iridophores over snout, brain, eyes and tail muscle; yolk whitish with network of melanophores dorsolaterally; lateral line organs faintly visible; tail fins dusky grey, melanophores anteriorly across dorsal and

partly lateral surface of muscle. Snout broad in dorsal view and rounded in lateral view; eyes well developed, cornea clear; external gills slightly reduced, upper and lower branches of similar length, 4–5 upper and 6–7 lower filaments; adhesive organs broad and flattened; nares perforated, opening anteriorly, quite widely spaced and situated right on tip of snout; labial ridges broader, upper ridge divided; jaw sheaths visible, keratin just visible on edge of upper sheath; operculum open on both sides, short tubular projection on edge of left side – juts outwards (probable early development of spiracle); tail fins well arched, tip broadly rounded; myotomes visible along muscle.

Tadpoles

The largest tadpole grew to a maximum total length of 52.0 mm and body length 17.5 mm (stage 38). Table 3 presents measurements of tadpoles. Tadpoles in captivity were predominantly bottom dwellers and mostly grazed on live algae on rocks and on sediments. Initially water was not aerated and while most tadpoles appeared to grow normally, some died. Aeration was then introduced and the remainder survived, became more agile and grew more steadily. Tadpoles frequently remained in the vicinity of the source of aeration, holding onto rocks with the oral disc. If disturbed, they rapidly darted under rocks or leaves.

Table 4 describes pigmentation development in life. In preservative, all golden, silver and copper iridophores are lost, together with lighter brown pigment, leaving only the darker melanophore patterns visible on the dorsum and tail. The venter

Table 3 Morphometric measurements of tadpoles of *Litoria staccato*, in mm (see Table 1B for abbreviations). Number of specimens: stages 20–21 = 7, 25 = 2, stages 26–29, 32, 38–40 = 1, stage 36 = 3, stage 46 = 2.

Stage	20–21	25	26	27	28	29	32	36	36	36	38	39	40	46
TL	5.72 (5.24–5.98)	12.39, 12.23	20.0	21.5	26.0	29.0	35.0	42.6	40.5	44.0	52.0	49.0	48.3	17.5, 19.0
BL		4.99, 4.99	7.72	8.05	11.1	12.07	13.36	16.74	15.77	16.3	17.5	17.7	17.7	
BD					6.15	6.76	7.24	9.01	8.69			9.98	9.66	
BW					6.72	7.08	7.24	9.98	9.33			10.94	10.78	
EBW					6.64	7.08	7.08	8.05	9.17			10.46	9.82	
BTM					2.29	2.73	3.22	4.18	3.54			5.0	4.83	
BTMW					2.09	2.41	2.57	3.54	3.7			5.15	5.15	
TD					5.49	6.27	6.6	8.05	8.13			9.17	8.69	
DF					1.88	2.09	2.25	2.57	2.65			2.98	3.05	
TM					1.88	2.25	2.25	3.22	3.13			3.7	2.57	
VF					1.72	1.93	2.09	2.25	2.33			2.57	3.05	
IO					3.44	3.78	3.86	4.34	4.34			4.5	4.34	
IN					1.88	2.09	2.09	2.57	2.57			2.57	2.57	
EN					1.93	2.09	2.09	2.57	2.57			2.73	2.73	
N					0.28	0.28	0.32	0.3	0.32			0.32	0.32	
SS					6.44	7.08	8.05	9.41	9.01			10.3	9.98	
SN					1.28	1.28	1.61	2.01	1.61			2.25	1.61	
SE					3.38	3.38	3.7	4.83	4.34			5.15	4.34	
ED					1.36	1.45	1.93	2.09	2.25			2.57	2.57	
ODW					3.19	3.28	3.36	4.18	3.93			4.51	4.67	

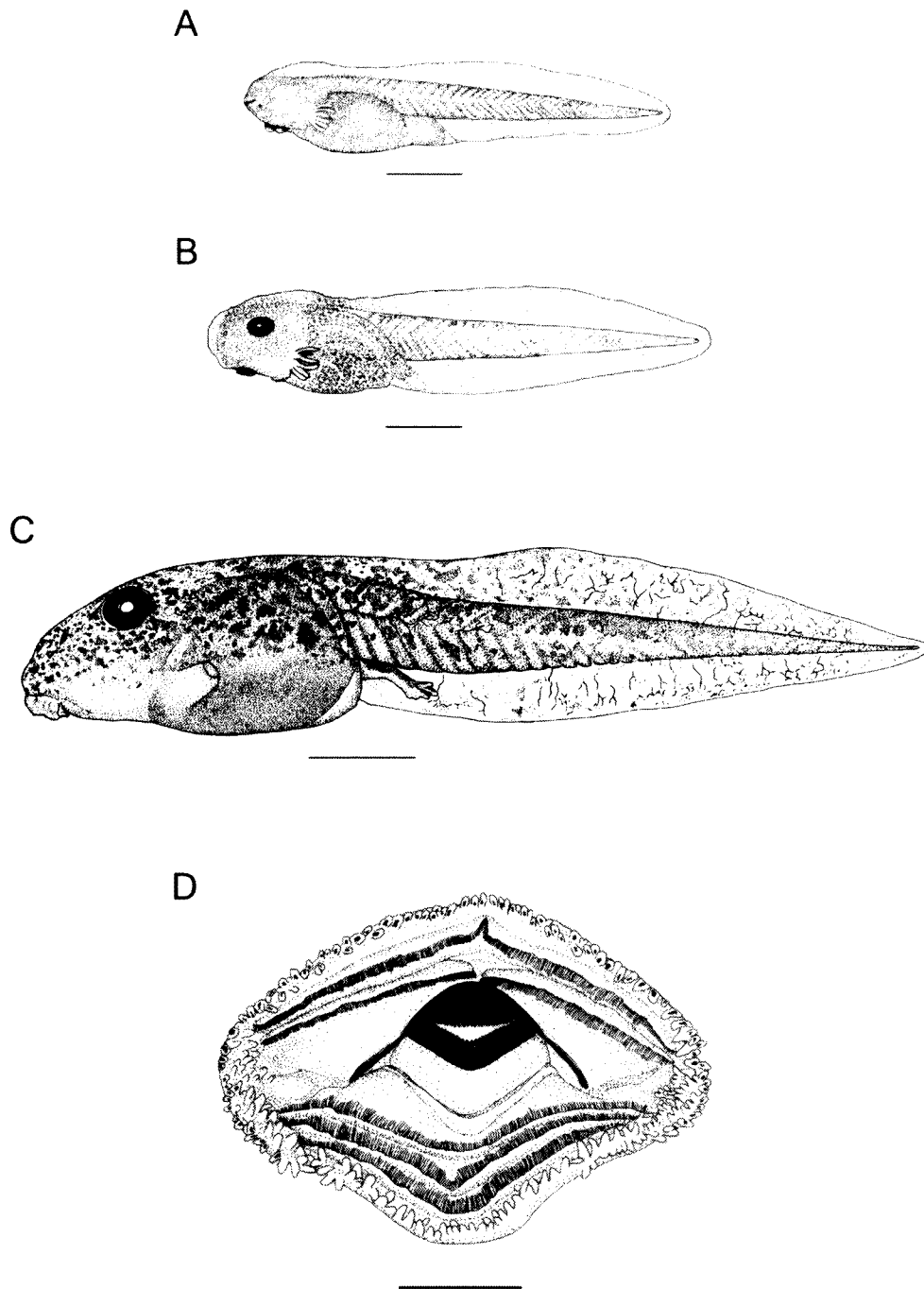


Figure 4 Embryos, tadpole and oral disc of *Litoria staccato*. A) hatching at stage 20, bar = 1 mm; B) stage 23, bar = 1 mm; C) tadpole at stage 36, bar = 5 mm; D) oral disc, specimen at stage 36, bar = 1 mm.

appears dark grey-blue and the paler snout colour is not visible. Description of the morphological changes during development are presented below.

Stage 25. – Reached by 14 January: body shape cylindrical, similar to Type 2 hylids (Anstis 2002); eyes near lateral; tail fins well arched, tail tip rounded.

Stages 26 and 27 (Figure 4A). – Mostly similar to later stages described below, apart from size and pigmentation changes (see below), in body features, mouthparts and tail features, but the distance from the eyes to the tip of the snout is shorter and the snout is a little narrower in dorsal view.

Stages 32–39. – Medium body size when full grown, as wide as deep across abdomen to about stage 32, slightly wider than deep across abdomen from about stage 36 onwards; snout rounded in dorsal view, gradually becomes broader and slightly more streamlined anterior to eyes from about stage 34 onwards; eyes near lateral, slightly dorsolateral in later stages; nares small, quite widely spaced, open anterolaterally, slightly closer to tip of snout than to eyes; spiracle fairly short, broad, opens dorsoposteriorly below horizontal body axis posterior to midpoint of body; vent tube dextral (type a; Anstis 2002), narrow, and opens

Table 4 Pigmentation of *Litoria staccato* tadpoles at different larval stages (Gosner 1960).

Stage	Dorsum and Eyes	Sides	Venter	Tail
25	Melanophores over dorsum; gold iridophores over most of dorsum (except over darker base of body); some small dark patches over vertebral region.	Gold patch beginning on each side of abdomen at base of body, denser iridophores posterior to gill region.	Mostly transparent, bordered by dense melanophores and gold stippling.	Fins clear, dorsal surface of muscle dark, capped with gold patches spaced along length, lateral surface stippled with melanophores, a few gold iridophores anteriorly.
26-27 (Fig. 5A)	Dorsum mostly uniform golden; areas above brain, around nares, over abdomen and base of body a little darker; iris golden above and below pupil, black at each side and across top.	Gold clusters cover upper half of abdomen, merging down sides to orange-gold, dark background beneath; lower half of abdomen orange-gold, opaque white beneath; orange-gold from gills to eyes, clearer below; distinct pale gold longitudinal patch midway down body along each side of abdomen, just anterior to base of body; another similar but narrower vertical patch just posterior to gill region; pigment lighter anteriorly.	Brilliant orange-gold over abdomen, sparser over gills and clear over buccal region.	fins mostly clear with some dark veins; few gold specks and melanophores on dorsal fin; fine melanophores over muscle anteriorly, gold stippling dorsolaterally over anterior third; lateral surface of muscle mostly unpigmented posteriorly; some gold clusters anteriorly over lower half. Anterior edge of ventral fin bordered with pale gold, gold clusters over vent tube.
32 (Fig. 5B)	Dull golden brown or darker brown with layer of fine copper-gold iridophores over most of head and body, dark longitudinal stripe down each side of vertebral region and dark patch over base of body, indistinct darker mask bridges eyes.	Distinct lateral gold bar present at base of body during at least stages 26-28 now mostly obscured.	Opaque silver-white with copper sheen, clearer below mouth.	Diffuse melanophore clumps over dorsal fin and muscle of tail; few diffuse gold clusters and flecks over muscle and both fins; darker pigmented veins over muscle and fins (some outlined with gold).
36-39 (Fig. 5C,D)	Diffuse melanophore clumps over dorsal fin and muscle of tail; a few diffuse gold clusters and flecks over muscle and both fins; darker pigmented veins over muscle and fins (some outlined with gold); copper stripe extends from middle of base of body just onto dorsal surface of muscle; dense copper-gold covers most of iris.	Mottling covers upper two-thirds of body, denser by stage 38 onwards.	Opaque silver right up to mouth from stage 36.	Darker mottling covers most of tail; numerous pigmented veins, some outlined with gold; gold clusters anteriorly on dorsal fin, copper-gold along anterior edge of ventral fin and over vent tube; darker mottling denser and covers entire tail by stage 38.
42 (Fig. 5E)	Pale triangle on snout anterior to eyes visible, demarcated posteriorly by diffuse darker bar bridging eyes.			

posteriorly, dorsal edge partly unattached behind. Fins moderately arched and taper to somewhat elongate, narrowly rounded tip; dorsal fin begins just onto base of body, initially low then rises more distinctly to highest point anterior to midpoint of tail before tapering; ventral fin less arched.

Oral disc (Figure 4D). – Near ventral in direction in life (anterior medial margin tilts slightly upwards); ventral in preservative. Marginal papillae surround entire disc; anterior marginal papillae mostly in a single row medially to partway down lateral margins, increasing to two offset rows

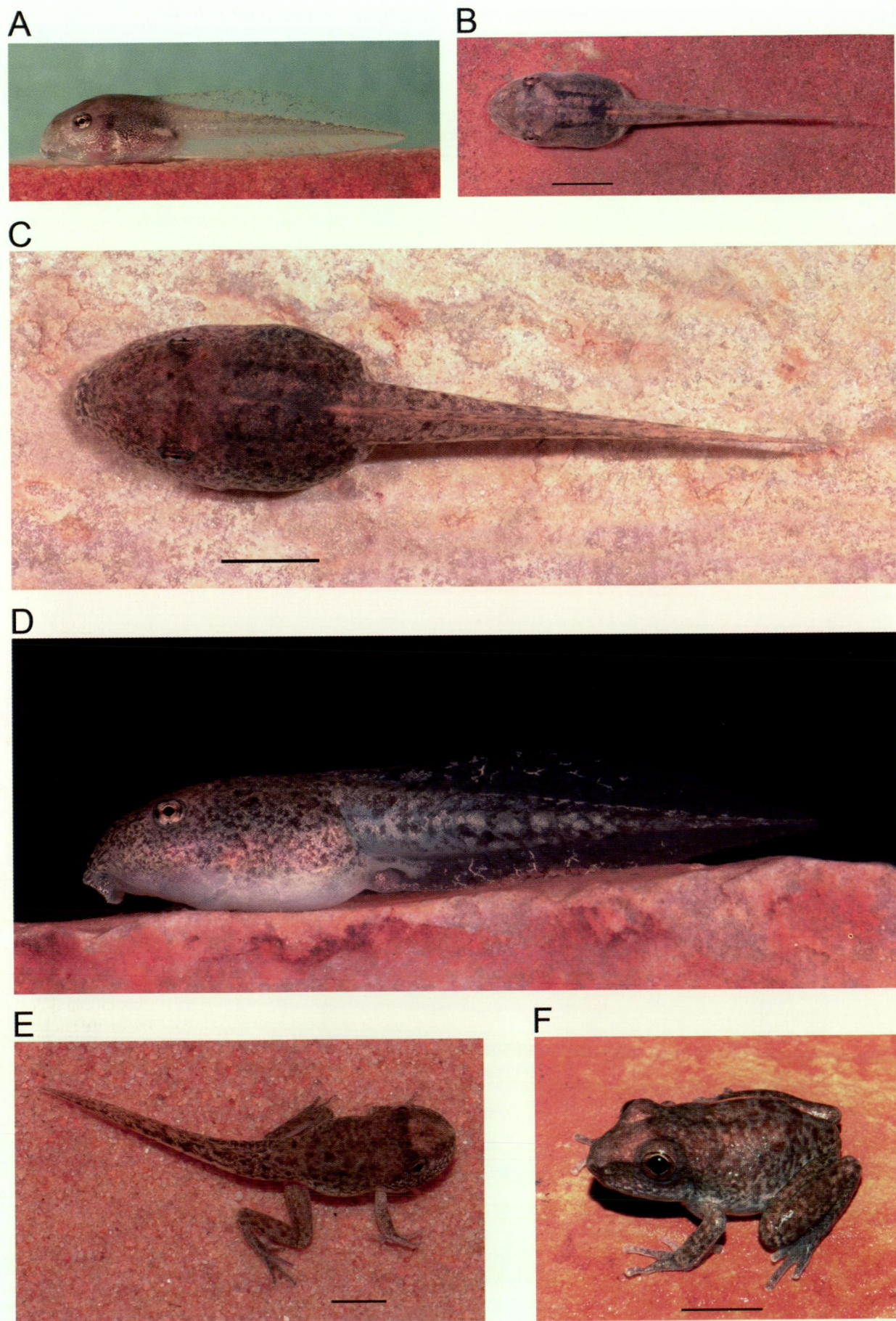


Figure 5 Live tadpoles and metamorph of *Litoria staccato*. A) stage 26 (lateral view); B) stage 32 (dorsal view); C, D) stage 36 (dorsal and lateral views); E) stage 42; F) stage 46. Bar in each photo = 5 mm.

beyond this down each side of anterior half; some have as few as 10–25 medial papillae in a single row across top of disc before two rows begin on each side. Four to six rows of mostly small submarginal papillae at each side of disc; two rows offset slightly longer papillae around posterior margin; may be only one row initially at each side of margin, to up to three rows medially in some. Two anterior and three posterior tooth rows, A¹ continuous, usually with medial pleat (Figure 5B), A² has a narrow medial gap, P^{1,2,3} rows continuous, P³ very slightly shorter. Jaw sheaths medium, quite distinctly serrated and fairly narrowly arched, with long flared lateral processes.

Metamorphosis. – Tadpoles collected at stage 26 on 9 January began to metamorphose on 11 February (33 d later), and hatchlings collected on 9 January first metamorphosed on 20 February (42 d later). Assuming that early development from egg to hatching is likely to take about 3 d in the shallow warm water of the initial pool, minimum larval life span in captivity for the hatchling group was about 45 d. Newly metamorphosed froglets had colouration similar to adults (Figure 5F). Head not quite as proportionately long yet as in adults. Terminal discs and webbing as for adults. Two newly metamorphosed froglets measured 17.5 and 19.0 mm SVL.

Distribution

Currently known from only two locations near "The Grotto", approximately 30 km south of Wyndham, Western Australia (Figure 6). Both locations occur in the rocky southern portion of Parry's Lagoon Nature Reserve east of the Great Northern Highway. The entire collections of *L. coplandi* at the WA Museum (529 specimens), SA Museum (98 specimens), Museum and Art Gallery of the Northern Territory (190 specimens), Queensland Museum (77 specimens) and Australian Museum (151 specimens) were checked for the diagnostic characteristics of *L. staccato*. No specimens of *L. staccato* were detected. This indicates *L. staccato*'s distribution is apparently restricted to the small area where the type series was collected. However, owing to the inaccessibility of the Kimberley region due to the rugged terrain and large areas with no vehicular access, it is likely that the new species will be found elsewhere in the eastern Kimberley, possibly to the northwest of the two known sites and to the east in the Northern Territory where similar habitats occur.

Habitat

Individuals of *L. staccato* were found in two areas with flowing water. The first was a steep rocky ridge with a slow trickle of water running under large boulders where males were calling, and where the eggs and tadpoles were collected (see above).

The second area (where the holotype was collected) was a creek that ran down a rocky ridge, about 2–3 km long (Figure 7). Both sources of water came from underground streams that flowed from near the top of ridges.

The vegetation at the rocky ridge sites where *L. staccato* occurs is sparse but dominated by *Triodia wiseana* with *Cochlospermum fraseri*, *Calytrix extipulata* and stunted *Erythrophlem chlorostachys*. Along the watercourses where *L. staccato* was calling were *Triodia pungens*, *Terminalia volucris*, *Ficus* sp. and occasionally the boab tree *Adansonia gregorii*.

Etymology

Specific name 'staccato' is from the Italian musical term, and refers to the short detached sound of the individual repeated notes of the male advertisement call. It is to be treated as a noun in apposition.

Comparison with other species

1. Adults

In the eastern Kimberley, *L. staccato* may be potentially confused with several species of ground-dwelling *Litoria* which have pointed snouts, such as *L. nasuta*, *L. pallida*, *L. inermis* and *L. tornieri*. All of these species have narrow terminal discs on the fingers, whereas *L. staccato* has wider, expanded discs. *Litoria nasuta* has an elongate head with a strongly pointed snout and prominent longitudinal stripes. *Litoria tornieri* has a smooth dorsum, uniform pale body colour and a strongly contrasting dark lateral head stripe that breaks up posterior to the tympanum. *Litoria inermis* has a poorly defined lateral head stripe similar to *L. staccato*, but possesses raised tubercles over the dorsal surface, unlike the smooth skin of *L. staccato*. Although some *L. pallida* also possess a poorly defined lateral head stripe, they can be distinguished by very narrow terminal discs on the fingers, slightly raised tubercles on dorsum, distinctive penetrating call with much longer notes and selection of mostly still water breeding sites. *Litoria wotjulumensis* often breeds along rocky streams, has moderately expanded discs on the fingers and toes and also has a complex call with elements similar to *L. staccato*. However, *L. wotjulumensis* is a much larger species (almost double the length of *L. staccato*), has a more elongate head, possesses a strong, broad lateral head stripe and has fully webbed toes. *Litoria meiriana* also occurs along rocky creeks and rock holes and occurs in the Kimberley and Northern Territory. However, its most obvious difference from *L. staccato* is its much smaller size (~20 mm). In addition, *L. meiriana* is dorsoventrally compressed, has tubercular skin and fully webbed toes.

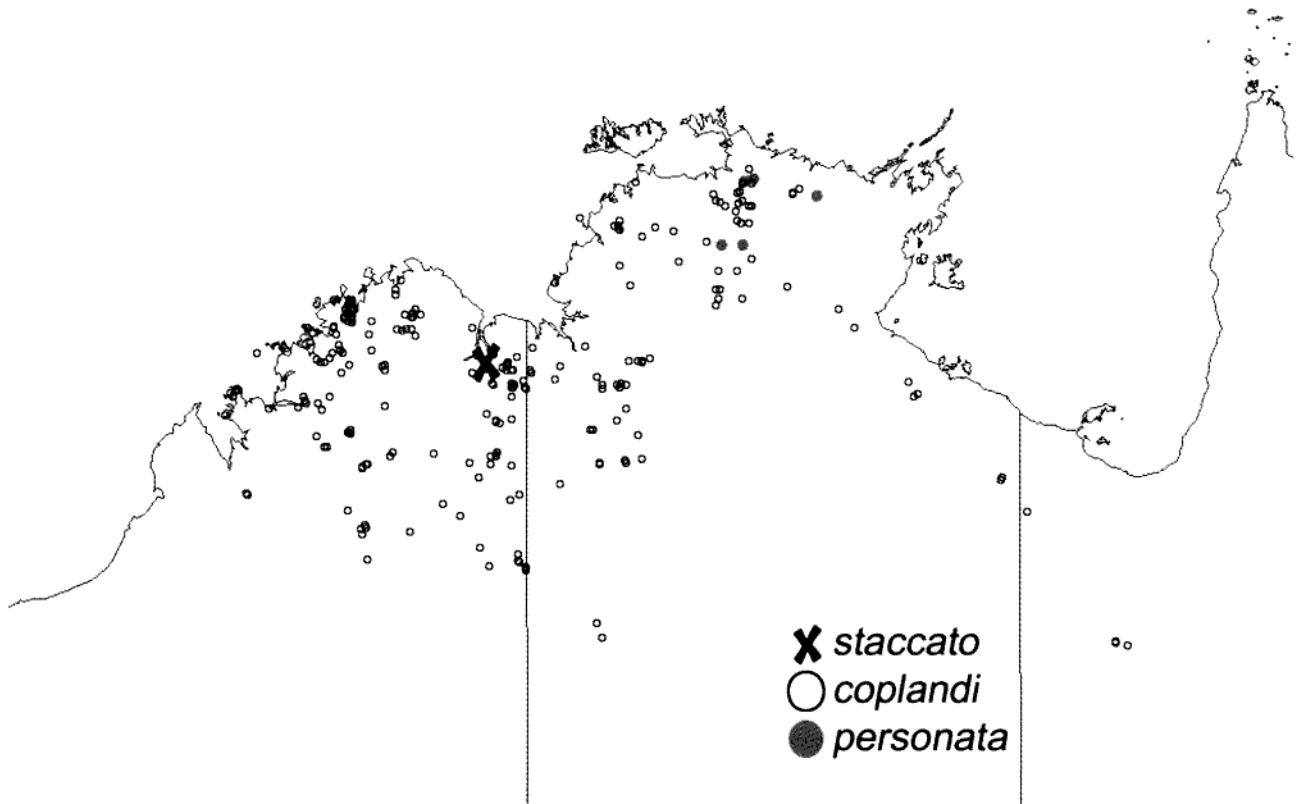


Figure 6 Distribution of *Litoria coplandi*, *L. personata* and *L. staccato* in northern Australia.

The two other rock-dwelling species with similar habits to *L. staccato* and thus most likely to be confused with it, are compared in more detail. Table 2 presents summaries of morphological measurements of *L. staccato*, *L. coplandi* and *L. personata*. *Litoria coplandi* reaches a larger body size, and females of both *L. coplandi* and *L. staccato* are larger than males. The relative head width of *L. coplandi* was wider than the other two species (Table 2). Hind limb proportions of *L. coplandi* and *L. staccato* were similar, but *L. personata* had longer hindlimbs. Thus, *L. staccato* is characterised by a narrower head relative to *L. coplandi* and shorter tibia and tarsus lengths compared to *L. personata*.

A number of other characters further distinguish these three rock-dwelling forms. The most reliable morphological character to distinguish the syntopic *L. staccato* and *L. coplandi* is the extent of webbing between the toes. In *L. staccato* the webbing is reduced, for example the distal two phalanges on the 4th toe are free of webbing and the distal phalanges of the other toes are also free of webbing. In *L. coplandi* the webbing extends to the last phalanx on the 4th toe and to the terminal discs on the remaining toes. The hands and feet of *L. staccato* are more gracile than the more heavily built *L. coplandi*. The webbing between the toes of *L. personata* is only slightly more extensive than *L. staccato* and much reduced relative to *L. coplandi*. Another consistent character among the three

species is the glandular tissue at the angle of the jaw. This tissue is pronounced and raised into several discrete nodules in *L. coplandi*, much reduced in *L. staccato* (fewer and lower in profile) and absent in *L. personata*.

All three rock-dwelling hylids possess differences in dorsal colour and patterns that can be used to distinguish them, but these are individually variable and some are not retained or less evident in preservative. Ground colour of *L. coplandi* and *L. personata* ranges from light to medium brown, whereas *L. staccato* ranges from beige to slate grey to reddish brown (the majority of individuals). *Litoria coplandi* and *L. personata* have a relatively uniform dorsal colour. In contrast, many *L. staccato* individuals have more extensive mottling and possess variably expressed vertebral, dorsolateral and lateral stripes. The presence and prominence of a lateral head stripe is another way to separate them. *Litoria personata* has a strong, clearly defined lateral head stripe, *L. staccato* has a less prominent stripe with diffuse borders and *L. coplandi* lacks a lateral head stripe (unique in the *L. lesueuri* complex; Tyler 1968a; Barker *et al.* 1995).

2. Advertisement call

For the purposes of comparison, we present the calls of two sympatric rock-dwelling hylids for which no sonograms have been published, *L. coplandi* and *L. meiriana* (Figure 3A,B). Both males called within 5 cm of the edge of exposed rock



Figure 7 Type locality of *Litoria staccato* near Wyndham, Western Australia.

pools. The temperature 1 cm above the calling *L. meiriana* was 28.2°C with a water temperature of 32.1°C; the *L. coplandi* male was recorded shortly after, and within 50 m of the *L. meiriana* male.

The call of *L. meiriana* is most similar to *L. staccato* owing to the notes of the main call being irregularly spaced (similar to Morse code). However, *L. meiriana* has a much higher-pitched call (dominant frequencies of 2–3 and 4–6 kHz) and the softer notes between main calls occur singly (Figure 3A), unlike in *L. staccato* (Figure 3C). The call of *L. coplandi* (Figure 3B) is easily distinguished by a combination of regularly-spaced notes, longer duration call (> 20 s), main call begins very softly then increases steadily in amplitude, dominant frequencies of 1–2 and 3–4 kHz and single softer notes between main calls (as in *L. meiriana*).

The call of *L. wotjulumensis* (not shown or analyzed) is highly distinctive and very complex (*personal observations*). The call contains loud, sustained sequences of calls that abruptly double in rate. The sustained calls can last for over 30 s and are usually followed by a series of complex trills, similar to the complex trill-like notes of *L. staccato*, but given more frequently. Owing to the few males

that were recorded, our comparative results are best considered preliminary. More detailed sound analyses of more individuals and species is likely to yield additional differences between species and also provide estimates of variation within species. The calls of all species discussed above may be heard on www.museum.wa.gov.au/frogwatch.

3. Eggs and tadpoles

The remains of the egg mass collected indicate that eggs may be laid in fairly loose clumps attached to substrate rock. The eggs of *L. coplandi* also have been found laid on the floor of shallow rock pools singly or in small clumps (Tyler *et al.* 1983).

The tadpoles of *L. staccato* are distinguishable from *L. coplandi* as early as at stage 25, when the mouthparts are complete, as *L. coplandi* tadpoles have two rows of continuous anterior papillae and *L. staccato* have only a single continuous row across part or all of the anterior margin. In addition, fully grown *L. coplandi* tadpoles have a more distinctly streamlined body form and a wider oral disc that appears to be slightly more suctional than that of *L. staccato*. Of the other species of hyloid tadpoles which are found in stream pools in the escarpment areas of the region, *L. staccato* have a generally similar body size and shape to those of *L. inermis* and *L. wotjulumensis* tadpoles, although they become slightly more streamlined anteriorly than *L. inermis* in later stages. Both *L. inermis*, *L. wotjulumensis* and all other known ground hyloid species (with the exception of *L. coplandi*) in the Kimberley region of northern Australia have a narrow medial gap in the anterior papillae.

Remarks

New species of frogs are still being described in Australia, especially in the northern tropics and the eastern margin of the continent, where they are most diverse. Recent descriptions include the discovery of a highly distinctive stream-dwelling tree frog in north Queensland, *L. andirrmalin* (McDonald 1997), and a cryptic species of *Uperoleia* near Darwin, *U. daviesae* (Young *et al.* 2005). Genetic techniques and analysis of calls are resulting in further cryptic species being uncovered in frogs previously considered to be one species (e.g., *L. lesueuri*, which has now been split into three species, Donnellan and Mahoney 2004; see also Donnellan *et al.* 1983; Hoskin 2004).

The recent discovery of *L. staccato* highlights the possibility that more undescribed species of frogs may occur in the Kimberley region. Other than the sealed Great Northern Highway and the unsealed Gibb River Road, only the Mitchell Plateau has been reasonably sampled for frogs. Many surveys to other regions (e.g., Kendrick and Rolfe 1991) were designed to collect surface-active terrestrial

vertebrates but did not specifically target frogs and did not involve night searches when breeding males are easily located by their calls. Future wet season frog surveys involving night work, recording of male calls and taking tissue samples for molecular analysis are likely to yield more undescribed species in the Kimberley Region.

Little is known of *L. staccato*. Breeding choruses occurred along rocky creeks up ridges or beside seeps running down rock faces. In the area near The Grotto where the type series was collected, several other species were calling. Calling from ponds on the flats between the ridges were the myobatrachids *Crinia bilingua*, *Opisthodon ornatus*, *Notaden melanoscapus* and *Uperoleia lithomoda*, and the hylids *Cyclorana australis*, *C. longipes*, *L. bicolor*, *L. pallida* and *L. nasuta*. Calling along large flowing rocky creeks at the base of the ridges were *U. borealis* and *L. wotjulumensis*. Further up the ridge, calling males of *U. borealis*, *Limnodynastes lignarius*, *Litoria coplandi* and *L. staccato* occurred along small flowing rocky creeks. Near the top of the ridge, only *Limnodynastes lignarius* and *Litoria staccato* occurred. The reduced webbing on the feet of *L. staccato* (compared to *L. coplandi*) may indicate they are somewhat less aquatic, consistent with their distribution further up the two ridges than *L. coplandi*, where there is less water in creeks. Much more work is needed to gain a better understanding of the habits and distribution of *L. staccato* in the Kimberley region and possibly in adjacent parts of the Northern Territory.

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paper is dedicated to the volunteer "toadbusters" of the Kununurra community.

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APPENDIX

Comparative material examined.

Abbreviations: SAM – South Australian Museum;
NT – Museum and Art Gallery of the Northern
Territory; QM – Queensland Museum; note
specimen numbers without one of these prefixes are
from the Western Australian Museum.

Litoria coplandi

Males – WAM R103060, R108792, R110746,
R114039, R114090, R119091, R114092, R129193,
R137838, R137384, R137385, R140357, R140362,
R152951, R162520, R162523, R162524, R162535,
R162536, R162539, R162547, R162548, R162549,
R162950, R162581, R162596, R162597, R162602,
R162603, R162609, R162610, QM J54933, QM J56592,
QM J56588, QM J56595, QM J56580.

Females – R97942, R114088, R127332, R137382,
R137389, R138879, R138883, R138894, R140351,
R140352, R140361, R140369, QM J53809, QM J56584,
QM J56596.

Juveniles (sex unknown) – R95599, R129194,
R95509, R87922.

Litoria personata

Males – NT R16886, NT R18794, NT R18795, NT
R19807, NT R19809, NT R20466, SAM R16773, SAM
R16774.

Females – NT R20467, NT R20468, SAM R16831,
SAM R16832.

Juvenile – SAM R16829.

Note added in proof.

Field trips in 2006–2007 have recorded *L. staccato*
from the Mitchell Plateau and Prince Regent Nature
Reserve, greatly extending its distribution.