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Front Cover: Aggressive displays of the Beach Stone-curlew *Esacus magnirostris* are described in this issue. (Trevor Collins)

Rear Cover: Weber's Mudskipper *Periophthalmus weberi* is a little-known species from northern Australia and Papua New Guinea. (Helen Larson)

Field key to the lycaenid butterflies of the Top End and Kimberley

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Abstract

A set of keys are presented for identification of the 41 species of lycaenid butterfly known to occur in the monsoonal Kimberley and Top End regions of north-western Australia. The key is designed for use in the field and to complement the field guide of Braby (2004).

Introduction

The distribution of butterfly species in the remoter parts of Australia remains poorly known despite a long tradition of collecting and study by amateur and professional entomologists (Moulds 1999). In the monsoonal (wet-dry) tropics of north-western Australia (Kimberley and Top End), most studies and collections are from the relatively accessible Darwin–Kakadu–Katherine area (Dunn & Dunn 1991; Moulds 1999; Meyer *et al.* 2006). Even there, studies of regional faunas are scant and mostly the work of visiting lepidopterists (Angel 1951; Le Souef 1971; Meyer 1996). Outside this limited geographic region, the only substantial, published regional studies are those of Tindale (1923) for Groote Eylandt and Hutchinson (1978) for the Daly River. The recent discovery of a new species of ant-blue, *Acrodipsas decima* (Miller & Lanc 2004), and the ease with which extensions to known distributions continue to be made (Field 1990a,b; Yeates 1990; Johnson 1993; Meyer & Wilson 1995; Grund 1996, 1998; Meyer 1996; Johnson & Valentine 1997, 2004; Grund & Hunt 2001; Franklin *et al.* 2005; Williams *et al.* 2006; Franklin 2007) highlight that much remains to be learnt.

Publication of two reference volumes and their companion field guide (Braby 2000, 2004) has made identification and survey of butterflies easier. However, the number of species to be considered can be challenging, and there is a scarcity of regional information about the distribution, habitat, food plants and habits of species to provide context for records. In this paper, we provide a key to adults of the 41 species of 'blues' (Lycaenidae) of monsoonal north-western Australia. It is designed for use in the field to complement Braby (2000, 2004). The key incorporates information presented by Braby (2000) and has been extensively tested and refined in the field.

Recognising a lycaenid

Lycaenids are generally delicate, small to medium-sized butterflies (Figure 1) of which many have iridescent or pastel shades of blue, lilac or purple on the upperside of the wings. A typical small 'blue' is among the smallest of butterflies. It has rounded wings, the undersides of which are finely barred and spotted pale brown. Close examination may reveal delicate, almost filamentous tails several millimetres long and black spots, edged or ringed orange, adjacent to the tail on the hindwing underside. Most 'blues' fly low amongst grass and herbs, or dash around bushes at eye level. However, though many species broadly fit this description, a similar number do not. The pastel or iridescent blues may be reduced to panels within a predominance of dull brown, or be replaced altogether by dull brown, vivid orange or white. They may be larger and fly high in the treetops; tails may be absent or broad, and the sub-terminal hindwing spots may also be absent. Indeed, it is difficult to formally characterise the family in a simple manner, and the features that distinguish the family are mostly technical in nature (see Braby 2000 for details).



Figure 1. The Spotted Pea-blue *Euchryops cnejus*, a typical small 'blue' (family Lycaenidae). Note the delicate tails and two prominent black sub-terminal spots on the underside of the hindwing. (Don Franklin)

For those unfamiliar with butterfly families, there is no better starting point than to match pictures to your observations. You may not be able to identify your butterfly to the level of species, but you will soon recognise a butterfly as a lycaenid with ease – and be ready to use this key.

The lycaenid fauna of the Top End and Kimberley

The key covers all species known to occur in monsoonal north-western Australia: the Kimberley region of Western Australia (WA) and the Top End of the Northern Territory (NT). The region extends from the north coast of these states (including offshore islands) southwards to c. 17–18° South, the southern limit defined here as being from Broome through Fitzroy Crossing and Halls Creek (WA), and from Kalkarindji, Dunmarra and Cape Crawford to Wollongorang (NT). The area receives monsoonal rainfall annually, with over 90% of rain falling between November and April inclusive. Maximum temperatures are high throughout the year (McDonald & McAlpine 1991; Cook & Heerdegen 2001). Though vast tracts of wooded savannas dominate the landscape, vine-thickets, riparian forests, spring-fed rainforests, wetlands, lancewood (*Acacia shirleyi*) thickets and grasslands occur within the savanna matrix, and open forests and mangroves are common in the north (Fox *et al.* 2001).

The known lycaenid fauna of the region comprises 41 species (Grund 1996; Braby 2000; Miller & Lane 2004). We have not included the Bright Cornelian *Deudorix dioris*, whose occurrence in the study area is questionable (M.F. Braby, pers. comm.).

As is the case for Australia generally, the Lycaenidae are the most speciose butterfly family in monsoonal north-western Australia. Kitching and Dunn (1999) identified a latitudinal gradient in species richness within the region that is positively correlated with rainfall; diversity is greatest around Darwin, the Tiwi Islands and Cobourg Peninsula in the Northern Territory with more than 30 species, and lowest inland with about half that number. However, the gradient may be less steep than suggested because the Darwin area is well surveyed whereas most inland areas, along with Arnhem Land, are not. The Kimberley fauna is for the most part a sub-set of that of the Top End, though further surveys may reveal additional species. However, two species – the Kimberley Spotted Opal *Nesolycaena caesia* and the Bitter-bush Blue *Theclinesstes albocincta* – have been recorded in the Kimberley but not from the Top End.

Using the field key

The key is designed for identification of adults using binoculars or a hand lens to examine netted individuals. It consists of a key to major groups followed by a key to each group. Keys consist of couplets and triplets arranged to form multiple-choice pathways leading to species. The groups and subsequent divisions are practical arrangements and do not necessarily correspond with systematic relationships. Nevertheless, where compatible with the primary aim, we have grouped congeners. Similarly, for the most part we have kept the sexes and seasonal morphs of a species together.

Sketches are provided to enhance some identifications, but we have generally avoided illustrating species as this duplicates information available in Braby (2004). Where it is likely to enhance the identification process, information on habits, habitat and geography is sparingly included.

We have made every effort to keep the terminology employed simple so that both experienced entomologists and new-comers to the identification of butterflies may make use of the key. We use the term 'tail' to describe any projection from the hindwing whether broad or slender, long or short, including tornal lobes (projections at the tornus, the bottom corner of the hindwing). Where the characteristics of the tail are useful for identification, we describe them.

Size is one of the more problematic characters employed in field identification because of variation among individuals, yet to ignore it completely would be to ignore a character that is at times most useful. We have kept its use to a minimum and employed it mostly where the differences are great. Sizes are presented as average wingspans, taken from Braby (2000), and as forewing length, measured as a straight line from the base of the leading edge to the apex (Figure 2). Wingspans generally cannot be measured in the field, but forewing length can. However, the temptation to treat measurements as fixed values should be avoided. Many species vary considerably in size. The forewing lengths presented are for the most part based on the regression presented in Figure 3 applied to wingspan measurements in Braby (2000), with some allowance ($\pm 1-2$ mm) for variation. For a few species, we have relied directly on forewing measurements of museum specimens.

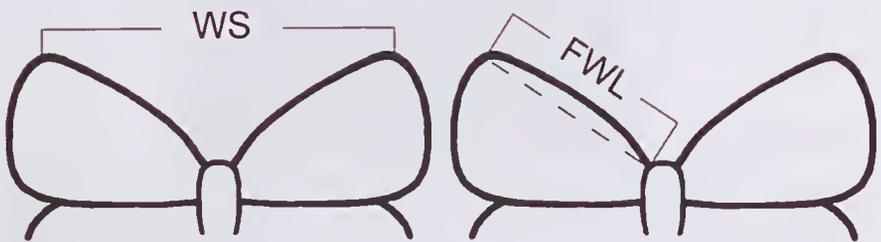


Figure 2. Wingspan (WS) and forewing length (FWL) in butterflies. Note that WS is measured with the trailing edge (dorsum) perpendicular to the body, a position usually only available in set specimens, but FWL can be measured on netted live individuals.

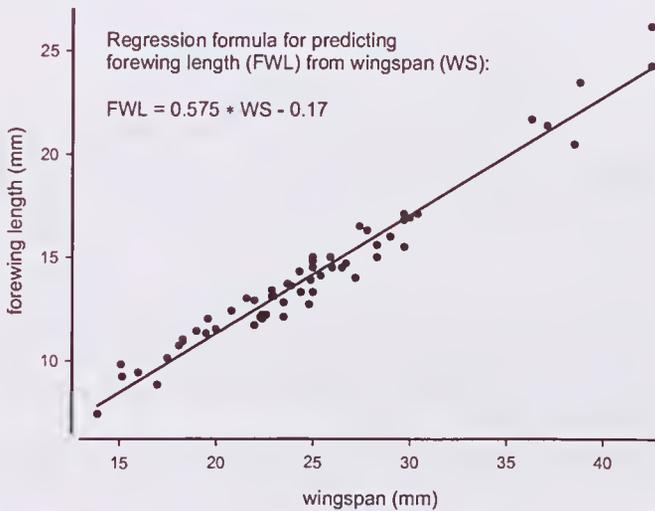


Figure 3. Relationship between forewing length (FWL) and wingspan (WS) for lycaenid butterflies based on 58 individuals of 22 species. Measurements were made with vernier callipers to 0.1 mm using individuals from the collection of the Museum and Art Gallery of the Northern Territory (NTM) mounted flat and with the forewing dorsum perpendicular to the body.

In making an identification, we cannot stress sufficiently the need for self-critical rigour. In particular, caution is needed to recognise and interpret wear. Colours fade and markings become less obvious with age. Areas of the hindwing often critical for identification – tails and sub-terminal hindwing spots – are particularly susceptible to damage. Iridescent scales within sub-terminal hindwing spots – a key character for a number of species – can wear to obscurity. For these reasons, some worn individuals cannot be identified using the key. In addition, differences between the sexes are not always represented in the keys. A further caution is that the regional lycaenid fauna has quite likely not been fully documented, so additional species may be encountered. However, we suspect such discoveries will be rare and noteworthy events.

The taxonomy and nomenclature employed, including common names, follows Braby (2004) with three exceptions: 1. the population of the Black Ant-blue *Acrodipsas birtipes* reported from the Top End by Braby (2000) was excluded from Braby (2004) and is now known as *A. decima* (Miller & Lane 2004); 2. the Purple Oak-blue, formerly *Arhopala centaurus*, is now known as *A. eupolis* (Vane-Wright & Gaonkar 2006); and 3. subspecies of the Satin Azure *Ogyris amaryllis* within the study area are no longer distinguished (Schmidt & Hughes 2006).

The keys

Abbreviations: WS = wingspan, FWL = forewing length
 > = greater than, < = less than, \approx = about (*circa*)
 NT = Northern Territory, WA = Western Australia

Number in brackets after species refer to the page number in Braby (2004). Dashed lines on the illustrations indicate the position of the wing not under consideration.

Key to groups

1. - small or very small butterflies (WS 14–32 mm, FWL 7–18 mm) (many species associated with the ground layer, though some are arboreal) 2
 - medium-sized butterflies (WS 32–47 mm, FWL 18–30 mm) (mostly arboreal) 6
 - large butterfly (WS > 65 mm; FWL > 36 mm) (thick-bodied; orange and brown-black above) **Moth Butterfly *Liphyra brassolis*** (204)
2. - underside of hindwing with numerous red spots coalescing to form prominent bands **Group A** (jewels, genus *Hypochrysois*)
 - underside of hindwing without prominent red bands 3
3. - underside of hindwing with 1–2 dark sub-terminal or sub-marginal spots (Figure 4a) (may have additional obscure sub-marginal spots or a diminishing series of spots) 4
 - underside of hindwing with 4–6 black, sub-marginal spots (Figure 4b) **Group B** (various small ‘blues’)
 - underside of hindwing lacking a discrete series of dark sub-terminal or sub-marginal spots **Group C** (various small ‘blues’)
4. - underside of hindwing with two distinct small black spots near the leading edge (Figure 4c) **Group D** (pea-blues)
 - underside of hindwing lacking two distinct small black spots near the leading edge 5

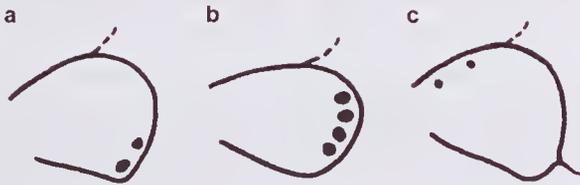


Figure 4. Markings of the hindwing underside of lycaenid butterflies: a. two sub-terminal spots; b. four sub-marginal spots; c. two spots near leading edge.

5. - hindwing with tail(s) absent or short (< 1 mm) (Figure 5a)
Group E (various small 'blues')
- hindwing with a single, long (> 1 mm) tail (Figure 5b)
Group F (various small 'blues')
- hindwing with two tails, either both long and delicate or one long and delicate and the other short, lobed and perpendicular to the plane of the hindwing (Figure 5c,d)
Group G (flashes)
6. - hindwing with at least one long, delicate tail (may also have lobed tail) (Figure 5c,d)
Group G (flashes)
- hindwing lacking a long and delicate tail (tails robust or absent) 7
7. - hindwing margin strongly wavy with a rounded, lobular tail (tornal lobe); hindwing may also have several pointed projections (Figure 5e)
Group H (azures, genus *Ogyris*)
- hindwing margin more or less rounded with a single broad, tapered tail (Figure 5f)
Group I (oak-blues, genus *Arhopala*)

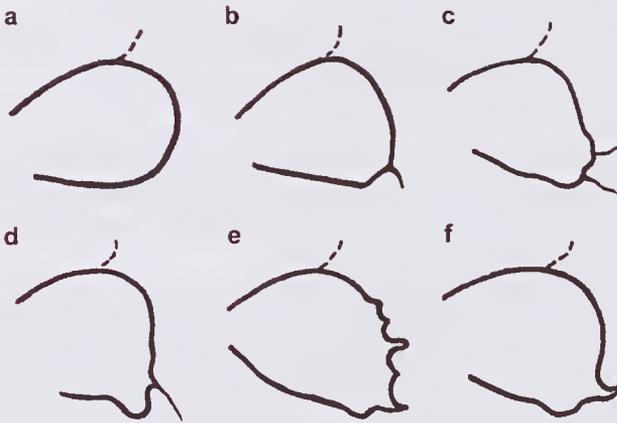


Figure 5. Features of the hindwing margin of lycaenid butterflies: a. rounded with no tail; b. rounded with a single, long, delicate tail; c. two long, delicate tails; d. one long tail and one lobed tail; e. wavy margin with projections; f. single broad tail.

Group A. Jewels (genus *Hypochrysops*)

- A1. - wings mostly blue or purple above; underside of forewing with a band of red spots toward the outer margin extending to the leading edge (species of woodland and open forest) **Fiery Jewel** *Hypochrysops ignita* (226)
 - wings mostly orange above; underside of forewing lacking a band of red spots (mangrove species) **Copper Jewel** *Hypochrysops apelles* (216)

Group B. Various small 'blues' (underside of hindwing with 4–6 prominent black sub-marginal spots)

- B1. - wings brown or purple above, brown below; very small butterflies (WS c. 14–17 mm, FWL c. 7–10 mm) **Jewelled Grass-blue** *Freyeria putli* (298)
 - wings whitish above; small butterflies (WS c. 24–25 mm, FWL c. 13–15 mm) (spotted opals, genus *Nesolycaena*) B2
- B2. - black lines (sex scales) present along the veins of forewing upperside; marginal band on upper forewing extending less than one third of the way along the leading edge (males) B3
 - black lines (sex scales) absent from veins of forewing upperside; marginal band on forewing upperside extending more than one third of the way along the leading edge (females) B4
- B3. - black lines (sex scales) on veins of forewing upperside fairly prominent and numerous male **Spotted Opal** *Nesolycaena urumelia* (268)
 - black lines (sex scales) on veins of forewing upperside rather obscure and less numerous male **Kimberley Spotted Opal** *Nesolycaena caesia* (268)
- B4. - dark marginal band on forewing upperside extending to the trailing edge female **Spotted Opal** *Nesolycaena urumelia* (268)
 - dark marginal band on forewing upperside not extending to the trailing edge female **Kimberley Spotted Opal** *Nesolycaena caesia* (268)

Note. Both spotted opals occur mainly on sandstone outcrops and/or on sandy soils where their larval food plants, shrubs of the genus *Boronia*, occur. The two species are not known to occur together, the Spotted Opal being recorded from near Darwin, east and south-eastwards to Queensland, and the Kimberley Spotted Opal only in WA. Any record from the Victoria River District of the NT should be evaluated with particular care. See Braby (1996, 2000) for more detail.

Group C. Various small 'blues' (no black sub-terminal or sub-marginal spots on underside of hindwing)

- C1. - hindwing tailed (known only from a few locations in the south Kimberley, WA) **Bitter-bush Blue** *Theclinessthes albocincta* (286)
 - hindwing rounded, without a tail C2
- C2. - underside of forewing with a pair of prominent dark spots near the outer edge (Figure 6a) (at rest, the spots may be concealed by the hindwing) C3
 - underside of forewing without a pair of prominent black spots near the outer edge, but may have a diminishing series of *c.* five smudged spots (Figure 6b) C4

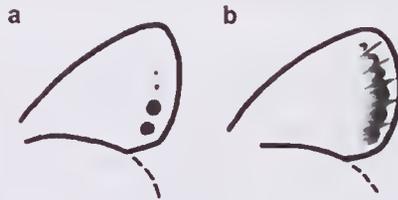


Figure 6. Diagnostic marks on the forewing underside of Dusky-blues: a. two prominent spots on the Twin Dusky-blue and Small Dusky-blue, with or without several smaller spots; b. the series of smudged spots of the Spotted Dusky-blue.

- C3. - WS *c.* 26–29 mm, FWL *c.* 14–18 mm; the faint line of spots beyond the middle of the hindwing underside curved (Figure 7a, evident only on fresh individuals) (known only from the Arnhem Land plateau) **Twin Dusky-blue** *Candalides geminus* (262)
 - WS *c.* 22–24 mm, FWL *c.* 10–13 mm; faint line of spots beyond the middle of the hindwing underside roughly straight (Figure 7b, evident only on fresh individuals) (widespread *) **Small Dusky-blue** *Candalides erinus* (262)

* The Small Dusky-blue is common much further inland in the NT than indicated by Braby (2000, 2004) – see Franklin *et al.* (2005).

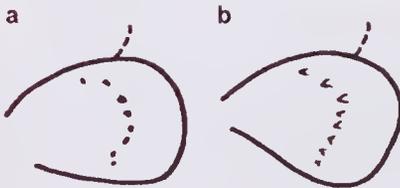


Figure 7. Diagnostic marks on the hindwing underside of: a. Twin Dusky-blue; b. Small Dusky-blue.

- C4. - arboreal species; WS 27–30 mm, FWL 14–18 mm; underside ground colour silvery white **Northern Pencil-blue** *Candalides gilberti* (258)
 - ground-layer species; WS 15–23 mm, FWL 8–14 mm; underside ground colour greyish-white, grey or grey-brown C5
- C5 - spots on underside of wings prominent, black, blackish or dark brown C6
 - spots on underside of wings obscure and pale brown (lawns and grassy savannas) **Common Grass-blue** *Zizina labradus* (300)
- C6. - outer edge of forewing underside with a series of prominent ‘smudged’ dots (Figure 6b) (sandstone areas, usually with spinifex) **Spotted Dusky-blue** *Candalides delospila* (264)
 - outer edge of forewing underside lacking a series of prominent smudged dots C7
- C7. - underside of forewing with no spots near the leading edge, but with one spot toward the base of the wing inward from the central ‘dash’ (= short, broad line) (Figure 8a) (WS \approx 20 mm, FWL \approx 9–12 mm) **Spotted Grass-blue** *Zizeeria karsandra* (300)
 - underside of forewing with two small dark spots near the leading edge more or less adjacent to the central ‘dash’, and no spot toward the base of the wing (Figure 8b) (WS \approx 15 mm, FWL \approx 8.5 mm) **Dainty Grass-blue** *Zizula bylax* (300)

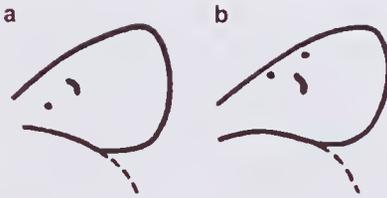


Figure 8. Diagnostic marks on the forewing underside of: a. Spotted Grass-blue; b. Dainty Grass-blue.

Group D. Pea-blues (underside of hindwing mostly with two black spots near the leading edge)

- D1. - underside of hindwing with two black spots near the leading edge (Figure 9a,b); wings grey-white or grey-brown below without prominent pale bands D2
 - underside of hindwing without black spots near the leading edge; underside of both wings fawn and with a prominent whitish band **Long-tailed Pea-blue** *Lampides boeticus* (294)

- D2. - the two sub-terminal black spots on the hindwing underside enclosed by a single, large orange patch **Orange-tipped Pea-blue** *Everes lacturnus* (294)
 - the two sub-terminal black spots on the hindwing underside not enclosed by a single, large orange patch, though spots may be individually edged with orange D3

- D3. - tail short; sub-terminal spots on underside of hindwing of about equal size; one black spot near the mid-base of the hindwing underside (Figure 9a)
Spotted Pea-blue *Euchrysops cnejus* (294)
 - tail long and delicate; one sub-terminal spot on the hindwing underside markedly larger than the other; no black spot near mid-base of hindwing underside (Figure 9b) (wings often strikingly pale grey-blue above)
Pale Pea-blue *Catochrysops panormus* (292)

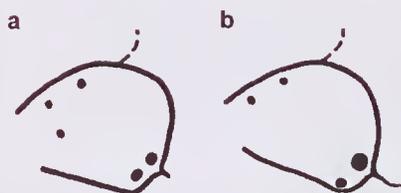


Figure 9. Diagnostic marks on the hindwing underside, and tail of: a. Spotted Pea-blue; b. Pale Pea-blue.

Group E. Various small 'blues' (hindwing with 1–2 black sub-terminal spots on the underside; hindwing tail absent or < 1 mm long; hindwing underside lacking two black spots near the leading edge)

- E1. - sub-terminal spot(s) on underside of hindwing inset with iridescent green scales E2
 - sub-terminal spot(s) lacking iridescent scales (iridescent scales may be lost with age; check carefully with hand lens before assuming absence) E4
- E2. - underside of wings an irregular mosaic of brown and white markings; WS 22–23 mm, FWL 12–14 mm (known only from vine-thickets in Kakadu National Park, NT) **Plumbago Blue** *Leptotes plinius* (288)
 - underside of wings with brown and white bars; WS 17–19 mm, FWL 9–11 mm E3
- E3. - two roughly equal-sized sub-terminal spots on underside of hindwing
Two-spotted Line-blue *Nacaduba biocellata* (274)
 - one prominent sub-terminal spot on the underside of hindwing; a second, inner spot is smaller and obscure **Purple Line-blue** *Prosotas dubiosa* (276)

E10. - underside of hindwings brown but heavily barred so that much of the base colouration is obscured; bands with heavy white edging; hindwing with a short, broad tail (may be obscure); upperside of forewing with a checkered brown-and-white fringe (coastal salt-marshes)

Samphire Blue *Theclinesstes sulphitius* (288)

- underside of hindwings grey-brown or pale brown with scattered barring that covers < 50% of the wing area; bands delicately edged with white; hindwing without a tail; upperside of forewing lacking a checkered fringe (known only from the upper Adelaide River area, NT, but may be more widespread) (ant-blues, genus *Acrodipsas*)

E11

E11. - upperside of wings with blue panels

female **Small Ant-blue** *Acrodipsas myrmecophila* (208)

- upperside of wings brown or sooty black above with at most scattered blue scales

E12

E12. - foreleg and hindleg femur swollen; mid-leg tibia shorter than the adjacent tarsal segment *

Northern Ant-blue *Acrodipsas decima* **

- femur not swollen; mid-leg tibia longer than the adjacent tarsal segment *

male **Small Ant-blue** *Acrodipsas myrmecophila* (208)

Note. Identification of these two species may require microscopic examination. See Sands (1979) for illustration of leg structure in *Acrodipsas*.

* 'tarsal segment' – the fifth and most distal segment of the leg (see Figure 3 in Braby 2000).

** For more information on this recently-described species, see Miller and Lane (2004).

Group F. Various small 'blues' (tailed and with sub-terminal spots on the hindwing underside)

F1. - wings with well-defined white or whitish bands > 1 mm wide on the underside of the forewing

F2

- wings lacking well-defined white or whitish bands on the underside of the forewing, but may have a whitish suffusion or fine white lines much < 1 mm wide

F4

F2. - underside of forewing with a prominent dark brown band towards the outer edge and framed with white; tail slender with a broad base;

WS 19 mm, FWL 10–11 mm **Glistening Line-blue** *Sabulana scintillata* (280)

- underside of forewing without a prominent dark brown band framed with white; tail entirely slender; WS 23–27 mm, FWL 12–16 mm

F3

- F3. - white or whitish bands on the underside of wings central and > 3 mm broad
White-banded Line-blue *Nacaduba kurava* (274*)
 - white or whitish bands on the underside of wings towards the outer margin and < 3 mm broad
Long-tailed Pea-blue *Lampides boeticus* (294)

* Note that the local subspecies *felsina* is not illustrated in Braby (2000, 2004) and lacks the very broad band of the illustrated female (non-local) subspecies *parma*.

- F4. - underside of forewing with two short white-edged brown inner bands and a long outer band (Figure 11a,b), bands distinctly darker than the ground colour (hindwing underside often with a whitish suffusion toward the outer edge) F5
 - underside of forewing with one short white-edged inner brown band and a broken, longer outer band (Figure 11c) (the bands on underside of wings not or scarcely darker than the ground colour and thus rather indistinct such that, at first examination, the wings may appear to be brown with narrow white bands) (hindwing underside lacking a whitish suffusion)
Purple Cerulean *Jamides phaseli* (292)

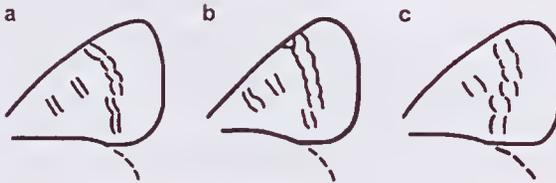


Figure 11. Diagnostic barring on the forewing underside of: a. Speckled Line-blue; b. Wattle Blue and Bitter-bush Blue; c. Purple Cerulean.

- F5. - band toward the outer margin on underside of forewing distinctly curved inward at the leading edge (Figure 11a)
Speckled Line-blue *Catopyrops florinda* (278)
 - band toward the outer margin on underside of forewing more or less straight or only slightly curved inward (Figure 11b) F6
 F6. - sub-terminal spots on the hindwing underside prominent
Wattle Blue *Theclinessthes miskini* (284)
 - sub-terminal spots on the hindwing underside small or indistinct (known only from a few locations in the south Kimberley, WA)
Bitter-bush Blue *Theclinessthes albocincta* (286)

Group G. Flashes

- G1. - hindwing with two long, delicate tails (Figure 5c); ground colour of underside of wings pale grey with an obscure long, narrow bar
Black-spotted Flash *Hypolycaena phorbas* (252)
- hindwing with one long, delicate tail (Figure 5d); ground colour of underside of wings grey-brown (sometimes tinged purple), with a number of prominent, short, broad bars
Princess Flash *Deudorix smilis* (254)

Group H. Azures (genus *Ogyris*)

- H1. - projections on the hindwing margin rounded and mostly broader than long; WS 32–39 mm, FWL 18–22 mm H2
- at least one of the projections on the hindwing margin strongly elongated and tail-like; WS 42–47 mm, FWL 24–28 mm
Northern Purple Azure *Ogyris zosime* (240)
- H2. - ground colour of underside of hindwing pale honey-brown; black bars on underside of forewing edged with iridescent blue on a brown or yellowish background (rare; known only from Darwin area and Tiwi Islands, NT)
Orange-tipped (Dodd's) Azure *Ogyris iphis* (238)
- ground colour of underside of hindwing brown, grey-brown or whitish-brown; bars on the underside of forewing pale iridescent blue on a black background, or alternating dark and white H3
- H3. - dark outer band on underside of forewing roughly straight (Figure 12a); antennal club thickened
Silky Azure *Ogyris oroetes* (236)
- dark outer band on underside of forewing displaced in middle (Figure 12b) (female has two broad orange bands near base of forewing underside); antennal club slender
Satin Azure *Ogyris amaryllis* (234)

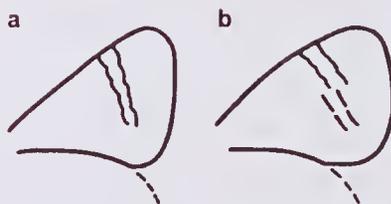


Figure 12. Diagnostic dark bars on the forewing underside of: a. Silky Azure; b. Satin Azure.

Group I. Oak-blues (genus *Arhopala*)

11. - underside of wings dark chocolate brown or dark purple-brown; upperside of wings deep iridescent blue with dark margin
Shining Oak-blue *Arhopala micale* (232)
- underside of wings pale brown or grey (tinged purple in males); upperside of wings purple (with dark margin in female)
Purple Oak-blue *Arhopala eupolis* (232)

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Features of lycaenids: (a) blue above (Wattle Blue *Theclinesthes miskini*); (b) red bands (Copper Jewel *Hypochrysops apelles*); (c) marginal spots on hindwing (Spotted Opal *Nesoalycaena urumelia*); (d) marginal spots on forewing (Small Dusky-blue *Candalides erinus*); (e) sub-terminal spots on hindwing, tail on each hindwing (Wattle Blue); (f) two tails on each hindwing (Black-spotted Flash *Hypolycaena phorbas*). (a. D. Franklin; b,c,f. M. Braby; d. D. Bisa; e. G. Brown)

Weber's Mudskipper *Periophthalmus weberi*: new record for the Daly River

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Weber's Mudskipper *Periophthalmus weberi* Eggert, 1935, is a little-known mudskipper restricted to northern Australia and Papua New Guinea (Murdy 1989). It is the only species of the genus *Periophthalmus* that is strongly sexually dimorphic in fin shape; males have a large triangular dorsal fin with up to 16 long spines and females have a tiny first dorsal fin consisting of four or five very short spines (Murdy 1989; Larson & Takita 2004). Weber's Mudskipper is known by published records from only a few localities: West Papua (type localities Noord and Lorentz Rivers; Bintuni River), New Guinea (Fly River; Oriomo River) and the Northern Territory (Darwin to Alligator Rivers; Cape Arnhem) (Eggert 1935; Roberts 1978; Murdy 1989; Allen 1991; Allen *et al.* 2002; Hoese & Larson 2006). It should be noted that the distribution map in Allen *et al.* (2002: 281) does not reflect actual records.

There are few specimens of this species in museum collections and limited information about its preferred habitat. Allen (1991: 191) states that "It appears to be restricted to tidal fresh waters in areas of mangrove and nipa palms". The National Museum of Natural History, Washington (USNM), has one specimen obtained by rotenone from freshwater Namboguru Creek, Cape Wom, near Wewak, New Guinea, obtained during the 1979 *Alpha Helix* Moro Expedition. The two Fly River specimens at USNM (also obtained by rotenone) came from a creek, strongly influenced by tides, 236 km up-river from Toro Pass on the lower Fly. The Western Australian Museum (WAM) holds five lots from West Papua (Bintuni River system) and five from Papua New Guinea (Kikori and Oriomo River systems). These fish were collected 20-30 km from the sea, in mud-substrate habitats in mangroves or from fresh water habitats with aquatic plants.

In Queensland, Weber's Mudskipper is so far only known from the Watson River, where a Queensland Museum specimen was collected at the edge of a freshwater pool at the road crossing 30 km east of the Aurukun airstrip.

The earliest known specimens of Weber's Mudskipper from the Northern Territory are two from fresh water at Cahill's Crossing, East Alligator River (collection method unspecified). These are lodged at the American Museum of Natural History, New York and USNM and were collected during the American-Australian Arnhem Land Expedition of 1948, but none of the records of gobioids were published (Taylor 1964;

Murdy 1989). The Australian Museum holds a single specimen from the Liverpool River (NT), collected in 1975 by Dan Grace.

From 11-18 June 2007, as part of the collaborative Daly River project "Water regime dependence of fish in the wet-dry tropics", fish survey work was undertaken on the Daly estuary downstream of Mango Farm Resort, using beam trawl, gill nets, hook and line and electrofisher. On 16 June, Brad Pusey, Mark Kennard and I worked in Elizabeth Creek, using a punt fitted with an electrofisher. The creek flows through floodplain on the west side of the Daly, and enters the main river at 13°34.553'S 130°31.129'E. It is freshwater (0.1 parts per thousand salt near the creek mouth), turbid, with many branches, becoming narrower upstream. The rather steep mud banks are lined with overhanging trees, *Pandanus* and other typical riparian vegetation (including tall grass patches) and the substrate is mud with many logs and leaf litter. The electrofisher was deployed along the banks and under logs to a depth of about 0.5 m. Many of the fishes obtained were freshwater species such as Pennyfish *Denariusa australis*, Western Rainbowfish *Melanotaenia australis* and Empire Gudgeon *Hypseleotris compressa*, but also present were estuarine species such as Diamond Mullet *Liza ordensis*, Barramundi *Lates calcarifer* and Bull Shark *Carcharhinus leucas*.

But the find of the trip was that Elizabeth Creek was the habitat for a single species of mudskipper, *Periophthalmus weberi*. Forty-four of them were obtained, mostly upstream of the creek mouth (at about 13°34.860'S 130°30.662'E). Twenty-one were female (34.5-72 mm standard length) and 17 male (36-71 mm standard length).

Specimens were preserved in formalin and absolute ethanol, for the Museum and Art Gallery of the Northern Territory reference collection, and for future DNA studies. Some individuals were photographed alive (photograph on rear cover). As I had never seen this species alive before, the black "racing stripe" exhibited by resting fish was something of a surprise, as this colour feature was known to be characteristic of the genus *Periophthalmodon* (Giant Mudskippers) (Murdy 1989), not *Periophthalmus*. However, Zeehan Jaafar of the National University, Singapore, has since told me that the species Walailak's Mudskipper *Periophthalmus walailakae* can also display a similar marking: "in ... walailakae the bars merge and so forming a "lateral stripe ..." (pers. comm.). The live specimens of Weber's Mudskipper were also the most colourful mudskippers I had ever seen. Allen (1991: 191, 265) described and illustrated the colour of New Guinea specimens, showing that the fins had blue and red markings and fine blue markings were scattered over the head and body. But seeing the living fish was another thing, so it is shown here in colour (photograph on rear cover).

Comparative examination of a small problematic mudskipper collected in 1997 from the now abandoned fish farm at Middle Point, Adelaide River, showed that it too, was a *Periophthalmus weberi*.

Acknowledgements

My many thanks to Brad Pusey and Mark Kennard (Griffith University), for introducing me to a new method of collecting mudskippers which does not involve getting wet and muddy, a new experience for me. Thanks to Jeff Johnson (QM), Sue Morrison (WAM) and Zeehan Jaafar (NUS) for *Periophthalmus* information, and to Grahame Webb (Crocodylus Park), for reminding me of Dan Grace.

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Dead fish and frogs associated with Cane Toads near Darwin

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History

Cane Toads *Bufo marinus* first entered the Northern Territory from Queensland in 1980 (Lever 2001; van Dam *et al.* 2002). Since then they progressed westwards and were first recorded in the greater Darwin region in 2005 (Phillips *et al.* 2007). Little has been documented about the impacts of Cane Toads on the aquatic fauna of the Northern Territory.

The Cane Toad Hotline was alerted about the presence of many Cane Toad metamorphs around the edge of a small lagoon near Darwin (12°25'S 130°57 "E) on 24 March 2007. Members of Frogwatch NT visited the site on 26 March, and Fisheries staff visited on 27 March after receiving reports of dead fish.

The ephemeral shallow lagoon was connected to a permanent waterbody by floods resulting from heavy rains during early March 2007. Small numbers of adult Cane Toads had been in this waterbody for at least two years.

Observations

Many thousands of Cane Toad tadpoles and toadlets were observed around the lagoon and associated waterbodies. Approximately 70 dead Spangled Perch *Leiopotherapon unicolor* (10-20 cm total length) were floating on the surface of the lagoon. No other dead fish were observed.

The dead fish were already severely decomposed when Fisheries staff visited the site on 27 March. Fourteen of the dead Spangled Perch were dissected but the fish and their guts were too decomposed for any stomach contents to be identified. However, on 26 March a dead Spangled Perch on the bank disgorged a tadpole when the fish was squeezed. This tadpole was positively identified as that of a Cane Toad (Figure 1).

Experienced Fisheries staff found no suggestion that the fish kills were related to low dissolved oxygen levels, which is the most common cause of fish kills in the Top End (Townsend 1994). Hundreds of active Black-banded Rainbowfish *Melanotaenia nigrans* were in the lagoon, but no dead Rainbowfish were observed. No sick or gulping fish

were observed, which further suggests that water quality did not cause the fish kill. The landholders assured us that there had been no chemical spill or leakage.

On the short grass surrounding the water, 11 young Northern Waterfrogs *Litoria dablii* and two Marbled Frogs *Limnodynastes convexiniscus* were also found dead. Many Northern Waterfrogs were seen active in a nearby drain where numerous Cane Toad tadpoles, but no toadlets or dead frogs, were observed.



Figure 1. Dead Spangled Perch with a partially digested Cane Toad tadpole (encircled) that was disgorgeed when the fish was squeezed. (Graeme Sawyer)

Discussion

Very little information has been published about interactions between Cane Toads and fish in the field. This paper is a step towards filling this knowledge gap.

Fish

Spangled Perch are opportunistic predators - their diet is typically a diverse mix of animal material with little plant material (Pusey *et al.* 2004). They have been recorded dying in the laboratory after tasting Cane Toad tadpoles, even though these had been spat out immediately (Hearnden 1991). Other native fish known to die after ingesting Cane Toad tadpoles include Banded Grunters *Amniataba percoides* (Hearnden 1991), Fly-specked Hardyheads *Craterocephalus stercusmuscarum* (Crossland & Alford 1998), and Northern Trout Gudgeons *Mogurnda mogurnda* (Pearse 1980, in van Dam *et al.* 2002).

Black-banded Rainbowfish are generally small (6 cm or less total length; Allen *et al.* 2002), and have much smaller mouths than Spangled Perch of a similar size, meaning they would be unlikely to attempt to swallow tadpoles or toadlets. Western

Rainbowfish *Melanotaenia australis* in aquaria did not consume offered Cane Toad tadpoles (Crossland & Alford 1998).

While many north Australian freshwater fish eat frogs and tadpoles, most fish appear to avoid Cane Toad tadpoles and eggs (Voris & Bacon 1966; Licht 1968; Lawler & Hero 1997). Other fish such as Barramundi *Lates calcarifer*, Sooty Grunter *Hepbaestus fuliginosus* and Mouth Almighty *Glossamia aprion* may take in tadpoles but spit them out almost immediately (Crossland 1997; R. Shine, unpubl.) with no obvious long term effects. Other fish have been observed spitting out toad eggs immediately after taking them into their mouths (Licht 1968). Northern Trout Gudgeons appear capable of rapidly learning to avoid attacking toad tadpoles (R. Shine, unpubl.). Conversely, a range of Northern Territory native freshwater fish including Glassfish (Family Ambassidae), Western Rainbowfish *Melanotaenia australis*, Fly-specked Hardyheads and Black Catfish *Neosilurus ater* that had never encountered Cane Toads all ate toad eggs in an aquarium and died, despite these fish being well fed (Wilson 2005).

Anecdotal reports also suggest that fish can die from Cane Toad toxins in the water. Wilson (2004) observed dead Sooty Grunter *Hepbaestus fuliginosus* immediately downstream of a dead Cane Toad in spring fed pools near Oenpelli, while Sooty Grunter in pools above the dead Cane Toad were still alive. Again water quality was unlikely to cause this fish kill. It is not known how common such incidents are.

Frogs

Our observations suggest that some frogs such as Northern Waterfrogs and Marbled Frogs may be impacted by small Cane Toads. Interestingly, no dead frogs were seen in the nearby waterway that contained many Cane Toad tadpoles, suggesting that they did not eat the tadpoles.

Adult Northern Waterfrogs are largely aquatic and predatory during the wet season (Cogger 2000), and as such may eat the relatively slow moving toadlets. Van Dam *et al.* (2002) listed Northern Waterfrogs as possibly susceptible to Cane Toads because they are known to eat small frogs. Interestingly, Northern Waterfrogs have been observed eating small Cane Toads and their tadpoles and surviving, while on other occasions they have been found dead in the vicinity of Cane Toads (G. Sawyer, unpubl.). This is an area that warrants further research.

Little information is available on feeding behaviour of Marbled Frogs. Laboratory trials on the related *Limnodynastes ornatus* found that nine out of ten tadpoles offered Cane Toad eggs ate the eggs and died. The *L. ornatus* tadpoles did not eat Cane Toad tadpoles (Crossland & Alford 1998). van Dam *et al.* (2002) also listed Marbled Frogs as being possibly susceptible to eating Cane Toads and being poisoned.

Do Cane Toads kill fish and frogs?

It appears that when large numbers of Cane Toad tadpoles or toadlets are present, some species of large-mouthed opportunistic predatory fish such as Spangled Perch

may eat these and die. Some frogs such as Northern Waterfrogs and Marbled Frogs may also be affected. It is, however, generally difficult to prove that an animal has died as a result of eating Cane Toads (Covacevich & Archer 1975). Several factors add weight to this theory; one Spangled Perch was found dead with a Cane Toad in its mouth, fish that are unlikely to swallow Cane Toad tadpoles or toadlets were unaffected, and fish did not die from low dissolved oxygen, the most common cause of fish kills in the Top End.

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A field guide to the fiddler crabs of East Point Reserve, Darwin, Northern Territory

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Introduction

Fiddler crabs (genus *Uca*) are small decapod crustaceans inhabiting intertidal mudflats and mangroves. They live in individual burrows in the substrate, into which they retreat to avoid predators and the incoming tide. Around its burrow each crab defends a small territory, in which it feeds by filtering microscopic organisms from the mud. Males are characterised by the great enlargement and modification of one feeding claw (the 'major claw' or cheliped), which is often conspicuously coloured and is used in aggressive encounters and mate attraction (Crane 1975).

Sixteen species of fiddler crab occur in Australia, nine of which are found in Darwin: *U. capricornis*, *U. elegans*, *U. flammula*, *U. hirsutimanus*, *U. mjoebergi*, *U. polita*, *U. seismella*, *U. signata* and *U. dampieri* (von Hagen & Jones 1989). Recent genetic analysis found that individuals described as *U. dampieri* by von Hagen and Jones (1989) are genetically indistinguishable from an east coast species, *U. vomeris* (Keogh & Backwell, unpubl.). We therefore correct the designation of *U. dampieri* in Darwin to *U. vomeris*.

All nine Darwin species can be found along the coast at East Point Reserve, where the habitat conditions preferred by each species can be found in a few different locations (Figure 1). Individual species occur in fairly discrete patches, largely influenced by elevation in the intertidal zone.

Here we present a basic description of each species to assist in identification in the field, based on our extensive behavioural and ecological field observations. Descriptions are arranged roughly in order of size, with the largest reported male carapace width (CW) and major claw (MC) sizes in millimetres provided where available (Crane 1975; George & Jones 1982).

Uca seismella (Figure 2a,b) CW 17.7, MC 22.5

Both sexes have a mottled brown carapace, grey-brown legs, and thin yellow eyestalks with bulbous eyes. Males have a pale, tear-shaped major claw with an orange-pink manus that may darken to purple and an orange patch on the underside. Juveniles are similar to adults.

Mating occurs outside female-occupied burrows and possibly within male burrows. Males have a frantic, 'flapping' wave which may be used to attract females and in territorial displays. Some individuals build intricate chimneys of mud-balls removed from the burrow.

Uca seismella are found in thick mud with regular tidal coverage, such as the steep muddy banks near the Ludmilla Creek boat ramp (Figure 1a), on the seaward edge of the *Sonneratia alba*/*Rhizophora stylosa* mangrove forest (Figure 1b), and near the Singapore observation post (Figure 1c).

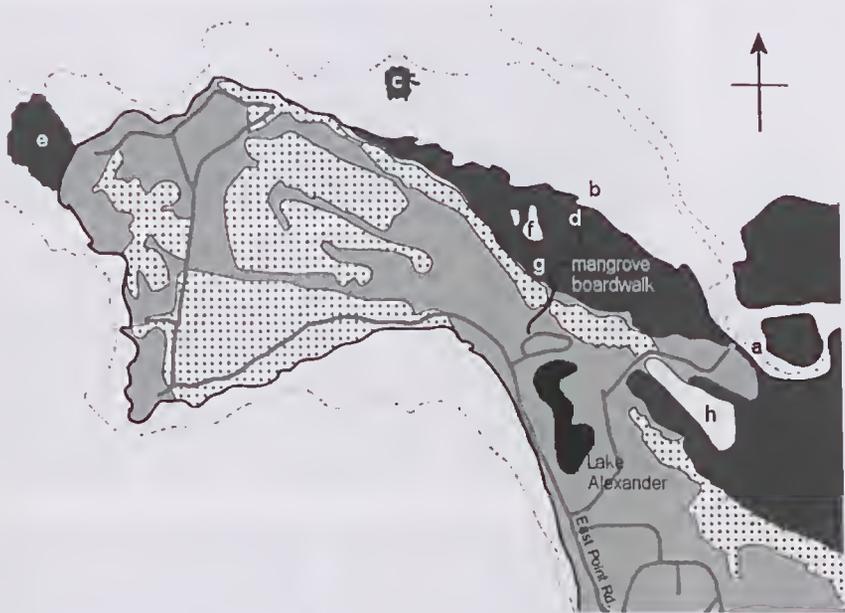
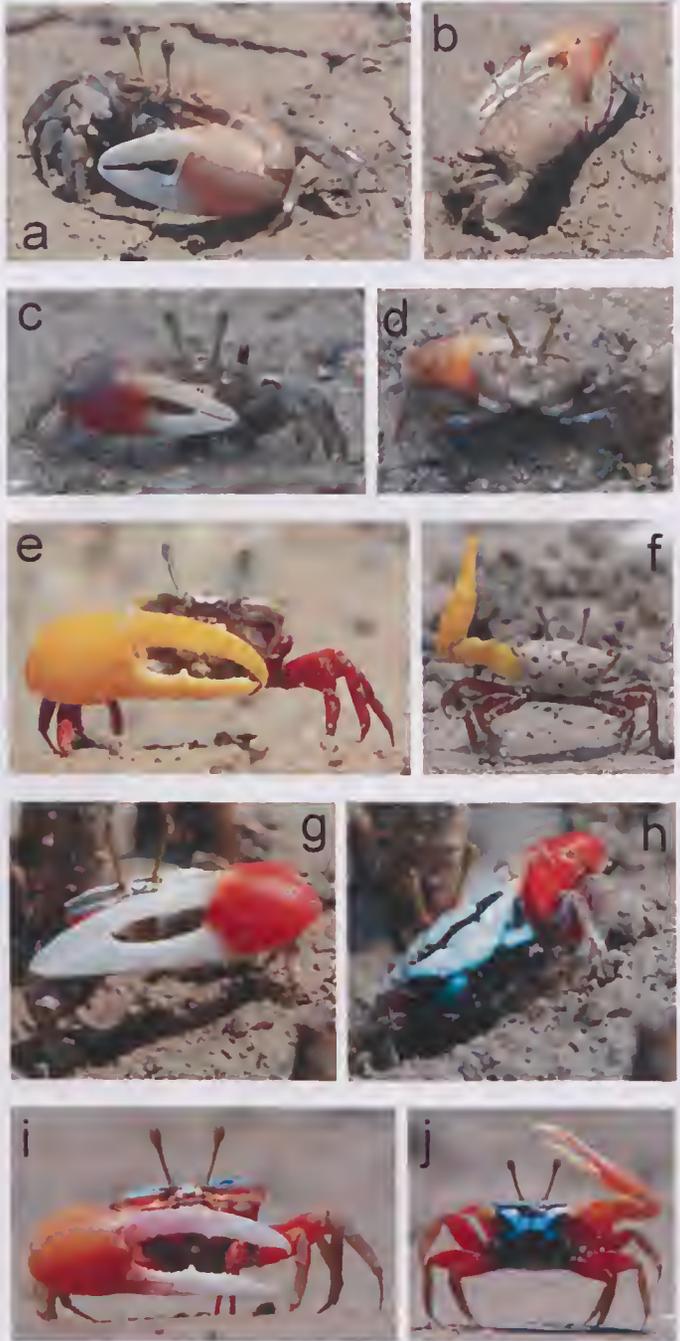


Figure 1. Map of East Point Reserve: species found in each location. The spotted areas represent monsoon forests, dark grey areas are mangrove forests, and light grey areas are grassed. Intertidal mudflats are delineated by dotted lines in the water.

(a) Steep banks of Ludmilla Creek near the boat ramp: *U. seismella*, *U. polita*, *U. capricornis*, *U. flammula*. (b) Seaward edge of the *Sonneratia alba*/*Rhizophora stylosa* forest below the mangrove boardwalk: *U. seismella*, *U. vomeris*, *U. polita*. (c) Open mudflats among the rock platforms surrounding the ruins of the Singapore observation post: *U. seismella*, *U. vomeris*, *U. polita*. (d) *S. alba*/*R. stylosa* forest at the end of the mangrove boardwalk: *U. hirsutumans*, *U. capricornis*, *U. flammula*. (e) Stunted Grey Mangroves *Avicennia marina* on the tip of East Point: *U. mjoebergi*. (f) Small clearings among the Grey Mangrove forest near the mangrove boardwalk: *U. mjoebergi*, *U. signata*, *U. elegans*, *U. vomeris*, *U. capricornis*, *U. flammula*. (g) Path towards the mangrove boardwalk: *U. signata*. (h) Salt flat behind the Ludmilla Creek boat ramp: *U. elegans*.

Figure 2. Front (left panels) and back (right panels) views of males of the nine species of fiddler crab (*Uca*) found in Darwin.
 (a,b) *U. seismella*;
 (c,d) *U. hirsutummanus*;
 (e,f) *U. mjoebergi*;
 (g,h) *U. signata*;
 (i,j) *U. elegans*;
 (k,l) *U. vomeris*;
 (m,n) *U. polita*;
 (o,p) *U. capricornis* adult and
 (q,r) *U. capricornis* final adult colour stage;
 (s,t) *U. flammula*.





Uca hirsutimanus (Figure 2c,d) CW 18.6

Both sexes have a mottled brown and white carapace, brown-grey legs, and stocky, dull yellow-green eyestalks. The male's major claw has an orange-red manus with a patch of purple-brown on the top edge, and white fingers with a single groove running along them. Juveniles are similar to adults.

The mating system of *U. hirsutimanus* is unknown although both sexes may build chimneys of surface mud.

Uca hirsutimanus inhabit soft mud in fairly sheltered sites. They can be found in the *S. alba*/R. *stylosa* forest at the end of the mangrove boardwalk (Figure 1d).

Uca mjoebergi (Figure 2e,f) CW 16.4, MC 25.0

Both sexes and all ages have a mottled brown carapace, often with traces of yellow or red, and grey-brown eyestalks. The legs are striped muddy brown, red, or yellow. Males have a uniformly yellow major claw.

Around neap tide, when the population is not covered by the tide, males attract burrowless, wandering females by waving with a large beckoning motion, extending the claw laterally and raising it over the eyestalks before lowering it in front of the body. Mating occurs primarily within the male's burrow but also on the surface. Individuals of both sexes may build chimneys.

Uca mjoebergi are found at elevated sites that are not covered by the tide for several days around neap tide. They occur on the tip of East Point (Figure 1e), in small clearings and along the landward edge of the Grey Mangroves *Avicennia marina* near the mangrove boardwalk (Figure 1f,g).

Uca signata (Figure 2g,h) CW 18.4, MC 21.0

Males have a black carapace with a pale blue to white 'X' marking and mustard yellow eyestalks. Females are mottled brown or white with an orange patch in the centre of the carapace. Both sexes have grey-brown or black legs, sometimes with traces of blue or red on the first segment of each. The male's major claw has an orange or red manus and bright white fingers with a single groove running along the lower finger, which also has a distinctive flat edge where the fingers meet. Juveniles have a mottled brown carapace, paler grey legs, and a paler manus.

Males wave at females with a quick jerky upward and outward movement accompanied by a small leap at the end. Males often build their burrows and wave on top of mounds of mud like those made by mud lobsters *Tbalassina squamifera*. Mating generally occurs above ground although males may also herd females towards their burrow to mate.

Uca signata are found in areas that are infrequently covered by the tide. At East Point they can be seen in small clearings among the Grey Mangroves (Figure 1f) and along the higher areas of the mangrove boardwalk (Figure 1g).

Uca elegans (Figure 2i,j) CW 26.6

Males have a black carapace with a pale blue to white 'V' or 'X' pattern and occasional patches of orange at the edges. Females are speckled brown, sometimes with a cream-coloured cross. The male's major claw has a pale orange, red, or pink manus that fades to white over the long 'elegant' fingers. Both sexes have muddy orange-red legs and yellow-green eyestalks. Juveniles have less distinct white markings on their carapace and paler claws.

Males wave by raising their claw above their eyestalks in front of their bodies while facing away from wandering females, in an attempt to herd them back to their burrows to mate. Mating also takes place on the surface. Males sometimes build large chimney-like mounds around their burrow using mud from inside their burrow.

Uca elegans generally inhabit dry, open areas that are not inundated by the tide for long periods, during which time the crabs remain underground. Females often prefer more sheltered, damper habitat. At East Point they occur in small clearings in the Grey Mangroves near the mangrove boardwalk (Figure 1f) as well as in the salt flat near the Ludmilla Creek boat ramp (Figure 1h).

Uca vomeris (Figure 2k,l) CW 29.2, MC 41.5

Both sexes have a black carapace with a patch of blue, yellow, cream, or green near the base that extends over the entire carapace in larger individuals. They have bright orange or red legs and pale grey-blue or grey-green eyestalks. Males have a solid major claw with prominent teeth and two deep grooves at the base of the lower finger that are often filled with algae or mud. The lower half of the claw is dark orange or red fading to a paler pink, orange, or white on the top half. Juveniles have a mottled brown carapace, striped brown legs, brown eyestalks, and a paler, more uniformly coloured claw.

Males display a simple vertical wave in front of the body to above the eyestalks, which they use in territorial interactions and when trying to herd wandering females towards their burrows. Mating commonly occurs on the surface outside female burrows and possibly within male burrows.

Uca vomeris inhabit relatively open areas of soft mud that are regularly inundated by the tide. At East Point they can be seen near the Singapore observation post (Figure 1e) and at the edge of the *S. alba*/*R. stylosa* forest at the end of the mangrove boardwalk (Figure 1b).

Uca polita (Figure 2m,n) CW 26.2, MC 41.0

The carapace of both sexes is marbled yellow, green or cream, and occasionally orange or pink. They have dark brown or black legs with pink or blue patches and pale yellow-green eyestalks. Males have a bright pink or orange major claw fading to white on the fingers. Juveniles are similar, with a marbled brown carapace.

Males use a simple vertical wave in front of the body to above the eyestalks in territorial interactions and when courting females. Males form resident breeding units with one or two females (von Hagen 1993), and mating occurs on the surface outside the burrow of the female. Males may also attract wandering females to their burrows to mate.

Uca polita inhabit regularly inundated, open areas of deep and sticky mud and can be found among the rocky shelves near the Singapore observation post (Figure 1c), on the creek banks by the Ludmilla Creek boat ramp (Figure 1a) and at the edge of the *S. alba*/*R. stylosa* forest at the end of the mangrove boardwalk (Figure 1b).

Uca capricornis (Figure 2o,p,q,r) CW 32.3, MC 45.0

The carapaces of both sexes change from a uniform blue to white or mottled white and brown or black. Adults develop a pattern of distinct white, yellow, or blue patches on a black background, generally a triangular yellow patch behind the eyestalks and three white, yellow or blue spots. The largest individuals are entirely black and were previously described as a separate species, *U. pavo* (George & Jones 1982). However, the conclusion by von Hagen and Jones (1989) that they are in fact *U. capricornis* is supported by recent genetic analyses (S. Keogh, pers. comm.). The colour of their legs also progresses from entirely blue to black or grey with purple or blue tinges. Adult males have black legs with bright blue or whitish spots on the last pair while adult females often have spots on all of their walking legs or entirely blue or aqua legs. Males have a tear-shaped major claw with a yellow or orange manus fading to white on the fingers, the claw of mature males are cream coloured with fingers longer than the manus. Mature adults have yellow-green eyestalks and black eyes; all other stages have yellow eyestalks and red eyes.

Males have a very simple vertical wave directed at females and other males. Mating occurs on the surface, often between neighbouring male and female 'pairs' (Detto *et al.* 2008). Some juveniles of both sexes construct chimneys of mud collected from the surface.

Uca capricornis are found in shaded areas of thick mud that are regularly covered by the tide. They occur on the creek banks by the Ludmilla Creek boat ramp (Figure 1a), throughout the *S. alba*/*R. stylosa* forest and along the mangrove boardwalk (Figure 1d,f).

Uca flammula (Figure 2s,t) CW 39.6, MC 69.0

Both sexes have a black carapace often with a red-orange strip behind the eyestalks and two white or orange 'eomma' markings in the centre. Their legs and eyestalks are bright red-orange. Males have a rough, tubercle-covered, bright red major claw, with orange to white fingers with prominent teeth. Juveniles have a white carapace which becomes a pale muddy grey colour. They have pale yellow claws and legs, and blue-black eyestalks.

Males direct a high vertical wave at females, and possibly also during territorial disputes with other males. Some juveniles of both sexes collect surface mud to construct chimneys. Mating takes place on the surface.

Uca flammula inhabit relatively open areas in soft mud and are most active at spring tide, particularly at high sites where they are left uncovered by the tide for long periods. They are found on the creek banks by the Ludmilla Creek boat ramp (Figure 1a), throughout the *S. alba*/*R. stylosa* forest and along the mangrove boardwalk (Figure 1d,f).

Watching fiddler crabs

The best time to view fiddler crabs is generally 3 hours before, to 3 hours after the diurnal low tide. However, during neap tides, populations that are not inundated can often be observed throughout the day. Fiddler crabs are easy to locate, by the presence of their small (<3 cm wide), circular burrows. They are very sensitive to movement and will retreat to their burrows when approached. However, they will emerge within 5-10 minutes and behave normally within metres of a completely motionless observer. With the exception of *U. mjoebergi*, who mate during neap tide, mating and waving behaviour is most common around spring tide. Fiddler crabs are charismatic and very interesting to watch, and this guide should facilitate the observation of the fiddler crabs around Darwin.

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Interspecific aggression in the Beach Stone-curlew *Esacus magnirostris*

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Introduction

Most waders (Aves: Charadriiformes) are small and not noted for their interspecific aggression. However, the relatively large Masked Lapwing *Vanellus miles* is well known for its vigorous defence of nests and young including diving attacks on humans. Agonistic displays in defence of nests or young are also widely reported amongst stone-curlews (Charadriiformes: Burhinidae) (Marchant & Higgins 1993). The Beach Stone-curlew *Esacus magnirostris* is a large, heavily built (*c.* 1 kg) resident shorebird and, unlike all other members of the Burhinidae family, can be readily seen feeding by day (Hume 1996). Strictly coastal, it has been recorded along the entire Northern Territory coast and most offshore islands (Chatto 2003). The species is mostly found singly or in pairs, but remarkably little is known about its behaviour (Marchant & Higgins 1993). In this note, we describe displays resembling the aggressive defence of young found in stone-curlews in general, and aggression directed towards a raptor.

Aggression directed at an observer

This account relates to a pair of Beach Stone-curlew that nested at East Point, Darwin, Northern Territory (12°24'S, 130°48'E). On the morning of 8 October 2006, the nest, a simple depression in the sand lined with leaves and twigs, contained a single egg, the usual full clutch size for the species (Marchant & Higgins 1993). Late on 10 October, the pair was observed with a small chick. The chick was again observed on 25 November, by which time it had grown significantly, having lost most of its downy feathers and developed the facial pattern of a juvenile.

At 7:14 am on 21 October 2006, one of the pair of stone-curlew was observed (by TC) in an elaborate display over a period of about four minutes. At first, and while making its weak 'quip quip' alarm call, the stone-curlew ran directly towards the observer from a distance of about 20 m, stopping about 15 m away (Figure 1a). It spread and flapped its wings while wagging its tail (Figure 1b), and then, with its wings

raised, back arched and raised tail fanned, kicked sand (Figure 1c). Then it again ran directly towards the observer while making an alarm call, this time stopping about 10 m away, and repeated the display. After a brief interval, the stone-curlew again briefly repeated the display, after which it walked slowly away from the observer. Neither the chick nor the other adult bird was observed during the encounter.



Figure 1. A Beach Stone-curlew *Esacus magnirostris* charges the observer (upper left panel). The Beach Stone-curlew spreads and flaps its wings while wagging its tail (upper right panel). With its wings raised, back arched and raised tail fanned, the Beach Stone-curlew kicks sand (lower panel). (Trevor Collins)

Aggression directed at a raptor

This account is of an interaction between a Beach Stone-curlew and an Osprey *Pandion haliaetus* observed at Nightcliff Rocks, Darwin, Northern Territory (12°20'S, 130°54'E), just before midday on 14 March 2008, about 90 minutes after the peak of the high tide.

On arrival at the high tide wader roost, the observer (AK) noticed two Beach Stone-curlew loafing on the rocks, one of which had a bath in a small rock pool left by the receding tide. About 30 m away, an Osprey was eating prey which appeared to be a fish. A few minutes later, the observer's attention was drawn to the presence of a third Beach Stone-curlew by its alarm call. The bird was lurking among small mangroves about 50 m away from the other two stone-curlew and about 30 m in the opposite direction from the Osprey. Just afterwards, the third stone-curlew walked towards the Osprey, stopping about 2 m away and facing the raptor. The Osprey continued to feed, ignoring the stone-curlew.

After walking around the Osprey, the stone-curlew moved slightly closer and, when side-on to the Osprey, spread its wings and jumped in the air two or three times. The Osprey did not react and continued to feed. The stone-curlew then walked around to the other side of the Osprey, but still close to it, and repeated the display. The Osprey was seemingly unconcerned, soon returning to feed on its prey. Again, the stone-curlew repeated the display but with the same result. Each time the stone-curlew landed after jumping, it bobbed its head and fanned and wagged its lowered tail. After a few more minutes during which it remained in close proximity to the Osprey, the stone-curlew moved slowly away back towards the mangroves from where it came. The Osprey continued to feed.

Discussion

The behaviours observed both involved the spreading of wings and the fanning and wagging of the tail, a response typical of members of the Burhinidae family when threatened by a potential predator and in intraspecific interactions (Hume 1996; Marchant & Higgins 1993) and previously reported in the Beach Stone-curlew (Woodall & Woodall 1989). However, the two observations occurred in quite different circumstances. In the first case, there was no evident threat to the bird (it could simply have moved away), and it seems likely that its behaviour was a parental anti-predator strategy. Though the chick was not observed during the incident, subsequent observations showed it was alive; it would have been about 11 days old at the time. We suggest the behaviour should be interpreted as aggression intended to chase off the observer rather than distraction because it was directed towards the observer rather than an attempt to lure the observer away. Beach Stone-curlew have previously been reported to charge humans who approach a nest or young (Clancy & Christiansen 1980).

The evident aggression towards the Osprey is less readily explained. The Osprey was not threatening the stone-curlews, and the first two birds were unconcerned by it. Regardless, it seems the stone-curlew was intent on chasing off the Osprey. While Beach Stone-curlew are not known to eat fish (crabs and other marine invertebrates are their main prey; Marchant & Higgins 1993), one plausible explanation for the aggressive behaviour is the stone-curlew wanted to take the Osprey's food. Another possible explanation is the stone-curlew attempted to chase off the Osprey wrongly believing the Osprey was a threat to it, perhaps because it was inexperienced. We know of no reports of similar behaviour.

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Nesting event of the Cicadabird *Coracina tenuirostris* in the Northern Territory

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Although found in a variety of habitats within Australia, including rainforests, paperbark woodlands, wet and dry sclerophyll forests and mangroves (Higgins & Peters 2006), Cicadabirds *Coracina tenuirostris* are generally confined to high rainfall areas. In Australia, two subspecies exist which can be distinguished by call and size (Higgins & Peters 2006; Schodde & Mason 1999). The northern subspecies *melvillensis* is smaller and has a slower song compared to the subspecies *tenuirostris* found along the east coast. *Coracina t. melvillensis* occurs mostly close to the coast north of the 16°S parallel, from the King Leopold Range in northern Western Australia across to Cooktown in northern Queensland (Schodde & Mason 1999). Recorded densities of Cicadabirds vary considerably between *C. t. tenuirostris* and *C. t. melvillensis*, being 0.1–0.5 and 0.08 birds per hectare respectively (Higgins & Peters 2006).

Breeding records for Cicadabirds are few (Higgins & Peters 2006) and are all for *C. t. tenuirostris* except for one record of *melvillensis* from 40 km south of Darwin (Noske *et al.* 1997); this particular nest was located in December 1997, and was situated six metres above the ground in a Yellow-barked Paperbark *Melaleuca nervosa*.

The following observations were of a pair of Cicadabirds nesting at Girrween Lagoon (12°31'02"S, 131°04'58"E), 30 km ESE of Darwin, Northern Territory. The habitat was regenerating, open tropical savannah dominated by Ironwood *Erythrophloeum chlorostachys*, Swamp Mahogany *Lophostemon lactifluus*, Woollybutt *Eucalyptus miniata* and Long-fruited Bloodwood *Corymbia polycarpa*. The understorey consisted of native grasses punctuated by sparse *Pandanus spiralis* and *Grevillea decurrens*. The site is adjacent to a permanent lagoon and rural residential allotments. Observations from the ground were for periods of less than 15 minutes on four days. On five days, observations were also made from an adjacent Ironwood tree, approximately 18 m distant and at a height of 8–9 m, during photography sessions lasting 1–2 hours.

On 18 December 2007, the distinctive call of a Cicadabird was heard and a male was observed to fly in the direction of a 14 m tall Ironwood tree. Located approximately 10 m above the ground between a near horizontal fork, the male was observed with its breast lowered (for bracing) and feet used to turn in an anti-clockwise direction, suggesting shaping during nest building. Nesting was confirmed on 23 December and again on 1 January when a female Cicadabird was observed sitting (Figure 1a) in the

same fork. On 12 January, the female vacated the nest immediately after the male arrived to feed a single chick which, due to the size of its head and shoulders, appeared to be up to three days old. By 19 January, the chick had emergent feathers visible on the crown, wings and tail through the pale ashy-grey down and by 30 January the chick showed considerable activity including reorientation about the nest and wing stretching. The chick was in the nest on the morning of 2 February (Figure 1b), but late on the next day, following a 30 minute search of the immediate vicinity, neither the chick nor parents were seen or heard. I presumed fledging to have occurred, however loss due to predation could not be ruled out.

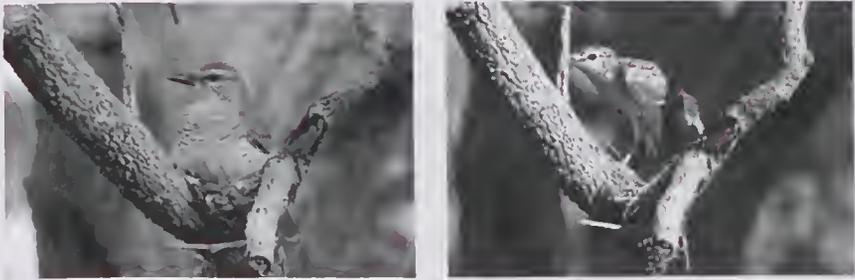


Figure 1. Female Cicadabird *Coracina tenuirostris* brooding while facing toward the outer canopy of an Ironwood *Erythrophleum chlorostachys* (left panel). Cicadabird chick stretching its wing on 2 February 2008 (right panel). (Ashley Carlson)

The nest was typical of *Coracina* species in being a shallow saucer, approximately 7 cm in diameter based on the relative size of the bird. It was built of thin bark strips and twigs bound together with cobweb and decorated with lichen. The nest was barely visible from below, blending with the fissured texture of the Ironwood. Access to the nest for close inspection was not possible due to the height and growth habit of the nest tree. Only the female was observed incubating and brooding. She was always observed facing towards the outer tree canopy as also noted by Purnell (1972). During all observations the female remained alert turning her head from side to side, including during photography sessions.

All feeding events consisted of a cautious approach to the nest by both the male and female. After landing in the upper canopy of the nest tree, the parents would stagger their descent over 2–3 stages taking several minutes to alight on the lead branch approximately 1 m below the nest. Feeding was of short duration, with no audible sounds or begging motions shown by the chick. The male departed immediately following feeding, while the female remained to either continue brooding or collect and swallow a faecal sac, produced after every second or third feeding and which followed several tail pumping actions from the chick. On 26 January, the female fed

the nestling twice in approximately one hour. On 28 January, the female fed the nestling three times, and the male once, during approximately two hours. This would suggest a feeding rate of approximately 2 times per hour, which is at the higher end of those observed by Marchant (1979). From at least 19 January, food was delivered crossways in the beak, allowing identification of Lepidoptera larvae and a grasshopper (Orthoptera).

The only foraging observation was of the male in a sapling approximately 20 m from the nest tree. The bird was observed hopping in small steps along a branch whilst cocking its head from side to side as well as hovering over leaves on the outside of the canopy. Defence of the nest was observed on 23 December when the male swooped at a White-bellied Cuckoo-Shrike *Coracina papuensis* to drive it away from the immediate vicinity, and on 28 January a Varied Triller *Lalage leucomela* was swooped. On both occasions, the Cicadabird gave a harsh rasp as it swooped. Activity interpreted as aggression directed towards me during photography sessions was noted on 26 and 28 January and 2 February. On these occasions, the female flew within 50 cm of me while emitting a grating buzz. These acts followed immediately after feeding the nestling.

Based on dates of nest building and the assumed age of the chick on 12 January, the incubation period is estimated to be between 17 and 23 days, which is consistent with Marchant's (1979, 1985) report of 22 days. Based on the assumed age of the chick on 12 January and that the chick fledged on either 2 or 3 February, the nestling period is between 22 and 24 days. This is less than Marchant's (1979) report of 27 days, but similar to his subsequent observation of 19 to 22 days (Marchant 1985).

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Burning following tree fall causes local elimination of annual sorghum

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Annual sorghum (*Sorghum* spp) is a dominant feature of the monsoonal tallgrass savannas of northwestern Australia. Its prolific seeding makes it a key resource for granivores (Andrew 1986; Woinarski & Tidemann 1991; Dostine *et al.* 2001), and its dominant biomass has a major influence on grass-layer dynamics and tree-grass interactions. In particular, the high biomass and early curing of annual sorghum make it a fundamental driver of the very high fire frequencies that are characteristic of these ecosystems (Andersen 1996; Cook *et al.* 1998; Russell-Smith *et al.* 2003).

Annual sorghum has a peculiar life history in that its seed bank is transient. Seed falls at the end of the wet season (March/April), undergoes a relatively brief period of dormancy and germinates following the first significant rains of the following wet season (Andrew & Mott 1983; Mott & Andrew 1985). Such a life history is successful because of the near-certain absence of significant rain events during the dry season, and the consequent likelihood of follow-up rain subsequent to germination early in the wet season, combined with seed set occurring before the earliest possible cessation of the wet season. However, it is also risky, because failure of a seed crop leads to elimination of the population (Smith 1960). This risk is exploited by fire managers wishing to reduce fuel loads, by burning annual sorghum populations in the wet season following germination but before seed set (Lane 1996).

Fire poses another potential risk to populations of annual sorghum through the burning of fallen seed. Given the high likelihood of fire over the dry season, protection from fire through seed burial in the soil is a key requirement for population persistence. The seeds of annual sorghum are relatively large (~12 mg, not including the awn), so they can potentially escape high intensity fire by germinating from relatively deep in the soil (Bond *et al.* 1999). To promote burial, the seeds possess long, hygroscopic awns that drill the seed into the soil following seed fall (Andrew & Mott 1983). Despite this, most seeds are buried less than 2 cm even in sandy soils (Andrew & Mott 1983), and significant seed mortality can occur during fire (Mott & Andrew 1985), with modelling suggesting that this can limit population size

(Watkinson *et al.* 1989; Cook *et al.* 1998). However, high density of annual sorghum readily persists under high fire frequency.

Rather than a threat, fire is considered a promoter of annual sorghum abundance by maintaining the open canopy conditions required for seedling establishment and by reducing competition with other grass-layer species (Cook *et al.* 1998). Indeed, the current landscape dominance by annual sorghum is seen by some as an artefact of the increased frequency and extent of high intensity, late season wildfires following the breakdown of Aboriginal fire management (Yibarbuk *et al.* 2001; Russell-Smith *et al.* 2003; Bowman *et al.* 2007).

Here we describe an unusual situation where fire has led to the local elimination of annual sorghum. This has occurred at a location immediately adjacent to the Mary River Ranger Station in southern Kakadu National Park, where a 'freak' tornado cut a swathe of destruction approximately 3000 x 800 m in area in early March 2007 (Figure 1). When we visited the site in March 2008, the core affected area had a dense grass-layer dominated by annual sorghum (Figure 2). The species-level taxonomy of annual sorghum is contentious (Spangler 2003). Our study species is a distinct taxon characterised by drooping infructescences and extremely long awns that is restricted to the sandstone hills of the southern Kakadu region (Kym Brennan, pers. comm.). Its density in the tornado-affected area was far higher than under the canopy of adjacent, intact vegetation, as reflects the broader preference of annual sorghum for canopy gaps (Cook *et al.* 1998; Scott 2007). However, there were numerous gaps in annual sorghum cover within the tornado-affected area, where fallen trees had burnt during the 2007 dry season. Some of these gaps were linear and associated with burnt logs (Figure 3), whereas others were far more extensive and associated with the burning of spreading branches (Figure 4). It was clear that the gaps were related to burning rather than directly to tree fall, as annual sorghum occurred in association with fallen trees that had not been burned (Figure 5). Although annual sorghum density was lower in such areas, this can be explained by reduced local seed production due to the direct damage to annual sorghum caused by tree fall (the tornado occurred before seed set).

The most likely explanation for the annual sorghum gaps is that the burning of fallen trees destroyed the sorghum seed bank. The soil at the site is sandy, so that seeds were likely to have been effectively buried. One possibility is that the fuel conditions associated with fallen trees resulted in unusually high fire intensity. The site was burned in May 2007, and although fire intensity was generally low (Rob Muller, pers. comm.) the extra fuel created by fallen branches might have resulted in localised areas of high fire intensity. However, high fire intensity seems to be an unlikely explanation given that annual sorghum readily persists under the highest intensity fires known in native grass-layers of Australian tropical savannas (Andersen *et al.* 2003). A more likely explanation is that the seed bank was affected by unusually long fire residence times associated with the burning of woody debris. The impact of fire on soil biology is determined by the extent and duration of soil heating, which is not simply related to

fire intensity (Alexander 1982). In particular, smouldering combustion is known to produce long heating duration times leading to lethal temperatures near the soil surface (Hartford & Frandsen 1992). We hypothesize that high fire residence times associated with the burning of fallen trunks and branches, possibly relating to smouldering combustion, has led to sub-surface soil temperatures at the tornado site that are lethal to annual sorghum seeds.



Figure 1. Tornado damage one week after the event in March 2007. (Alan Andersen)



Figure 2. Tornado damage one year after the event in March 2008, showing dominance of the grass layer by annual sorghum. (Alan Andersen)



Figure 3. Linear gap associated with a burnt log. (Alan Andersen)



Figure 4 (a,b). Extensive gaps associated with spreading branches. (Alan Andersen)



Figure 5. Annual sorghum associated with fallen branches that have not been burnt. (Alan Andersen)

It is interesting to note that the annual sorghum gaps were often almost completely bare (Figures 3, 4b), which indicates that other herbaceous species were similarly affected by high fire residence times. However, in some cases the gaps had a high cover of forbs such as *Commelina* sp. Sandstone (R.J.Fensham 739, NT Herbarium) (Figure 4a) and species of *Spermacoce*, which indicates that these species were not as sensitive as annual sorghum to high fire residence times. Such reduced sensitivity may be due to deeper seed burial or to greater tolerance of high temperatures. It is unclear if such patchy forb cover was related to local variation in fire residence times or to variation in soil seed banks.

To our knowledge, such an observation of localised elimination of an annual sorghum population by fire has never previously been reported. Given the frequent and widespread damage caused by cyclones across sub-coastal northern Australia (Cook & Goyens 2008), such fire-induced gaps in annual sorghum are likely to be very common. However, their longer term implications for grass-layer dynamics are unclear. The seeds of annual sorghum are poorly dispersed (with maximum dispersal distances of about 2.5 m; Andrew & Mott 1983), so that although the gaps are relatively small it might take several years for them to be completely recolonised from surrounding areas (see Lane 1996). There will be a persistent legacy if the absence of annual sorghum allows for the establishment or expansion of other grass-layer species (such as species of *Commelina* and *Spermacoce*) that then limits sorghum re-colonisation.

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The taxonomic and nomenclatural status of the Northern Australian Greater Blue-ringed Octopus (*Hapalochlaena* sp.): a correction with potentially significant consequences

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Australia is a big place and much remains to be discovered about its marine fauna. This is especially true of the invertebrates, which account for about 99% of all species in our seas. Time and again there are instances where a species that was traditionally interpreted as being widespread within Australia and/or the wider Indo-Pacific Ocean is reassessed as a complex of narrow-range endemic species. These reassessments are based on (frequently rather subtle) morphological differences and subsequently validated by genetic studies. Recent examples of molluscs whose status have been reassessed are periwinkles of the genus *Echinolittorina* (Reid 2007), longbums (more generally called mud creepers or mudwhelks) of the genus *Cerithidea* (Reid *et al.* 2008), and nerites of the genus *Nerita* (Spencer *et al.* 2007).

A case in point is that of the blue-ringed octopuses, of which the Northern Australian Greater Blue-ringed Octopus is the subject of this note. The genus *Hapalochlaena* (Cephalopoda: Octopoda: Octopodidae) accommodates those small octopuses which are united by the synapomorphies (unique derived characters) of reduction in size compared to other octopuses, skin pigment arranged as blue circles and/or stripes that become iridescent when an animal is irritated, enlarged salivary glands, and the mantle extended posteriorly into a nipple-like papilla (Norman 2000; Guzik *et al.* 2005). Prior to the turn of the millennium, the taxonomy and nomenclature of the blue-ringed octopuses seemed settled, with just two species recognised: *H. lunulata* (Quoy and Gaimard, 1832) from the Philippines, Indonesia, Melanesia and northern Australia diagnosed by having blue rings confined to its head and mantle, a small ink sac and relatively small eggs (3.5 mm in length); and *H. maculosa* (Hoyle, 1883) widespread from southern Japan to Tasmania diagnosed by having meandering blue stripes in addition to (rarely instead of) rings on the head, mantle and arms, and relatively large eggs (7-8 mm in length) (Nesis 1982). However, it soon became clear to malacologists specialising in the taxonomy of these cephalopods, in particular Tim Stranks and Mark Norman of Museum Victoria, that the situation was far more complex with at least 10 species (at least six being undescribed) separated by different body sizes and the particular arrangements of their blue markings (Norman 2000; M.

Norman, pers. comm.). Of particular relevance in the Northern Territory is the realisation that the species called *H. lunulata* is in fact two completely different species. True *H. lunulata* from the Philippines, Indonesia and Melanesia is an inhabitant of coral reefs in clear waters, is relatively smaller, has a less muscular body form, and is generally active during the day (diurnal), whereas the second species, which is apparently endemic to the tropical northern coast of Australia, is an inhabitant of silty areas in turbid waters, is relatively larger, has a more muscular body, and is generally nocturnal – thus it is often described as "elusive" (Norman 2000), although it is not that uncommon in favourable habitats (R.C. Willan unpubl.). There are no human fatalities attributed to the former species, whereas the death of a man in Darwin in 1954 is attributed to the latter species (see Jacups & Currie 2008 for details). Preserved specimens of the latter species from the Northern Territory (11 lots ranging from Joseph Bonaparte Gulf to Groote Eylandt) are stored in the wet mollusc collection of the Museum and Art Gallery of the Northern Territory (NTM).

It is crucially important to recognise the taxonomic distinction between these two species and, having realised their status as separate species, then to use the correct scientific names (nomenclature) for each to reflect this distinction. Since the northern Australian species presently has no specific name, it should be called either *Hapalochlaena* sp. 1 (as in Norman 2000; Guzik *et al.* 2005) or *Hapalochlaena* aff. *lunulata* [a technical shorthand way of saying the *Hapalochlaena* species that is similar to, but different from, *H. lunulata*], but the name *Hapalochlaena lunulata* is definitely incorrect.

This species of blue-ringed octopus does in fact already appear in recent technical literature under the name *Hapalochlaena* sp. 1. It appears, albeit rather cryptically, in a paper published in *Molecular Phylogenetics and Evolution*. This paper reports on a specimen from Darwin (stored in Museum Victoria, registration number MV F101643) that was included in a study on the molecular phylogeny of all the benthic shallow-water octopuses (Guzik *et al.* 2005: Figures 2 & 3, Appendix A, line 6).

Establishing the correct taxonomy and nomenclature for the Northern Australian Greater Blue-ringed Octopus is far more than merely semantic because it relates directly to the identification of the octopus that caused the fatality in Darwin in 1954. The actual octopus that bit the man was thrown back into the water, but later his companion produced what he claimed was an "identical" octopus which, although reported as "iridescent blue", was incorrectly identified in the original article in the *Medical Journal of Australia* as *Octopus rugosus*, a much larger species which can cause local allergic effects similar to a bee sting (Flecker & Cotton 1955). The patient was known to be asthmatic and so the possibility of hypersensitivity should not be ruled out. The second octopus was preserved and stored in the mollusc collection at the Australian Museum in Sydney. When re-examined (by a malacologist who did not specialise in cephalopods) 10 years later it was re-identified as a species of *Hapalochlaena* (McMichael 1964), and henceforth this species became synonymous with fatalities from octopus bites in northern Australia.

However, the case should not rest there. It is possible that the offending octopus (i.e., the octopus that caused the fatality in Darwin) was not a blue-ringed octopus at all, even though the second specimen definitely was *Hapalochlaena* sp. 1. Firstly, its size is contentious. Flecker and Cotton (1955) reported it as "6 inches" (approx. 18 cm) long. This size, if correct, is far too large for *Hapalochlaena* sp. 1 which, according to Norman (2000), has a maximum body size of only 6 cm. Secondly, is the fact the specimen was active during the daytime; hence the octopus may have been a different species. So in conclusion, it is just possible that the original specimen is not the species that bit the victim and, as a consequence, the bite of a Northern Australian Greater Blue-ringed Octopus is not fatal to humans after all!

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Blue-ringed octopuses: a brief review of their toxicology

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Abstract

Blue-ringed octopuses *Hapalochlaena* (Cephalopoda: Octopoda: Octopodidae) live in shallow waters on rocky reefs in the intertidal and subtidal zones along the Australian coast. Their toxic saliva (venom) is used to subdue their prey of principally small crabs. The predominant toxin found in the saliva is tetrodotoxin (TTX), a sodium channel blocking neurotoxin, which causes dose-dependent muscle paralysis. The somewhat elusive Northern Australian Greater Blue-ringed Octopus *Hapalochlaena* sp. 1 is attributed to the first documented human fatality (at East Point, Darwin, in 1954) from a blue-ringed octopus; however the octopus was not correctly identified until 1964. This paper clarifies the first documented fatality from a blue-ringed octopus envenoming and briefly reviews the literature on the natural history and toxicology of blue-ringed octopuses, focusing on the Northern Australian Greater Blue-ringed Octopus, the only species of *Hapalochlaena* in the Northern Territory.

Introduction

The genus *Hapalochlaena* comprises the blue-ringed octopuses, which are found along the entire Australian coast (Sutherland & Tibballs 2001). They frequent shallow rocky reefs in the intertidal and subtidal zones, avoiding surf conditions. At rest, the body of blue-ringed octopuses is a mottle of yellow to brown or grey with the defining blue rings blended into the brown-grey patches. Octopuses have the ability to darken and lighten patches to adapt to surroundings and assist with camouflage (Williamson 1996). Blue-ringed octopuses have additional powers of command over their skin pigmentation: their characteristic iridescent blue markings fluoresce when distressed or when desired (Hanlon & Hixon 1980; Hanlon 2007). There remains some uncertainty in the taxonomy of *Hapalochlaena* from northern Australia and in octopuses in general (see Willan 2008).

Following a sighting of the Northern Australian Greater Blue-ringed Octopus *Hapalochlaena* sp. 1 in the shallows of a muddy reef off East Point, Darwin, on a low tide midnight 18-19th May 2007 NT Field Naturalists' field trip, interest was sparked in this small, seemingly innocuous, yet highly dangerous sea creature. There are no data available on the abundance or distribution of this undescribed species within the Darwin coastal region. Marine biologists from Darwin estimate that while known to be common, they are rarely sighted (M. Meekan, pers. comm.). Of additional local importance, is the historical link with the first fatal envenoming from a Northern Australian Greater Blue-ringed Octopus, which also occurred off East Point, although the species of octopus responsible for the fatality was not confirmed until many years later. Members of the genus *Hapalochlaena* are the only octopuses known to be capable of causing toxic morbidity or mortality in humans (Meier 1995). This paper briefly reviews the natural history and toxicology of blue-ringed octopuses and clarifies details of the first documented fatality from envenoming by a Northern Australian Greater Blue-ringed Octopus in Darwin Harbour.

Taxonomy and distribution

There are many species of *Hapalochlaena* of which three from Australia are broadly characterised as follows:

Hapalochlaena maculosa – Southern or Lesser Blue-ringed Octopus. Maximum size 20 cm across arms, body length 12 cm (Sutherland & Tibballs 2001); occurs along the coastline of south Western Australia to eastern Victoria, including Tasmania.

Hapalochlaena fasciata – Differs from *H. maculosa* in the appearance of blue rings, which appear as lines, instead of rings on the body; occurs chiefly along the coastline of eastern Australia to Victoria (Sutherland & Tibballs 2001).

Hapalochlaena sp. 1 – Northern Australian Greater Blue-ringed Octopus. Previously known under the name *H. lunulata*, which is restricted to tropical western Pacific Ocean including Papua New Guinea, Solomon Islands, the Philippines and Indonesia (see Willan 2008 for nomenclature). Slightly larger than *H. maculosa*; occurs along the coastline of Northern Australia.

Life cycle and diet

Most species of blue-ringed octopuses live less than two years, reaching sexual maturity at four months (Tranter & Augustine 1973). The newly hatched juveniles feed on the yolk sac until about four weeks of age when as juveniles they begin attacking live crabs. Observational studies indicate that venom is active even at this early age (Tranter & Augustine 1973).

Octopuses possess two sets of salivary glands; the larger set contains the potent tetrodotoxin (TTX)-like venom (Williamson 1996). *Hapalochlaena* use their poison to subdue their prey, predominantly crabs (Tranter & Augustine 1973; Walker 1983), but the method of attack depends on food availability. When food is plentiful, the octopus moves over its prey and disperses its toxic saliva into the surrounding water (Tranter & Augustine 1973; Walker 1983), the victim absorbs or inhales the venom and is paralysed within minutes (Tranter & Augustine 1973; Walker 1983). However, when starved, the octopus will actively capture prey with its arms and puncture its victim's shell with its beak, paralyzing it rapidly (Tranter & Augustine 1973; Walker 1983).

Toxins

There remains some confusion concerning the precise molecular and toxicological differences between the structurally similar organic compounds maculotoxin, derived from *Hapalochlaena maculosa*, and TTX, derived from pufferfishes. Some authors have classified any 'non-pufferfish'-derived tetrodotoxin to be TTX-like (Freeman & Turner 1970), while others claim they are pharmacologically and biochemically indistinguishable (Freeman 1976; Sutherland & Broad 1978), with the same chemical formula $C_{11}H_{17}N_3O_8$ (Kao 1972). Sutherland highlighted the complexity of the saliva and described the potential toxins contained in the posterior salivary glands of *H. maculosa* as follows: (a) tetrodotoxin-like substances (maculotoxin); (b) hapalotoxin; (c) antigenic, non-toxic components; (d) histamine, tyramine, serotonin and other phenolic amines; and (f) a potent hyaluronidase (suggested to be a dispersion agent) (Williamson 1996). Regardless of the names and possible molecular variations, TTX and maculotoxin ultimately have very similar and possibly identical clinical effects and outcomes (Mebis 2002).

TTX was named after the family of pufferfish the Tetraodontidae (four teeth) from which it was first isolated and purified in 1964 (Williamson 1996). Commonly eaten in South-east Asia as a delicacy called 'fugu' (Isbister *et al.* 2002), a minuscule portion of a poisonous organ from pufferfish (liver, ovaries, skin) can cause a tingling of the lips together with a lingering excitement that each bite is potentially a gamble with death. Too much TTX, a dose-dependent toxin, exclusively blocks nerve conduction by reducing the movement of sodium through membrane channels. This causes paralysis of muscles including the diaphragm, leading to respiratory failure and death (Mills & Passmore 1988; Williamson 1996; Isbister *et al.* 2002). TTX/maculotoxin has been isolated from all body parts of *H. maculosa* not just the posterior salivary gland, with high concentrations in the arms followed by the abdomen (Yotsu-Yamashita *et al.* 2007a). As in pufferfish, bacteria are thought to be responsible for the manufacture of TTX in *Hapalochlaena* (Hwang *et al.* 1989; Yu *et al.* 2004), possibly acquired through ingestion (Mills & Passmore 1988). Both pufferfish and newts bred in captivity do not acquire TTX (Mills & Passmore 1988).

TTX is widespread in nature. It has been identified in animals from six different major groups including pufferfish (Mills & Passmore 1988), central American frogs and newts (Yotsu-Yamashita *et al.* 2007b), goby fish (Hashimoto & Noguchi 1971), xanthid and horse-shoe crabs (Kanchanapongkul *et al.* 1996; Llewellyn *et al.* 2002), the gastropod *Nassarius glans* (Yin *et al.* 2005) and octopuses (Mills & Passmore 1988). Although TTX is thought to be produced by bacteria, the origins of these bacteria, their diversity in the natural world, how they disseminate and how frequently they can be taken up by animals remains unknown. It also remains to be elucidated as to whether TTX is found in other octopuses or other marine or terrestrial animals. Interestingly, saxitoxin (SXT) has recently been isolated in a species of octopus of the subgenus *Octopus (Abdopus)* (Robertson *et al.* 2004) from Port Hedland, Western Australia, and furthermore, homobatrachotoxin (homoBTX) has been found in the skin and feathers of birds of the genus *Pitohuis* from Papua New Guinea (Dumbacher *et al.* 1992; Dumbacher 1999). Further investigation of relationships between organisms and toxins in the food chain would help clarify the origins and potential distributions of these toxins in nature.

Human envenoming and fatalities

Of all the octopuses, only *Hapalochlaena* is known to present an envenoming risk to humans (Sutherland & Tibballs 2001). Even so, blue-ringed octopuses are generally not aggressive to humans, biting only when provoked. In almost all recorded cases of envenoming, the octopus was clearly aggravated, such as by removal from the water. Furthermore, of the 12 documented bites by *Hapalochlaena*, six cases did not experience serious symptoms or deleterious respiratory consequences (Meier 1995). There have been two fatalities in Australia attributed to *Hapalochlaena*; the first in Darwin in 1954, and the second at Camp Cove near Sydney in 1967. Additionally, several envenomings have required life-preserving artificial ventilation until the neurotoxic effect of TTX had abated.

The bite of a blue-ringed octopus is often, but not always, painless and may go unnoticed (Flecker & Cotton 1955). Once envenomed, the toxin may advance rapidly, weakening and even paralysing the skeletal muscles of the victim. If the diaphragm is affected, respiratory failure and death may follow (Sutherland & Tibballs 2001). Dilated and unreactive pupils may be due to the toxin itself and not a true indication of cerebral dysfunction (Walker 1983). Victims usually remain mentally lucid and conscious throughout paralysis, with one report giving a terrifying account of hearing all that was said, including the statement "it looks as if this chap has had it" (Hopkins 1964). As there is no antidote to TTX, respiratory support together with reassurance may result in the victim surviving.

The 1954 Northern Territory fatality

The following is a summary of the first documented fatal envenoming from an octopus. It occurred off East Point beach, Darwin, on 19 October 1954 and was initially reported in the Medical Journal of Australia (Flecker & Cotton 1955). The victim, identified as 21 year old Kirke Dyson-Holland (Underhill 1996), a sailor and regular spear fisherman, was tossed a small octopus by his companion. Dyson-Holland placed the octopus on his shoulder while walking ashore. As he left the water, the octopus was thrown back into the water. A small trickle of blood was then noticed by his companion on the shoulder where the octopus had been. Shortly afterwards Dyson-Holland complained of dryness in the mouth and difficulty in breathing (Flecker & Cotton 1955). Initially he refused to see a doctor, but as his condition deteriorated he was rushed to the old Darwin hospital four miles (6.4 km) away at Myilly Point. During the trip he was heard to murmur "It was the little octopus, it was the little octopus" (Lane 1962). Upon arrival at hospital he was cyanosed (blue) and not breathing; despite respiratory assistance together with adrenaline, his heart stopped within 15 minutes of arriving at hospital. The time between octopus bite and death was estimated to be 90 minutes.

The victim was known to be asthmatic and the possibility of a hypersensitivity reaction was initially not ruled out. The octopus that caused the envenoming was thrown back into the sea, but later his diving companion produced an "identical" octopus which, although reported as being "iridescent blue", was incorrectly identified in the original Medical Journal of Australia article as *Octopus rigosus*, a much larger species of octopus which can cause local allergic effects similar to a bee sting (Flecker & Cotton 1955). However, this "identical" specimen was preserved and when re-examined many years later at the Australian Museum, Sydney, was found to be consistent with *Hapalochlaena* sp. 1 and not *O. rigosus* (McMichael 1964). The fatal clinical scenario described is consistent with classical TTX envenoming rather than asthma and/or an allergic reaction (Isbister *et al.* 2002).

McMichael (1961) recorded the effects of a bite from the Southern Blue-ringed Octopus (*Hapalochlaena maculosa*) from Wollongong, New South Wales, in 1950. At that time, he pointed out that the symptoms were very similar to those produced from cone snails *Conus* envenoming. McMichael (1964) subsequently identified a second octopus (also *Hapalochlaena maculosa*) responsible for the envenoming of a 33 year old man, who recovered with the aid of artificial respiration, in 1962 (Cleland & Southcott 1965; Sutherland & Tibballs 2001). An additional non-fatal envenoming occurred earlier in 1961 (Cleland & Southcott 1965; Sutherland & Tibballs 2001). Thus, by 1964 at least three documented envenomings but no deaths had occurred from the temperate Australian species *H. maculosa*. McMichael then reviewed and correctly identified the original preserved 1954 'identical' Darwin octopus, confirming that it was a blue-ringed octopus (McMichael 1964). Species in the genus *Hapalochlaena*

remain the only octopuses known to be potentially lethal, capable of causing toxic morbidity or mortality in humans (Meier 1995).

The 1967 New South Wales fatality

There has only been one other documented fatality from a blue-ringed octopus envenoming, which occurred in 1967 in New South Wales and was attributed to the Southern (or Lesser) Blue-ringed Octopus *Hapalochlaena maculosa*. A 23 year old army recruit found a purple octopus in a rock-pool near Sydney and placed it on the back of his hand. Within 10 minutes he complained of dizziness and the inability to remove the octopus. After a few minutes he could not swallow and was soon unable to breathe. Mouth-to-mouth resuscitation was commenced together with cardiac massage. He was transferred to the nearest hospital, but despite further resuscitation attempts, he was declared dead approximately 90 minutes after initial contact with the octopus (Sutherland & Tibballs 2001; Meier 1995). The octopus was identified and reported by Lane and Sutherland (1967). This case confirmed that fatal neurotoxic envenoming can occur from bites from more than one of the *Hapalochlaena* species.

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The Northern Australian Greater Blue-ringed Octopus *Hapalochlaena* sp. 1, photographed at low tide on a reef at East Point, Darwin. (Bart Currie)

Cockatoo Grass *Alloteropsis semialata* as a keystone species in northern Australia

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Introduction

There are two main ways for a grass species to survive the long dry season typical of the monsoonal tropics of Australia. The first strategy is to be short-lived, but produce thousands of seeds capable of lasting at least six months exposed on, or shallowly-buried in, baking-hot soils. Annual or ephemeral grasses generally shed their seeds in the transition between the wet and dry seasons, dormant and well-encased in fibrous spikelets. After their defences have been broken by repeated tumbling and heating and cooling through the dry season, they are ready to soak up the first wet season rains and germinate (Andrew & Mott 1983; Crowley & Garnett 1999). The main risk of this strategy is of too many seeds germinating and then dying if there is a false start to the wet season. To counter this, annual grasses pour all their resources into producing copious numbers of seeds, so a few always get through. Annual grasses such as Annual Sorghum *Sorghum intrans* and Fire Grass *Setiglycerium fragile* dominate much of the northern Australian savannas. As a result, the dry season begins as a time of plenty for seed-eating birds. As the dry season progresses, seed abundance declines as a result of fire, seed burial and predation of seeds by granivores (Tothill 1969; Crowley & Garnett 1999).

In contrast, the perennial grasses of northern Australia produce fewer seeds, generally at the start of the dry season (Tothill 1977; Mott 1978). As the soil dries out, perennial grasses store most of their resources underground. This second strategy, of persisting as dormant plants rather than seeds, means that existing plants can take advantage of the first wet season rains. In this case, false starts to the wet season are a boon, giving resprouting perennials an extra advantage over seedlings struggling to establish. This strategy is typified by the bulky perennial grasses Plume Sorghum *Sorghum plumosum* and Black Spear Grass *Heteropogon contortus*. These grasses can form a dense sward to the exclusion of smaller plants, but they are overtaken by annual grasses where the soils are too poor to support a continuous grass layer, or where the ground cover is more substantially disturbed by fires or grazing.

Cockatoo Grass

Cockatoo Grass *Alloteropsis semialata*, found through northern and north-eastern Australia (Figure 1), has a completely different strategy (Table 1). This small-statured perennial (Figure 2) is unable to compete with the bulkier perennial grasses (Walker *et al.* 1997). Instead, it focuses its growing phase into the very early wet season before other perennial grasses reach a competitive size. So Cockatoo Grass is the first grass of the northern savannas to sprout after rain, no matter how early the rains fall. Before the end of the wet season, Cockatoo Grass shoots are already dying back, storing up new fleshy basal shoots ready to sprout at the start of the next wet.



Figure 1. Australian bioregional distribution of Cockatoo Grass, based on herbarium collections. The species may occur as isolated populations outside the indicated range.

Table 1. Characteristics of Cockatoo Grass.

Name	Cockatoo Grass <i>Alloteropsis semialata</i> (R.Br.) Hitchcock
Distribution	Eastern Africa, Tropical Asia and Australia (see Figure 1)
Soils	Prefers acid, sandy, usually well-drained soils that may be seasonally saturated
Climate	Monsoonal, summer dominant rainfall (600-1600 mm/year in Australia)
Reproduction	Seeds and reproductive tillering
Habit	Perennial tufted grass, dormant over the dry season
Size	0.3 – 1.2 m high
Flowering	October to April (McFarlane 1992); approximately six weeks after the first rains (Crowley & Garnett 2001)
Inflorescence	Two to five (usually three) racemes of overlapping spikelets with ciliate margins that flare when seeds are fertilised
Seeds	Can germinate immediately after seed fall; viability lost within six months. Ephemeral seed bank (Crowley & Garnett 2001)

Cockatoo Grass also seeds early in the wet season. Within six weeks, its three-pronged inflorescences have already shot (Figure 3). Not being dormant, the seeds are ready to germinate as soon as they fall (Crowley & Garnett 2001). Because Cockatoo Grass grows, seeds and dies back earlier than most other grasses, its leaves and seeds provide food at a period of scarcity in the early wet season, and its fleshy basal shoots (Figure 4) a staple diet through the dry season.

At the start of the wet season, when most grass seeds germinate, seed-eating birds are faced with a shortage of food. As soon as they are produced, Cockatoo Grass seeds become an important food for parrots and finches, which take the seeds both from the stem (Garnett & Crowley 1994, 1995) and after they fall (S. Legge, pers. comm.). In many places where Cockatoo Grass grows, few other large-seeded grasses produce seed at the same time (Garnett & Crowley 1995), although Golden Beard Grass or Ribbon Grass *Chrysopogon fallax*, with a similar life cycle, also produces seed at this time of the year (Garnett & Crowley 1995). On Cape York Peninsula, seeding of Cockatoo Grass marks the end of food scarcity, and the start of breeding activity by Golden-shouldered Parrots *Psephotus chrysopterygius* (Crowley *et al.* 2004). Cockatoo Grass seeds are also eaten by Brush-tailed Rabbit-rats *Conilurus penicillatus* (Firth *et al.* 2005). In a study on Cape York Peninsula, most of the seeds that reached the ground without being eaten by birds or mammals were taken by ants (Crowley & Garnett 2001). With this level of predation, regeneration of Cockatoo Grass from seed is likely to be a rare event, so it is all the more important for plants to survive the dry season.



Figure 2. Cockatoo Grass in Golden-shouldered Parrot nesting habitat. (Gabriel Crowley)



Figure 3. Cockatoo Grass in flower. (Stephen Garnett)

As soon as Cockatoo Grass begins to shoot early in the wet season, cattle seek out its tender green shoots, which are also a preferred food of the Pale Field Rat *Rattus tunneyi* through much of the year (Braithwaite & Griffiths 1996). Cattle certainly reduce plant vigour and seed production, and if left to graze unchecked in the wet season, could eliminate Cockatoo Grass from pastures. In most places, Cockatoo Grass has a reputation as being poor quality forage with a low selection preference by cattle (Petheram & Kok 1986) and buffalo (Abeare 2004). This is because palatability is typically assessed late in the growing season, when Cockatoo Grass plants have already started to cure: digestibility declines faster in Cockatoo Grass than it does in most other perennial grasses (Eggington 1986). In fact, when newly sprouted, Cockatoo Grass is one of the most nutritious perennial grasses in the savannas (Eggington 1986; O'Reagain *et al.* 1995). Its young shoots are not only important forage for domestic cattle grazing, but also for wild cattle, including the Tamarau *Bubalus mindorensis* of the Philippines (Talbot & Talbot 1966).



Figure 4. The nutritious base of Cockatoo Grass. (Gabriel Crowley)



Figure 5. Chewed and regurgitated Cockatoo Grass. (Gabriel Crowley)

Having to survive long periods as dormant plants also means Cockatoo Grass provides animals with a rich store of underground food (Figure 5). Its fleshy stem bases are one of the main food sources for northern Australian bettongs and bandicoots (McIlwee & Johnson 1998), and are relied upon by the Northern Bettong *Bettongia tropica* in the late dry season and during extended dry periods when truffles are scarce (Abell *et al.* 2006). The stem bases are also the principal food of Common Mole-rats *Cryptomys hottentotus* in Africa (Genelly 1965) and are eaten by Common Wallaroos *Macropus robustus* (Telfer & Garde 2006). Pigs also seek out the grasses, digging up whole plants to feed on the tiller bases (Crowley *et al.* 2004).

Conclusions and recommendations

Cockatoo Grass fills an important role in the tropical savannas of Australia and elsewhere, providing food for seed-eating birds and small mammals, often at times when other foods are scarce or difficult to obtain. It can be considered a “keystone” species for at least two animal species that rely on it to survive when other foods are unavailable, the Golden-shouldered Parrot (Crowley *et al.* 2004) and Northern Bettong (Abell *et al.* 2006). Cockatoo Grass is also highly susceptible to overgrazing by pigs and cattle. Protection of healthy stands of Cockatoo Grass is therefore important for the conservation of biodiversity in the Australian savannas. While exclusion of cattle and pigs from important stands will allow the greatest development of plants and maximise seed production, healthy stands can also persist under recommended best practice pastoral management for Australian rangelands. This includes spelling native pastures from cattle grazing in the early wet season, and light to moderate pasture utilisation rates (Hunt 2003). In some circumstances, disturbance from fire may also be beneficial in allowing the species to compete with more vigorous grasses (Walker *et al.* 1997; Crowley & Garnett 2001; B. Bateman, pers. comm.).

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