

# A review of distribution, field observations and precautionary conservation requirements for sicydiine gobies in Australia

by

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**ABSTRACT.** - The tropical Indo-Pacific is considered the centre of sicydiine goby diversity. Nevertheless, these amphidromous gobies have only occasionally been recorded in Australia, and this probably relates to the existence of limited suitable habitat (perennial streams that drain steep coastal mountain ranges and enter the sea via poorly developed estuaries). We provide new records of the distribution of sicydiine gobies within Australia, and review the Australian biogeography of the group to confirm at least seven species from four genera (*Sicyopterus*, *Sicyopus*, *Smilosicyopus*, *Stiphodon*) occur in north-eastern Australia (North Queensland). We provide the first Australian records of three species: *Sicyopus discordipinnis*, *Smilosicyopus* sp. and *Stiphodon birdsong*. Current records of sicydiines in Australia are centred on and are almost exclusive to the Wet Tropics region, spanning just a few hundred kilometres of coastline. Longitudinal within-stream distributions of the fauna are species-specific (and to a large extent, genus-specific) corresponding with altitude and migration ability in relation to instream barriers (e.g., waterfalls). Sicydiines are colourful, and attractive to aquarists. This in combination with the apparently low densities and restricted ranges of sicydiines in Australia, suggests that collecting should be limited, at least until the population structure and ecology of these assemblages is better understood.

**RÉSUMÉ.** - Répartition, observations de terrain et recommandations pour la conservation des gobies Sicydiinae en Australie.

La région indo-pacifique tropicale est considérée comme le centre d'origine des Sicydiinae. Néanmoins, ces gobies amphidromes n'ont été que très occasionnellement rencontrés en Australie, et ceci reflète probablement une pauvreté en habitats favorables (rivières pérennes côtières avec des pentes montagneuses et un estuaire peu développés). Nous donnons ici de nouvelles observations sur la distribution des Sicydiinae en Australie et discutons de la biogéographie du groupe en confirmant la présence de 4 genres (*Sicyopterus*, *Sicyopus*, *Smilosicyopus*, *Stiphodon*) dans le nord-est (North Queensland). Trois espèces sont signalées pour la première fois: *Sicyopus discordipinnis*, *Smilosicyopus* sp. et *Stiphodon birdsong*. Les observations de Sicydiinae en Australie sont centrées presque exclusivement sur la région tropicale humide, comprenant quelques centaines de kilomètres de côtes. La distribution des espèces (voire des genres) est spécifique le long d'un gradient longitudinal (altitude) et correspond aux capacités migratoires des espèces en fonction des barrières (e.g., cascades). Les Sicydiinae sont très colorés et recherchés par les aquariophiles. Ceci, mis en relation avec des densités faibles et des aires de distribution réduites en Australie, nous suggère de limiter les collectes, au moins jusqu'à ce que la structure des populations et l'écologie de ces communautés soit mieux comprises.

Key words. - Altitude - Amphidromy - Australia - Biogeography - Conservation - Sicydiinae.

The Australian freshwater fish fauna comprises at least 166 solely freshwater species and 79% of these are endemic to the continent (Hoese *et al.*, 2006). At the scale of major drainages, the southern, central and western drainages of the continent contain strikingly high levels of freshwater fish endemism, whereas the northern and north-eastern coastal drainages share about 35 species with nearby Papua New Guinea (Morgan *et al.*, 1998; Unmack, 2001; Allen *et al.*, 2002; Morgan and Gill, 2004; Hoese *et al.*, 2006; Morgan, *et al.*, 2011). This shared freshwater fish fauna between Papua

New Guinea and Australia is the result of historical cyclic and relatively recent (6000-8000 years ago) continental connections under conditions of lower sea levels (Allen, 1989; Unmack, 2001; Allen *et al.*, 2002). Three major Australian drainages support this shared fauna with Papua New Guinea: the North-eastern Coast, Gulf of Carpentaria and Timor Sea drainages (Allen *et al.*, 2002); and this roughly equates to what Unmack (2001) delineates as the Northern Province. However, there have been a number of fishes discovered and reclassified in the past decade since Unmack (2001) pub-

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lished his important synopsis of the biogeography of Australian freshwater fishes. Among these discoveries is a growing list of amphidromous species including sicydiine gobies occupying streams in the Wet Tropics of north-eastern Queensland (Pusey and Kennard, 2001; Allen *et al.*, 2002; Pusey *et al.*, 2008; Ebner and Thuesen, 2010).

Gobioids (Gobiidae and Eleotridae) comprise about one quarter of all freshwater fishes in Australia (*cf.* Unmack, 2001; Allen *et al.*, 2002) and are especially species rich in the Wet Tropics Region (Pusey *et al.*, 2004). The Wet Tropics constitute a relatively small area spanning about 300 km

of narrow coastline in north-eastern Queensland. The region is characterised by high annual rainfall including more consistent rainfall during the dry season than is experienced elsewhere in the dry-tropics of northern Australia (Pusey *et al.*, 2008). Spanning almost 9000 km<sup>2</sup>, the Wet Tropics has a high topography (relative to the surrounding dry tropics) and supports rainforests with permanent cool streams that drain steep coastal mountains up to 1600 m in elevation (Kiese *et al.*, 2005; Pusey *et al.*, 2008). Pusey *et al.* (2008) note that most of the endemic freshwater fishes in this region are associated with shallow, fast-flowing habitats such as riffles.

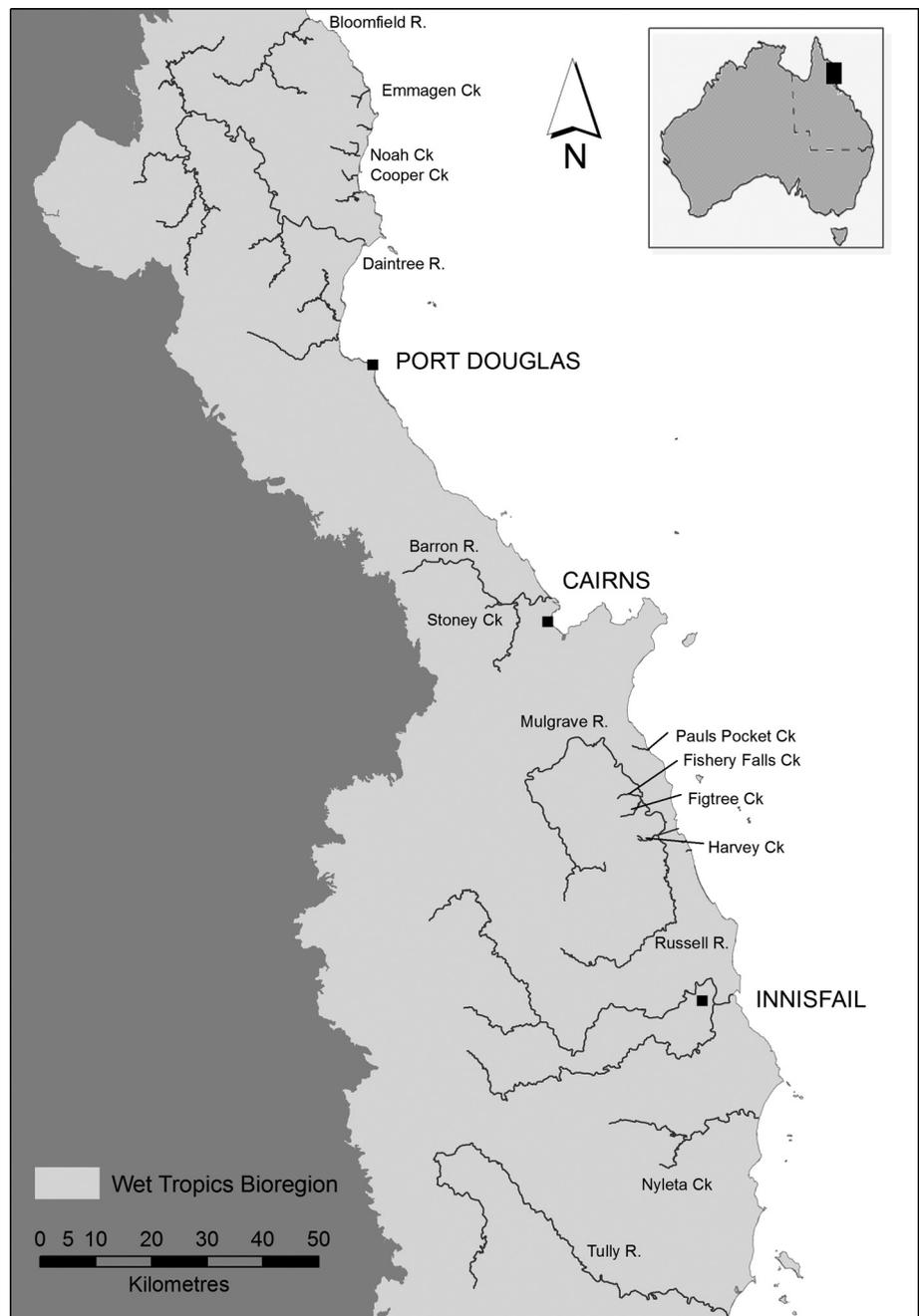


Figure 1. - The Australian Wet Tropics of northeast Queensland and small coastal streams where sicydiine gobies have been recorded. A selection of larger rivers and towns are also shown for spatial reference.

The Sicydiinae is the most diverse sub-family of the Gobiidae in freshwater habitats of tropical islands in the Indo-Pacific area. The Sicydiinae is a monophyletic group of gobies comprising 10 genera: *Akihito*, *Cotylopus*, *Lentipes*, *Parasicydium*, *Stiphodon*, *Sicyopterus*, *Sicydium*, *Sicyopus*, *Smilosicyopus* and one undescribed genus (Keith *et al.*, 2011). These gobies spawn in freshwaters, whereby the free embryos drift downstream to the sea and undergo a planktonic phase before returning to rivers to grow and reproduce (Keith, 2003) via a strategy known as amphidromy (Myers, 1949; McDowall 1997, 2007, 2009). A few sicydiines have occasionally been recorded in the Australian Wet Tropics, being *Sicyopterus lagocephalus* and at least three species of *Stiphodon* (Allen *et al.*, 2002; Pusey *et al.*, 2008; Ebner and Thuesen, 2010). Our aims here, were to i) describe new records of sicydiine gobies from Australia, ii) review the Australian biogeography of the group, and iii) discuss conservation and research priorities for this relatively newly discovered Australian fauna. Additionally, recent snorkel-based surveys in streams (Ebner and Thuesen, 2010) has substantially added to our knowledge of sicydiines in Australia. As a consequence we provide descriptions of external appearance and behavioural characteristics of the male and female of each species based on observation in the field and aquaria, to facilitate further visual survey and nondestructive sampling of these fishes. These descriptions are not necessarily in agreement with previous descriptions of colour in life (*cf.* Watson, 1996) and are intended to aid field identification rather than serve as formal taxonomic descriptions.

## MATERIALS AND METHODS

In a pilot study we developed a visual survey technique for stream fishes based on snorkelling a 1 km lowland reach of Cooper Creek at the base of the Daintree Range and a few hundred metres at the lower end of Pauls Pocket Creek, on the eastern side of the Malbon Thompson Range (Ebner and Thuesen, 2010) (see Fig. 1 for location of streams). We then surveyed longitudinally along streams, specifically: in Noah Creek starting at 200 m downstream of the high tide mark (but still freshwater) to 282 m above sea level (ASL) (on Thornton Peak; December 2009), from the lower tidal limit to the headwaters of Pauls Pocket Creek (413 m ASL) (on the Malbon Thompson Range; February 2010), and from the upper tidal limit to the headwaters of two first-order creeks on the Graham Range (February 2010) immediately to the south of the Russell-Mulgrave river mouth (Fig. 1). These four streams were selected as examples of small non-adventitious coastal streams (This stream type comprises low stream order (order  $\leq 3$ ), of steep gradient, and draining directly into the sea without passing through an extensive estuary/lowland environment). We also kept records of

sicydiines observed during ad-hoc snorkelling in other small non-adventitious coastal streams (e.g., a number of streams draining the eastern side of Thornton Range in the Cape Tribulation area) and low-order adventitious coastal streams of the Wet Tropics, including Harvey Creek, Fishery Falls Creek and Fig Tree Creek (draining Mount Bellenden Kerr) and Nyleta Creek (a tributary of Liverpool Creek draining the Walter Hill Range). Note that adventitious streams are feeder tributaries of mainstreams at least three orders greater in magnitude (Schaefer and Kerfoot, 2004) and therefore, invariably form part of catchments comprising large tidal estuaries in the Australian Wet Tropics.

We identified sicydiines in the field by snorkelling (*cf.* Ebner and Thuesen, 2010), with later reference to regional field guides for Australia and neighbouring islands of the Indo-Pacific for identification (Allen *et al.*, 2002; Keith *et al.*, 2002a; Marquet *et al.*, 2003; Keith *et al.*, 2010). The location and altitude of species was recorded in the stream using a hand-held geographic positioning system (GPS) to an accuracy of  $< 10$  m. Examples of the male and female of each species were also collected in dip nets and photographed in aquaria (in the laboratory) before being euthanised using  $80 \text{ mg.l}^{-1}$  of Aqui-S (Aqui-S NZ Ltd, Lower Hutt, New Zealand) and stored in 70% ethanol as voucher specimens. The taxonomic status of specimens was validated by Larson based on meristic and morphometric measures under stereomicroscope, and by Keith using comparative genetics (COI) based on previous reference data for Sicydiinae (P. Keith, unpubl. data; Keith *et al.*, 2011).

We combined our records with published records of sicydiines and museum records from Australia to determine the distribution of different species in Australia, which we used to develop a history of sicydiine discovery in Australia (i.e., a chronology of first record). Using this regional biogeographic knowledge of the group, we formulated further research priorities and current conservation requirements for sicydiines in Australia.

## RESULTS & DISCUSSION

### Sicydiine discovery and diversity

Available records validate the occurrence of four genera and seven species of sicydiine gobies in Australian streams (Figs 2, 3). The first collection of a sicydiine goby in Australia was made by G. Allen in 1987 and comprised a single male specimen from Harvey Creek (Fig. 1) (Allen *et al.*, 2002). This specimen was subsequently described as *Stiphodon allen* Watson, 1996 (Fig. 3), although recent inspection of this specimen indicates that it is likely *Stiphodon semoni* (Weber, 1895). We plan to investigate the identity of this specimen more fully in the future, but for the purposes of the current review we do not consider *Stiphodon allen* a valid

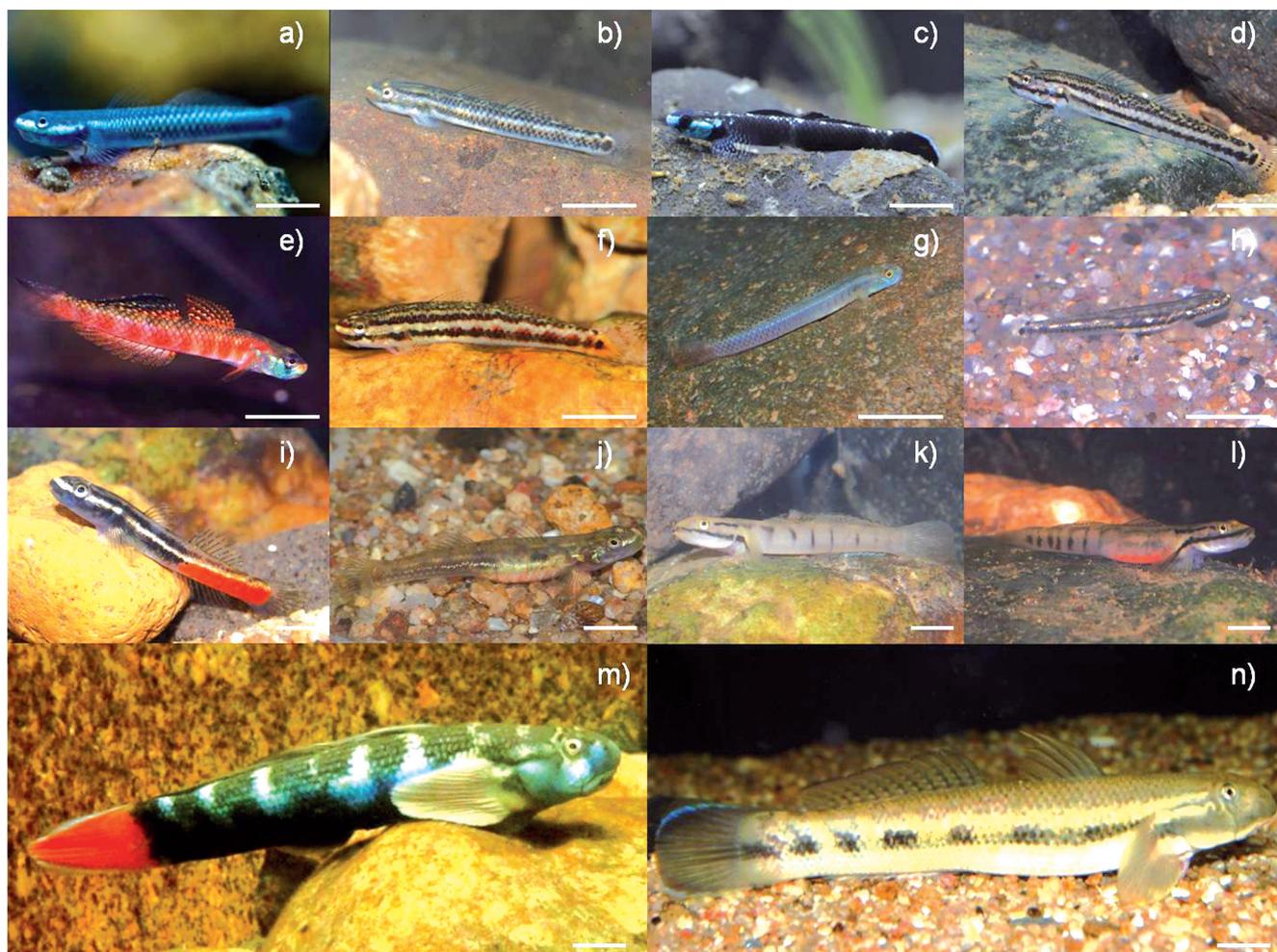


Figure 2. - Adult sicydiine gobies recorded in Australia: a) *Stiphodon semoni* (male), b) *S. semoni* (female), c) *Stiphodon atratus* (male), d) *S. atratus* (female), e) *Stiphodon rutilaureus* (male), f) *S. rutilaureus* (female), g) *Stiphodon birdsong* (male), h) *S. birdsong* (female), i) *Sicyopus discordipinnis* (male), j) *S. discordipinnis* (female), k) *Smilosicyopus* sp. (male), l) *Smilosicyopus* sp. (female), m) *Sicyopterus lagocephalus* (male) and n) *S. lagocephalus* (female). Scale bars = 1 cm.

species. In 1993, Pusey and Kennard collected three specimens of *Sicyopterus* in the Bloomfield River at the time of discovering the Bloomfield River cod *Guyu wujalwujalensis* Pusey & Kennard, 2001 (Pusey and Kennard, 1996, 2001). The first published records of these specimens as *Sicyopterus lagocephalus* (Pallas, 1770) appear in Allen *et al.* (2002) and Pusey *et al.* (2004). In 2003, Thuesen collected a *Stiphodon* in Cooper Creek (Thuesen, 2004a, 2004b) and this was recently validated as *Stiphodon atratus* Watson, 1996 (Ebner and Thuesen, 2010). In April and May of 2009 all three of the species that had previously been collected in Australia (*Sicyopterus lagocephalus*, *Stiphodon atratus*, *Stiphodon semoni*) and *Stiphodon rutilaureus* Watson, 1996, were recorded in the study of Ebner and Thuesen (2010). The current study provides first records of *Stiphodon birdsong* Watson, 1996, *Sicyopus discordipinnis* Watson, 1995, and

*Smilosicyopus* sp. in Australia (Figs 2, 3). The discovery and identification of sicydiine gobies is a recent phenomenon in Australia and if this trend continues we can expect to find more sicydiines in North Queensland (Fig. 3). The recent discovery of sicydiines on the Australian continent may be due to recent application of snorkel-based surveys in non-adventitious coastal streams (Ebner and Thuesen, 2010), and/or a consequence of recent arrival of sicydiines to Australia via larvae as a function of increased sea temperatures (climate change).

In the following section we provide information on the distribution and identification of sicydiines encountered in Australia. We include an outline of the external appearance of each species and briefly mention feeding behaviour to assist researchers in field identification, with a view to facilitating nondestructive sampling of these rare species.

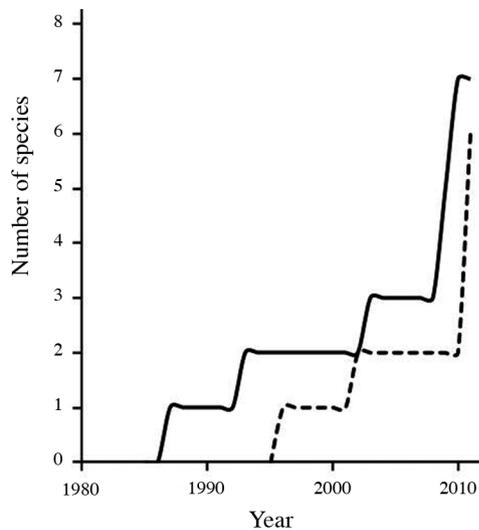


Figure 3. - First records of sicydiine species in Australian streams based on field collection (black line) and published account of the species (dashed line).

### Distribution and identification of Australian Sicydiinae

#### *Sicyopterus lagocephalus*

*Sicyopterus lagocephalus* attains a maximum size of about 130 mm total length (TL) (Allen *et al.*, 2002; Marquet *et al.*, 2003) and is commonly observed grazing on algal biofilms. The upper body side and dorsal of females is drab brown, or olive to creamy in coloration, with darkened blotches along the midline and a white underside. A light blue margin is sometimes present on the trailing edge of the caudal in females. Males have a blue-green body sheen when not in display colours (Allen *et al.*, 2002; Marquet *et al.*, 2003) and a blue body with black bars, solid-white pectorals and a bright-red tail during the spawning season (approaching and during the wet-season in Australia) (Fig. 2). *Sicyopterus lagocephalus* occurs in the Indo-Pacific throughout 18000 km from the Indian Ocean in the west (Mascarene and Comoro Islands) to central Pacific Ocean (Austral Islands in French Polynesia) in the east (Keith *et al.*, 2005; Lord *et al.*, 2010).

*Sicyopterus* has rarely been encountered in Australia but based on published records is probably the most frequently recorded genus of sicydiine goby from electro-fishing surveys in the Wet Tropics (Pusey *et al.*, 1996; Russell *et al.*, 1998, 2000, 2003). More recently, *Sicyopterus lagocephalus* has been commonly encountered in snorkel-based surveys along continuous lengths of stream (e.g., Ebner and Thuesen, 2010; this study). The most northerly record of *S. lagocephalus* in Australia is the Bloomfield River above the Bloomfield River Falls based on backpack electro-shocking of three specimens (Pusey and Kennard, 1996, 2001). The species inhabits creeks of the Cape Tribulation region including Noah Creek and Emmagen Creek (this

study) (Fig. 4). Russell *et al.* (1998) report collecting a single *Sicyopterus* sp. from the Daintree River, and presumably this was *S. lagocephalus* as no other species from this genus has been recorded in Australia despite recent surveys targeting sicydiines (Ebner and Thuesen, 2010; this study). Similarly, Russell *et al.* (2003) reported collecting *Sicyopterus* sp. from Stoney Creek in the Barron River catchment. *Sicyopterus lagocephalus* has also been observed in streams on the easterly and westerly sides of the Malbon Thompson Range including in Pauls Pocket Creek and an unnamed creek (Ebner and Thuesen, 2010; this study) (Fig. 4). The species was present in both unnamed creeks surveyed on the eastern side of the Graham Range (this study) (Fig. 4). *Sicyopterus lagocephalus* is occasionally seen in Harvey Creek, Fishery Falls Creek and Fig Tree Creek which drains from the Bellenden Kerr Range into the Russell-Mulgrave River system and is present in Nyleta Creek (this study) (Fig. 4). The latter record represents the current known southerly distribution limit of the species in Australia.

From our recent observations in Australia, *S. lagocephalus* is found from lower to upper reaches of freshwater streams. This species has been observed just a few metres from the upper tidal limit in Pauls Pocket Creek (~1 m ASL), and is occasionally observed in Harvey Creek at the Bruce Highway Bridge (~10 m ASL) and at the road crossing of Emmagen Creek (~5 m ASL) near Cape Tribulation to about 2 km upstream (~30 m ASL). *Sicyopterus lagocephalus* appears to be at highest density in second and third order streams where the gradient starts to increase sharply (e.g., 10-50 m ASL in Noah Creek and Pauls Pocket Creek, Ebner and Thuesen, unpubl. data). Individuals have been recorded at 150-180 m ASL in the Bloomfield River (Pusey and Kennard, 2001) up to 202 m ASL in Noah Creek and 280 m ASL in Pauls Pocket Creek (this study) (Fig. 5).

#### *Stiphodon atratus*

*Stiphodon atratus* (Fig. 2) occurs in Indonesia, on the northern coast of New Guinea, Admiralty Islands, Halmahera Island, Bismarck Archipelago, Bougainville, Vanuatu and New Caledonia (Keith *et al.*, 2010). *Stiphodon atratus* attains 80 mm TL in Australia, a size greater than reported elsewhere. Females have black or brown horizontal banding over a cream or white body (Fig. 2), whereas males are often emerald-green, black or grey in colour. In display coloration the male is jet-black with fluorescent-blue cheeks (Fig. 2). This species is commonly observed grazing on algal biofilms.

*Stiphodon* sp. (which is now recognised as *Stiphodon atratus*) (Ebner and Thuesen, 2010) was first collected in Australia from the Blue Hole in Cooper Creek (Thuesen, 2004a, 2004b) and has subsequently been recorded in that catchment on a number of occasions (Briggs, 2007; Jeff Johnson, Queensland Museum, personal communica-

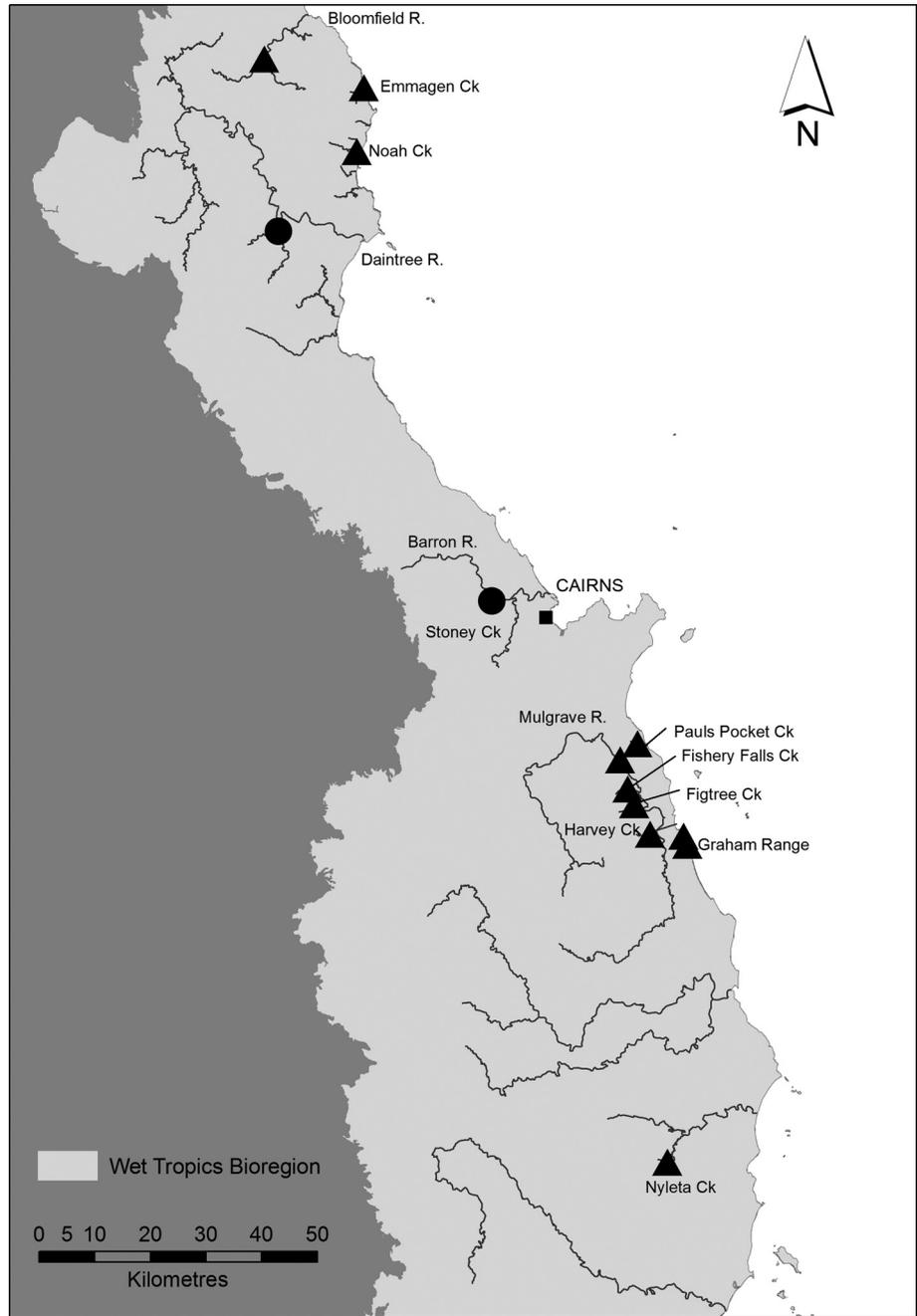


Figure 4. - Records of *Sicyopterus lagocephalus* (▲) and unidentified *Sicyopterus* sp. (●) (that were likely also *S. lagocephalus*), from the Australian Wet Tropics. See text for detail of data sources.

tion; Jonathon Marshall, Department of Environment and Resource Management, personal communication). We have recently become aware that the Blue Hole is a sacred site for Australian Aboriginal women, and people are asked to avoid scientific survey in that area due to cultural sensitivities (Veronica Solomon, pers. comm.). In Australia, the most northerly record of *S. atratus* is 160 km north-north-west of Cooktown based on observation of about 20 individuals and collection of a single female specimen from Camp Creek, a first-order, spring-fed creek catchment (Jason Carroll, South

Cape York Catchments, personal communication). *Stiphodon atratus* has been recorded in Noah Creek and Emmagen Creek immediately to the north of the Daintree River (and Cooper Creek). The species has also been found in Pauls Pocket Creek on the Malbon Thompson Range (Ebner and Thuesen, 2010) (Fig. 6). The most southerly known record is Nyleta Creek in the Liverpool Creek Catchment near the town of Silkwood (Fig. 6). Therefore *Stiphodon atratus* is currently the most widespread sicydiine in Australia.

*Stiphodon atratus* inhabits low elevations, having been

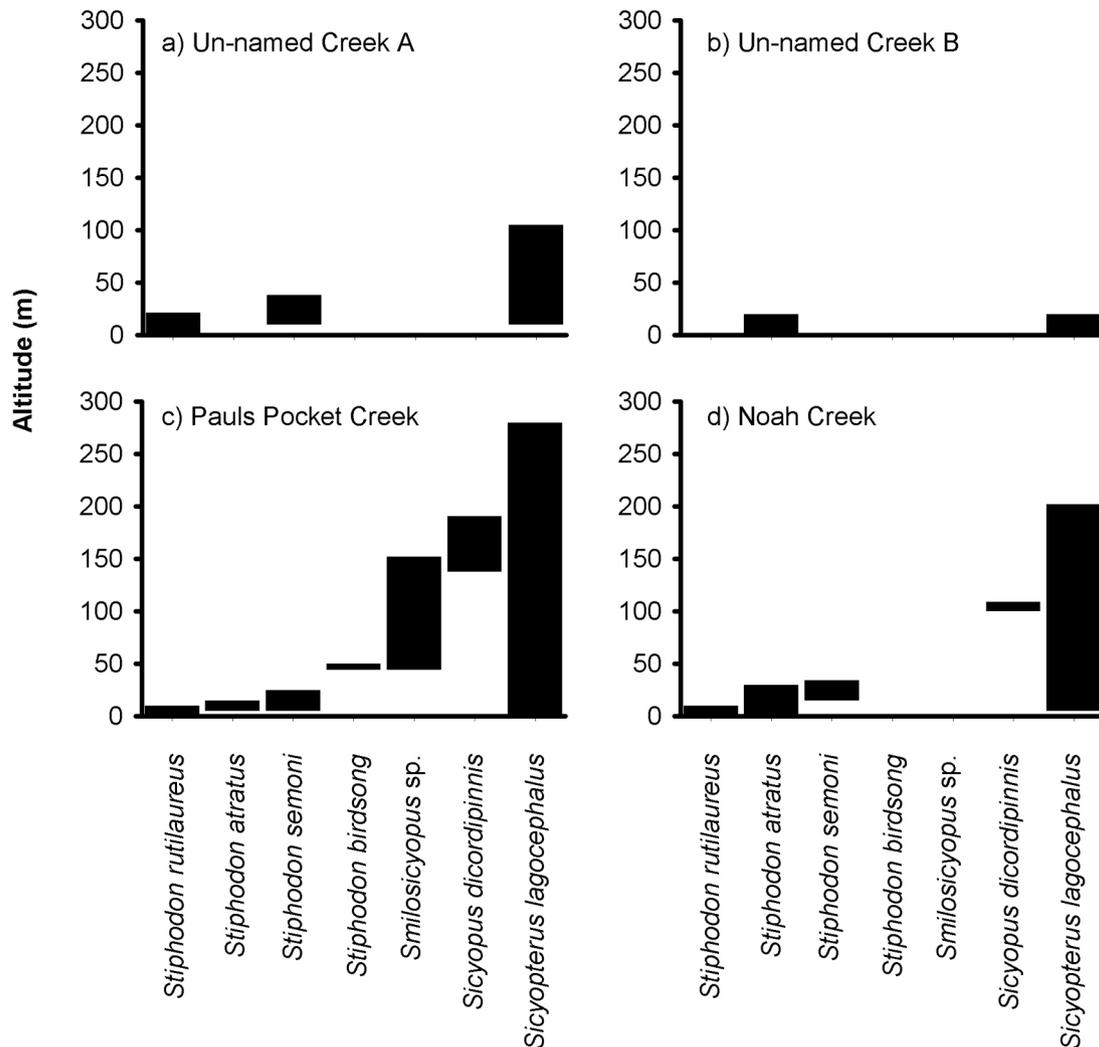


Figure 5. - Altitudinal distribution of sicydiine gobies in four non-adventitious coastal streams of the Australian Wet Tropics. Note that both un-named creeks are located on the Graham Range immediately to the south of the Russell-Mulgrave river mouth.

recorded from less than 10 m ASL in Cooper Creek, less than 20 m ASL in a first-order creek on the Graham Range, 0-34 m ASL in Noah Creek and 5-25 m ASL in Pauls Pocket Creek (Ebner and Thuesen, 2011; this study) (Fig. 5). The species was observed at about 30 m ASL in Camp Creek (Jason Carroll, South Cape York Catchments, personal communication).

### *Stiphodon birdsong*

*Stiphodon birdsong* is an extremely small-bodied species that usually attains less than 35 mm TL and has a much more slender head and body than the other species of *Stiphodon* recorded in Australia. The female has black horizontal stripes over a white/somewhat translucent body (Fig. 2). The male is sometimes semi-transparent in appearance, with a vivid-crimson sheen when in display coloration or drab-green sheen when not displaying (Fig. 2). *Stiphodon birdsong* is an

algal grazer. Outside of Australia, the species is known from Papua, Papua New Guinea and Indonesia (Keith, unpubl. data).

In Australia, *S. birdsong* is known from a small number of individuals observed and collected in Pauls Pocket Creek on the Malbon Thompson Range ( $n = 11$ ) and a small second order creek on the Graham Range ( $n = 6$ ) (this study) (Fig. 7). Based on these few observations by Ebner and Thuesen, this species appears to occupy sections of stream with low fish species richness. This includes the lower part of first order streams draining directly to the sea (i.e., on the Graham Range) or immediately upstream of the larger-bodied *Stiphodon* species in Pauls Pocket Creek (44-50 m ASL) (Fig. 5). *Stiphodon birdsong* is the only *Stiphodon* species to have been found above a waterfall (~10 m in height, at an altitude of ~30 m ASL in a small second order stream on the Graham Range) in Australia.

***Stiphodon rutilaureus***

*Stiphodon rutilaureus* (Fig. 2) is also an algal grazer and a relatively small-sized species of *Stiphodon* attaining 42 mm TL (this study). The female has a horizontal brown striped appearance but close inspection reveals cherub blotches above and below the lower stripe (Fig. 2). An orange tinge is sometimes present on the caudal peduncle (Fig. 2). The male is pale cream and a dull orange when not displaying, has a black border to the upper margin of the second dorsal and an extended black filament on the first dorsal. Occasion-

ally the male has dark blotching on the midline of the lateral body surface and light-blue flecks on some scales (e.g., Briggs 2007). In display coloration the male is bright orange (Fig. 2) with bright, light-blue cheeks. Outside of Australia, this species occurs in Northern Papua New Guinea, Solomon Islands, Vanuatu, Bismarck Archipelago and New Caledonia (Keith *et al.*, 2010).

In Australia, the first scientific collection of *S. rutilaureus* was from Pauls Pocket Creek in 2007 (Ebner and Thuesen, 2010), however, it has likely been collected from Fig Tree

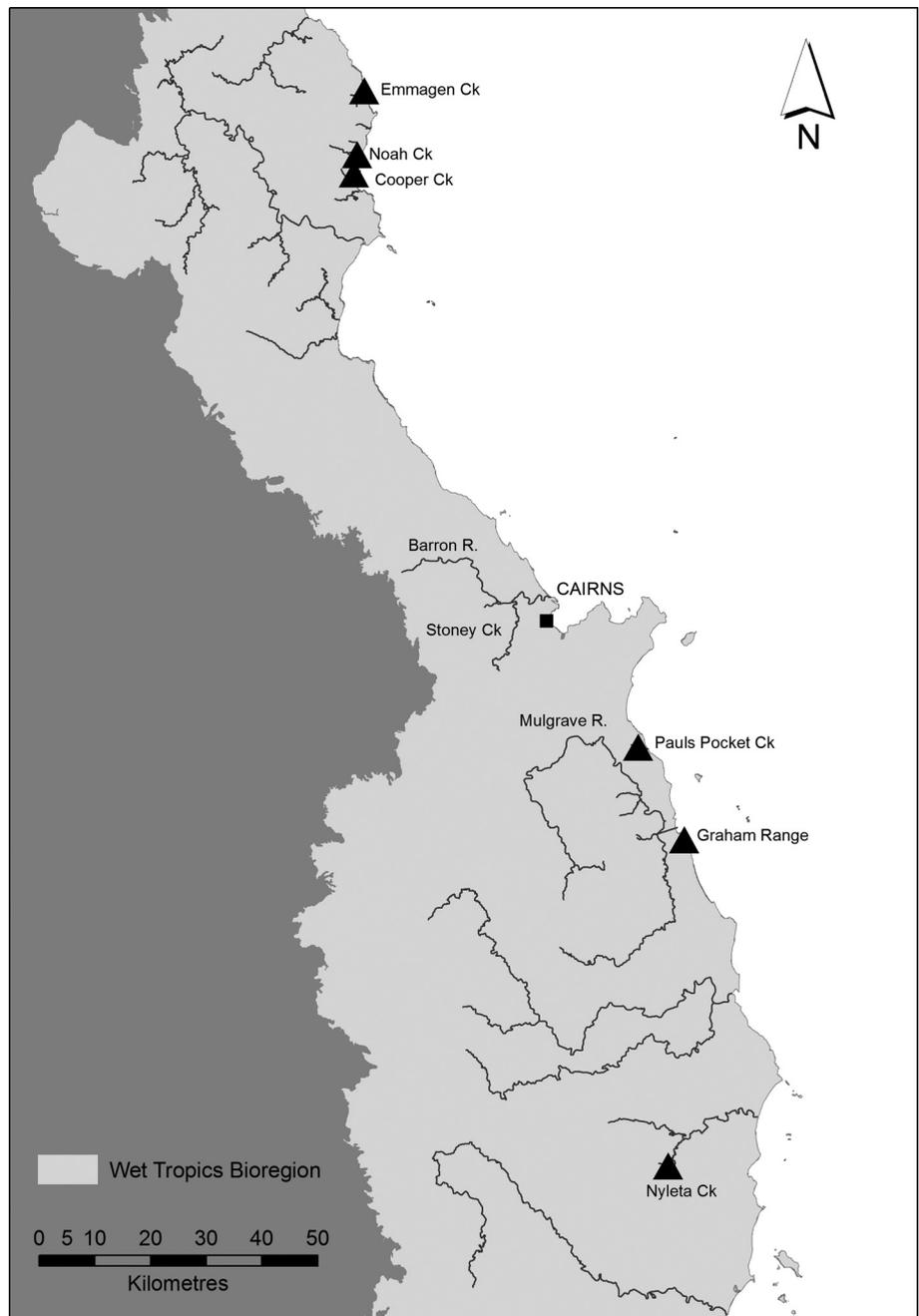


Figure 6. - Records of *Stiphodon atratus* from the Australian Wet Tropics. Note that this species has also been recorded in Camp Creek, to the north of Emmagen Creek and approximately 300 km north of the Wet Tropics. See text for detail of data sources.

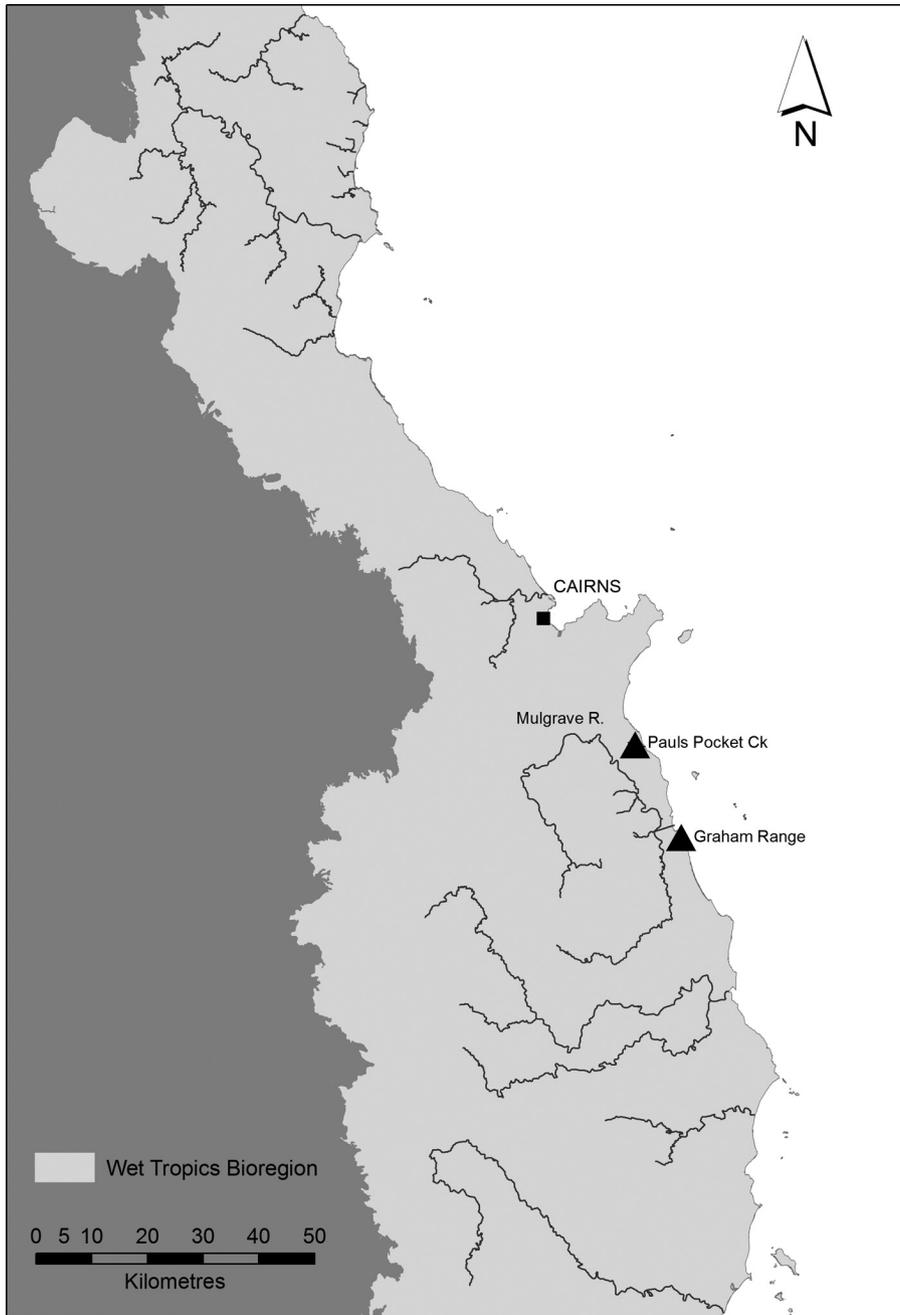


Figure 7. - Records of *Stiphodon* birdsong from the Australian Wet Tropics. See text for detail of data sources.

Creek (Mulgrave River catchment) a couple of times by aquarists (Briggs, 2007). *Stiphodon rutilaureus* has been observed in Emmagen Creek to the north of Cape Tribulation and collected from Noah Creek (this study, Fig. 8). It has also been observed and collected from Pauls Pocket Creek on the Malbon Thompson Range (Ebner and Thuesen, 2010) and just to the south in a small first-order creek on the Graham Range (this study).

*Stiphodon rutilaureus* is mostly found in streams immediately upstream of the high-tide influence (e.g., Ebner and Thuesen, 2010). For instance it has been located in the

first few hundred metres upstream of the tidal influence in Emmagen Creek, Noah Creek, and Pauls Pocket Creek (this study). It sometimes penetrates further upstream but has not been recorded more than 100 m and 400 m upstream in Pauls Pocket Creek and Noah Creek, respectively (the two larger streams in which a detailed continuous survey has been undertaken). It may penetrate further upstream in gentle gradient streams. *Stiphodon rutilaureus* can overlap in longitudinal range with *Stiphodon semoni* and especially *Stiphodon atratus* in Australian streams (e.g., Ebner and Thuesen, 2010). In Noah Creek and Pauls Pocket Creek, *S. rutilaureus*

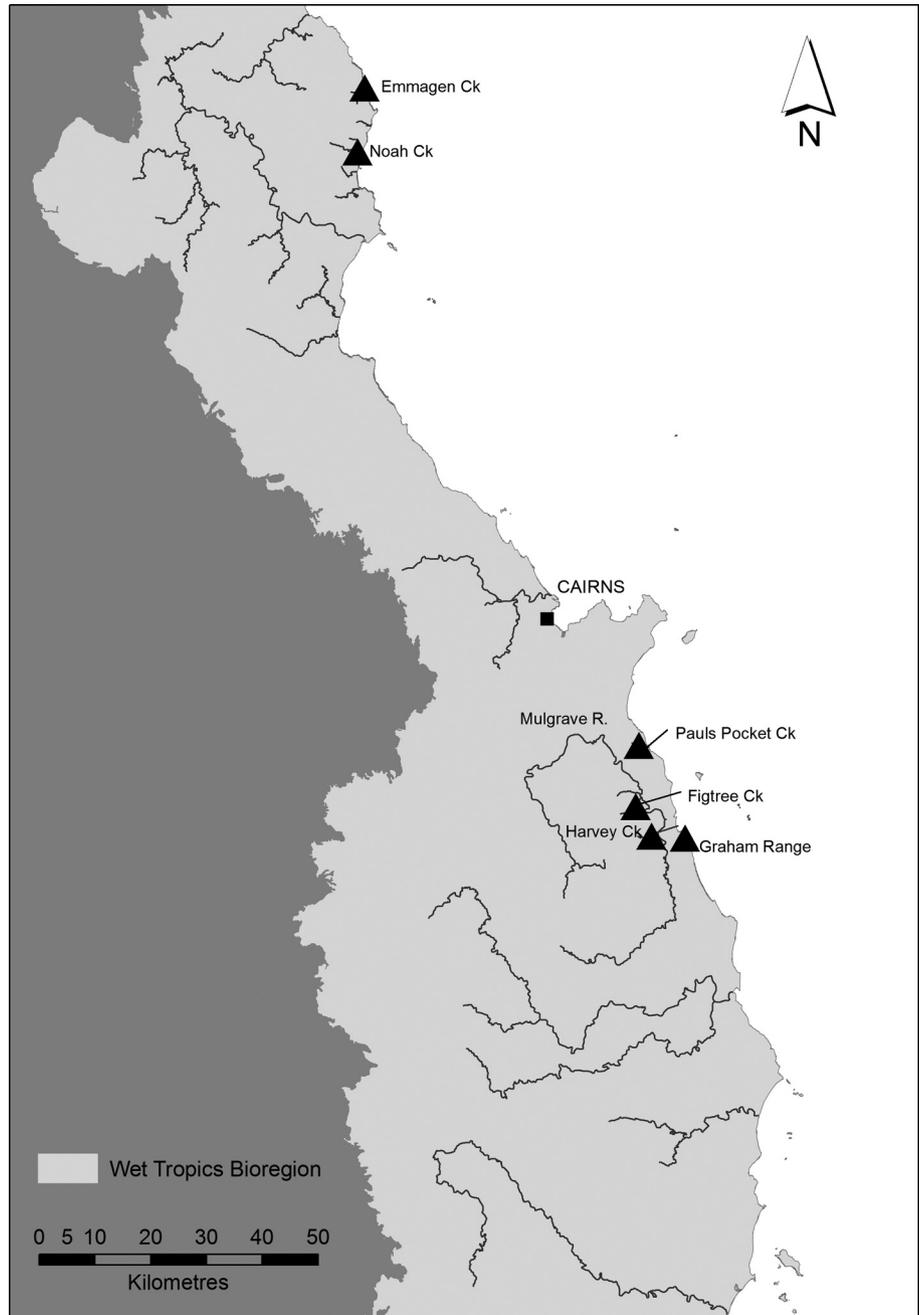


Figure 8. - Records of *Stiphodon rutilaureus* from the Australian Wet Tropics. See text for detail of data sources.

does not penetrate upstream as far as any of the other *Stiphodon* spp. (Ebner and Thuesen, 2010; this study) (Fig. 5). Ebner and Thuesen (2010) suspected this species may have been downstream of their study reach in Cooper Creek, but were unable to validate this due to the presence of a saltwater crocodile. A solitary male *S. rutilaureus* was recorded 196 m downstream of the upper tidal influence (but still equating to freshwater at time of survey) in Noah Creek in December 2009 (this study).

#### ***Stiphodon semoni***

*Stiphodon semoni* attains about 50 mm TL in Australia (Ebner and Thuesen, 2010) and is often observed feeding on algal biofilms. The female has brown horizontal stripes (Fig. 2). The nondisplaying male is a white, grey or grey-black colour with or without a pink horizontal band along the side (Allen *et al.*, 2002). The displaying male exhibits a green or blue horizontal band (Fig. 2). In full display the male is jet-black with a bright-blue band (not shown). This species occurs in Indonesia, the Philippines, Papua New

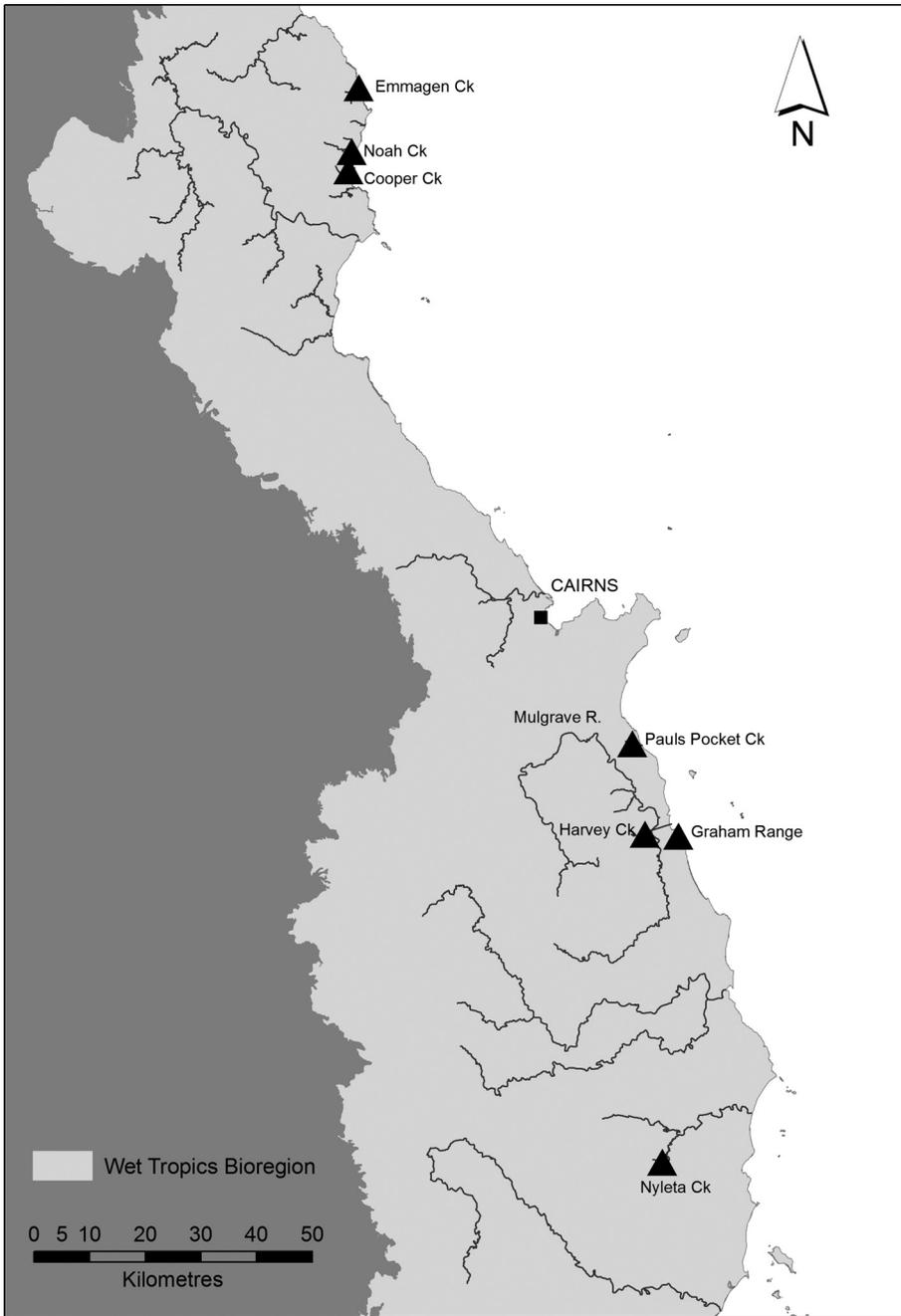


Figure 9. - Records of *Stiphodon semoni* from the Australian Wet Tropics. See text for detail of data sources.

Guinea, New Caledonia, Vanuatu and the Solomon Islands (Keith *et al.*, 2010).

*Stiphodon semoni* was first knowingly observed in Cooper Creek immediately to the north of the Daintree River (Ebner and Thuesen, 2010) but a single individual was also collected in 1987 from Harvey Creek (Allen *et al.*, 2002). Ebner and Thuesen (2010) report *S. semoni* from nearby Pauls Pocket Creek on the Malbon Thompson Range. The species has also been observed from one small stream (first order) on the Graham Range (this study) and occasionally

in very low abundance (1-4 individuals observed in 2010-2011) from Nyleta Creek in the Liverpool River catchment (Ebner, unpubl. data) (Fig. 9).

*Stiphodon semoni* was found at less than 10 m ASL in Cooper Creek (n = 4) and the two streams of the Graham Range (n = 8) (Ebner and Thuesen, 2010), but is more typically at 10-30 m ASL in streams where it has been observed in any kind of abundance (e.g., Pauls Pocket Creek: June 2009 n = 15, February 2010 n = 14; Noah Creek: July 2009 n ~ 30, December 2009 n = 12) (Ebner and Thuesen, 2010;

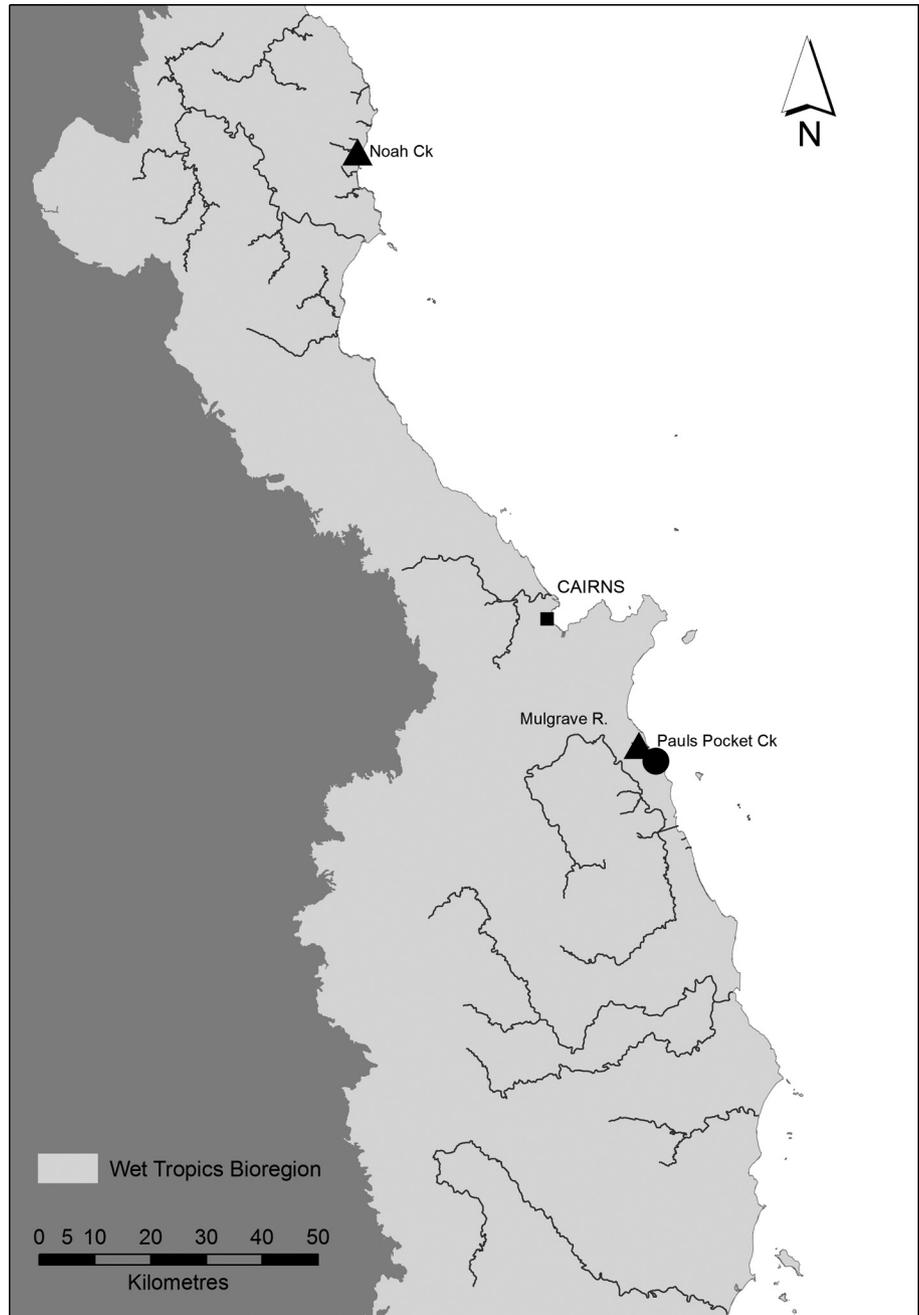


Figure 10. - Records of *Sicyopus discordipinnis* (▲) and of *Smilosicyopus* sp. (●) from the Australian Wet Tropics. See text for detail of data sources.

this study).

### *Sicyopus discordipinnis*

*Sicyopus discordipinnis* is a microcarnivore that attains about 65 mm TL (this study). The female is pale and relatively translucent with a pale orange belly (Fig. 2). A detailed description of the female is provided in Watson (1995). The nondisplaying male has two grey horizontal stripes that border a white horizontal stripe (the latter passing through the eye) on the head and continuing to halfway along the

body. The upper grey stripe and the white stripe continue high along the dorsal side of the body to the caudal peduncle. The remainder (and majority) of the rear half of the body is orange to the posterior of the caudal peduncle. The fins are transparent. The grey stripes on displaying males turn jet-black and the orange posterior rapidly transitions to a brighter orange and then red (Fig. 2). The white stripe can at times have a golden sheen. The species is known from Papua, Papua New Guinea and the islands of New Hanover and Bougainville (Watson, 1995; Keith, unpubl. data).

This study reports the first observations and collection of *Sicyopus discordipinnis* in Australia from a male and female in Noah Creek catchment in December 2009 and a small population in Pauls Pocket Creek ( $n = 10$ ) in February 2010 (Fig. 10). This species was found in a single pool at 100–109 m ASL in Noah Creek (Fig. 5). *Sicyopus discordipinnis* occupied two separate pools each above successive major waterfalls in Pauls Pocket Creek at altitudes of 138–147 m ( $n = 5$ ) and 186–191 m ASL ( $n = 5$ ) (Fig. 5). The species is known from altitudes of 350 m and 500 m ASL in Papua New Guinea (Watson, 1995).

### ***Smilosicyopus* sp.**

*Smilosicyopus* has recently been elevated to full generic status (Keith *et al.*, 2011). *Smilosicyopus* sp. attains about 65 mm TL. This species found in the Australian Wet Tropic Region has been recorded elsewhere on Pacific islands and has a wide distribution (Keith, unpubl. data). As the genus *Smilosicyopus* is currently under revision, the correct name for this species remains to be determined. Only three individuals have been observed and collected in Australia (Ebner and Thuesen, unpubl. data) (Fig. 10). A juvenile was recorded near a school of *Stiphodon birdsong* in Pauls Pocket Creek at 44–50 m ASL (Fig. 5). An adult male and female *Smilosicyopus* sp. were located higher in that catchment at 147–152 m ASL (Fig. 5). The species does not graze on algae and is a microcarnivore in captivity.

### **Biogeography of Australian sicydiines**

The current study advances our understanding of biogeographical patterns of Australian freshwater fishes by highlighting the presence of amphidromous assemblages of sicydiine gobies (comprising four genera and seven species) in north-eastern Australia. The presence of these assemblages in Australia is not surprising, as streams in the Wet Tropics and particularly near Cape Tribulation, resemble those on Indo-Pacific high islands (Thuesen *et al.*, 2011a) and oceanic currents are capable of carrying sicydiine goby larvae to this part of the Australian continent (Keith *et al.*, 2011). Previous studies have acknowledged shared freshwater fishes of northern Australian coastal drainages and Papua New Guinea, largely as a consequence of past connection between these landmasses in geological time (Unmack, 2001; Allen *et al.*, 2002). However, there are some shared temperate species between southern Australia and New Zealand in which marine dispersal is at least part of the explanation for that biogeography (McDowall, 2002). Marine dispersal also explains species connections between the south-west of Australia, south-eastern Australia, New Zealand and South America (e.g., McDowall and Frankenberg, 1981). Despite the above, the biogeography of the diadromous assemblages of the Australian continent remains to be fully addressed. The seven sicydiines now recognised

from north-eastern Queensland (Australia) are a subset of a much wider stream fauna in the Indo-Pacific region, and their amphidromous life-cycle (specifically the marine larval phase) has the potential to connect this stream fauna across an ocean-basin scale (Parenti, 1991; Hoareau *et al.*, 2007; Lord *et al.*, 2010). Connectivity of these inter-oceanic populations could be a function of population size, duration of larval phase and/or oceanic currents constricting populations that reside on islands located at ‘downstream’ extremities, to sinks (McDowall, 2010). Whether or not the Australian sicydiines are source or sink populations remains unknown. However, preliminary indications of small population sizes (e.g., Ebner and Thuesen, 2010) and the absence of endemic species (this study) suggest that Australia sicydiines contribute little to the overall Indo-Pacific gene-pool.

Almost all of the current records of sicydiines in Australia are from streams in the Wet Tropics region and this probably relates partly to their habitat requirements as adults. Specifically, good water clarity for visual contests and courtship displays, permanent flowing water availability (in the context of the adult life-cycle) in habitats with few predators, and possibly relatively cool streams with high dissolved oxygen. Pusey *et al.* (2008) commented on the endemic freshwater fishes of the Wet Tropics as mainly having a requirement for permanent flow unlike most other stream fishes in Australia. While none of the sicydiines currently known from Australia appear to be endemic to Australia, they are likely to be associated with permanently flowing streams. Indeed, preliminary observations suggest that *Sicyopterus lagocephalus* is associated with high flow environments including riffles and cascades (Ebner and Thuesen, pers. obs.). Additionally, larval sicydiines have strict requirements in terms of rapid access to marine environments to avoid starvation (Fitzsimons *et al.*, 2002; McDowall, 2007, 2009; Valade *et al.*, 2009). In reality, the combined habitat requirements of the adult and larvae of sicydiines probably restrict these assemblages to specific high rainfall catchments in Australia akin to what has been observed on the ‘wet-side’ of mountains on high-islands elsewhere in the tropical Indo-Pacific region (Fitzsimons *et al.*, 2002).

*Stiphodon atratus* has been located north of the Wet Tropics near Cooktown. *Stiphodon atratus* does not appear to occupy high flow microhabitats and is typically located in pools within high discharge streams (Ebner and Thuesen, 2010). Therefore this species may be more widespread in streams of Cape York Peninsula than has been previously realised. Although it may actually be confined to perennial, spring-fed, low-order streams similar to the only record from that region. Additionally, this raises the possibility that sicydiines may occupy a number of streams of Cape York and that further surveys are required to confirm the fish fauna of that region. It is also possible that this species and indeed other sicydiines may occupy low-order streams to the south

of the Wet Tropics but to date remain undetected, as a consequence of coarse scale surveys, and possibly the limitations of certain sampling techniques currently employed by freshwater fish biologists in that region (Ebner and Thuesen, 2010).

### Altitudinal and longitudinal distribution

Based on current knowledge, the habitats occupied by sicydiine goby assemblages in Australia are generally characterised by steep low-order streams that drain directly to the ocean (i.e. in non-adventitious coastal streams). The species- and genus-specific longitudinal distribution patterns of sicydiine gobies within these streams relate to altitudinal limits posed by instream migratory barriers (particularly waterfalls) (Fehlmann, 1960; Maciolek and Ford, 1987; Parham, 1995; Holmquist *et al.*, 1998; Fossati *et al.*, 2002; Keith *et al.*, 2002a, 2002b; Lim *et al.*, 2002; Keith, 2003; this study). Specifically, the differing abilities of sicydiines to negotiate waterfalls results in climbing species occupying the upper catchments as adults and poor climbing species occupying the lower catchments (Keith, 2003). Additionally, the upstream dispersal of predatory fishes including *Kuhlia* species may also structure sicydiine assemblages (Fossati *et al.*, 2002; Keith, 2003). Two kuhliids, *Kuhlia rupestris* and *K. marginata*, occupy steep gradient streams in the Australian wet tropics (Herbert and Peeters, 1995; Pusey and Kennard, 1996; Russell *et al.*, 1998; Ebner and Thuesen, 2010). As such, it should be informative to progress from correlations in longitudinal distribution of predator and prey to quantifying behavioural interactions between kuhliids and sicydiine gobies in non-adventitious streams. In Australia, it would also be interesting to determine if non-kuhliid predators are important structuring agents of sicydiine assemblages in adventitious streams. For instance, *Hephaestus tulliensis* De Vis, 1884, is sympatric with *Stiphodon atratus* and *S. semoni* in Nyleta Creek, a tributary of Liverpool Creek (Ebner, pers. obs.).

In Australia, *Smilosicyopus* sp. and *Sicyopus discordipinnis* are found at moderately high elevation in catchments above waterfalls, whereas, *Stiphodon* species (with the exception of *S. birdsong*) are immediately above the high-tide mark and below the first major waterfall (this study). This is comparable with patterns observed elsewhere on Pacific high islands (Keith, 2003). The specialist higher-elevation taxa (*Smilosicyopus*, *Sicyopus*) are therefore most likely to have a highly restricted distribution in Australia, as a consequence of few high-elevation streams that drain directly to the sea (see earlier discussion of adult and larval habitat requirements). However, increasing survey effort in the high elevation habitats of steep, low-order coastal streams of the Wet Tropics (both adventitious and non-adventitious coastal stream types) is required to develop an understanding of the

biogeography and ecology of these genera in an Australian context.

In contrast, *Stiphodon* species are more widespread in Australia (and are likely to be more widespread within and beyond the Wet Tropics) relative to the higher elevation specialists *Smilosicyopus* and *Sicyopus*, based on current information (this study) and the availability of suitable habitat. Specifically, *Stiphodon* appears to inhabit permanent, low-elevation sections of non-adventitious coastal streams, whereas, adventitious coastal streams may represent less desirable or marginal habitat for this group of gobies. Additionally, based on investigations of the larger non-adventitious coastal streams surveyed comprehensively to date (i.e., Noah Creek and Pauls Pocket Creek), *Stiphodon* species demonstrate longitudinal zonation relating to change in elevation (Ebner and Thuesen, 2010) (Fig. 5). Similar patterns in *Stiphodon* distribution have been observed elsewhere (Keith *et al.*, 2010).

*Sicyopterus lagocephalus* occupies low and high elevation stream position in Australia (Fig. 5). For instance, this is the only amphidromous species currently recorded above the Bloomfield River Falls where the endemic non-diadromous *Guyu wujalwujalensis* has a highly localised distribution (Pusey and Kennard, 2001). Similarly, *S. lagocephalus* is found at high altitude above major waterfalls elsewhere in the Pacific (Keith *et al.*, 2002a) and this is not surprising given the waterfall climbing abilities of members of the genus *Sicyopterus* (e.g., Schoenfuss and Blob, 2003). Given the paucity of fish surveys conducted in high elevation sites in non-adventitious streams in the Australian Wet Tropics, it is likely that *Sicyopterus lagocephalus* is far more widespread than has been recognised and that other sicydiines remain undiscovered on the continent.

### Research and conservation directions

Clearly, additional field surveys are required to further determine the composition and distribution of the sicydiine fauna in the Australian Wet Tropics. A focus on altitudinal distribution patterns by surveying continuous lengths of streams is necessary to detect species that occupy specific elevations/zones and occur at low density or are highly aggregated (Keith *et al.*, 2002a; Ebner *et al.*, 2008; Ebner and Thuesen, 2010; this study). Inevitably this reduces the number of catchments that can be effectively surveyed for a given cost and it may be some time until we have more than a rudimentary understanding of the distribution of sicydiine biogeography in Australia.

It is important to understand and mitigate the negative effects of field-based scientific sampling, particularly where rare or threatened species are concerned (Groombridge *et al.*, 2004; Marsh and Kenchington, 2004; Ebner *et al.*, 2009). The collection of voucher specimens for taxonomic and genetic purposes is an important issue for ongoing

research of sicydiines in Australia owing to the extremely low numbers of several species observed to date. Obviously, nondestructive survey methods confirming taxonomic identity (e.g., photography, fin clips) are to be encouraged where possible as a precaution until population structure(s) is determined. Scientific sampling of rare species can be central to conservation of species (Remsen, 1995) but may itself represent a threatening process for especially rare species if not managed in a coordinated and considered manner. It would also be useful to garner expertise to develop guidelines for the application of destructive and nondestructive sampling methods upon encountering rare sicydiines and small sicydiine populations.

Overharvesting of sicydiines by aquarists is of major concern (e.g., Iwata, 1997; Amarasinghe *et al.*, 2006; Yamasaki and Tachihara, 2006), since many of the species (particularly the males) are colourful and attractive (Fig. 2) and are apparently rare (Ebner and Thuesen, 2010; this study). In Australia, *Stiphodon* species should be protected immediately under national and state legislation until the ecology and conservation significance of this group is established (Ebner and Thuesen, 2010). The lure of collecting *Stiphodon* for private aquaria is likely to be high with native fish hobbyists (Bob Kroll, Cairns Ultimate Aquariums, personal communication). Further, *Stiphodon* are relatively easy to collect by dip net (Ebner and Thuesen, pers. obs.) and are accessible to the public at low altitude in small streams (this study). Indeed, the Opal cling goby, *Stiphodon semoni*, has recently been listed nationally under the Environment Protection and Biodiversity Conservation Act (<http://www.environment.gov.au/biodiversity/threatened/index.html>) primarily because of its rarity combined with the threat of overharvest. However, insufficient information has rendered nominations of *S. rutilaureus* and *S. atratus* unsuccessful to date. Paradoxically, publications like this one increase the likelihood of successfully listing the latter species in the future while potentially informing private collectors of the presence of these rare species.

In comparison with the *Stiphodon* species that essentially occupy lowland stream reaches, *Sicyopterus lagocephalus* occupy low and high altitudes (this study). The higher-altitude reaches of steep gradient streams are typically difficult to access (for scientists and private collectors) making overharvest of the entire adult population in a catchment unlikely. The adults of *S. lagocephalus* are far more cryptic and elusive than *Stiphodon* species and are also much more difficult to catch once sighted (Ebner and Thuesen, pers. obs.). Further, *S. lagocephalus* appears to be present in a number of low-order streams of major river systems in the Australian Wet Tropics (e.g., Liverpool Creek, Russell-Mulgrave, Bloomfield River). Subsequently, *S. lagocephalus* probably does not warrant interim protective status in Australia.

Insufficient information is available to make anything but a preliminary comment on the vulnerability of *Sicyopterus* and *Smilosicyoptus* to over-harvest or indeed other potential threats. These genera are likely to be difficult to access as a function of their altitudinal preference; however, they are relatively easy to capture (Ebner and Thuesen, pers. obs.), and are apparently rare in Australia given substantial survey effort for freshwater fishes in the Australian Wet Tropics (Pusey and Kennard, 1996; Russell *et al.*, 1998, 2000, 2003, 2004; Pusey *et al.*, 2004, 2008; Rayner *et al.*, 2008). It would be beneficial to explore the social dimensions of sicydiine collection and conservation in relation to the recreational and commercial aquarium sector in Australia. Congruently, we should also be assessing the potential for habitat specialisation in higher altitude specialists (*Sicyopterus* & *Smilosicyoptus*) in the context of climate change. Certainly, there has been plenty of such attention given to terrestrial vertebrates that occupy high-altitude habitats in this part of Australia (e.g., Williams *et al.*, 2003; Meynecke, 2004).

An urgent conservation priority is determining population and metapopulation structure of sicydiines in Australia and at the oceanic scale (cf. *Sicyopterus* research by Lord-Daunay, 2009; Lord *et al.*, 2010). This will require collaboration among researchers across the Indo-Pacific. There is a need for ecological studies on the larvae of sicydiine in Australian waters. To understand larval transport and source/sink relationships it would be beneficial to collaborate with oceanographers including those with a working knowledge of the Great Barrier Reef Lagoon. Furthermore, the sicydiines may make excellent flagship species for attracting public interest and galvanising land, freshwater and sea management initiatives, since these fishes are beautifully coloured, have the remarkable ability of climbing waterfalls (at least in a subset of species), and a life-cycle that involves occupation of both rainforest streams and sea.

Small numbers of sicydiines currently observed in Australian streams (this study), combined with indications of distinct species zonation along stream gradients (Fig. 5) highlight the need for detailed investigation of the specific instream habitat requirements of sicydiines in the Australian context. Given increasing human water-harvesting demands in north Queensland and climate-related risks to the constancy of water discharge (Pusey *et al.*, 2008), future studies should be quantifying flow requirements for migration of larvae, juvenile and adult sicydiines in streams. This should extend to where streams open permanently or intermittently to the sea, since maintenance of stream and sea connection is critical for this fauna (Fitzsimons *et al.*, 2002; Keith *et al.*, 2010). Riparian vegetation and related shading of streams is also thought to be important for sicydiines (Keith, 2003; Jenkins *et al.*, 2009). Microhabitat use (including flow selectivity) of adult-phase sicydiines also has the potential to inform water management in coastal streams. For instance,

our observations indicate that *Sicyopterus lagocephalus* has an affinity for high-flow habitat including riffles, runs and cascades (Thuesen and Ebner, pers. obs.) and therefore this species may make a useful indicator in relation to water resource management in coastal Wet Tropics streams.

The sicydiines also require evaluation for risks to pest fish invasions. The recent study of Jenkins *et al.* (2009) highlights the dual threat of loss of riparian vegetation and stream invasion by *Oreochromis mossambicus* in Fiji. Similarly, tilapia are invasive species in the Australian Wet tropics and few control options are available to managers (Thuesen *et al.*, 2011b) once they have been introduced into a catchment. Furthermore, Climbing perch *Anabus testudineus*, present in the Torres Strait Islands directly to the north of Queensland (Storey *et al.*, 2002; Burrows, 2010), potentially pose a direct threat to all sicydiines in north-eastern Australia including the specialist high-elevation sicydiines *Sicyopus* and *Smilosicyopus*.

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