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Discovery of stream-cling-goby assemblages (*Stiphodon* species) in the Australian Wet Tropics

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Abstract. Amphidromous stream-cling-gobies of the genus *Stiphodon* comprise an important component of the fish communities in insular streams of tropical Indo-Pacific high islands. We aimed to develop an effective and rapid method of surveying *Stiphodon atratus* in a continental stream and then apply the method in an untested stream. Triple-pass snorkelling of a single pool revealed the reliability of single-pass estimates of the abundance of *S. atratus*. Single-pass survey of a reach in each of two streams then confirmed the presence of *S. atratus*, *Stiphodon semoni* and *Stiphodon rutilaureus*, in Australia. However, *Stiphodon* were in low abundance (*S. atratus*, Cooper Creek, $n = 38$, Pauls Pocket Creek, $n = 45$; *S. semoni*, Cooper Creek, $n = 4$, Pauls Pocket Creek, $n = 14$; *S. rutilaureus*, Cooper Creek, $n = 0$, Pauls Pocket Creek, $n = 38$). Preliminary indications are that particular streams provide critical habitat for newly discovered assemblages of *Stiphodon* within the Australian Wet Tropics. Small population sizes, coupled with the attractiveness of *Stiphodon* as aquarium pets, warrants that national protective status is provided to this genus until a comprehensive understanding of species distribution, abundance and population genetic structure is achieved.

Introduction

The freshwater fish fauna of tropical high islands differs from that of continental islands in the Indo-Pacific region. The fauna of large continental land masses (e.g. Australia, Papua New Guinea) comprises numerous fishes that complete their entire life-cycle in freshwater (e.g. Allen *et al*. 2002), whereas high island streams (e.g. in Fiji) are dominated by marine vagrants or diadromous species, especially those exhibiting an amphidromous life history (where hatched embryos are swept out to sea to develop as pelagic larvae before recruiting back to streams as post-larvae: McDowall 1997; Keith 2003; Jenkins *et al*. 2010). In tropical high-island streams the gobies (Gobiidae), sleepers (Eleotridae), flagtails (Kuhliidae), pipefishes (Syngnathidae), mullets (Mugilidae) and eels (Anguillidae) are among the more common teleost residents (Fitzsimons *et al*. 2002), with the gobies having been particularly successful colonists of these ecosystems (Ryan 1991). The dispersal of the marine larvae phase underpins a diverse amphidromous goby fauna in the Indo-Pacific (Ryan 1991; Fitzsimons *et al*. 2002; McDowall 2010).

Adult stream-cling-gobies of the amphidromous genus *Stiphodon* (Sicydiinae: Gobiidae) are generally confined to clear, island streams of the central and western Pacific region (Ryan 1986, 1991; Nelson 1994; Keith 2003). Highly adapted to exploit riffle-run habitats, members of this group of gobies possess disc-like fused pelvic fins that enable them to 'cling' to rocky substrates in high-flow streams while feeding on microinvertebrates, diatoms and algae (Ryan 1991; Jenkins *et al*. 2008). Prior to the current study, *Stiphodon allen* Watson, 1996 was the only described *Stiphodon* species known from the Wet Tropics of north-eastern Australia. This species is endemic to Australia and was described from a single male holotype, collected in Harvey Creek, 25 km south of Cairns (Watson 1996; Allen *et al*. 2002), and is arguably the continent's rarest freshwater fish. Harvey Creek is a third-order stream that drains into the Russell–Mulgrave River estuary where there is a short distance (~3 km) for amphidromous larvae (and presumably *S. allen* is amphidromous akin to other *Stiphodon* species) to negotiate migrations to and from the sea. A second, more widespread species, *Stiphodon atratus*, which has a distribution extending to islands of the Western Pacific, is known to inhabit Cooper Creek immediately north of the Daintree River catchment (cf. the *Stiphodon* sp. recorded in Thuesen 2004). Cooper Creek is a third-order stream with a very short estuarine section (~2 km) connecting it to the sea. On the basis of the record of *S. atratus* in Cooper Creek, and knowledge of the life-cycle of *Stiphodon* species in general, we hypothesised that *Stiphodon* species are likely to inhabit steep gradient, low-order (≤ 3) streams that empty directly into the Great Barrier Reef Lagoon in high-rainfall areas, analogous to insular streams of high islands elsewhere in the tropical Indo-Pacific. We aimed to trial rapid visual census of *S. atratus* to estimate population size and develop an understanding of the demography and habitat use of *Stiphodon* species in the context of Australian continental streams.

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Methods

Triple-pass observations

Triple-pass snorkelling was used to determine the effectiveness of single-pass visual survey of *S. atratus*. For this purpose we selected the largest and deepest pool in Cooper Creek and confirmed the presence of the target species. We believed that the dimensions of this pool and the presence of woody structure and rock bars provided for a high degree of difficulty for our survey method. On 25 April 2009 we conducted a triple-pass census for *Stiphodon* in that pool (Fig. 1). Initially, we spent about two hours haphazardly searching the pool to familiarise ourselves with the fish community and resident *Stiphodon* (the only *Stiphodon* present was *S. atratus*). After a 30-min break we applied a first pass of the pool, involving three researchers snorkelling side-by-side and performing an upstream pass of the right bank (to the centre line of the pool) and a downstream pass on the left bank (i.e. moving clockwise). Record was made of the sex of each *Stiphodon* individual encountered (species of the genus are sexually dimorphic, therefore sexes are readily distinguished in the field) (Fig. 2). Total length (TL) (±1 mm) was recorded by placing a small ruler near to individuals on the benthos. On the basis of collection and direct measurement of a subsample of individuals, this method proved to be accurate to <5 mm based on records from all three observers combined (mean measured TL = 47 mm, range = 28–62 mm TL, s.e. = 0.26, $n = 19$ comparisons of observed and measured TL). Record was made of the proximity of each individual to shore (±1 m), depth (±0.1 m), substratum according to the sediment classification outlined by Cummin and Lauff (1969) (estimated % coverage in 1 m^2) and surface flow was estimated (0.1 m s^{-1}) (by recording the time required for a floating leaf to move 1 m). Distance between individuals seen in a single field of view was estimated (±1 m) and note was made of individuals that were in groups (generally within 0.5 m of one another and/or moving as a school).

A second and third pass were made of the pool following a 30-min break between passes. Triple-pass confirmed that *Stiphodon* were generally highly conspicuous and primarily occupied shallow water. Consequently, we concluded that it would be more time effective to perform a single-pass of the entire stream with one researcher scanning each bank and a third researcher scanning the mid-channel region (generally deep) in wide pools (>15 m maximum width).

Single-pass census

Single-pass visual census of the fish community was conducted by snorkelling a continuous stream reach in Cooper Creek (26 April 2009, 1.1 km) and Pauls Pocket Creek (25 May 2009, 0.2 km) (Fig. 3). Side-by side, three researchers longitudinally traversed the stream to locate *Stiphodon*. In especially wide pools (>15 m) a researcher observed the shallow edges of the pool on each bank, whereas a third researcher zig-zagged to cover the larger open-water expanse (that was typically deep and uninhabited by *Stiphodon*). In narrow parts of the stream the number of researchers was tailored to stream width (i.e. one researcher per 5 m stream width). In the lowermost part of Pauls Pocket Creek, up to four braids of the channel were present and were each surveyed. We made underwater observations in all habitats where it was physically possible to place our heads underwater (i.e. sufficient depth), including high-energy microhabitats (e.g. in chutes, and immediately below cascades). Otherwise data relating to *Stiphodon* were recorded as described above for the triple-pass. Estimates of TL and record of sex were not obtained from a small subset of *Stiphodon* in one pool within Pauls Pocket Creek to avoid possible duplicate measurements of individuals that were encountered at high density. Specimens

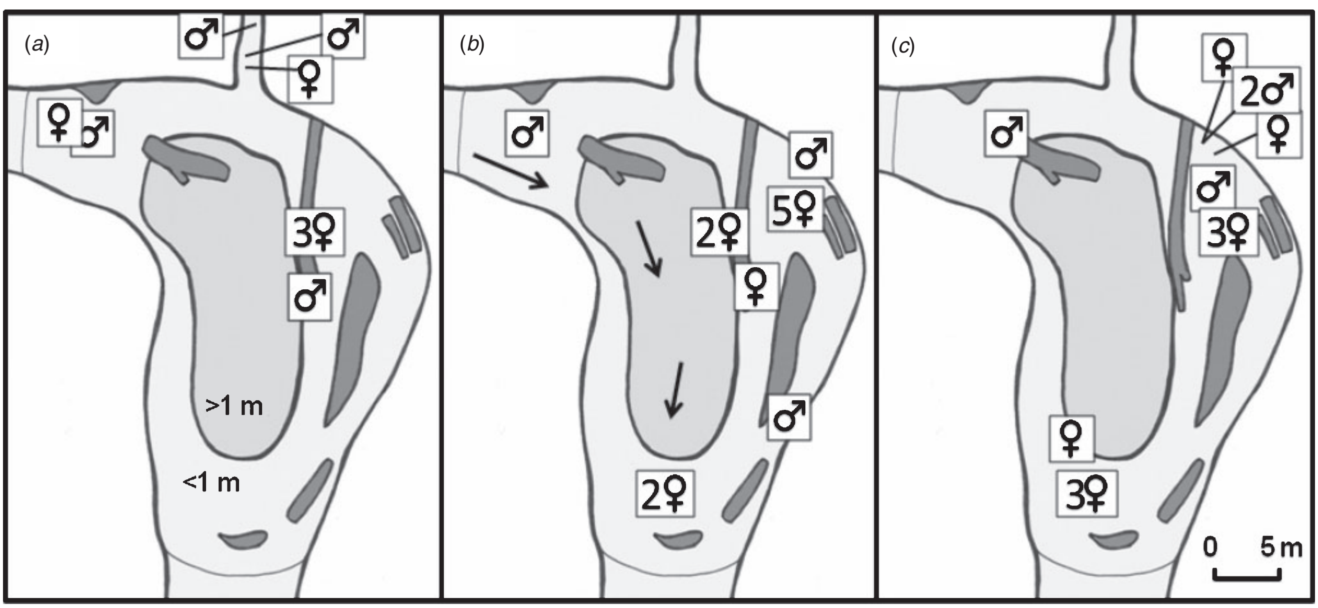

Fig. 1. Location of *Stiphodon atratus* showing the schooling of females and relatively solitary males in a large pool, based on triple-pass observations (*a*–*c*). Numbers indicate more than one individual per square metre. The deepest section of the pool (>1 m) is demarked in (*a*), and the direction of flow is shown by arrows in (*b*). Darkened objects signify log and rock bar structures.

Fig. 2. Male (left) and female (right) of (*a*, *b*) *Stiphodon semoni*, (*c*, *d*) *Stiphodon atratus*, and (*e*, *f*) *Stiphodon rutilaureus*.

were obtained for performing meristic and morphometric counts in order to validate the identification of species. However, we chose not to collect *Stiphodon semoni* from Cooper Creek due to the extremely low numbers of individuals encountered in that Creek. Visual identification of *Stiphodon* species was performed in the field and the identity of specimens was validated by Helen K. Larson, Emeritus Curator of Fishes, Museum and Art Gallery of the Northern Territory, Darwin. Photographs of male and female *Stiphodon* are provided in Fig. 2.

Upon completion of surveying each riffle, run or pool section, a record was made of the fish community structure (species presence and relative abundance) observed. This involved making a conservative estimate of relative abundance based on the highest count made by any one researcher of each species (counts were not pooled unless it was obvious that it was appropriate; i.e. multiple individuals of a relatively immobile species were in view of multiple researchers at the same time, or individuals traversed separate braids of the stream simultaneously). Fish species were identified from field guides (Allen *et al*. 2002; Keith *et al*. 2002; Marquet *et al*. 2003). In cases where *Stiphodon* density was relatively high in certain pools (and consequently our passing was slowed and discontinuous) we resurveyed the pool to obtain relative abundance estimates as the basis for describing fish community composition. The fish community data were used to determine whether *Stiphodon* co-occur in the presence or absence of particular species at the within- and among-catchment scale.

Results

Developing a single-pass method

Initial thorough searching for *S. atratus* in a large pool of Cooper Creek immediately before the triple-pass exercise indicated that 13 individuals inhabited that pool. Triple-pass revealed that replicate counts of *S. atratus* were relatively consistent, although four fewer females were recorded on the first pass compared with the second and third passes (Figs 1 and 4). At completion of the first pass a group of four females was located immediately adjacent to our finish point, indicating that they had possibly moved clockwise within the pool, avoiding us in space and time (Fig. 1). The first pass spanned about half an hour, whereas subsequent passes lasted ~15 min as we became familiar with the survey protocol. The process led us to refine our survey method to a single pass of the stream longitudinally rather than clockwise passes in wide pools.

Triple-pass revealed some discrepancy in estimates of size structure (Fig. 4); however, this can partly be explained by the absence of four females from the first pass. It can also partly be

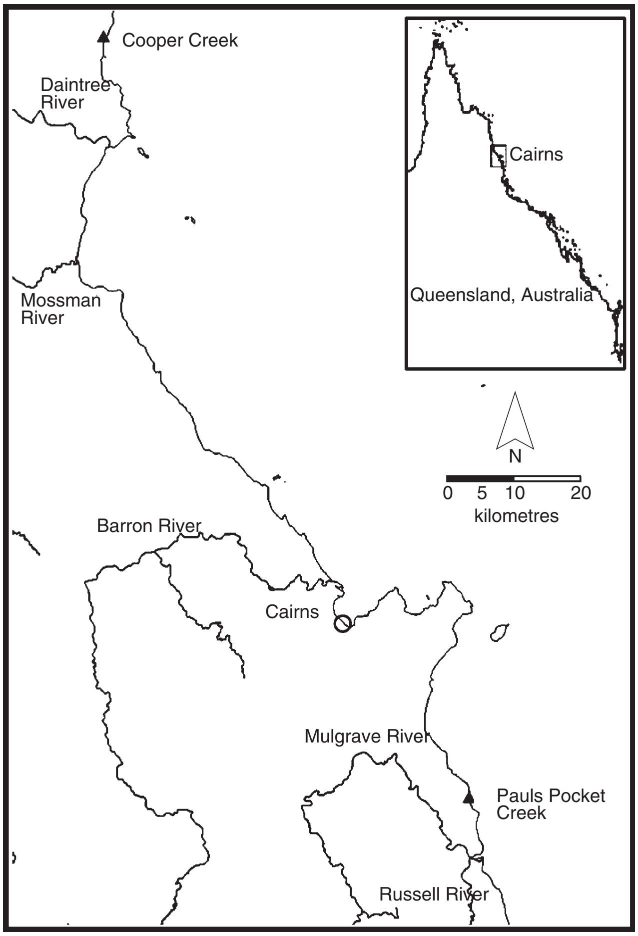

Fig. 3. Study sites within two small catchments in the Australian Wet Tropics.

explained by minor discrepancies in length estimates and a subset of individuals being placed in adjacent size classes. In the context of comparing size structure of different *Stiphodon* species this error is not likely to be important (cf. Fig. 5). Variability in habitat use among passes might be expected to vary even on the same day; however, variability in depth and substratum use were minimal on the basis of the triple-pass exercise (Fig. 4).

Initial observations in the large pool and the triple-pass exercise revealed that female *S. atratus* frequently occurred in small groups (2–5 individuals) (Fig. 1). These groups were sometimes associated with a male although males were rarely found near other males (Fig. 1).

Occurrence and distribution

Our surveys revealed the presence of three species of *Stiphodon* in the Australian Wet Tropics: *Stiphodon semoni* Weber, 1895; *Stiphodon atratus* Watson, 1996; and *Stiphodon rutilaureus* Watson, 1996. All three species were observed in Pauls Pocket Creek and the former two species occurred in Cooper Creek (Table 1). *S. rutilaureus* occupied the lowest freshwater reaches of Pauls Pocket Creek immediately upstream of a small brackish closed-estuary lagoon. *Stiphodon semoni* was found further upstream. *Stiphodon atratus* generally had an intermediate longitudinal distribution relative to these other two *Stiphodon* species, with all three species coinhabiting a major plunge pool. Within Cooper Creek, *S. semoni* was found closer to the intertidal limit, with *S. atratus* occurring further upstream.

Population size and structure

Stiphodon atratus was the most abundant *Stiphodon* species encountered, with a population estimate of 38 and 45 individuals in Cooper Creek and Pauls Pocket Creek, respectively. The male to female sex ratio was 1 : 1.9 ($n = 38$) in Cooper Creek and 1 : 2.3 ($n = 39$) in Pauls Pocket Creek. One juvenile that could not be externally sexed was also observed in Pauls Pocket Creek. In total, 38% of *S. atratus* in Pauls Pocket Creek were between 51 and 80 mm TL and the species was generally of larger body size than its congeners (Fig. 5).

Four individuals of *S. semoni* were observed together in Cooper Creek and a further 14 individuals were present in Pauls Pocket Creek. The sex ratio in Cooper Creek was based on an extremely small sample ($n = 4$). The sex ratio was 1 : 1.3 in Pauls Pocket Creek ($n = 14$). The total length of *S. semoni* was between 31 and 50 mm TL (Fig. 5).

Stiphodon rutilaureus was not seen in Cooper Creek but 38 individuals were recorded from Pauls Pocket Creek. The sex ratio was 1.7 : 1 ($n = 24$). All individuals were less than 40 mm TL.

Habitat use and behaviour

Only four *S. semoni* were observed in Cooper Creek and these individuals were together in shallow water (0.2–0.3 m) at the foot of a pool with slow or no flow (0.0–0.1 m s^{-1}). The first of the male *S. semoni* observed was in grey-pink coloration, and turned grey-green very quickly (~30 s). This male then turned blue-black within minutes (see Fig. 2*a*) and made multiple bites to a female (Fig. 2*b*), indicative of a courtship or precourtship ritual. This essentially confirmed the species status of the female as *S. semoni*. A second male was then encountered by the first male and both individuals displayed to each other in vivid blue-black coloration, while a third male was generally submissive nearby (remained on the benthos in green-grey or green-black coloration). Occasionally, this third male engaged in male–male display (turning blue-black and entering the water column). These observations of *S. semoni* were obtained over a 15-min period in the early afternoon. *S. atratus* inhabited pools in Cooper Creek (2–3 m maximum depth) but selectively occupied shallow water (71% frequency of occurrence (FO) in <0.5 m) on cobble substratum (68% mean proportion of 1 m quadrat: MPQ) (Fig. 6).

Conversely, in Pauls Pocket Creek *S. atratus* associated with boulders (80% MPQ) and inhabited pools but made use of shallow and deep water (FO = 34% in 0–0.5 m; 20% in 0.6–1.0; 46% in 1.1–1.5 m), whereas *S. rutilaureus* (FO = 71% in 0–0.5 m) and *S. semoni* (FO = 93% in 0–0.5 m) were primarily in shallow water (Fig. 6). *S. semoni* was exclusively associated with bedrock (FO = 87%) and boulder (FO = 13%) in Pauls Pocket Creek (Fig. 6). *S. rutilaureus* was commonly located in riffle-run sequences immediately upstream of the tidal mark. This species was frequently found in the absence of other *Stiphodon* species. However, all three species co-occurred in a single pool at

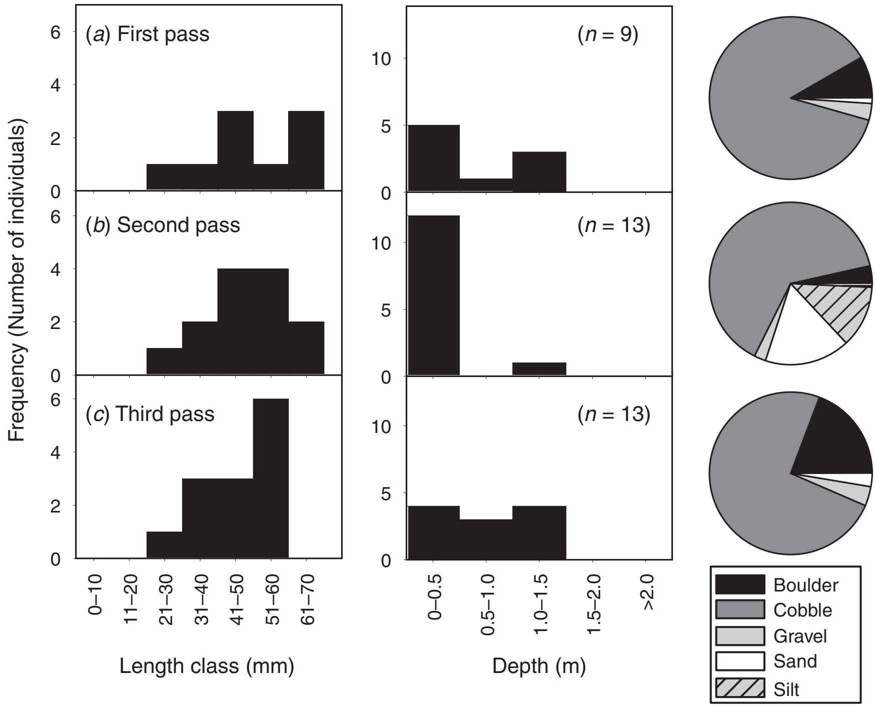

Fig. 4. Findings from a triple-pass snorkel survey of the abundance, size structure and habitat use (depth and substratum) of *Stiphodon atratus* in a large pool of Cooper Creek.

the upstream limit of *S. rutilaureus* in Pauls Pocket Creek. The range of *S. semoni* was found to extend further upstream than that of *S. atratus* (by a few pools equating to less than 100 m).

All three species of *Stiphodon* were consistently benthic and resided in areas with no water-surface flow or low flow (Fig. 6). However, *S. rutilaureus* was occasionally observed close to high water-surface flow (Fig. 6). In these instances, *S. rutilaureus* was grazing on biofilms in shallow water, generally facing head-first into the current. *S. rutilaureus* was also frequently associated with cobbles and, to a lesser extent, sand (Fig. 6). This contrasts with *S. atratus*, which mainly associated with boulders, and *S. semoni*, which associated with bedrock in Pauls Pocket Creek (Fig. 6). These variations in microhabitat association generally reflect longitudinal differences in the distribution of the three *Stiphodon* species in that stream. Specifically, the upstream section of the stream surveyed was steep and dominated by large boulders and bedrock, whereas, downstream habitat contained primarily smaller boulders and cobbles, with some sand.

Fish communities

We recorded 1661 individual fish in Cooper Creek and 554 fish in Pauls Pocket Creek (Table 1). The fish community of these two creeks differed in species composition (Table 1). *Kuhlia rupestris* was the dominant large-bodied species observed in both systems; however, *Kuhlia marginata* was also relatively abundant in Pauls Pocket Creek (Table 1). In terms of small-bodied fishes, *Pseudomugil signifer* was conspicuous in Cooper Creek and *Glossogobius* sp.1 was abundant in both streams (Table 1). Members of the Atherinomorpha (including Melanotaeniidae) were at very low density in Cooper Creek and were entirely absent from Pauls Pocket Creek. Observations of *Melanotaenia trifasciata* in a small tributary of Cooper Creek represent a southerly extension to the known range of the species. Gobies were major contributors to species richness (Fig. 7) of the fish community in Pauls Pocket Creek (8 of 14 species) and, to a lesser extent, in Cooper Creek (4 of 17 species). In fact, gobioids, in the form of gobies and eleotrids, accounted for 71% and 41% of fish species in Pauls Pocket Creek and Cooper Creek, respectively.

Discussion

Stiphodon

The discovery of fish assemblages comprising up to three species of *Stiphodon* in the Wet Tropics of Australia is a major finding of the current study. This contrasts with reports of assemblages of *Stiphodon* that have almost entirely come from high island streams in the tropical Indo-Pacific (Ryan 1991; Watson 1996; Keith 2003). A more complete knowledge of the biogeography of *Stiphodon*, which includes both a continental- and island-based distribution of adults, can be developed by considering the typical life-cycle of these fishes and their requirements for particular catchment geomorphology and hydrology. The life-cycle of *Stiphodon* species is typically amphidromous, involving an adult freshwater phase, a brief demersal egg phase, and larvae that hatch and move passively to the ocean for a substantial period in the marine environment before returning to streams as post-larvae (Keith 2003; Yamasaki and Tachihara 2006; McDowall 2007). The requirement for larvae to rapidly access the marine environment is probably relevant in partly explaining why certain

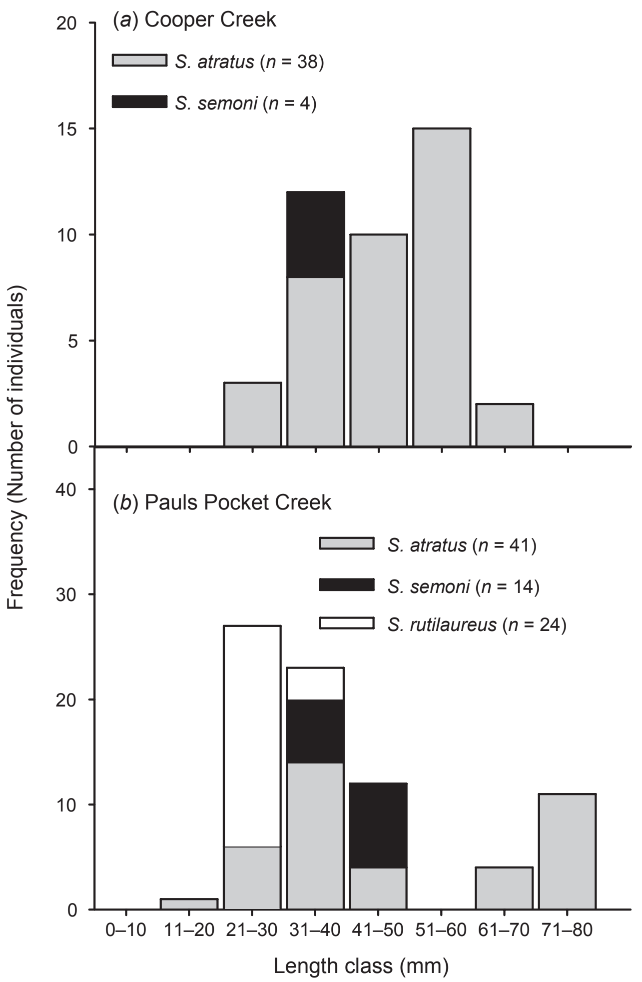

Fig. 5. A comparison of the size structure of *Stiphodon* species observed in Cooper Creek and Pauls Pocket Creek.

Table 1. Fish community composition of Cooper Creek and Pauls Pocket Creek from snorkel-based observations

Taxa	Cooper Creek	Pauls Pocket Creek
Anguillidae		
Anguilla reinhardtii	1	5
Eleotridae		
Bunaka gyrinoides	9	0
Eleotris fusca	0	1
Hypseleotris compressa	206	66
Giurus margaritacea	3	0
Gobiidae		
Awaous acritosus	138	10
Awaous ocellaris[A]	0	2
Glossogobius sp.1	229	107
Stiphodon atratus	38	45
Stiphodon semoni[A]	4	14
Stiphodon rutilaureus[A]	0	38
Schismatogobius sp.	0	1
Sicyopterus lagocephalus	0	17
Kuhliidae		
Kuhlia rupestris	591	146
Kuhlia marginata	19	92
Lutjanidae		
Lutjanus argentimaculatus	3	0
Megalopidae		
Megalops cyprinoides	1	0
Melanotaeniidae		
Melanotaenia splendida	2	0
Melanotaenia trifasciata	2	0
Plotosidae		
Tandanus tandanus	8	0
Pseudomugilidae		
Pseudomugil signifer	401	0
Sygnathidae		
Hippichthys sp.	6	0
Dorichthys sp. nov.[B]	0	10
Total individuals	1661	554
Total species	17	14

[A]Previously unrecorded in Australia.
[B]First record of undescribed species.

continental catchments support *Stiphodon*. The Indo-Pacific island streams inhabited by adult *Stiphodon* are typically high-gradient rainforest streams that flow directly into the ocean without passing through an extensive estuary (e.g. Fiji, Solomon Islands) and are termed insular streams (see Ryan 1991; Keith 2003). The fish communities of comparable streams in the Wet Tropics of Australia have received relatively limited attention in terms of fish community surveys and this at least partly explains the relatively recent discovery of *Stiphodon* species in the region (Allen *et al*. 2002; Thuesen 2004; this study). Prior surveys have encompassed relatively large drainages of the Wet Tropics region (e.g. Pusey *et al*. 2004) or a subset of these catchments (Pusey and Kennard 1996; Russell *et al*. 2003; Rayner *et al*. 2008). These surveys have involved applying substantial sampling effort in large river catchments that inevitably open to the sea via major estuaries.

A second explanation for the absence of *Stiphodon* in fish community surveys of streams of the Australian Wet Tropics is likely related to the sampling techniques that have been used. Previous studies have primarily been based on backpack or boat electro-fishing. The effectiveness of electro-fishing is highly variable across species and is usually more effective for sampling larger, migratory fishes (Reynolds 1996). In contrast, its efficacy is considered poor for the collection of gobiids, as most, including *Stiphodon*, do not possess a swim bladder and are negatively buoyant (Ryan 1991; Johnson *et al*. 2005). Therefore, individuals remain close to the bottom and will not rise to the surface once electro-narcosis is induced. This effect would be compounded in swiftly flowing streams such as in the current study, where individuals are likely to be quickly swept into rocky interstitial spaces.

A third and potentially the more relevant explanation for the lack of *Stiphodon* recorded in previous surveys is the patchy distribution of the assemblages. Preliminary indications are that *Stiphodon* aggregate in short reaches of streams on a scale of a few hundred metres in the Australian Wet Tropics (this study). Such a highly localised distribution is not likely to be intercepted with broad-scale, coarse-resolution survey designs (e.g. Pusey *et al*. 2004). Rather, *Stiphodon* are probably better

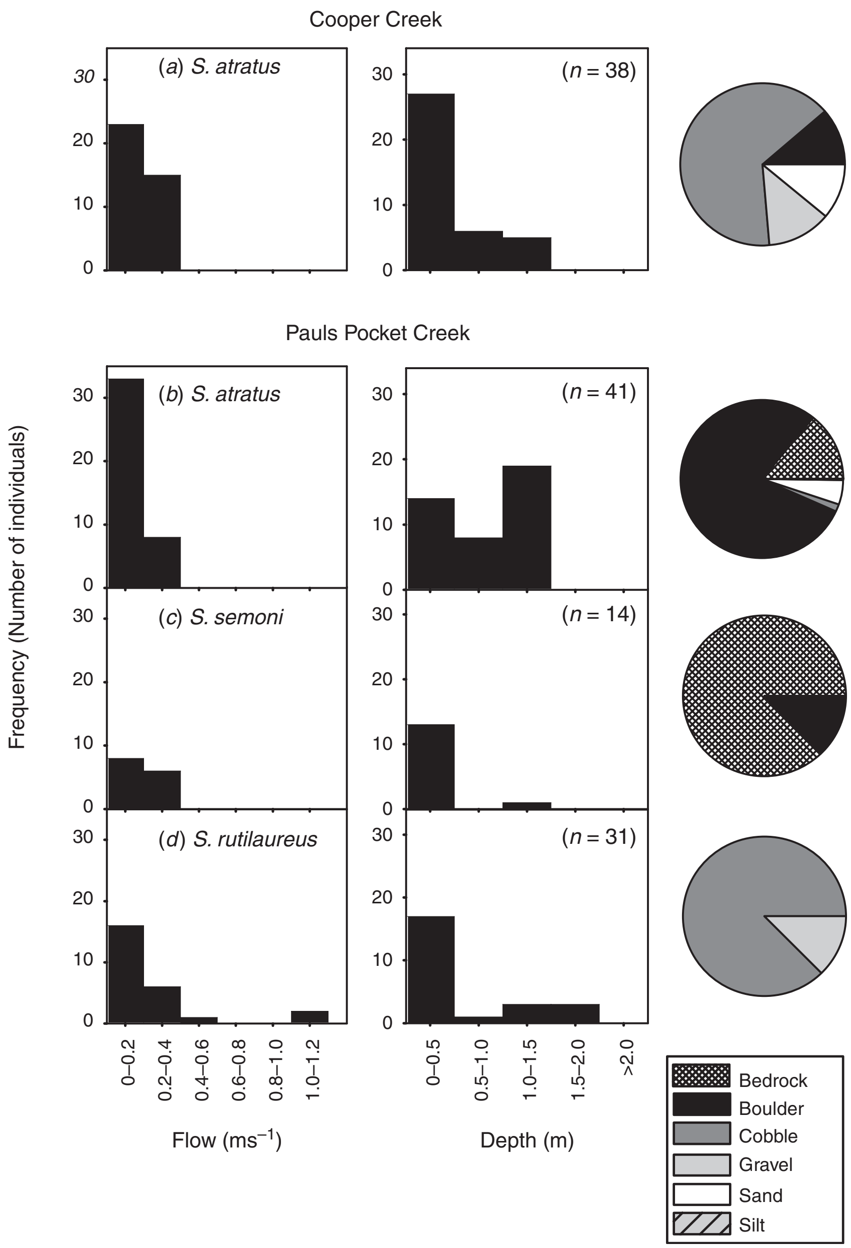

Fig. 6. Microhabitat association of *Stiphodon* species in Cooper Creek and Pauls Pocket Creek. Note that *S. rutilaureus* was not observed in Cooper Creek and the data for *S. semoni* are not shown due to an insufficient sample size at that location.

surveyed, studied and conserved by considering the continuous and longitudinal dimensions of the riverscape (Fausch *et al.* 2002).

Population size and structure

In total, we encountered 83 individual *S. atratus*, 38 *S. rutilaureus* and 18 *S. semoni* in the current study. We do not claim that these numbers approximate population sizes at the extent of the Australian Wet Tropics. In fact, caution must be applied even in assuming that these numbers represent true abundance within the respective catchments (Sutherland 1998). However, our surveys (including opportunistic surveys in these streams beyond the reaches reported here) do indicate that *Stiphodon* occupy a very short reach within these streams. The triple-pass and thorough searching of a single pool also indicated that single-pass counts closely approximate true adult density. Furthermore, the behaviour of these species, which includes continuous grazing on biofilms, male–male and male–female displays, renders *Stiphodon* species as good candidates for complete visual census. The counts recorded in the current study far exceed any previous records in the Australian context but represent alarmingly small

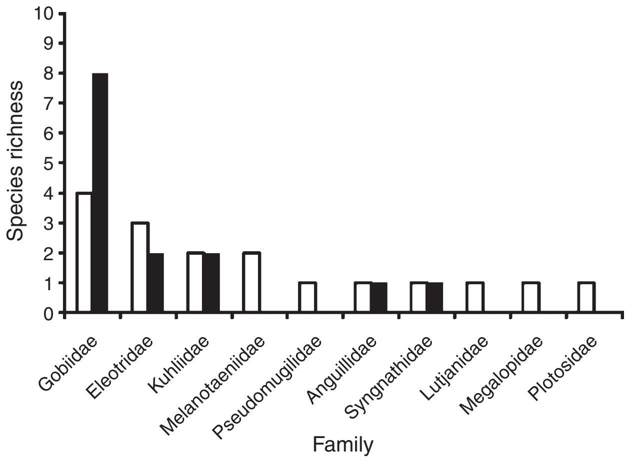

Fig. 7. Fish species richness by family in two Wet Tropics streams, Cooper Creek (white) and Pauls Pocket Creek (black).

numbers in reality. Further surveys of steep-gradient streams draining directly to the sea in the Wet Tropics are required before the extent and abundance of populations of these species can be clearly defined.

We encountered only 18 individuals of *S. semoni* in the current study. We observed males displaying and rapidly transitioning from grey-pink to grey-green to vivid black-blue colour phases in a matter of minutes. Similar rapid changes in colour have been considered important sexually selected traits in other fishes (Arai and Tetsu 2007). The small body size and relative ease of keeping *Stiphodon* in aquaria coupled with ease of observation in the field make these fishes a potential model group for sexual selection experiments.

Stiphodon are highly desirable aquarium subjects due to their brightly coloured bodies (Fig. 2) and visual contests among males. Indeed, populations of *Stiphodon* are threatened by over-harvesting for the aquarium trade elsewhere in the Pacific (e.g. Iwata 1997; Amarasinghe *et al*. 2006; Yamasaki and Tachihara 2006). Furthermore, *Stiphodon* are particularly vulnerable to collection by dip net, since they frequently graze on rocks and display to one another and display a relative indifference to snorkelers, even at very close range (~1 m). Therefore, on the basis of current knowledge of small adult populations in Australia coupled with the attractiveness of *Stiphodon* as aquarium pets, we recommend that this group of fishes receive protective status under state and national legislation at least until a comprehensive understanding of their distribution, abundance and genetic structure is achieved.

Habitat use

The current study suggests that steep-gradient streams draining directly to the sea are an important habitat for *Stiphodon* in the Australian Wet Tropics. Preliminary indications from Pauls Pocket Creek are that the *Stiphodon* assemblage comprises a species-specific longitudinal distribution pattern within streams. Specifically, a transition from *S. rutilaureus* to *S. atratus* to *S. semoni* was observed in an upstream direction in Pauls Pocket Creek. Similarly, amphidromous gobies have been found to exhibit species-specific longitudinal and elevation-related distributions elsewhere (Keith 2003; Kido 2008). Extensive surveys of these systems may help to construct the assemblage distributions of *Stiphodon* along the stream gradient. However, surveys in lower, tidally influenced sections will require application of innovative methods such as underwater video (e.g. Ebner *et al*. 2009) since crocodiles (*Crocodylus porosus*) pose a serious risk to researchers in these areas.

There were also indications of species-specific patterns of distribution at smaller scales in the current study. For instance, *S. atratus* and *S. semoni* were frequently associated within pools, whereas, *S. rutilaureus* were found in pools but were also much more common in riffle-runs. Within pools, *Stiphodon* species were commonly found at the upstream and downstream limits in shallow water. Occupation of shallow water may be a function of increased availability of food and benthic productivity (particularly production of turf algae) and/or the importance of sunlight in enhancing body coloration of males (Keith 2003). Additionally, there is likely be a greater availability of interstitial spaces at the head and tail of pools as a function of flow-related scouring effects. Access to interstitial spaces as predator refuges or spawning sites may underlie the apparent preference of *Stiphodon* for the extremities of pools. Longitudinal/altitudinal distribution of predators, including *Kuhlia* species, can be a particularly important structuring agent of tropical goby and shrimp communities in small tropical streams (Keith 2003). However, *Kuhlia* species cohabited pools with *Stiphodon* in Cooper and Pauls Pocket Creeks in the current study. Interestingly, despite being renowned for using specially adapted pelvic fin discs to cling to rocks in flowing water (e.g. Jenkins *et al*. 2008), *Stiphodon* were not generally found in high-flow habitats in the current study. This may partly be a function of the difficulty of observing fish and fish behaviour in riffles. Again, underwater video may provide a means of redressing this bias in sampling method.

Fish communities

In addition to the records of *Stiphodon* species, the fish community of Cooper Creek and especially Pauls Pocket Creek shared several elements in common with high island streams in the nearby Pacific. For instance, *Kuhlia marginata* was present in both creeks and was essentially as abundant as *Kuhlia rupestris* in Pauls Pocket Creek. *Kuhlia marginata* is recorded from Japan, Papua New Guinea, French Polynesia and New Caledonia (Keith *et al*. 2002). This species is often not recorded in freshwater fish surveys of the Wet Tropics (Pusey and Kennard 1996; Russell *et al*. 2003; Pusey *et al*. 2004; Rayner *et al*. 2008), although it has previously been recorded from streams in the Bloomfield and Daintree region, the Mossman River and near Behana Creek and Harvey Creek (Herbert and Peeters 1995). *Awaous occelaris* was recorded for the first time in Australia (in Pauls Pocket Creek) in the current study, and this species is widespread in the Western Pacific Region (Keith *et al*. 2002; Marquet *et al*. 2003). Similarly, *Sicyopterus lagocephalus* was recorded in Pauls Pocket Creek and this species is widespread in the Indo-Pacific (Keith *et al*. 2002; Lord *et al*. 2010). The presence of these amphidromous gobies (e.g. *A. occelaris* and *S. lagocephalus*) including three species of *Stiphodon*, indicate strong affinities between the fish fauna of steep-gradient streams draining directly to the sea in the Wet Tropics of Australia and those from insular streams on high islands elsewhere in the tropical Pacific.

Steep-gradient streams draining directly into the sea in the Wet Tropics may also represent important habitat for other rare species as evidenced by records of *Dorichthys* sp. in the current study. Alternatively, this inconspicuous species may be more widespread across north-eastern Australia than has been realised. Further surveys and taxonomic research of pipefish species is required before the conservation of this group can be assessed in the context of freshwater ecosystems in the Australian Wet Tropics.

Several non-diadromous fish families commonly encountered in streams of the Wet Tropics were notably absent from our surveys, more so in relation to Pauls Pocket Creek than Cooper Creek. For instance, grunters (Terapontidae) and hardyheads (Atheriniidae) were not encountered in either creek. The blue-eye *Pseudomugil signifer* (Pseudomugilidae) was common in Cooper Creek, whereas, rainbowfishes (Melanotaeiniidae) were rarely encountered (Table 1). Rainbowfishes and blue-eyes were absent from Pauls Pocket Creek and this is unusual in the context of lowland Wet Tropic streams (cf. Pusey *et al*. 2004). Additionally, the presence of *Melanotaenia trifasciata* in the Cooper Creek catchment represents a southerly range extension of this species (previously Gap Creek to the north of Cape Tribulation: Allen *et al*. 2002).

Differences between the composition of the fish community in Cooper Creek and Pauls Pocket Creek include a greater proportion of amphidromous species (particularly gobies) and a greater number of non-diadromous freshwater species in the latter. This may be partly a function of differences in stream and catchment geomorphology. Pauls Pocket Creek is less than 5 km long, and is a steep-gradient stream terminating in an estuary that is less than 200 m long. In contrast, Cooper Creek is more than 10 km long, is low gradient and has an estuary length in the order of two kilometres. Therefore Cooper Creek probably provides marginal habitat for lowland, non-diadromous freshwater species, whereas Pauls Pocket Creek is unsuitable for these species. Pauls Pocket Creek may also be more accessible to outgoing or incoming larvae of certain amphidromous species (e.g. *Stiphodon rutilaureus*) due to its lack of a significant estuarine zone.

Clearly, further investigation is required to develop a comprehensive understanding of the fish community of steep-gradient streams draining directly into the sea in the Australian Wet Tropics (including in Cooper Creek and Pauls Pocket Creek). Our count data (Table 1) were obtained from rapid census that likely provides relatively accurate estimates of *Stiphodon* distribution and abundance, as indicated from the triple-pass trial. However, in relation to other species (including less conspicuous, high-density or highly-mobile species) these counts almost certainly represent major underestimates of total abundance and even relative abundance. Nocturnal species (e.g. eels, catfishes) may have also been entirely missed since our observations were made in daylight. Nevertheless, the current study has uncovered several novel findings in terms of freshwater fish community composition in the context of the Australian Wet Tropics.

Conclusion

The current study affirms our hypothesis that *Stiphodon* are likely to inhabit low-order streams that empty directly into the Great Barrier Reef Lagoon in high-rainfall areas, analogous to insular streams of high island streams that empty directly to the ocean elsewhere in the tropical Indo-Pacific. However, preliminary indications are that the Australian populations are small (i.e. tens of individuals per catchment). Small population sizes coupled with the attractiveness of *Stiphodon* as aquarium pets, warrants that protective status be provided to this genus until a comprehensive understanding of species distribution, abundance and population genetic structure is achieved. Additionally, our surveys indicate that further investigation of fish communities inhabiting steep-gradient streams draining directly to the sea in the Australian Wet Tropics is required to understand biogeographic links with nearby Pacific Islands.

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