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The restricted distribution of the Emu (*Dromaius novaehollandiae*) calls for a more nuanced understanding of traditional Aboriginal environmental management

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Abstract

The historical absence of the Emu (*Dromaius novaehollandiae*) on a number of large northern Australian islands is speculated to be at least partially a result of overpredation by Aboriginal people in the late Holocene. If this observation is correct, the prevalent opinion, that traditional Aboriginal society had a totally benign impact on the Australian environment, needs to be reconsidered.

The jury is still out on whether Aboriginal hunting impacted upon the extinction of Australia's marsupial megafauna in the late Pleistocene, as outlined in Australian archaeological writings in the past 30 odd years (White & O'Connell 1982; Mulvaney & Kamminga 1999; Hiscock 2008). No kill sites have been conclusively identified, whereas in North America many butchery sites have been described, which indicates that human hunting was a major factor in the megafaunal extinctions there. In Australia, climate change is nominated as the primary factor by many observers, but it is argued here that much more recent regional extinctions appear to be due, in part at least, to Aboriginal predation. This observation challenges the current, populist orthodoxy that Aboriginal hunting and resource management practice had a seamless and harmonious interaction with the Australian environment.

Some years ago I was bushwalking on Groote Eylandt and observed paintings of what appeared to be Emus (*Dromaius novaehollandiae*) in the rock art in a sandstone shelter on Central Hill. Frederick McCarthy, anthropologist with the American-Australian Expedition to Arnhem Land in 1949, also noted paintings of Emus, identified by a local indigenous informant, on the adjacent Chasm Island and published a representation of this site (McCarthy 1960) (Figure 1). George Chaloupka also recorded a rock art image at "Anguru" (possibly a misspelling of Angurugu) on Groote Eylandt of what he labelled as an Emu in 1988, which is held in the archive of the Museum and Art Gallery of the Northern Territory (image number 6270.0007.0001). What is noteworthy about these depictions, is that the Emu does not currently live on this large continental island (measuring some 2326 sq km).

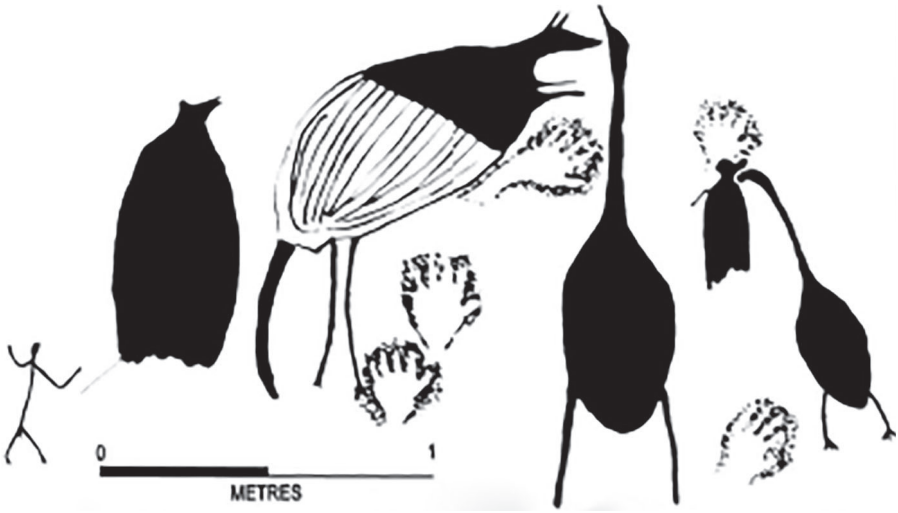

Figure 1. Representation of a Chasm Island rock painting including two Emus identified by informants, drawn by Frederick McCarthy (in Mountford 1960: volume 2, figure 32, p. 376). Original image courtesy of Melbourne University Press. This image was adapted from the original by Mike Owen.

Before the area became an island approximately 3000–4000 years ago, the island would have been suitable habitat for the Emu and one can confidently assume that a viable island population was isolated from the mainland at that time. Maps of the current geographic distribution of the Emu indicate this species is highly adaptable with a high reproductive rate and occupies a very broad range of habitats in Australia, ranging from "woodlands to semi-deserts, especially savanna [sic]" (Macdonald 1978). Given the large size of Groote Eylandt, it is highly improbable that, when the sea level stabilised at its current level, a viable population of Emus was not isolated there. The area now covered by the Gulf of Carpentaria was likely to have been a savannah grassland/woodland with lower rainfall before the seas rose. This is a preferred habitat of the Emu and as the sea rose relatively quickly, due to the low gradient of this landscape, the then 'Groote Eylandt upland' would have served as a refuge for this species, as for other flightless terrestrial species.

Of course, the Emu depictions in rock art could have dated to a period when these birds did inhabit the island or they could have been painted by people who had visited the mainland and recorded observations made elsewhere. But, in fact, the identification of these motifs as being of Emus is irrelevant; for example medieval British iconography features the African Lion prominently despite its absence from that landscape: it only serves to plant the question in one's mind: "Why aren't there Emus on Groote Eylandt anymore?"

As well as Groote Eylandt, Melville Island (5786 sq km) and Bathurst Island (2600 sq km) are similarly-sized isolates, with similar vegetation patterns, and they also now lack this species. [Fraser Island is excluded from this discussion since it is largely forested, thus a less preferred Emu habitat]. I argue these newly created islands, formed after the post-glacial stabilisation of sea level around 3000–4000 years ago, were sufficiently large to support the genetic viability of Emu populations over the long term and that their local extinction was due to unsustainable Aboriginal hunting practices. It is acknowledged, as Gammage (2011) has argued in his *The Biggest Estate on Earth*, that Aboriginal people in traditional times had an intimate knowledge of the environment in which they lived. However, this knowledge has been translated by many in the mainstream press as being a seamless synergy, incomparable to the impact of all other cultures on their environments. Sometimes this understanding seems to suggest that Aboriginal people were uniquely attuned to their complex environment, forgetting the formidable power of fire management, for instance, that humans have held over their environment around the world for perhaps a quarter of a million years.

I assert that the fate of the Emu on Groote Eylandt, and Melville and Bathurst Islands, is the same as the fate of the Dodo on Mauritius and the Moa in New Zealand. As large, isolated, conspicuous and flightless species, they were unable to withstand sustained human predation. The anthropologist Frederick McCarthy speculated that the Emus of Groote Eylandt "may have been exterminated during the period of native occupation" (McCarthy 1960). Other factors, such as the impact of fire, other predators and dwindling genetic diversity may have also been at play. But there are countless references in the historical literature to the desirability of Emu eggs and Emu flesh to Aboriginal hunting parties. Their eggs are large, their nests are easy to detect, and once they were hunted out, being flightless, they could not recolonise these newly-created islands.

It is conceded that the diversity of species on islands is generally lower than on equally sized, nearby continental areas, and in a recent survey of Groote Eylandt's birds, a number of other species present on the adjacent mainland were not found on Groote Eylandt (Noske & Brendan 2002). It is argued here that, whereas many of these species are not present on Groote due to less diverse vegetation communities on the island, this argument does not explain the Emu's absence, given its highly adaptable diet and its range of environmental tolerance.

I am not arguing that Aboriginal communities do not have a special insight into the Australian flora and fauna and the continent's land systems, but I believe the regional extinctions of certain species around the continent suggest that a more nuanced approach to this relationship is required. To suggest that Aboriginal interaction with the environment was uniquely and completely harmonious is a view that is commonplace in a lot of 'new age' literature; that denies the community its basic humanity. Of course these communities impacted on their environment less than industrialised societies with more sophisticated technologies and larger populations, but to say they had no impact

Figure 2. An early nineteenth century painting of the now extinct Kangaroo Island Emu/ Dwarf Emu (*Dromaius novaehollandiae baudinianus*), derived from the Baudin expedition to Australia of 1803–1804. Image courtesy of the National Gallery of Victoria.

on the environment is, it is argued here, not correct; it is only the scale of the impact that should be in question.

The current distribution of other terrestrial species in Australia may provide further evidence of localised Aboriginal overpredation. The status of the Brush Tail Possum (*Trichosurus vulpecula*) (How & Kerle 2004) and the Echidna (*Tachyglossus aculeatus*) (Augee 2004) on Groote Eylandt are similar to that of the Emu – absent from this large island in historic times, and yet both are common on the adjacent mainland, and both were favoured food species for Aboriginal groups. This same species of possum also existed in the small isolated woodlands of Uluru, surrounded by a sea of Spinifex grassland, until the establishment of a permanent Aboriginal settlement at Mutitjulu in the mid-twentieth century. Shortly after this permanent Indigenous community was established, the possum became locally extinct. Some authors (for instance Breeden 2000) have suggested that this local extinction was due to changed fire regimes and/or introduced pest species, but they do not venture to suggest that Aboriginal hunting may have also played a part. Further south, the first historical record of the Koala occurred ten years after the First Fleet arrived, and Lee & Martin (2004) have argued that this late observation is at least partially due to the cessation of Aboriginal hunting of this docile and conspicuous animal, due to the disruption to the traditional lifeway at that time, and the rebound in numbers of this species (see also Hermes 1992).

Further dispassionate studies into the historical distribution of other terrestrial species around Australia's larger islands may shed more light on the complex relationship between Indigenous people and the continent's biota.

If it had not been for the human occupation of Groote Eylandt and the other northern islands after the post-glacial sea level stabilisation, could we have expected Dwarf Emus (Figure 2) on all of these islands, like those encountered by the first European visitors to Tasmania, Kangaroo Island and King Island off our southern coast? Both King and Kangaroo Islands have Pleistocene Aboriginal histories, but due to a number of possible factors, they were unable to sustain viable human populations in the long term such that by the eighteenth century they were uninhabited.

Acknowledgements

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Update on Myrtle Rust in the Top End

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Abstract

Potential impacts of the plant pathogen Myrtle Rust (*Austropuccinia psidii*) on Myrtaceae in the Top End of the Northern Territory were discussed in the previous issue of the *Northern Territory Naturalist* (Westaway 2016). This note provides an update on the spread and effect of this disease in this part of the Northern Territory. Myrtle Rust is newly reported from Bathurst Island and, importantly, also from East Arnhem Land. The native host shrub *Lithomyrtus retusa* is highly susceptible to this disease, suffering serious dieback and ultimately plant mortality.

Myrtle Rust is a fungal plant disease that attacks various species of Myrtaceae (the myrtle plant family). Myrtle Rust is believed to be native to South and Central America but is now found in many parts of the world, including Australia where it was first detected on the east coast in 2010 (Carnegie *et al.* 2010).

The pathogen infects not only young, actively-growing foliage and new shoots, but also flower buds and fruit, causing lesions that coalesce (Figure 1) resulting in tissue dehydration, distortion and plant dieback.

Myrtle Rust has been known in the past as Guava Rust or Eucalyptus Rust, and scientifically as *Puccinia psidii* of the family Pucciniaceae. However, following recent phylogenetic analysis (Beenken 2017), Myrtle Rust has been renamed as *Austropuccinia psidii*, and placed within the redefined family Sphaerophragmiaceae.

Myrtle Rust was first detected in the Northern Territory in May 2015 at a remote location on Melville Island during a survey by the Northern Australia Quarantine Strategy (Westaway 2016). On Melville Island it was found infecting a single cultivated Beach Cherry (*Eugenia reinwardtiana*), several cultivated Ti-trees (*Leptospermum madidum*) and extensive stands of the native shrub *Lithomyrtus retusa* (Westaway 2016). It was found in suburban and rural Darwin later that year. Myrtle Rust seemed confined geographically in the Northern Territory and was limited to only a small number of host plants, that is those listed above plus cultivated White Bush Apple (*Syzygium armstrongii*). The pathogen also appeared not to have spread far, being reported from only one additional location in the rural Darwin–Howard Springs area (pers. comm. Northern Territory Department of Primary Industries and Resources, May 2017). Nor had it caused significant plant damage (until apparently recently).

Figure 1. Symptoms of Myrtle Rust infection on *Eugenia reinwardtiana* (left) and *Lithomyrtus retusa* (right). (John Westaway)

On 9 May 2017, Myrtle Rust was found infecting a single cultivated *Eugenia reinwardtiana* at Gapuwiyak, the first record of this pathogen in Arnhem Land. A second cultivated *E. reinwardtiana* at nearby Galiwinku showed unconfirmed early signs of infection, though the rust on this plant was not sporulating. How the pathogen reached remote East Arnhem Land is unclear but North Australian Quarantine Survey (NAQS) plant host survey data indicate that the particular *E. reinwardtiana* plant was present in Gapuwiyak since at least 2014 and so the rust is unlikely to have arrived as infected plant material, thus subsequent contamination by spores seems likely. Myrtle Rust spores are microscopic and can spread readily across large distances by wind, or via insects, birds, people, or machinery. The spores are believed to be capable of crossing oceans on wind currents as Myrtle Rust reached New Zealand, and Norfolk Island, and the Kermadec Islands (approx. 1000 km north-east of New Zealand) in 2017, all presumably by wind-borne spores from Australia.

On 30 May 2017, Myrtle Rust was found at a remote outstation and on the roadside in the southern part of Bathurst Island. The infection was on *Lithomyrtus retusa,* the same native shrub that was observed to be heavily infected on Melville Island in 2015. This is the first report of the disease from Bathurst Island, although inspection of plants in 2015 was confined to the main community Wurrumiyanga.

Myrtle Rust was also observed on cultivated Ti-tree (*Leptospermum madidum*) at Milikapiti airport on Melville Island in May 2017. Also on Melville Island, light Myrtle Rust infection of several *L. madidum* trees at the Yapilika forestry station was recorded in 2015, and these trees were maintaining their apparent health despite ongoing light infection.

Interestingly, Rose Myrtle (*Syzygium jambos*), which also occurs at the forestry station, has remained asymptomatic despite it being regarded as a highly susceptible host (Anderson & Uchida 2008; Morin *et al.* 2011; Makinson 2012). *Syzygium jambos* plants at Parap in Darwin have also remained unaffected, as has the cultivated *E. reinwardtiana* at the George Brown Darwin Botanic Gardens.

Figure 2. *Lithomyrtus retusa* mortality, Melville Island, June 2017. (John Westaway)

Myrtle Rust has subsequently been recorded on Groote Eylandt in East Arnhem Land in May 2018, infecting the widespread susceptible native shrub *Lithomyrtus retusa*. (pers. comm. Ian Cowie). Myrtle Rust was also recorded for the first time in the neighbouring country of Timor-Leste in September 2017, where a number of cultivated *Syzygium jambos* trees and the shrub *Eugenia reinwardtiana* are infected (NAQS survey data).

The most significant development in the three years since the first detection of Myrtle Rust in the Northern Territory is that *Lithomyrtus retusa*, the main native host plant affected, has now been observed to suffer major mortality of individuals, at least on Melville Island, where the original infection levels were high. In 2015 disease symptoms on *L. retusa* included minor distortion and abscission of young foliage and dieback of severely infected branch tips, but three years later many shrubs are now dead (Figures 2–5). Mortality appeared to be most prevalent in shaded firebreaks perpendicular to a main road (Figure 4) and may consist of a substantial proportion of the *L. retusa* population in places. Other individuals were in advanced stages of infection with several branches dying back. Dead or dying *L. retusa* shrubs were also observed at the Taracumbi Falls area (Figure 5).

Figure 3. Patchy dieback of *Lithomyrtus retusa* shrubs on roadside (with *Acacia mangium* plantation behind), Melville Island, June 2017. (John Westaway)

Figure 4. *Lithomyrtus retusa* mortality along a forestry firebreak, Melville Island, June 2017. (John Westaway)

Although there are now hundreds of myrtaceous plant species known to be capable of being infected by Myrtle Rust (Anderson 2006), in Australia (Makinson 2012; Giblin & Carnegie 2014), only very few of these are presently known to be so detrimentally impacted that plants are actually killed (Tommerup *et al.* 2003; Carnegie *et al.* 2015). Arguably the Australian species most severely affected by Myrtle Rust thus far are the east coast rainforest trees *Rhodamnia rubescens* and *Rhodomyrtus psidioides*, where a causal association between pathogen rust and tree mortality has been demonstrated in field experiments (Carnegie *et al.* 2015).

The *Lithomytus retusa* shrubs at Berry Springs that were seen to be relatively lightly infected with Myrtle Rust in 2015, were observed in June 2017 to have deteriorated considerably in the intervening period, with plants showing significant levels of infection, abundant leaf tip damage and even some branch death leaving some shrubs half dead (Figure 6). Plant loss in the shrub stratum may have implications for these vegetation communities

Figure 5. *Lithomyrtus retusa* dieback, Taracumbi, Melville Island, June 2017. (John Westaway)

Figure 6. *Lithomyrtus retusa* dieback, Berry Springs, June 2017. (John Westaway)

and their associated wildlife. Heavy Myrtle Rust infection of *L. retusa* shrubs and the accompanying spore loads in, and adjacent to, *Acacia mangium* plantations on Melville Island may pose a potential quarantine issue for export of wood products.

Detection of Myrtle Rust in Arnhem Land, the apparent low level of disease spread around Darwin, and the serious impact of the pathogen on the native shrub *Lithomyrtus retusa,* confirm that the long-term effects of Myrtle Rust on Top End environments remains uncertain.

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Nest, eggs and breeding season of the Arafura Fantail (*Rhipidura dryas*)

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Abstract

The breeding biology of the monsoon-tropical Arafura Fantail (*Rhipidura dryas*) is poorly known. The only descriptions of the eggs of this species in Australia prior to 1998 were based on one full clutch and two partial clutches collected from the Top End of the Northern Territory about 100 years earlier. The Nest Record Scheme (administered by BirdLife Australia) contains records of only two nests, both found in Kakadu National Park during the late 1970s. Here we provide details of nine nests found in the Cambridge Gulf between 1998 and 2006, and of two more recent nests from the Top End. These records suggest that the breeding (egg-laying) season extends from September to March, a slightly longer period than that of the closely-related Rufous Fantail (*R. rufifrons*) of eastern Australia, but shorter and later than that of the sympatric Northern Fantail (*R. rufiventris*). The eggs are similar in colour to, but slightly smaller on average than, those of the Rufous Fantail. The nests of both species have long tapering 'tails', but while those of the Rufous Fantail typically hang below the middle of the cup, some nests of Arafura Fantails had 'tails' arising from the side of the cup.

Introduction

Originally described by John Gould in 1843 from specimens collected at Port Essington, Cobourg Peninsula, Northern Territory (North 1901–1904; Fisher & Calaby 2009), the Arafura Fantail (*Rhipidura dryas*) was treated as a subspecies of the Rufous Fantail (*R. rufifrons*) by most authors (Mayr & Moynihan 1946; Keast 1958; Boles 1988; Christidis & Boles 1994) until Storr (1984) and Johnstone (1990) elevated it to species rank, a change followed by Schodde & Mason (1990) and Christidis & Boles (2008). Formerly known as the Wood Fantail (e.g. North 1901–1904), it differs morphologically from *R. rufifrons* mainly in being smaller, and having more white, and less rufous, on the tail (North 1901–1904; Keast 1958; Schodde & Mason 1999; Higgins *et al.* 2006). Moreover, while the Rufous Fantail is largely migratory, breeding in south-eastern Australia and wintering as far north as southern New Guinea, the Arafura Fantail is thought to be resident over much of its range, which in Australia extends across the monsoon tropics from the tip of Cape York west to the Kimberley region, Western Australia.

Until recently, *R. dryas* was considered to comprise up to eleven subspecies, most of which are found in eastern Indonesia and western New Guinea (Coates & Bishop 1997; Beehler & Pratt 2016; del Hoyo & Collar 2016; Boles 2017). However, based on vocalisations and minor plumage details, Eaton *et al.* (2016) treat the Indonesian forms as a full species – the Supertramp Fantail (*R. semicollaris*) – separate from the Australian form. In short, the species limits in this group are still under review.

In the Top End of the Northern Territory, the Arafura Fantail is generally uncommon and largely confined to closed habitats, such as mangals (mangrove forests) and riparian forests (Storr 1977; Brooker & Parker 1985; Woinarski *et al.* 1988; Robinson *et al.* 1992; Woinarski 1993; Noske 1996). In the Darwin region, and sub-coastal parts of Kakadu National Park, the overwhelming majority of records of the species coincide with the dry season (May–October), suggesting that birds move to more inland areas for the wet season (Blakers *et al.* 1984; McCrie & Noske 2015). This contradicts an earlier claim that Top End birds tend to move inland during the dry season (Storr 1977).

There is very little published information about the breeding season and biology of this species. Treating it as a subspecies of the Rufous Fantail, Higgins *et al.* (2006) documented only four breeding records for the Arafura Fantail, claiming that no breeding data were available from northern Western Australia or Queensland. With texts finalised for publication in December 2004, they were unable to include information on the species published in volume 2 of the *Handbook of Western Australian Birds* (Johnstone & Storr 2004). This paper provides details of observations of breeding by the species in Western Australia, mostly from 1998 to 2001, as well as recent observations from the Northern Territory. Information from Indonesia is also included for comparative purposes.

Historical records

The first complete Australian clutch of the Arafura Fantail was part of a large collection of eggs allegedly from the "Port Darwin District" and described by Le Souëf (1903). This clutch was collected on 18 November, probably between 1898 and 1903, since one of the three contributors to the collection was probably Mr E Olive, who collected specimens and eggs in the Northern Territory from October 1898 to January 1899 (Le Souëf 1899). However, many of the species included in the "Port Darwin" collection are not known to occur in the Northern Territory, let alone near Darwin, and the collection dates of many clutches are dubious in the light of present knowledge of breeding seasons in the Top End (Noske 2018). The only other early descriptions of eggs of the Arafura Fantail concern single eggs derived from two separate clutches collected around the same time as the clutch described by Le Souëf. One egg was taken from the Daly River during January 1902, while the other was taken from "Port Darwin" but is undated (North 1901–1904).

Apart from the above accounts, the only record of Arafura Fantails nesting in Australia prior to the first *Atlas of Australian Birds* (1977–1982; Blakers *et al.* 1984) is that of

William McLennan, who collected eggs and bird specimens in Arnhem Land for Henry (H.L.) White, the eminent grazier-ornithologist of New South Wales. Sailing from Thursday Island, McLennan spent four months in the vicinity of the King River, approx. 80 km WNW of present-day Maningrida, from 26 September 1915 to 23 January 1916. He had collected a single Arafura Fantail on the King River during October, but it was only on his return journey that he observed a pair of birds building a nest on an islet at the mouth of the Liverpool River on 27 January 1916 (White 1917a,b).

Breeding records since 1916

The Nest Record Scheme (NRS), administered by BirdLife Australia, contains records of only two Arafura Fantail nests, both from the same locality in Kakadu National Park. The first nest, containing young (number unknown), was found on 24 September 1978, while the second, containing two eggs, is dated 26 September, allegedly from the following year (1979). The geographical co-ordinates of the two sites suggest that they were 11 km apart (using Google Earth), and situated approx. 5 and 10 km, respectively, from the lower reaches of the South Alligator River. Although the first site (12°40'S, 132°45'E) appears to have potentially suitable habitat, having dense vegetation, the other (12°33'S, 132°53'E) is further from the river, in eucalypt woodland, 2.5 km from the nearest thicket. Given that the sites are 30–34 km from the nearest point on the Arnhem Highway, and there do not appear to be any tracks going to them, the sites may have been accessed from the river, or more likely, the co-ordinates are erroneous. In addition, there is an alleged *Atlas of Australian Birds* record from the Top End of young birds being fed in mid-July, although it was not stated whether they were nestlings or fledglings (Higgins *et al.* 2006). On Groote Eylandt, the first author observed a juvenile Arafura Fantail on 29 November 1997, suggesting nesting before or during October (Noske & Brennan 2002).

Between 1998 and 2001, R. Johnstone and G. Lodge carried out extensive bird surveys of Cambridge Gulf, Kimberley region, Western Australia, during which they found nine active nests, eight of which were located on small islands off Wyndham, and one on the mainland. All were situated in dense stands of Small-leaved Orange Mangroves (*Bruguiera parviflora*) 50–200 m from the seaward edge of mangals on small islands in the Cambridge Gulf, offshore from Wyndham, Kimberley region, Western Australia. Nests with eggs were found in September (1), October (4), November (2) and early March (1), while a nest with hatchlings found on 10 October 2001 suggests egg-laying in September. During January 2006, no active nests were found on the islands, but one pair was observed building a nest on the mainland at Thurburn Bluff, northwest of Wyndham, on 10 January, while another pair was seen with two fledglings on 22 January. The latter date suggests egg-laying in December.

On 20 February 2015, C. Brady (in litt.) discovered an active nest of the species in a small patch of dry monsoon vine forest on the edge of an escarpment near Delamere Station in the southwest of the Top End. The location (15°49'S, 131°49'E; approx. 240 m

Figure 1. Arafura Fantail nest under construction, Murwangi Billabong, 24 September 2016. (Richard Noske)

above sea level) was 157 km SSW of Katherine and 77 km ESE of Victoria River Roadhouse. The contents of the nest could not be checked, but as an adult was sitting on it, it presumably contained eggs or small nestlings.

Finally, on 24 September 2016, while employed as a bird tour guide, R. Noske observed an adult Arafura Fantail adding material to an incomplete nest (Figure 1) near Murwangi Safari Camp on the western fringe of the Arafura Swamp in northern Arnhem Land (12°28.500'S, 134°57.733'E), approx. 25 km inland from the nearest coast. At least five pairs of Arafura Fantails were found inhabiting thickets of 'Freshwater Mangroves' (*Barringtonia acutangula* and *Cathormium umbellata*) around the edges of Murwangi Billabong and adjoining creeks. The site was a dense grove of young Gebang Palms (*Corypha elata*), mostly approx. 4–8 m high, dead fronds of which hung close to the nest. The grove was fringed by scattered taller *Corypha* palms and Cajaput (*Melaleuca*

Figure 2. Habitat of the nest of Arafura Fantail at Murwangi Billabong, 24 September 2016. (Richard Noske)

Figure 3. Arafura Fantail incubating eggs at Murwangi Billabong, 8 October 2016. (Wayne Turner)

cajaputi) (Figure 2), and adjoined a seasonal extension of the billabong, though the nearest free-standing water was approx. 100 m away. When the nest was checked on 8 October, an adult was found sitting (Figure 3), and with the aid of a step ladder, the nest was found to contain two eggs (Figure 4).

Figure 4. Nest and eggs of the Arafura Fantail at Murwangi Billabong, 8 October 2016. (Richard Noske)

Ten minutes after the nest and eggs had been photographed and the ladder removed, an adult was seen sitting on the nest again.

Nests and nest sites

Le Souëf (1903) described the nest of the Arafura Fantail as being similar to that of the Rufous Fantail, situated on a thin fork near the end of a branch approx. 3 m from the ground, and composed of "fine shreds of bark and lined with fine grass seed-stalks and lightly covered outwardly with cobwebs". Although Le Souëf made no mention of a 'tail' below the nest he described, it may be inferred from his comparison to Rufous Fantails that reference to this feature was inadvertently omitted. In the Cambridge Gulf, Western Australia, all the nests were placed on a thin, usually green, horizontal twig, often in a 2- or 3-way fork, of Small-leaved Orange Mangroves, 1.0–2.0 m (mean = 1.22 m, n = 6) above the ground or water (R. Johnstone, unpubl. data). These nests were composed of thin strips of decaying wood fibre bound tightly together with spiderweb and lined with rootlets, wiry tendrils, pieces of thin flat grass and decaying wood fibre (Johnstone & Storr 2004) (Figure 5).

In Kakadu, one NRS nest was situated 2.5 m up in a 4.5 m high plant, while the other was at 1.5 m in an 18 m high tree. At Delamere Station, the nest was on a dead branch approx. 2.5 m up in a 6 m high tree. At Murwangi, the nest was situated on a slightly sloping

bare twig approx. 3 m from the ground in a 9 m high *Cathormium umbellata* (Figure 1). The nest was composed of the bark of paperbarks interlaced with grass stems and scattered dead leaves and other unidentified fibrous material, and bound with spiderweb. The lining inside the cup was entirely composed of thin grass stems (Figure 4). The supporting twig was slightly forked, with a short twiglet protruding from one side of the cup (Figure 3). The nest completely enveloped the main twig, with over one-third of the nest mass below the latter, while the tail-like appendage, characteristic of the nests of most members of the fantail family (Rhipiduridae), was drooped over one side of the twig, arising from the side of the cup (Figure 6), rather than below its centre as is normal in the Rufous Fantail (see photographs in Boles 1988). Interestingly the illustration of a nest from Cambridge Gulf shows the 'tail' hanging below an extension of the nest base on a side-twig (Johnstone & Storr 2004: Fig. 129), such that its axis was approx. 3 cm from the axis through the centre of the nest cup. However, three other nests from the Gulf had the 'tail' in line with the central axis (Figure 5).

Figure 5. Two nests of the Arafura Fantail from Cambridge Gulf, 1998. (Kim Sarti)

Figure 6. Nest of the Arafura Fantail, Murwangi Billabong, showing asymmetrical 'tail', 8 October 2016. (Richard Noske)

Data on the dimensions of nests of the Arafura Fantail are sparse because most sources do not separate them from those of the Rufous Fantail. Moreover, measurements from the historical literature suffer from imprecision due to the conversion of inches to millimetres. The width of the alleged "Port Darwin" clutch of Arafura Fantails measured approx. 51 mm externally and approx. 38 mm internally (Le Souëf 1903; Higgins *et al.* 2006), while at least two nests of Rufous Fantails measured approx. 57 mm and approx. 64 mm externally (North 1901–1904 and Campbell 1900, respectively;

Higgins *et al.* 2006), and approx. 44 mm internally. Three nests of Arafura Fantails from the Cambridge Gulf measured 52–57 mm externally and 40–42 mm internally (Johnstone & Storr 2004). These scant data suggest that the nest of the Arafura Fantail may be slightly smaller than that of the Rufous Fantail.

Clutch size and egg characteristics

All complete clutches from the Northern Territory (n = 4, including the "Port Darwin" clutch) and Western Australia (n = 8) comprised two eggs. Moreover, one nest in the Northern Territory and another in Western Australia contained two young. This is also consistent with the contents of four nests on Banda Neira, Maluku Selatan (South Moluccas), which had two eggs (n = 1), two hatchlings (n = 1), and two feathered chicks (n = 2) (Johnstone & Sudaryanti 1995). Based on this sample, therefore, the clutch size of the species appears to be two, but it is noteworthy that 90% of clutches of Rufous Fantails consist of two eggs, the remaining 10% being three eggs (Higgins *et al.* 2006).

Eggs in the "Port Darwin" clutch were "light buff in colour, and marked at the larger end only, where the small reddish-brown and greyish markings form a confluent zone" (Le Souëf 1903: 55). The single eggs from the two other Top End clutches were dull yellowish- or creamy-white in ground colour, with an indistinct zone of confluent spots and blotches of dark yellowish- or umber-brown and bluish-grey, around the thicker end (North 1901–1904). Eggs from two clutches from the Cambridge Gulf were light buff, with dots, spots and small blotches of buff-brown and cinnamon-brown, and with underlying violet-grey, the markings forming a well-defined zone on the larger end (Johnstone & Storr 2004). The eggs in the Murwangi nest were dull white, possibly with a faint pinkish wash, but liberally marked in a broad ring at the larger end with small spots of reddish-brown, dull purple and pale olive, and larger irregular chocolate-brown markings (Figure 4). These descriptions suggest considerable variation in the ground colour and markings of eggs of Arafura Fantails, but whether they have a geographical basis is unknown. As the eggs of the Rufous Fantail show similar variation in ground colour and markings (Higgins *et al.* 2006), it is unlikely that the eggs of the two species are distinguishable in appearance.

On the other hand, measurements suggest that eggs of the Arafura Fantail are slightly smaller on average than those of the Rufous Fantail. The length and width of four eggs from two Western Australian clutches (Johnstone & Storr 2004) and four eggs from three clutches from the Northern Territory (North 1901-04; Le Souëf 1903; Higgins *et al.* 2006) averaged 16.3 (SD = 0.60) x 12.5 mm (SD = 0.38), with the range being 15.3–17.0 mm for length, and 11.9–13.2 mm for width. Measurements for ten eggs of Rufous Fantails averaged 17.2 (SD = 0.81) x 12.9 mm (SD = 0.38), with the range being 15.7–18.3 mm for length, and 12.4–13.5 mm for width (Higgins *et al.* 2006). Calculating standard errors, and multiplying them by 1.96, indicates that upper 95% confidence limits for the Arafura Fantail are 16.76 mm and 12.83 mm for length and width, while lower limits for the Rufous Fantail are 16.70 mm and 12.66 mm, respectively. In summary,

mean measurements of the two species are almost, but not quite significant at the 95% probability level.

Conclusions

Combining data from Western Australia and Northern Territory, the breeding season of Arafura Fantails apparently extends from September to March (Figure 7), though the *Atlas* record of dependent young in mid-July would extend the season to June. This breeding season is longer than that of the Rufous Fantail in south-eastern Australia, usually given as October or November to January (Higgins *et al.* 2006). In the South Moluccas of eastern Indonesia, Johnstone and Sudaryanti (1995) found four active nests of Arafura Fantails (*sensu lato*) from 25 to 29 September 1992, on Banda Neira, near Ambon. On the other hand, ten clutches of the species were collected from western Flores in April and May during the 1950s (Verheijen 1964), and another in April 1969 from Roti island, west of Timor (Verheijen 1976). These two months correspond with the peak in egg-laying of most bird species in western Flores and the Greater Sundas, but not that in Timor, or even eastern Flores, where many species have been found nesting in the austral spring and summer (Noske 2003; Schellekens & Noske, unpubl. data).

The Northern Fantail (*R. rufiventris*), which is widely sympatric with the Arafura Fantail, lays eggs from May to January in the Top End, although over 80% of clutches (n = 49) are laid from August to November (McCrie & Noske 2015; R. Noske, unpubl. data). The breeding season of the former species therefore appears to start and finish earlier

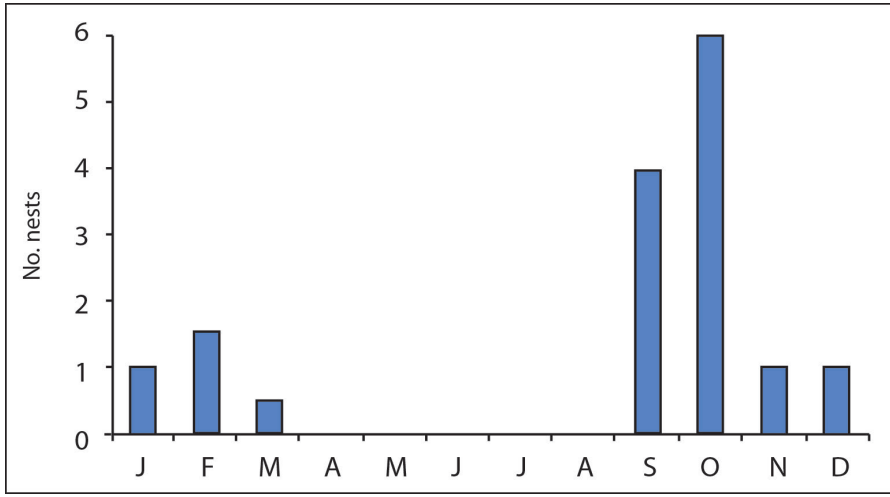

Figure 7. Estimated months of egg laying of Arafura Fantails, assuming incubation and nestling periods are similar to that of the Rufous Fantail (i.e., approx. 15 days and approx. 11 days, respectively) (Higgins *et al.* 2006). If egg laying was estimated to occur in either the last week of month X or the first week of month X+1, both months scored 0.5. The alleged breeding record for July from the *Atlas of Australian Birds* is omitted (see text).

than the latter. This apparent difference is probably related to the seasonal availability of their main insect food resources, as even within mangals the two species differ in their foraging behaviour (Noske 1996; Mohd-Azlan *et al.* 2014). Moreover, in the Top End, Northern Fantails are sedentary, whereas many Arafura Fantails in the Darwin-Kakadu region appear to make seasonal movements, being largely absent from mangals and other coastal habitats during the wet season, and presumably moving inland to breed towards the end of the dry season (McCrie & Noske 2015). In the Cambridge Gulf, however, the species appears to be sedentary in mangals on islets off the coast, and McLennan's observation of a pair of birds building a nest was on an islet at the mouth of the Liverpool River in Arnhem Land, Northern Territory. At Edward River settlement on the west coast of Cape York Peninsula, Queensland, the species is said to be resident in mangals, and to breed during the wet season (Garnett & Bredl 1985), but no supportive data were provided.

The Delamere Station breeding record is remarkable in that it almost certainly represents the most inland occurrence of the species at least in the Northern Territory, as the nearest coastline is at the mouth of the Victoria River, in the Joseph Bonaparte Gulf, approx. 250 km away. The area may be considered semi-arid with a mean annual rainfall of 724 mm (n = 32 years; Bureau of Meteorology 2017). It is noteworthy, however, that the habitat in which the nest was found occurs intermittently along the edge of an escarpment that continues almost unbroken to the headwaters of the Daly River in the north.

Finally, it is noteworthy that there are even fewer breeding records of the Mangrove Fantail (*R. phasiana*) in the Northern Territory than of the Arafura Fantail (McCrie & Noske 2015), though its breeding biology is moderately well known in Western Australia (Johnstone 1990; Johnstone & Storr 2004). We hope this article stimulates birdwatchers to look for nests of both the Arafura Fantail and Mangrove Fantail in the Top End.

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Postscript

Since the final version of this paper was written, R. Johnstone was provided with details of four clutches of Arafura Fantails in the collection of Nick Kolichis. All were collected from mangals along the edge of the Norman River, 11–20 km from Normanton, Gulf of Carpentaria, Queensland. One clutch was of two eggs, but the other three had only one egg, apparently already being incubated (N. Kolichis, pers. comm.). All clutches were collected at the end of the breeding season as delineated above (22 and 26 February 2004, and 6 and 12 March 2006).

Mangrove Robins breeding outside mangroves on the Arafura Swamp, Northern Territory

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Abstract

Thought to be restricted to coastal mangrove forests in Australia, the Mangrove Robin (*Peneothello pulverulenta*) (formerly *Peneonanthe pulverulenta*), is also known to occur locally in subcoastal paperbark swamp forest in New Guinea, and less often further inland in riparian reed-beds mixed with shrubs. Here we report the existence of a population inhabiting dense thickets of vegetation surrounding a permanent billabong on the Arafura Swamp in central Arnhem Land, Northern Territory. The location is 25 km inland from the nearest coastline and 8.5 km from the nearest mangroves. The birds foraged in the litter on dry soil and were observed eating insect larvae. One pair had a recently-fledged young bird in October 2016, indicating that the population was sedentary and breeding.

Introduction

The Mangrove Robin (*Peneothello pulverulenta*) (formerly *Peneonanthe pulverulenta*), is endemic to tropical coastal Australia, Aru Islands and New Guinea. In Australia it is considered to be restricted to mangals (mangrove forests), where it usually hunts for crabs and other invertebrates on the mud (Boles 1988; Johnstone 1990; Noske 1996; Mohd-Azlan *et al.* 2014). At very high tides, however, when the ground is covered by water, it gleans ants and other insects from the branches of mangroves (Johnstone 1990; Noske 1996). The species is said to prefer frequently inundated forest dominated by Stilt-root Mangroves (*Rhizophora* spp.) in northern Western Australia and northeast Queensland (Johnstone 1990; Higgins & Peter 2002), whereas in the Darwin region of Northern Territory it is most abundant in irregularly flooded thickets of Spurred Mangroves (*Ceriops australis*) and Rib-fruited Mangroves (*Bruguiera exaristata*), often close to the landward edge (Noske 1996; Mohd-Azlan *et al.* 2012). Here we report the discovery of a breeding population of the species on the edge of a seasonally-inundated floodplain some distance from mangroves.

The poor state of knowledge of the Mangrove Robin is reflected in its vexed taxonomic history. Mayr (1941) placed it in the small genus *Poecilodryas,* confined to tropical Australia

Figure 1. Adult Mangrove Robin at Murwangi Site B. (Richard Noske)

and New Guinea, while Keast (1958) thought it sufficiently distinct to constitute a monotypic genus, resurrecting *Peneoenanthe*. Based on superficial similarities, Schodde (1975) relegated it to the genus *Eopsaltria*, which includes the Yellow Robins (Boles 1988; Christidis & Boles 1994), but its monotypic status was defended by Noske (1978) and eventually re-instated by Christidis & Boles (2008). Indeed, a multi-locus DNA phylogenetic study suggested a closer relationship with New Guinean *Peneothello* and Australian *Melanodryas* than with *Eopsaltria* (Loynes *et al.* 2009). These findings were corroborated by Christidis *et al.* (2011) who consequently placed the species in *Peneothello*, a move followed by Beehler & Pratt (2016) and herein.

Observations

From 26 September to 9 October 2016, the authors were employed as guides for a birdwatching tour, during which we spent six days at Murwangi Safari Camp, previously part of a large cattle station, on the western fringe of the Arafura Swamp in northern Arnhem Land (12.475°S, 134. 962°E), 16 km south of the township of Ramingining. Arafura Swamp is a large freshwater basin (approx. 700 km^2) on the broad floodplain of the Goyder and Gulbuwangay Rivers, and is unique because of its extensive perennial swamps and lack of a continuous river channel to the sea (Weston *et al.* 2012).

Mangrove Robins (Figure 1) were frequently heard calling from the dense vegetation fringing the dry floodplain adjacent to the camp, and regularly seen during boat cruises along nearby Murwangi Billabong, a narrow permanent waterbody approx. 1.9 km long but only approx. 100 m at its widest point. The nearest coastline is at the mouth of the tidal Glyde River, which meanders southwards, its main arm connecting to the northern end of the billabong, albeit via a broken channel. Using Google Earth, we estimate that the straight-line distance between these two points is 25 km, whereas by river and channels, it is approx. 56 km. Fringing mangroves appear to continue upstream for approx. 47 km, after which the river and channel to Murwangi billabong are largely unlined for 4.5 km, then pass through paperbark woodland for another 4 km before reaching the billabong. Thus, the nearest mangroves to the billabong appear to be 8.5 km away.

Figure 2. Dense section of habitat of Mangrove Robins at Murwangi Site A, dominated by *Cathormium umbellatum*. (Richard Noske)

Figure 3. Open section of habitat of Mangrove Robins at Murwangi Site A, dominated by *Barringtonia acutangula*. (Richard Noske)

Figure 4. Habitat of Mangrove Robins at Murwangi Site B (right). (Richard Noske)

Robins were found at three sites around Murwangi. Three pairs occupied Site A, a narrow thicket of low (5-7 m) but densely-foliaged trees between the camp and the edge of the billabong, with which it was parallel. The approximate dimensions of the thicket were 30-50 m wide by approx. 600 m long, indicating each pair occupied a territory of approx. 0.8 ha. The density of vegetation varied along the length of the thicket, from large groves of closely-packed, spreading trees with abundant vines, a dense understory of saplings and well-developed litter layer, to small, widely-spaced copses with no understorey and a sparse grassy ground cover (Figures 2, 3). The dominant tree species was *Barringtonia acutangula*, while *Cathormium umbellatum* was co-dominant in the dense sections, and *Antidesma ghesaembilla* was patchily common.

Site B, on the other side of the floodplain on the northern side of the Camp and approx. 1 km from Site A, comprised a narrow (approx. 30 m wide by 400 m long) but very dense thicket of young Gebang Palms (*Corypha utan*), mostly approx. 4-8 m high, fringed by scattered taller palms and Cajaput (*Melaleuca cajaputi*), along a drainage line that emptied into a narrow arm of the billabong (Figure 4).

The nearest free-standing water was approx. 100 m away. This thicket was occupied by three or four Mangrove Robins, suggesting a density of 0.3–0.4 birds per hectare. Finally, at least one pair was present in recently burnt vegetation along a short but relatively deep channel (Site C) draining into the billabong, approx. 600 m from Site B. The pair was regularly seen perched on half-submerged logs and cane grass on the banks of the channel, which was lined with tall (12–15 m) Leichhardt Trees (*Nauclea orientalis*) and *Barringtonia acutangula*, with patches of Bamboo (*Bambusa arnhemica*).

Figure 5. Mangrove Robin at Murwangi Site A preparing an insect larva for ingestion. (Richard Noske)

Robins at Site A were observed foraging in litter on the ground shaded by the dense canopy. Two birds were observed pouncing on the ground five times during 15 minutes. Both were observed capturing insect larvae on the ground, then returning to elevated perches, where the prey was whacked on a branch before being ingested (Figure 5). On 8 and 9 October, R. Noske found one or both members of another pair repeatedly performing feigned injury distraction displays when encountered. The bird would fly to the ground, spread one or both wings, and hop away from the observer, dragging one or both wings (Figure 6), and sometimes erecting

Figure 6. Adult Mangrove Robin feigning injured wings in an attempt to draw the observer away from its offspring at Murwangi Site A. (Richard Noske)

Figure 7. Fledgling Mangrove Robin at Murwangi Site A on 9 October 2016. (Richard Noske

the feathers of the back. After more than one hour of searching by R. Noske, a recently-fledged young bird was found (Figure 7).

Discussion

The Top End and Kimberley region of northern Australia is endowed with more mangal-specialised birds than anywhere else in the world (Noske 1996). While many common inhabitants of Top End mangals, such as the Shining Flycatcher (*Myiagra alecto*) and Brown (Grey) Whistler (*Pachycephala simplex simplex*), are also common in monsoonal rainforests, the Mangrove Robin is one of several species that is generally considered as dependent on coastal mangals, apparently specialised for feeding on crustaceans in the mud (Schodde *et al.* 1982; Boles 1988; Johnstone 1990; Noske 1996). Indeed Johnstone (1990) posited that the distribution of the species in northern Western Australia was closely tied to the presence of *Rhizophora,* which provided numerous low level perches in the form of prop roots, and contained a greater density of insects than other mangroves.

In contrast to the above, our observations around Murwangi Safari Camp show that there is a small localised population of Mangrove Robins inhabiting floodplain-fringing thickets on the edge of a permanent freshwater billabong, 25 km from the coast. Given the presence of other perennial water bodies and potentially suitable habitat in the Arafura Swamp, and the brevity of this study, it is possible that this inland population is more substantial. In New Guinea, as well as inhabiting Melaleuca swamp forest on seasonally inundated subcoastal lagoons, the species has been recorded well inland at Lake Daviumba, middle Fly River, and along the middle Sepik River, where it inhabits riverside reed beds mixed with shrubs (Coates 1990).

A somewhat similar case of habitat variation is provided by the Chestnut Rail (*Eulabeornis castaneoventris*), which is normally considered one of the most specialised mangal-dwellers, feeding almost entirely on crabs and other crustaceans from the mud (Johnstone 1990; Noske 1996; Mohd-Azlan *et al.* 2012). Yet on the Wessel and British Company Islands, Woinarski *et al.* (1998) found this species foraging on intertidal sandstone platforms and boulders that were far from mangroves, and once even in eucalypt forest 400 m inland. Moreover, evidence suggested that the Rails frequently used stone anvils to break open snail shells, most likely containing hermit crabs. Accordingly, Woinarski *et al.* (1998) cautioned against characterising a species from studies in a single habitat or a few locations.

Typical of Australia's tropical birds, the breeding biology of Mangrove Robins is poorly known, few nests having been reported in the last century (McCrie & Noske 2015). Given that its closest Australian relative is thought to be the Hooded Robin (*Melanodryas cucullata*), which has incubation and nestling periods of 15 and 12 days (Higgins & Peter 2002), the young bird at Murwangi probably hatched from an egg that was laid around 12 September 2016. This date is consistent with data from elsewhere in the Top End, which suggest a long breeding season from at least September to May (Higgins & Peter 2002; McCrie & Noske 2015). However, dates of sightings of fledglings and of moult on captured adults hint at a biannual breeding season, similar to that of the Lemon-bellied Flyrobin (*Microeca flavigaster*), with peaks in March–May and September–October (Noske 2003, unpubl. data). A detailed study of the species would be useful in clarifying its annual cycle.

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Distribution and abundance of migratory shorebirds in Darwin Harbour, Northern Territory, Australia

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Abstract

Here we report the results of an aerial survey of migratory shorebirds in Darwin Harbour, Northern Territory, Australia, as part of a new project on strategic planning for the Far Eastern Curlew (*Numenius madagascarensis*). On one day in January 2017 we surveyed the intertidal zone of a large part of upper and middle Darwin Harbour at low tide and counted all shorebirds and waterbirds present, and then we also surveyed all saltpans and potential roosting areas at high tide. There were 724 birds of 19 species recorded during the low tidal survey and 789 birds from 13 species recorded during the high tidal survey (i.e. a total of 24 species for the day). We found a total of 329 Far Eastern Curlews during the high tide survey, an increase in the Darwin Harbour maximum previously recorded. We will use these results to guide future monitoring work on the Far Eastern Curlew in Darwin Harbour, and to help mitigate the effects of coastal developments on shorebirds.

Introduction

Most shorebirds in Australia are long-distance migrants that breed in Siberia, Alaska or China, and visit Australasian shores during the austral summer. These shorebirds migrate between hemispheres along the East Asian-Australasian Flyway (hereafter the EAAF), but habitat destruction in the Yellow Sea region is driving population decline for many species (Szabo *et al.* 2012; Murray *et al.* 2014; Clemens *et al.* 2016; Conklin *et al.* 2016; Piersma *et al.* 2016). Once in Australia, shorebirds spend the duration of the austral summer seeking out high quality food resources. As most coastal shorebirds feed on benthic invertebrates on exposed mudflats during low tide, foraging and roosting times are dictated by tidal cycles. At high tide, when the foraging grounds are submerged, shorebirds retreat to roosts on sandy beaches, rocky reefs, dykes and ponds, where they preen or rest.

Figure 1 (above). Far Eastern Curlews (*Numenius madagascariensis*) in flight. (Amanda Lilleyman)

Figure 2 (inset right). A male Far Eastern Curlew in flight. (Amanda Lilleyman)

There are 37 species of migratory shorebirds that regularly visit Australia (Commonwealth of Australia 2015), and 25 of them occur along the coastlines of Darwin Harbour in the Northern Territory (A. Lilleyman, unpubl. data). There are seven species of shorebirds classified as Threatened under the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act); all occur in Darwin Harbour. The focal species of this study is one of them, the Far Eastern Curlew (*Numenius madagascariensis*) (Figures 1 and 2). In fact its conservation status was recently upgraded to Critically Endangered under the EPBC Act due to reported population declines over the last thirty years from monitoring sites around Australia (Department of the Environment and Energy 2015). Internationally it is listed as Endangered (BirdLife International 2016). It is the largest of the annual migrant shorebirds that travel along the EAAF, to which it is endemic (Higgins & Davies 1996).

Darwin Harbour has a variety of coastal habitats that migratory shorebirds use during the non-breeding season. This includes natural sites such as beaches, rocky reefs, intertidal sand and mud flats, but also an artificial site – the dredge ponds at Darwin Port's East Arm Wharf (Figure 3). This site regularly provides safe roosting habitat for over 1000 shorebirds of 25 species plus 45 species of other waterbirds or water-associated birds (Lilleyman 2016). In contrast to the rest of the species' range (Clemens *et al.* 2016;

Studds *et al.* 2017), the Far Eastern Curlew has been counted in increasing numbers in the Darwin region – at Lee Point in Darwin's northern suburbs – over the last 30 years, and at East Arm Wharf since 2009 (Lilleyman *et al.* 2016b).

In Australia, the key threats to migratory shorebirds are coastal development that destroys habitat and disturbance that disrupts their normal activities (Harding *et al.* 2007). These threats are both present in the Darwin region and the effects of anthropogenic disturbance to shorebirds have been documented (Lilleyman *et al.* 2016a). Safe roosting sites are critically important for shorebirds that feed on coastal intertidal zones that become inundated by the tide twice a day. East Arm Wharf provides secure and safe roosting habitat for shorebirds because human access to the site is restricted. Far Eastern Curlews regularly occur at the site in nationally important numbers (criterion: 0.1% of the EAAF population) during spring high tides (Lilleyman *et al.* 2016b), suggesting that a large proportion of the population uses this site when other roosting sites are not available. The connectivity and availability of these sites at various tide cycles is crucial for managing the shorebird populations in Darwin Harbour.

Migratory shorebirds select roosting sites that are close to feeding grounds to allow short commutes twice a day. In tropical locations, both roosting and feeding sites need to be in areas where birds can thermoregulate to avoid heat stress (Rogers *et al.* 2006; Rosa *et al.* 2006; Zharikov & Milton 2009). Shorebirds will often use a network of sites in a region for roosting and feeding to ensure that there is always one site available at which they can forage. Far Eastern Curlews are solitary foragers and defend small territories across intertidal mudflats (Jackson 2017). On Stradbroke Island, in southern Queensland, territory size varies from 0.22–0.85 ha, depending on densities of favoured prey (Zharikov & Skilleter 2004) and in Moreton Bay, also in southern Queensland, the Curlews operate daily at scales of 5–10 km (Finn *et al.* 2002). Prey abundance and thus territory size are yet to be measured in Darwin Harbour but will affect both the abundance and dispersion of Curlews across the Darwin Harbour intertidal zone.

Darwin Harbour is likely to undergo substantial development over coming decades. Under the *EPBC Act*, new developments need to take the needs of protected threatened species into account. This can only be done if there is a greater understanding of how the different species use the available habitat and the extent to which sites are connected. This project on the Far Eastern Curlew will contribute to this understanding so the deleterious effects of coastal development can be minimised. This preliminary survey builds on an intensive monitoring program for shorebirds at the Port of Darwin. The aim of the aerial survey was to record all migratory shorebirds and other waterbirds observed in the study area. While our main focus was on Far Eastern Curlews, we took the opportunity to survey all other bird species that utilise the intertidal zone. The result is a detailed survey of shorebird abundance and distribution at low and high tide during the core non-breeding period in Darwin Harbour. We also present the first full count of Far Eastern Curlew numbers in the Harbour.

An additional factor in the research of which this survey forms part, is that it is a partnership between researchers at Charles Darwin University and the Larrakia people, the Traditional Owners of the habitat where the Curlew occurs. Far Eastern Curlews and other shorebird species have been recorded at the Larrakia sacred site Yirra (Catalina Island) to the east of East Arm Wharf. There is extensive overlap between the habitat used by Far Eastern Curlews and areas that are culturally important to Larrakia people. Extensive middens around the fringes of Darwin Harbour attest to a long and continuing history of use of the mangroves and mudflats around the edges of the Harbour that are non-breeding habitats for the Far Eastern Curlew. Such resource use, however, can only continue if the environment remains in a healthy and productive state. Larrakia people are already working with university researchers to monitor pollution levels in shellfish around the Harbour. The current project will allow us to understand how the resources are being used by the threatened birds that also use Larrakia's land and sea areas.

The Darwin Port corporation, a major stakeholder in the long-term planning of Darwin Harbour and the associated coastline, is a partner in this project and aims to assist in the management of globally-threatened shorebirds through appropriate and sustainable decision-making. The Port of Darwin corporation currently manages the nationally important habitat for the Far Eastern Curlew at East Arm Wharf and will seek to understand how the species uses other feeding and roosting habitats in Darwin Harbour as a contribution to long-term strategic planning.

Methods

We conducted an aerial survey of Darwin Harbour using a helicopter on Thursday 12 January 2017 during low tide (10.15 hr to 12.15 hr) and then again at high tide (17.00 hr to 18.30 hr). Low tide (0.75 m) occurred at 12.09 hr and high tide (7.63 m) occurred at 18.44 hr that day. An aerial survey allowed full coverage of Darwin Harbour during one full tidal cycle and gave us access to saltpan habitat that would otherwise be inaccessible by road.

During the low tidal phase of the survey, we flew over the intertidal zone along the edge of the mangroves starting from Dinah Beach Boat Ramp (12.44°S, 130.85°E) through to Mandorah Wharf (12.44°S, 130.76°E) (Figure 3). We circumnavigated all the small islets and flew over exposed sandbars. During the high tidal phase of the survey, when the intertidal zone was covered, we flew low over mangroves and supratidal saltpans where, from experience, we expected shorebirds to be roosting (Figure 4). This meant that we omitted the southern ends of the three arms of the Harbour because there are no saltpans behind the mangroves where roosting birds were likely to be visible from the air. For surveying, A. Lilleyman and S. Garnett called out counts of all shorebirds and waterbirds, and A. Lilleyman recorded all birds observed and made notes on habitats into a hand-held voice recorder (Sony ICD-PX440). Survey personnel avoided duplicating observations by making counts from different sides of the helicopter. When shorebirds

Figure 3. Far Eastern Curlews roosting with other waterbirds in a dredge pond at Darwin Port's East Arm Wharf. This photo alone yields a count of Far Eastern Curlews that exceeds the national threshold for that species of bird. (Amanda Lilleyman)

were not easily identified from the air, they were classed as either 'Small' or 'Medium' based on their size. The recording data were later transcribed into a database.

During the high tidal phase of the survey, an experienced shorebird counter (G. O'Brien) was stationed at East Arm Wharf roost to count all birds present at the site, while A. Lilleyman and S. Garnett surveyed additional sites in the region. This on-ground survey was conducted between 16.00 hr and 19.00 hr. Once all high tidal sites had been surveyed, we flew over East Arm Wharf to count shorebirds at the Darwin Port corporation's ponds and later ground-truthed this by comparing with the East Arm Wharf on-ground count. The timing of arrival of birds at the Port's ponds was recorded and this was checked against records of birds away from the site to avoid duplication in the final estimate of birds.

Results

Abundance of migratory shorebirds in Darwin Harbour

We recorded 724 individuals of 19 species of bird during the low tidal phase of the survey (Table 1) including 160 Far Eastern Curlews. All the Curlews were feeding on the exposed intertidal mud alone or in loosely associated pairs. At the lowest tide they were commonly feeding in the middle of the mudflat, often along small drainage channels, though this was difficult to quantify.

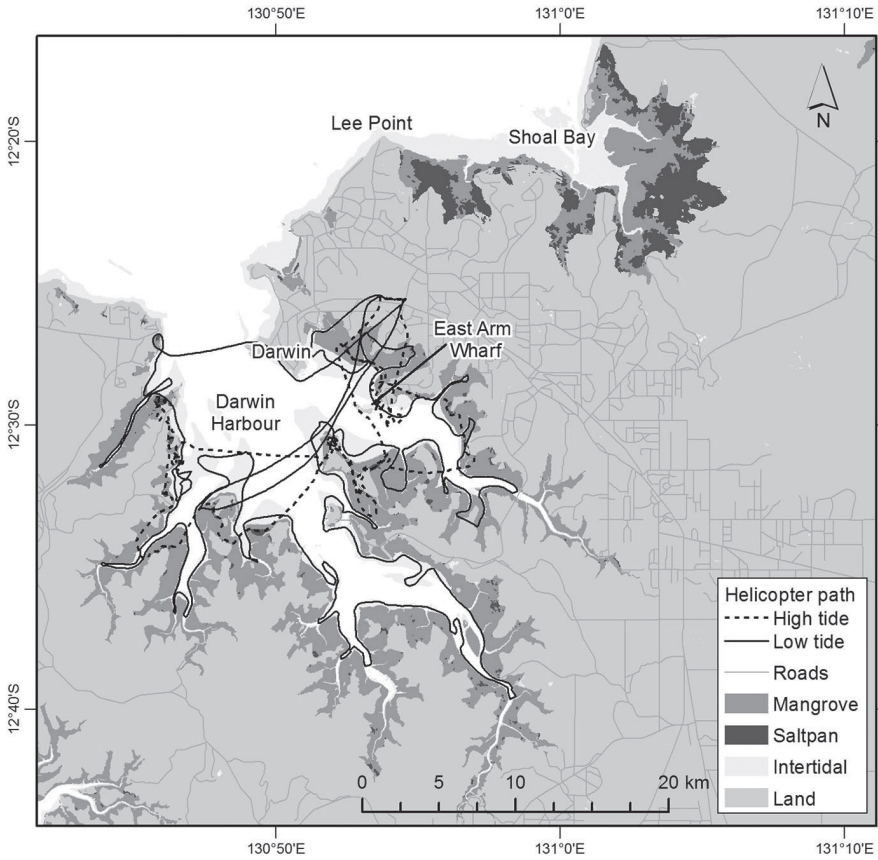

Figure 4. Map of the survey area in Darwin Harbour and the path flown during high tide and low tide.

At high tide we located 789 individual shorebirds belonging to 13 species (i.e. a total of 24 species for the day), including 185 Far Eastern Curlews. Many of the Curlews were roosting in small flocks with a median group size of 2 individuals, a mean group size of 7 and a maximum of 60.

At East Arm Wharf, 388 individuals from 14 species were counted from the ground (Table 2). This included 144 Far Eastern Curlews. These individuals were in addition to the 185 Far Eastern Curlews that we recorded in Darwin Harbour during the high tidal survey. The total population of Far Eastern Curlews in Darwin Harbour on 12 January 2017 was therefore 329 individuals. This is greater than the previously recorded maximum count of Far Eastern Curlews for the East Arm Wharf site (264 individuals recorded during the December monthly high tide count).

Table 1. Total count of migratory shorebirds recorded in Darwin Harbour during low tide and high tide on 12 January 2017.

Species	Low tide	High tide
Grey Plover	0	3
Bar-tailed Godwit	0	30
Whimbrel	104	344
Far Eastern Curlew	160	329
Terek Sandpiper	2	0
Common Sandpiper	42	0
Grey-tailed Tattler	14	0
Common Greenshank	46	16
Small	167	66
Medium	118	13

Note: The 'Small' component of this count comprises Red-necked Stint, Common Sandpiper, Terek Sandpiper, Grey-tailed Tattler, Red Knot, Great Knot, Ruddy Turnstone, Sharp-tailed Sandpiper, Greater Sand Plover, and Lesser Sand Plover. The 'Medium' component of this count comprises Common Greenshank, Grey Plover, and Bar-tailed Godwit.

Table 2. Count of migratory shorebirds from East Arm Wharf (on-ground count) during the high tidal survey of 12 January 2017.

Species	Total count
Grey Plover	6
Bar-tailed Godwit	3
Whimbrel	116
Far Eastern Curlew	144
Common Greenshank	50
Marsh Sandpiper	2
Sharp-tailed Sandpiper	8

Distribution of the Far Eastern Curlew in Darwin Harbour

Far Eastern Curlews were found to be widely distributed throughout Darwin Harbour during the aerial survey conducted at low tide (Figure 5). Most were recorded foraging on the inner section of the mud flats closer to the mangroves than the outer section of the mud flats towards the lowest tide height (see 'Intertidal' layer on map of Figure 5). They were recorded in small flocks during the high tidal period when they were roosting, primarily in supratidal saltpans, above the high-water mark (Figure 6). Shorebirds were forced out of these saltpans once the tide had reached its peak height and they flew to roosts on islands, in mangroves, or on beaches. Some shorebirds, including Far Eastern Curlews, roosted at the East Arm Wharf site, and even when perturbed at the site during the aerial survey, they returned to roost in the artificial dredge ponds.

Curlews recorded during the low tidal survey had to fly from different parts of the Harbour to roost at East Arm Wharf. The straight line distance between foraging sites at low tide and the East Arm Wharf roost site varied from 2.5 to 19.6 km, with an average of 9.7 km. Although birds recorded on the intertidal zone at low tide were always close

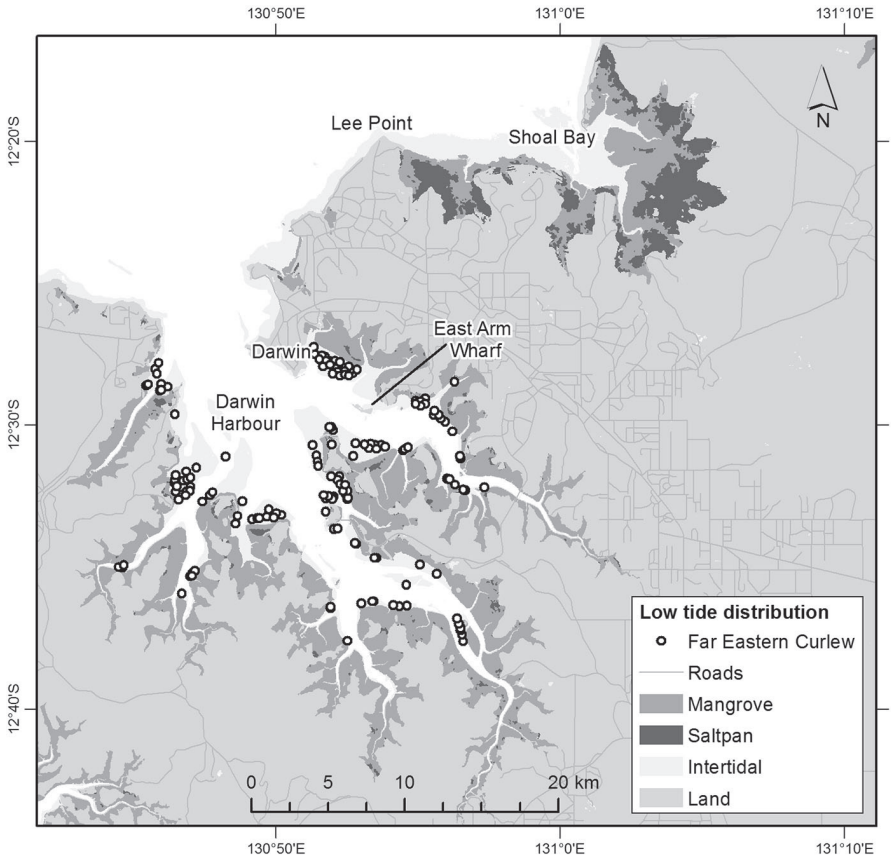

Figure 5. Distribution of Far Eastern Curlews recorded during low tide in Darwin Harbour.

to supratidal saltpans, these are not available during high spring tide heights because they are covered in deep water. At such times we believe that most, if not all, the Curlews around the Harbour roost at East Arm Wharf, although other roosting sites may be important on lower high tides or as staging posts while the tide is rising.

Nationally important roosting sites

During the count of high tidal roosts, we recorded two locations where flocks of Far Eastern Curlews had more than 31 individuals (Figures 3, 6). This meets the threshold for protection of threatened shorebirds under the EPBC Act, which is 0.1% of the flyway population. One flock was recorded at East Arm Wharf, where large congregations of greater than or equal to 31 individuals assemble frequently. The other flock was at the saltpan, south-east of East Arm Wharf, adjacent to the ConocoPhillips LNG Plant, although this roosting site may not be available at the highest tides.

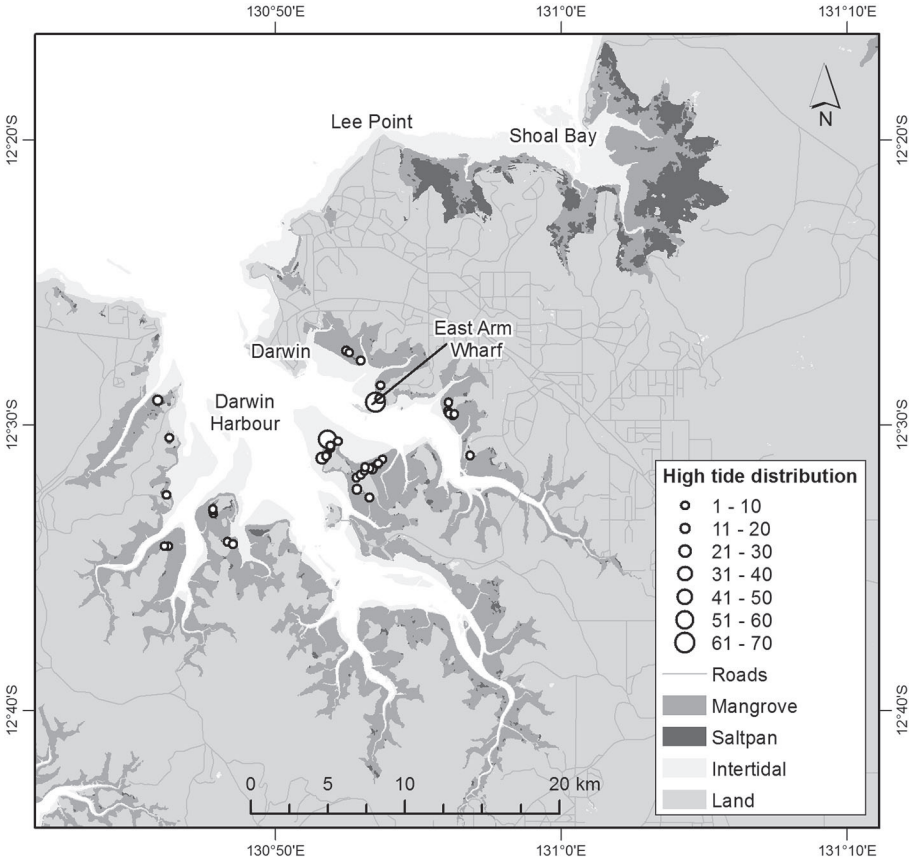

Figure 6. Distribution of Far Eastern Curlews recorded during high tide in Darwin Harbour. Legend shows count size classifications. Flocks of this species greater than or equal to 31 individuals indicate representation at sites considered as nationally important under the *Environmental Protection and Biodiversity Conservation Act* 1999.

Discussion

Distribution and abundance

Most migratory shorebirds observed in this study were sparsely distributed over the intertidal mudflats of Darwin Harbour during low tide. Some areas were devoid of birds, whilst at others individuals had congregated in small feeding flocks. Most Curlews were feeding on the upper half of the mudflat exposed at low tide during which we surveyed from near the mangroves to half way out to the sea with only a few at the edge of the water. This suggests that Far Eastern Curlews may not strictly follow the tide when foraging. We observed high abundances of crabs in the middle of the exposed areas at low tide and this might influence where Far Eastern Curlews forage, as crustaceans are

its preferred prey (Finn *et al.* 2008). Also, if Curlews are defending territories, they may only defend mudflats exposed at most tides and not those exposed only at the lowest spring low tides (the timing of the current survey).

The abundance and distribution data reported from this aerial survey will be used to guide the fieldwork program for the strategic planning project on the Far Eastern Curlew, including the benthic invertebrate monitoring component which will examine the availability of food for Curlews. Understanding the types of prey and how much of it is available to shorebirds will help determine the habitat requirements of these birds in Darwin Harbour. Prey distribution influences shorebird distribution across the intertidal habitat (Ponsero *et al.* 2016), and tidal cycles constrain both the movement of benthic invertebrates and the available time for shorebirds to forage (Kraan *et al.* 2009). Our aerial survey has shown where Far Eastern Curlews forage during low tide, but it has not shown the distances these birds move within the Harbour during a complete tidal (high to low) cycle. Our next project is to examine the movement of individuals in Darwin Harbour to explore the connectivity within the region. Migratory shorebirds require a network of high-quality sites at both a flyway scale and at a local regional scale to migrate and breed successfully each year (Aharon-Rotman *et al.* 2016).

Understanding habitat choice of shorebirds allows informed management of important habitat, which in turn can secure the protection of these birds. Migratory shorebirds will require a range of roosting and feeding sites in Darwin Harbour so they can move between sites if the optimal habitat is disturbed or unavailable due to tidal conditions. It will be important to ensure there is an adequate array of roosting sites for shorebirds as a reduction in these may lead to increased competition for resources (Goss-Custard *et al.* 2002) or, in extreme circumstances, a population crash if suitable habitats are not available (Burton *et al.* 2006).

The use of the East Arm Wharf site by Far Eastern Curlews (and many other species of shorebirds) (Figure 3) documented during the survey reported here suggests an ongoing attraction to this artificial habitat. The high count from the current survey represents a substantial increase in Curlews for the Darwin Harbour area compared to those reported previously (Chatto 2003). The results from this study coupled with the local-scale increases as reported by Lilleyman *et al.* (2016b) show that this species can adapt to local habitat changes if the alterations to the environment provide a net increase in habitat availability. The East Arm Wharf site is evidently now providing high quality roosting habitat for Far Eastern Curlews and other shorebirds and waterbirds. These birds roost there in preference of all other roosting sites in Darwin Harbour, as evidenced by the large number of birds at the site, relative to the total Darwin Harbour population.

In Darwin Harbour, shorebird numbers may be constrained by the availability of roosting sites. Feeding grounds appear to be widely available with extensive intertidal areas within the region, although the quality of these mudflats is yet to be tested.

Although Far Eastern Curlews were always close to potential saltpan roost sites when they were feeding at low tide, the saltpans are inundated at the highest tides. The birds can then roost in mangroves or fly to East Arm Wharf. This latter site is apparently being adopted by increasing numbers of migratory shorebirds, including the Curlews. Indeed, the increasing numbers counted at East Arm Wharf may be because the availability of the roosting site there is allowing more birds to feed in Darwin Harbour. Given the length of time over which the increases have been sustained, this seems a more probable explanation than the alternative explanation, which is that birds traditionally using the Harbour have only gradually come to know the quality of the East Arm Wharf roosting site. However, the distance the Curlews appear to be travelling to East Arm Wharf from feeding areas is longer than is usual among shorebirds (Jackson 2017). This in turn implies that the creation of additional roosting sites could further increase the quality of the Harbour to migratory shorebirds if food is available.

Conclusion

The low tidal survey revealed a high level of usage of mudflats by the Far Eastern Curlew with birds feeding on mudflats around almost all the Harbour, particularly on the broader tidal flats. Roosting occurred on saltpans but, when these were inundated, many birds moved to East Arm Wharf. The survey confirmed that the artificial East Arm Wharf site has become the most important roosting site for the Far Eastern Curlew within Darwin Harbour. The site is also particularly important for other species of migratory shorebirds throughout the austral summer. The new maximum count for the Far Eastern Curlew of 329 birds is an increase in the population estimate for this species and shows that there are more birds in the Darwin region than previously recorded. This study, along with recent research (Lilleyman *et al.* 2016b), provides an opportunity to further manage an artificial site for positive conservation outcomes for migratory shorebirds. Management of the Far Eastern Curlew in Darwin Harbour requires a holistic approach so that the species, and other migratory shorebirds, are adequately protected against the potential impacts of coastal development.

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Nematodes from northern Australian reptiles

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Abstract

Twenty-one species of nematode were identified from the gastrointestinal tract or body cavity of 131 individual lizards and snakes comprising 26 species. In 13 host species, only a single individual specimen was available, and the aquatic Keelback snake (*Tropidonophis mairii*) comprised almost half the specimens examined. In general, nematode intensity was low, and only a single adult nematode specimen was present in most of the reptiles examined. Most nematode species showed specificity to one host family, except for *Abbreviata bancrofti,* which was recovered from six species across four families. A total of 21 new host-parasite records and one new locality record are listed, with a number of reptile species reported as a host for a nematode for the first time.

Introduction

Nematode parasites are widespread in snakes and lizards in Australia (Pichelin *et al.* 1999). Gastrointestinal nematodes of varanid lizards and of pythons have been relatively well studied from northern Australia, revealing that these reptiles support a rich nematode fauna, some species showing marked host specificity and geographical range limitations (Jones 1979, 1988; Mulder & Smales 2015). A recent study on the nematodes of the Keelback snake (*Tropidonophis mairii*) showed very high infection prevalence with the spirurid nematode *Tanqua anomala* but with limited negative impacts on the health of the host (Mayer *et al.* 2015). Little is known, however, of nematodes found in other reptile groups in northern Australia. During the course of various projects undertaken on reptiles in this area over many years, reptiles were dissected, and any helminths found were removed for subsequent study. For this paper we examined previously unstudied nematodes dissected from host specimens in the collections of the Museum and Art Gallery of the Northern Territory, the Queensland Museum, and the Australian Museum, as well as from the personal collections of the authors. These nematodes were identified, host specificity and associations between species investigated, and the host habitat and geographical range noted.

Methods

Preservation of nematode specimens varied, depending on host source (dissections of fresh road-killed specimens or previously preserved museum specimens) and the collector of the nematodes. Thus, some specimens were initially preserved in 10% formaldehyde whereas others were preserved in 70% ethanol; all specimens were subsequently stored in 70% ethanol. Before examination, the nematodes were cleaned then cleared in chlorolactophenol and examined under a BA series Olympus microscope.

Museum reference numbers and infections of every individual reptile examined in this study are given in Table 1. The listed intensity of infection data needs to be treated with caution, especially for records from museum host specimens. Many of these specimens were difficult to dissect due to preservation shape (for example, snake specimens are coiled into jars), the inability to complete a full dissection to preserve the host specimen intact as much as possible, and in many cases, prior dietary studies conducted on the specimens had removed or emptied the contents of their stomach. Accurate records for uninfected snakes sourced from other studies were unavailable, thus prevalence data presented here are incomplete and should also be treated with caution.

Results

A total of 131 individual host specimens, comprising 26 species across 9 families were found to be infected with nematodes (Table 1). The hosts were lizards of the families Agamidae (3 species), Carphodactylidae (1), Diplodactylidae (2), Gekkonidae (1), Scincidae (2) and Varanidae (3), and snakes of the families Boidae (4), Colubridae (2) and Elapidae (8). Twenty-two reptile species were represented by five or less individuals. The samples were dominated by the aquatic colubrid snake *Tropidonophis mairii*, which accounted for almost half of the host specimens examined.

Species identified

At least 21 nematodes (excluding larvae) were identified from the reptiles examined in this study (Table 2); 13 were identified to species, 6 were identified to genus and 2 could only be identified to family level. Larval and immature stages were also reported (Table 1). Eleven new host-parasite records were observed: *Physalopteroides filicauda* in the Eastern Water Skink (*Eulamprus quoyii*)*; Abbreviata hastaspicula* in the Woma (*Aspidites ramsayi*); *Tropidonophis mairii* in Spencer's Monitor (*Varanus spenceri*); *Abbreviata bancrofti* in *Tropidonophis mairii*, the Lesser Black Whipsnake (*Demansia vestigiata*) and the Eastern Brown Snake (*Pseudonaja textilis*)*; Tanqua tiara* in the Northern Death Adder (*Acanthophis praelongus*); *Dracunculus mulbus* in *Tropidonophis mairii* and the Black-headed Python (*Aspidites melanocephalus*); and *Maxvachonia brygooi* in the Asian House Gecko (*Hemidactylus frenatus*). In addition, the following genera were recorded for the first time from these hosts: *Ophidascaris* sp. 1 in the Coastal Taipan (*Oxyuranus scutellatus*)*; Ophidascaris* sp. in the Orange-Naped Snake (*Furina ornata*); *Pharyngodon* sp. in the Chameleon Gecko (*Carphodactylus laevis*); *Skrjabinodon* sp. and Pharyngodonidae sp. in the Northern Velvet Gecko (*Oedura castelanui*); and *Kalicephalus* sp. in the Slatey-grey Snake (*Stegonotus cucllatus*),

Tropidonophis mairii and *Acanthophis praelongus*. The presence of immature *Eustrongylides* sp. in *Tropidonophis mairii* and larval Physalopteridae in the Zigzag Velvet Gecko (*Amalosia rhombifer*) and the Eastern Barred Wedgesnout Ctenotus (*Ctenotus strauchii varius*) are new host records. The report of *Parapharyngodon maplestoni* in *Hemidactylus frenatus* is a new locality record.

Intensity of infection

For most of the nematode species, the intensity of infection was low. Additionally, for a large number of records, only one individual of each host species was examined. Thus the true range of intensity of infection remains unknown. In skinks and geckoes, all of which were physically small, the intensity of infection, primarily by pharyngodonids, was generally less than five individuals. However, in snakes, intensity of infection was often greater than 10 individuals, although where more than one species of nematode was present, one was usually present in much higher levels than the other. The parasites with highest intensity were: *Tanqua tiara* in the Yellow-spotted Monitor (*Varanus panoptes*) (intensity over 400); *Abbreviata hastaspicula* in *Varanus spenceri*) (Spencer's Monitor) (intensity of 250) and the Sand Monitor (*Varanus gouldii*) (intensity ranging from 35 to more than 100); and *Abbreviata bancrofti* from *Demansia vestigiata* at a mean intensity of 48 (27–69) for the two Northern Territory specimens and at 17 (1–50) for the six northern Queensland specimens. However, for all of these host species, less than 10 specimens and often only one specimen, were examined. For the most represented host in this study, *Tropidonophis mairii*, the nematode *Tanqua anomala* was recovered at a mean intensity of 31 (1–201). This would be a truer reflection of the range of intensity of infection in this host species as the snakes were specifically examined for infection levels as part of the study by Mayer *et al.* (2015).

Host specificity

Pharyngodonid nematodes and physalopterid larvae occurred only in the smaller skinks and geckoes. *Maxvachonia brygooi* was only found in the introduced gecko *Hemidactylus frenatus*. *Strongyluris paronai* only occurred in the agamid lizards. *Kalicephalus* sp., Spiruridae sp., *Eustrongylides* sp. and adults of *Ophidascaris* spp. were all reported only from snakes. *Tanqua anomala* was reported only from *Tropidonophis mairii*, whereas *Tanqua tiara* was reported from a range of snakes and varanids. The various species of *Abbreviata* were found to infect a range of hosts across the major families; for example *Abbreviata bancrofti* was recovered from six species of reptile, across four families.

Discussion

Most reports of nematode infections in reptiles in Australia are anecdotes associated with the descriptions of new species of nematodes. However, a few recent studies have reported aspects of the ecological relationship between nematodes and their hosts (Barton 2015; Mayer *et al.* 2015; Mulder & Smales 2015). Although a wide range of hosts were examined in this study, just one species, *Tropidonophis mairii*, dominated the study and it is the only host for which good ecological data can be presented.

It is unfortunate that many of the specimens of nematodes collected in this study were not in an optimal condition, being poorly preserved, incomplete, immature, or having only one sex available. And in many cases, only a single individual nematode was recovered. For this reason, full identification to species level was often not possible. However, this study has reported at least nine new host-parasite records and one new locality record, as well as increasing the knowledge of nematodes of many species of reptiles in northern Australia. This is especially true for the Northern Territory, an area that has been severely under-represented in previous studies. *Carphodactylus laevis, Oedura castelnaui, Amalosia rhombifer, Ctenotus strauchii varius, Stegonotus cucullatus, Acanthophis praelongus, Furina ornata, Demansia vestigiata* and *Oxyuranus scutellatus* are all reported as hosts for a nematode parasite for the first time.

In this study, representatives of the nematode genus *Ophidascaris* were recovered from a number of snakes as well as from a single varanid lizard. As discussed above, many of the specimens collected could only been identified to the genus *Ophidascaris*. Both *Ophidascaris moreliae* and *Ophidascaris robertsi* have previously been identified in the Children's Python (*Antaresia childreni*), *Aspidites melanocephalus* and the Carpet Python (*Morelia spilota*), with its congener *Ophidascaris robertsi* reported only from *Aspidites ramsayi* (Mawson 1955; Sprent & Mines 1960; Sprent 1969; Jones 1979). Differentiation of these two closely-related species depends on several characters, including the form of the lips, the presence or absence of a post-oesophageal caecum, cervical alae, and pitting on the surface of the eggs. Identification of specimens to *Ophidascaris moreliae/robertsi* was only possible for nematodes collected from a single *Morelia spilota* from an unknown collection location in northern Queensland. However, the quality of the specimens did not allow for identification to one or the other of the species.

Ophidascaris pyrrhus was originally described from a Red-bellied Black Snake (*Pseudechis porphyriacus*) originating from the central New South Wales coast (Johnston & Mawson 1942). It has subsequently been reported from a number of other elapid snakes from across Australia (Jones 1980; Pichelin *et al.* 1999). *Ophidascaris pyrrhus* was only found in one snake (a specimen of *Pseudechis porphyriacus* from northern Queensland) in the present study as an encysted larval stage.

Two males and one female of a species of *Ophidascaris* were recovered from *Oxyuranus scutellatus* from northern Queensland, in which the male copulatory spicules were abnormally long, being more than 10 mm in length, which is twice the length of those reported in *Ophidascaris pyrrhus* (Johnston & Mawson 1942). This suggests that the specimens collected belong to a different, possibly new, species of *Ophidascaris*. However these specimens were not in a sufficiently good condition to compare other morphological features. Nematodes are commonly found in *Oxyuranus scutellatus* (Hoser 2008), but none has previously been identified to species. Further collections of *Oxyuranus scutellatus* from northern Queensland, as well as other locations, are required for the collection of more nematodes to allow for accurate species identification.

The life cycle for most members of the genus *Ophidascaris* remains unknown, however, a mammalian intermediate host is required for development of *Ophidascaris moreliae* to an infective third stage larva (Sprent 1969), whereas *Ophidascaris pyrrhus* is thought to use lizards as its intermediate host (Sprent 1988). The diet of the snakes *Morelia spilota* and *Oxyuranus scutellatus* are both dominated by mammals, whereas the snakes *Antaresia childreni, Aspidites ramsayi,* the Rough-scaled Snake (*Tropidechis carinatus*) and *Pseudonaja textilis* have a more varied diet, with 30–50% being mammals, and *Pseudechis porphyriacus* has a diet dominated by reptiles and amphibians (Shine 1991). Interestingly, none of the colubrid snakes examined in this study were infected with any *Ophidascaris* species. The diet of *Tropidonophis mairii* is almost exclusively amphibians, whereas *Stegonotus cucullatus* has a reptile-dominated diet (Shine 1991), but as only two *Stegonotus cucullatus* were examined in this study, this needs to be treated with caution. *Strongyluris paronai* appears to be restricted to members of the Agamidae (Pichelin *et al.* 1999), and it was reported from both the Frill-neck Lizard (*Chlamydosaurus kingii*) and a Bearded Dragon (*Pogona* sp.) in this study. Previous reports of *Strongyluris paronai* are mainly from the Kimberley region in northern Western Australia (Jones 1986, 1994), with one study of the seasonality of infection in *Chlamydosaurus kingii* in Kakadu National Park (Griffiths *et al.* 1998). Due to the patterns of observation of larval and adult nematodes in *Chlamydosaurus kingii* by Griffiths *et al.* (1998), it is assumed that *Strongyluris paronai* has a direct life cycle, although Anderson (2000) suggested that insects might be utilised as transport hosts, with no development of the parasite within. Both *Chlamydosaurus kingii* and *Pogona* species are known to feed extensively on insects (Cogger 2014).

Representatives of the genus *Maxvachonia* have been reported from a number of lizards, mostly agamids, in Australia, with one dubious report from an elapid snake (Mawson 1972). Species of *Maxvachonia* have also been reported from a few skinks and varanids (Pichelin *et al.* 1999). Further examination of the specimens reported in Barton (2015) collected from *Hemidactylus frenatus* allowed for the specific identification to *Maxvachonia brygooi*. This represents a new host record for *Maxvachonia brygooi*. The life cycle of *Maxvachonia* has not been studied, but other members of the family Cosmocercidae have a direct life cycle, with the infective larva penetrating the host via the mouth or skin (Anderson 2000). As with *Strongyluris paronai*, described above, this nematode may utilise insects as transport hosts, although this has yet to be shown.

Members of the Pharyngodonidae are strictly monoxenous, with direct transmission through the ingestion of infective larvae within eggs (Anderson 2000). Members of the Pharyngodonidae are exclusively found in lizards, especially skinks (Pichelin *et al.* 1999). Pharyngodonids were only collected from geckoes in this study, however all other groups of lizards were only represented by one to three specimens. The vast majority of infections were of *Spauligodon hemidactylus* in *Hemidactylus frenatus*, as reported previously in Barton (2015).

Parapharyngodon maplestoni has previously been reported from *Hemidactylus frenatus* in various locations outside of Australia (South-East Asia and Oceania; Barton 2015),

but this is the first published record of this parasite in Australia. As with *Spauligodon hemidactyli* (Barton 2015), it is assumed that *Parapharyngodon maplestoni* has been introduced to Australia with its host. Further research will be required to determine if this species has spread to other native Australian reptiles.

A number of *Pharyngodon* species have been reported from a range of skinks and geckoes across Australia (Pichelin *et al.* 1999). The presence of a species of *Pharyngodon* in *Carphodactylus laevis* is a new host record.

A small number (seven) of species of *Skrjabinodon* have been reported from skinks and geckoes in Australia (Pichelin *et al.* 1999; Jones 2013). The presence of a species of *Skrjabinodon* in *Oedura castelnaui* is a new host record.

Dracunculus mulbus was originally reported from the tissues surrounding the organs in the body cavity of the Water Python (*Liasis fuscus*) from Fogg Dam, Northern Territory (Jones & Mulder 2007). *Dracunculus mulbus* occurs in the tissues or body cavity of its host and the true intensity of infection as well as potential range of host species may have been higher. Both *Tropidonophis mairii* and *Aspidites melanocephalus* are new host records, with both species collected from close to the type locality.

It is assumed that *Dracunculus mulbus* has an aquatic-based life cycle, as other members of the genus release larvae into the water from a blister in the skin, and the larvae develop to the infective stage within copepods before being ingested by a paratenic host, such as a tadpole (Anderson 2000). Thus, the aquatic snakes here could be infected via infected frogs, with *Tropidonophis mairi* known to feed primarily on them, although *Liasis fuscus* and *Aspidites melanocephalus* are not known to eat them, preferring either mammals or reptiles (Shine 1991).

The two species of *Tanqua* identified in this collection, *Tanqua tiara* and *Tanqua anomala,* were described by Linstow (1879, 1904) and both were redescribed by Baylis (1916), the former from species of *Varanus* and other aquatic and semi-aquatic reptiles in the Old World tropics, and the latter from the Checkered Keelback (*Xenochrophis piscator*) (previously known as *Tropidonophis piscator*) in Sri Lanka. *Tanqua tiara* occurred in high numbers in the single specimen of *Varanus panoptes* examined, and has been recorded at moderately high prevalence (25% to greater than 50%), at intensities of up to 120, in three species of *Varanus* from northern Australia (Jones 1988). *Tanqua anomala* occurred exclusively in the aquatic colubrid *Tropidonophis mairii*, with a mean intensity of 31 from the snakes examined in this study. Mayer *et al.* (2015) reported a mean intensity of 35 nematodes (0–243) for 93 *Tropidonophis mairii* examined from Fogg Dam; it is from these snakes that the nematodes examined in this study were taken.

The cases of *Tanqua tiara* infections reported in this study were from the Darwin and Fogg Dam region. Additionally, only in the Northern Territory was *Tropidonophis mairii* infected with *Tanqua anomala*, with none of the four *Tropidonophis mairii* collected from Queensland infected with any species of *Tanqua*. The collection location of *Tropidonophis*

mairii in Queensland is an area affected by tidal intrusion, thus the required intermediate hosts may not be able to survive in this area; however, further collections of snakes from other areas of northern Queensland are required to determine if this parasite does occur there or is restricted to the Northern Territory.

Physalopterid nematodes are the dominant gastric nematode in a number of Australian reptile families (Jones 1991, 2014). Adults of *Abbreviata* are the dominant genus in the larger reptiles (Jones 1991, 2014).The high intensities of *Abbreviata hastaspicula* in species of *Varanus* have been previously documented by Jones (2014). Physalopterid nematodes possess a two host life cycle, with an arthropod intermediate host and a paratenic host where the larva is found coiled within a cyst in the stomach wall (Jones 1991, 2014), as was found often in this study in the smaller species of reptiles examined. Identification of these larvae to species cannot be done through morphology alone (Jones 1991). It is unknown whether this cyst stage is a prerequisite for final maturity or whether there is some physiological clue in the (usually) larger final host for development to occur to adult (Jones 1991). Adult physalopterids were thought to be absent in colubrid snakes, with the exception of an unpublished report in Jones (2014). Reports from boid snakes were considered spurious, with nematodes found thought to actually have been infections in the prey items (Jones 2014). This study, however, confirms the presence of *Abbreviata* species in members of both these families in Australia.

Abbreviata bancrofti has a widespread distribution, and had been reported from 21 species across three families (Jones 2014). The colubrid *Tropidonophis mairii* is confirmed as a host species, as well as the additional elapids *Demansia vestigiata* and *Pseudonaja textilis*. The boids *Aspidites melanocephalus* and *Morelia spilota* are also reported as hosts in this study with infection levels similar to those found in the 'usual' hosts, which would tend to confirm that they are true hosts for these parasites. *Abbreviata bancrofti* is found in regions along the coastal eastern and southern fringe of Australia as well as the northern tropics in areas with higher rainfall levels (Jones 2014).

Abbreviata hastaspicula if predominantly found in drier areas and the northern tropics where the mean annual temperature is greater than 18°C (Jones 2014). *Abbreviata hastaspicula* had been exclusively reported from varanid lizards (see Jones 2014); this study reports the snakes *Aspidites ramsayi*, *Stegonotus cucullatus* and *Tropidonophis mairii* as hosts, although at much lower levels of infection that that reported for varanids.

Most of the reports for *Abbreviata* spp. were for immature specimens which were unable to be identified to species due to the lack of required taxonomic characters.

Physalopteroides filicauda was originally described from the Smooth Knob-tail Gecko (*Nephurus laevissimus*) (Jones 1985) and has subsequently been reported from a variety of lizards across all families, with the majority of records from Western Australia (Pichelin *et al.* 1999; Goldberg & Bursey 2012).

Members of the genus *Kalicephalus* have been reported from a small number of snakes across Australia (Pichelin *et al.* 1999). Unfortunately, none of the specimens collected in this study was suitable for providing a species identification, although they were considered closest to *Kalicephalus australiensis*. The life cycle of *Kalicephalus*, like other strongylids, is considered direct via ingestion of the infective larva, although the use of paratenic hosts cannot be ruled out (Anderson 2000). All of the infected snakes in this study came from Fogg Dam and all are new host records for members of this genus of nematode in Australia.

There are two previous records of *Eustrongylides* in Australia: *Eustrongylides acrochordi* (immature female) from the stomachs of two (out of eight) Arafura File Snakes (*Acrochordus arafurae*) (Jones 1978), an aquatic fish-eating snake, plus encysted in the livers of water pythons (*Liasis fuscus*) (Mulder & Smales 2015). Nematodes in the genus *Eustrongylides* usually have two intermediate hosts, with fishes being the usually recorded second intermediate host (Anderson 1992). Species of *Eustrongylides* mature in the proventriculus of fish-eating aquatic birds, and it is likely that *Acrochordus arafurae*, *Liasis fuscus* and *Tropidonophis mairii* were paratenic or accidental hosts (Jones, 1978; Mulder & Smales 2015; present study).

The host-specificities of nematodes recovered during this study correspond with those of previous studies (Jones 1980, 1983, 1988). The low host specificity of *Abbreviata bancrofti* has been noted previously (Jones 2014). The habitat range of this nematode's hosts is exemplified by its high prevalence and intensity in *Demansia vestigiata*, which normally inhabits drier habitats (Cogger 2014), and it was the second most common nematode in the aquatic *Tropidonophis mairii*. In 16 host species, only a single adult nematode specimen was recovered (Table 2). The intensity of most nematodes was low, and this finding in several host species accords with the conclusions of Mulder & Smales (2015) for infections in the python *Liasis fuscus*. In some cases however the finding of a single nematode may have been the result of accidental infection, the nematode having been ingested within the prey.

This study, therefore, confirms previous observations on host specificities and intensities of infection, and extends the known hosts of several species. Further studies with larger samples would provide a fuller picture of the nematode fauna of reptiles in northern Australia. Such basic data is needed to monitor possible faunal changes with both the advance of the Cane Toad (*Rhinella marina*) and changes in climate.

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Table 1. Individual reptile hosts of nematodes examined in this study, separated into A) lizards and B) snakes. Sources of hosts are listed as those dissected from the collections of the Museum and Art Gallery of the Northern Territory (NTM), the Queensland Museum (QM) and the Australian Museum (AM) and from specimens donated to DPB by staff of the University of Sydney Tropical Ecology Research Facility (TERF) or dissected by DPB at James Cook University, Townsville (JCU). The host registration number for museum specimens, where applicable, is listed; registration numbers for the collected nematodes is provided in the last column. Unreg denotes an unregistered specimen; unk denotes unknown information.

A. LIZARDS

Host Family	Host Species	State Collected	Location Collected	Source	Identification	Stage	Location in host	No.	Parasite Museum Deposit Number
Agamidae	*Chlamydosaurus kingii*	NT	Elcho Island	JCU	*Strongyluris paronai*	Adult	Stomach	1	NTM D1810
	Intellagama lesueurii	Qld	Tully Rd/Landstone Rd, Tully	JCU	*Abbreviata* spp.	Adult	Intestine	1	NTM D1778
	Pogona sp.	Qld	No collection data	JCU	*Strongyluris paronai*	Adult	Intestine	6	NTM D1809
Carphodactylidae	*Carphodactylus laevis*	Qld	Iron Range	JCU	*Pharyngodon* sp.	Adult	Intestine	2	N/A
Diplodactylidae	*Amalosia rhombifer*	NT	Cape Fourcroy, Bathurst Island	NTM R7889	Physalopteridae sp.	Larva	Wall of Stomach	1	NTM D1812
				NTM R7969	Physalopteridae sp.	Larva	Wall of Stomach	1	N/A
	Oedura castelnaui	Qld	Ayr District	JCU	Pharyngodonidae sp.	Adult	Rectum	1	NTM D1828
					Skrjabinodon sp.	Adult	Rectum	1	NTM D1798
Gekkonidae	*Hemidactylus frenatus*	NT	Beatrice Hill	NTM R1640	*Spauligodon hemidactylus*	Adult	Rectum	3	NTM D1648
			Berry Springs Reserve	NTM R6346	*Spauligodon hemidactylus*	Adult	Rectum	1	NTM D1631
			Black Point	NTM R20939	*Spauligodon hemidactylus*	Adult	Rectum	1	NTM D1639
			Croker Is, Mindjilang Community	NTM R20409	*Spauligodon hemidactylus*	Adult	Rectum	1	N/A
			Darwin	NTM R19816	*Maxvachonia brygooi*	Adult	Intestine	1	NTM D1819
					Spauligodon hemidactylus	Adult	Rectum	1	NTM D1638
				NTM R25671	*Parapharyngodon maplestoni*	Adult	Rectum	5	NTM D1641
				NTM R25980	*Spauligodon hemidactylus*	Adult	Rectum	1	NTM D1822
				NTM R0010	*Spauligodon hemidactylus*	Adult	Rectum	10	NTM D1625
				NTM R19815	*Spauligodon hemidactylus*	Adult	Rectum	1	NTM D1637
			Katherine	NTM R8142	*Spauligodon hemidactylus*	Adult	Intestine	1	NTM D1632
			New Year Island	NTM R7687	Physalopteridae sp.	Larva	Wall of Stomach	1	N/A
			Ti Tree	NTM R6564	*Spauligodon hemidactylus*	Adult	Rectum	1	NTM D1829
		WA	Christmas Island	NTM R19503	*Spauligodon hemidactylus*	Adult	Rectum	1	N/A
		Unknown	No collection data	NTM R3566	*Spauligodon hemidactylus*	Adult	Rectum	1	NTM D1628
Scincidae	*Ctenotus strauchii varius*	NSW	Sturt National Park	AM R151609	Physalopteridae sp.	Larva	Intestine	1	AM W49136
				AM R152920	Physalopteridae sp.	Larva	Intestine	1	AM W49137
				AM R152957	Physalopteridae sp.	Larva	Intestine	1	AM W49138

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Host Family	Host Species	State Collected	Location Collected	Source	Identification	Stage	Location in host	No.	Parasite Museum Deposit Number
	Eulamprus quoyii	Qld	Mimosa Creek, Blackdown Tableland, near Rockhampton	JCU	*Physalopteroides filicauda*	Adult	Intestine	1	NTM D1827
Varanidae	*Varanus gouldii*	NT	Darwin	NTM unreg	*Abbreviata hastaspicula*	Adult	Stomach	105	NTM D1771
				NTM unreg	*Abbreviata bancrofti*	Adult	Stomach	9	NTM D1747
					Abbreviata hastaspicula	Adult	Stomach	51	NTM D1747
					Ophidascaris sp.	Larva	Stomach	1	NTM D1797
					Tanqua tiara	Adult	Stomach	2	NTM D1782
				NTM unreg	*Abbreviata bancrofti*	Adult	Stomach	10	NTM D1772
					Abbreviata hastaspicula	Adult	Stomach	35	NTM D1772
					Tanqua tiara	Adult	Stomach	1	NTM D1781
		Qld	Ayr	NTM unreg	*Abbreviata* spp.	Adult	Stomach	1	NTM D1775
	Varanus panoptes	NT	Darwin	NTM unreg	*Tanqua tiara*	Adult	Stomach	420	NTM D1786
	Varanus spenceri	NT	Barkly Tablelands	NTM R28049	*Abbreviata hastaspicula*	Adult	Stomach	250	NTM D1774
B. SNAKES									
Host Family	**Host Species**	**State Collected**	**Location Collected**	**Source**	**Identification**	**Stage**	**Location in host**	**No.**	**Parasite Museum Deposit Number**
Boidae	*Antaresia childreni*	NT	Fogg Dam	TERF	*Ophidascaris* spp.	Adult	Intestine	25	NTM D1807
	Aspidites melanocephalus	NT	Darwin	NTM R8254	*Dracunculus mulbus*	Larva	Mesenteries	1	NTM D1633
			Katherine	NTM R242	*Abbreviata bancrofti*	Adult	Stomach	6	NTM D1626
		Qld	Clermont-Alpha Road	QM J60006	*Abbreviata bancrofti*	Adult	Intestine	8	QM G222593
			Longreach-Jundah Hwy, near Stonehenge	QM J73843	*Abbreviata bancrofti*	Adult	Intestine	9	QM G222591
		Unknown	No collection data	QMJ2259	*Abbreviata* spp.	Adult	Intestine	1	QM G222590
	Aspidites ramsayi	NT	Frewana	NTM R8498	*Abbreviata hastaspicula*	Adult	Stomach	5	NTM D1634
					Ophidascaris spp.	Larva	Body wall	1	NTM D1806
			No collection data	NTM unreg	*Ophidascaris* spp.	Adult	Stomach	5	NTM D1706
			Stirling Creek	NTM R31612	*Abbreviata hastaspicula*	Adult	Stomach	26	NTM D1643
					Abbreviata spp.	Adult	Rectum	1	NTM D1780
			Stuart Highway, 116km E of Three Ways	QM J52856	*Abbreviata hastaspicula*	Adult	Intestine	10	QM G222595
			Tennant Creek	NTM R26517	*Abbreviata hastaspicula*	Adult	Intestine	1	NTM D1642
		Qld	Bedourie	QM J18010	*Ophidascaris* spp.	Adult	Stomach	1	QM G222596
			Glenmorgan area	QM J40053	*Abbreviata* spp.	Adult	Intestine	3	QM G222594
	Morelia spilota	Qld	Bruce Highway, Ayr	JCU	*Ophidascaris* spp.	Adult	Stomach	1	NTM D1805
			Kareesa Power station, Cardstone Rd	JCU	*Ophidascaris* spp.	Adult	Stomach	1	NTM D1808

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Host Family	Host Species	State Collected	Location Collected	Source	Identification	Stage	Location in host	No.	Parasite Museum Deposit Number
			Nelly Bay, Magnetic Island	JCU	*Abbreviata bancrofti*	Adult	Intestine	1	NTM D1776
			Tomoulin (near Ravenshoe)	JCU	*Ophidascaris* spp.	Adult	Stomach	3	NTM D1802
			No collection data	JCU	*Ophidascaris moreliae/ robertsi*	Adult	Stomach	9	NTM D1800
Colubridae	*Stegonotus cucullatus*	NT	Fogg Dam	TERF	*Abbreviata hastaspicula*	Adult	Intestine	1	NTM D1768
					Tanqua tiara	Adult	Intestine	1	N/A
				TERF	*Abbreviata* spp.	Adult	Intestine	1	NTM D1745
					Kalicephalus sp.	Adult	Intestine	1	NTM D1814
	Tropidonophis mairii	NT	Darwin	TERF	*Unknown*	Larva	Mesenteries	1	NTM Unreg
			Fogg Dam	TERF	*Abbreviata bancrofti*	Adult	Intestine	1	NTM D1714
					Tanqua anomala	Adult	Intestine	20	NTM D1670
				TERF	*Abbreviata bancrofti*	Adult	Intestine	10	NTM D1720
					Tanqua anomala	Adult	Intestine	135	NTM D1682
				TERF	*Abbreviata* spp.	Adult	Intestine	7	NTM D1742
					Dracunculus mulbus	Adult	Intestine	1	NTM D1815
					Tanqua anomala	Adult	Intestine	7	NTM D1707
				TERF	*Abbreviata bancrofti*	Adult	Intestine	21	NTM D1722
					Tanqua anomala	Adult	Intestine	145	NTM D1687
				TERF	*Tanqua anomala*	Adult	Intestine	135	NTM D1705
				TERF	*Eustrongylides* sp.	Larva	Intestine	1	NTM D1787
					Tanqua anomala	Adult	Intestine	45	NTM D1691
				TERF	*Abbreviata* spp.	Adult	Intestine	2	NTM D1737
					Tanqua anomala	Adult	Intestine	12	NTM D1674
				TERF	*Abbreviata bancrofti*	Adult	Intestine	4	NTM D1710
					Eustrongylides sp.	Larva	Intestine	1	NTM D1792
				TERF	*Abbreviata bancrofti*	Adult	Intestine	1	NTM D1732
					Tanqua anomala	Adult	Intestine	22	NTM D1658
				TERF	*Abbreviata bancrofti*	Adult	Intestine	32	NTM D1715
					Tanqua anomala	Adult	Intestine	21	NTM D1698
				TERF	*Abbreviata* spp.	Adult	Intestine	3	NTM D1731
					Tanqua anomala	Adult	Intestine	54	NTM D1692
				TERF	*Abbreviata* spp.	Larva	Intestine	3	NTM D1736
					Tanqua anomala	Adult	Intestine	24	NTM D1659
				TERF	*Kalicephalus* sp.	Adult	Intestine	1	NTM D1793

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Host Family	Host Species	State Collected	Location Collected	Source	Identification	Stage	Location in host	No.	Parasite Museum Deposit Number
					Tanqua anomala	Adult	Intestine	4	NTM D1699
				TERF	*Abbreviata bancrofti*	Adult	Intestine	8	NTM D1709
					Tanqua anomala	Adult	Intestine	60	NTM D1669
				TERF	*Abbreviata bancrofti*	Adult	Intestine	6	N/A
					Abbreviata spp.	Adult	Intestine	5	NTM D1741
					Kalicephalus sp.	Adult	Intestine	1	NTM D1794
					Tanqua anomala	Adult	Intestine	201	NTM D1690
				TERF	*Abbreviata bancrofti*	Adult	Intestine	2	NTM D1718
					Tanqua anomala	Adult	Intestine	50	NTM D1678
				TERF	*Abbreviata hastaspicula*	Adult	Intestine	1	NTM D1746
					Tanqua anomala	Adult	Intestine	37	NTM D1673
				TERF	*Tanqua anomala*	Adult	Intestine	2	NTM D1708
				TERF	*Abbreviata bancrofti*	Adult	Intestine	2	NTM D1752
				TERF	*Abbreviata bancrofti*	Adult	Intestine	3	NTM D1740
					Tanqua anomala	Adult	Intestine	54	NTM D1696
				TERF	*Abbreviata bancrofti*	Adult	Intestine	17	NTM D1734
					Tanqua anomala	Adult	Intestine	26	NTM D1695
				TERF	*Abbreviata bancrofti*	Larva	Intestine	1	NTM D1719
					Eustrongylides sp.	Larva	Intestine	1	NTM D1791
					Tanqua anomala	Adult	Intestine	10	NTM D1683
				TERF	*Abbreviata* spp.	Adult	Intestine	1	NTM D1738
					Tanqua anomala	Unk	Intestine	4	NTM D1703
				TERF	*Tanqua anomala*	Adult	Intestine	54	NTM D1676
				TERF	*Abbreviata bancrofti*	Adult	Intestine	8	NTM D1733
					Tanqua anomala	Adult	Intestine	56	NTM D1660
				TERF	*Tanqua anomala*	Adult	Intestine	17	NTM D1667
				TERF	*Abbreviata* spp.	Adult	Intestine	1	NTM D1743
					Eustrongylides sp.	Larva	Intestine	4	NTM D1789
					Kalicephalus sp.	Larva	Intestine	1	NTM D1795
					Tanqua anomala	Adult	Intestine	1	NTM D1702
				TERF	*Tanqua anomala*	Adult	Intestine	21	NTM D1675
				TERF	*Abbreviata hastaspicula*	Adult	Intestine	1	NTM D1744
					Tanqua anomala	Adult	Intestine	10	NTM D1684
				TERF	*Eustrongylides* sp.	Larva	Intestine	2	NTM D1790
					Tanqua anomala	Adult	Intestine	9	NTM D1677
				TERF	*Abbreviata bancrofti*	Adult	Intestine	26	NTM D1751
					Eustrongylides sp.	Larva	Intestine	1	NTM D1788

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Host Family	Host Species	State Collected	Location Collected	Source	Identification	Stage	Location in host	No.	Parasite Museum Deposit Number
					Tanqua anomala	Adult	Intestine	7	NTM D1784
				TERF	*Abbreviata bancrofti*	Adult	Intestine	2	NTM D1713
					Tanqua anomala	Adult	Intestine	20	NTM D1701
				TERF	*Abbreviata bancrofti*	Adult	Intestine	11	NTM D1766
					Tanqua anomala	Adult	Intestine	10	NTM D1783
				TERF	*Tanqua anomala*	Adult	Intestine	34	NTM D1749
				TERF	*Abbreviata bancrofti*	Adult	Intestine	6	NTM D1721
					Tanqua anomala	Adult	Intestine	12	NTM D1689
				TERF	*Abbreviata bancrofti*	Adult	Intestine	2	NTM D1729
					Tanqua anomala	Adult	Intestine	19	NTM D1688
				TERF	*Abbreviata bancrofti*	Adult	Intestine	1	NTM D1724
					Dracunculus sp.	Adult	Tissues	1	NTM D1816
					Tanqua anomala	Adult	Intestine	20	NTM D1672
				TERF	*Abbreviata bancrofti*	Adult	Intestine	19	NTM D1716
					Tanqua anomala	Adult	Intestine	15	NTM D1680
				TERF	*Abbreviata bancrofti*	Adult	Intestine	1	NTM D1717
					Tanqua anomala	Adult	Intestine	8	NTM D1668
				TERF	*Abbreviata bancrofti*	Adult	Intestine	1	NTM D1735
					Tanqua anomala	Adult	Intestine	13	NTM D1661
				TERF	*Abbreviata bancrofti*	Adult	Intestine	5	NTM D1711
					Tanqua anomala	Adult	Intestine	5	NTM D1704
				TERF	*Abbreviata bancrofti*	Adult	Intestine	8	NTM D1727
					Tanqua anomala	Adult	Intestine	25	NTM D1693
				TERF	*Tanqua anomala*	Adult	Intestine	1	NTM D1666
				TERF	*Tanqua anomala*	Adult	Intestine	6	NTM D1657
				TERF	*Tanqua anomala*	Adult	Intestine	65	NTM D1706
				TERF	*Abbreviata bancrofti*	Adult	Intestine	3	NTM D1748
					Tanqua anomala	Adult	Intestine	23	NTM D1785
				TERF	*Abbreviata bancrofti*	Adult	Intestine	6	NTM D1750
					Tanqua anomala	Adult	Intestine	1	NTM D1761
				TERF	*Abbreviata bancrofti*	Adult	Intestine	22	NTM D1726
					Tanqua anomala	Adult	Intestine	16	NTM D1686
				TERF	*Abbreviata bancrofti*	Adult	Intestine	7	NTM D1730
					Tanqua anomala	Adult	Intestine	10	NTM D1656
				TERF	*Abbreviata* spp.	Adult	Intestine	1	NTM D1739
					Tanqua anomala	Adult	Intestine	9	NTM D1663
				TERF	*Tanqua anomala*	Adult	Intestine	10	NTM D1662

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Host Family	Host Species	State Collected	Location Collected	Source	Identification	Stage	Location in host	No.	Parasite Museum Deposit Number
				TERF	*Tanqua anomala*	Adult	Intestine	1	NTM D1681
				TERF	*Abbreviata bancrofti*	Adult	Intestine	32	NTM D1728
					Tanqua anomala	Adult	Intestine	24	NTM D1679
		Qld	Cape Cleveland	JCU	*Abbreviata bancrofti*	Adult	Stomach	4	NTM D1765
					Spiruridea sp.	Adult	Stomach	5	N/A
				JCU	*Abbreviata bancrofti*	Adult	Stomach	5	NTM D1759
				JCU	*Abbreviata bancrofti*	Adult	Stomach	1	NTM D1754
				JCU	*Abbreviata* spp.	Adult	Stomach	4	NTM D1755
Elapidae	*Acanthophis praelongus*	NT	Fogg Dam	TERF	*Unknown*	Larva	Intestine	1	NTM unreg
				TERF	*Kalicephalus* sp.	Adult	Intestine	1	NTM D1813
				TERF	*Tanqua tiara*	Adult	Intestine	1	NTM D1665
	Furina ornata	NT	Fogg Dam	TERF	*Ophidascaris* spp.	Adult	Intestine	41	NTM D1803
	Demansia vestigiata	NT	Fogg Dam	TERF	*Abbreviata bancrofti*	Adult	Intestine	27	NTM D1758
				TERF	*Abbreviata bancrofti*	Adult	Intestine	69	NTM D1767
		Qld	Cape Cleveland	JCU	*Abbreviata bancrofti*	Adult	Stomach	1	NTM D1773
			Townsville	JCU	*Abbreviata bancrofti*	Adult	Stomach	41	NTM D1756
				JCU	*Abbreviata bancrofti*	Adult	Stomach	4	NTM D1769
				JCU	*Abbreviata bancrofti*	Adult	Stomach	2	NTM D1760
				JCU	*Abbreviata bancrofti*	Adult	Stomach	50	NTM D1763
				JCU	*Abbreviata bancrofti*	Adult	Stomach	5	NTM D1757
			Nelly Bay, Magnetic Island	JCU	*Abbreviata* spp.	Adult	Stomach	2	NTM D1770
	Oxyuranus scutellatus	Qld	Tinaroo Falls	JCU	*Ophidascaris* sp. *1*	Adult	Stomach	3	NTM unreg
	Pseudechis australis	NT	Howard Springs	NTM R5245	*Abbreviata* spp.	Adult	Intestine	10	NTM D1630
	Pseudechis porphyriacus	Qld	Paluma Dam	JCU	*Ophidascaris pyrrhus*	Larva	Wall of Stomach	7	NTM D1801
				JCU	*Abbreviata* spp.	Adult	Intestine	1	NTM D1779
	Pseudonaja textilis	NT	Cockatoo Ck crossing	NTM unreg	*Abbreviata bancrofti*	Adult	Stomach	1	NTM D1764
					Ophidascaris spp.	Adult	Stomach	1	NTM D1796
		Qld	Bruce Highway, S of Townsville	JCU	*Abbreviata bancrofti*	Adult	Intestine	27	NTM D1777
			Gootchy Ck turnoff, Gootchy Ck Road, Bruce Highway	JCU	*Ophidascaris* spp.	Adult	Stomach	1	NTM D1804
	Tropidechis carinatus	NSW	Kingscliffe Beach	QM J21054	*Ophidascaris* spp.	Adult	Stomach	1	QM G222597
		Qld	Noosa area	QM J25983	*Ophidascaris* spp.	Adult	Stomach	1	

Table 2. List of nematode species and their hosts found in this study. Prevalence is given as the number of hosts infected from the sample of hosts examined. Intensity of infection is presented as the range with the mean in parentheses. The abbreviation Unk denotes unknown information. Symbols: * = New host record; # = New locality record; † = possibly an undescribed species.

Order	Family	Identification	Host Family	Host Species	State Collected	Prevalence	Intensity
Ascaridida	Ascarididae	*Ophidascaris morelaie/robertsi*	Boidae	*Morelia spilota*	Qld	1/5	9
		Ophidascaris sp. 1†	Elapidae	*Oxyuranus scutellatus**	Qld	1/1	3
		Ophidascaris pyrrhus	Elapidae	*Pseudechis porphyriacus*	Qld	1/1	7
		Ophidascaris spp.	Boidae	*Antaresia childreni*	NT	1/1	25
				Aspidites ramsayi	NT	2/5	1–5 (3)
					Qld	1/2	1
				Morelia spilota	Qld	3/5	1–3 (1.7)
			Colubridae	*Tropidechis carinatus*	NSW	1/1	1
					Qld	1/1	1
			Elapidae	*Furina ornata**	NT	1/1	41
				Pseudonaja textilis	NT	1/1	1
					Qld	1/2	1
			Varanidae	*Varanus gouldii*	NT	1/3	1
	Cosmocercidae	*Maxvachonia brygooi*	Gekkonidae	*Hemidactylus frenatus**	NT	1/12	1
	Heterakidae	*Strongyluris paronai*	Agamidae	*Chlamydosaurus kingii*	NT	1/1	1
				Pogona sp.	Qld	1/1	6
Enoplida	Dioctophymatidae	*Eustrongylides* sp.	Colubridae	*Tropidonophis mairii**	NT	6/54	1–4 (1.7)
Oxyurida	Pharyngodonidae	*Parapharyngodon maplestoni*	Gekkonidae	*Hemidactylus frenatus#*	NT	1/12	5
		Pharyngodon sp.	Gekkonidae	*Carphodactylus laevis**	Qld	1/1	2
		Pharyngodonidae sp.	Gekkonidae	*Oedura castelnaui**	Qld	1/1	1
		Skrjabinodon sp.	Gekkonidae	*Oedura castelnaui**	Qld	1/1	1
		Spauligodon hemidactylus	Gekkonidae	*Hemidactylus frenatus*	NT	10/12	1–10 (2.3)
					WA	1/1	1
					Unk	1/1	1
Spirurida	Dracunculidae	*Dracunculus mulhus*	Boidae	*Aspidites melanocephalus**	NT	1/2	1
			Colubridae	*Tropidonophis mairii**	NT	1/54	1
		Dracunculus sp.	Colubridae	*Tropidonophis mairii*	NT	1/54	1
	Gnathostomatidae	*Tanqua anomala*	Colubridae	*Tropidonophis mairii*	NT	51/54	1–201 (31.2)
		Tanqua tiara	Colubridae	*Stegonotus cucullatus*	NT	1/2	1
			Elapidae	*Acanthophis praelongus**	NT	1/3	1
			Varanidae	*Varanus gouldii*	NT	2/3	1–2 (1.5)
				Varanus panoptes	NT	1/1	420

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Order	Family	Identification	Host Family	Host Species	State Collected	Prevalence	Intensity
	Physalopteridae	*Abbreviata hancrofti*	Boidae	*Aspidites melanocephalus*	NT	1/2	6
					Qld	2/2	8–9 (8.5)
				Morelia spilota	Qld	1/5	1
			Colubridae	*Tropidonophis mairii**	NT	30/54	1–32 (8.9)
					Qld	3/4	1–5 (3.3)
			Elapidae	*Demansia vestigiata**	NT	2/2	27–69 (48)
					Qld	6/7	1–50 (17.2)
				*Pseudonaja textilis**	NT	1/1	1
					Qld	1/2	27
			Varanidae	*Varanus gouldii*	NT	2/3	9–10 (9.5)
		Abbreviata hataspicula	Boidae	*Aspidites ramsayi**	NT	4/5	1–26 (10.5)
			Colubridae	*Stegonotus cucullatus*	NT	1/2	1
				*Tropidonophis mairii**	NT	2/54	1
			Varanidae	*Varanus gouldii*	NT	3/3	35–105 (63.7)
				*Varanus spenceri**	NT	1/1	250
		Abbreviata spp.	Agamidae	*Intellagama lesueurii*	Qld	1/1	1
			Boidae	*Aspidites melanocephalus*	Unk	1/1	1
				Aspidites ramsayi	NT	1/5	1
					Qld	1/2	3
			Colubridae	*Stegonotus cucullatus*	NT	1/2	1
				Tropidonophis mairii	NT	8/54	1–7 (2.9)
					Qld	1/4	4
			Elapidae	*Demansia vestigiata*	Qld	1/7	2
				Pseudechis australis	NT	1/1	10
				Pseudechis porphyriacus	Qld	1/1	1
			Varanidae	*Varanus gouldii*	Qld	1/1	1
		Physalopteridae sp.	Gekkonidae	*Hemidactylus frenatus*	NT	1/12	1
				*Oedura rhombifer**	NT	2/2	1
			Scincidae	*Ctenotus strauchii varius**	NSW	3/3	1
		Physalopteroides filicauda	Scincidae	*Eulamprus quoyii**	Qld	1/1	1
	Spiruridae	Spiruridae sp.	Colubridae	*Tropidonophis mairii*	Qld	1/4	5
Strongylida	Diaphanocephalidae	*Kalicephalus* sp.	Colubridae	*Stegonotus cucullatus**	NT	1/2	1
				*Tropidonophis mairii**	NT	3/54	1
			Elapidae	*Acanthophis praelongus**	NT	1/3	1
Unknown	Unknown	Unknown	Colubridae	*Tropidonophis mairii*	NT	1/61	1
			Elapidae	*Acanthophis praelongus*	NT	1/3	1

Notes on the diet of the Black-spotted Croaker (*Protonibea diacanthus*) across northern Australia

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Abstract

This study has provided some baseline data on the diet of the Black-spotted Croaker (*Protonibea diacanthus*) in coastal waters off northern Australia. Black-spotted Croakers were found to be opportunistic predators, feeding on a variety of fishes and crustaceans. Larger individuals contained more fish remains, with prawns dominating the diet of smaller individuals. Seasonality of diet is suggested by the results, however a wider range of samples across all months of the year would be required to confirm this.

Introduction

The Black-spotted Croaker (*Protonibea diacanthus*) (family Sciaenidae), known locally as the Black Jewfish, is a widespread species throughout tropical Indo-West Pacific marine waters and forms an important component of both commercial and recreational fisheries (Phelan *et al.* 2008a, 2008b; Froese & Pauly 2015; Saunders *et al.* 2016). Within Australia, it is found from Shark Bay in Western Australia, across northern Australia, to Hervey Bay on the central coast of Queensland (Phelan 2008; Froese & Pauly 2015; Saunders *et al.* 2016). Despite its importance in fisheries within these regions, and the suspected overfishing in many locations, especially within waters of the Northern Territory (Phelan 2008; Saunders *et al.* 2016), little is known of the biology of this species of fish, including its diet (Phelan *et al.* 2008a, 2008b).

Black-spotted Croakers caught in waters greater than 10 m are susceptible to barotrauma, a symptom of which is eversion of the stomach through the mouth, as they are brought to the surface, thus expelling the stomach's contents (Phelan *et al.* 2008a, 2008b; Saunders *et al.* 2016). This makes the collection of diet data difficult, with large percentages of fish previously studied having everted stomachs (Rao 1963; Thomas & Kunju 1981; Phelan *et al.* 2008b). Despite this, the Black-spotted Croaker has been reported to be an opportunistic predator, with crustaceans (crabs and prawns) and fishes being the primary prey items. In studies in Indian waters, Rao (1963) found prawns were the dominant prey item, but Thomas and Kunju (1981) found fishes to be the dominant prey item. Conversely, Phelan *et al.* (2008b) found that crabs were the dominant prey item in Black-spotted Croakers in waters off Cape York Peninsula in tropical northern Australia.

As part of a wider study on the parasites of the Black-spotted Croaker in northern Australian waters, data on diet from stomach content analysis were noted and will be presented here for increasing knowledge of aspects of the basic biology of this species of fish.

Materials and Methods

Protonibea diacanthus is a large species of fish, attaining over 1.5 m maximum length (Froese & Pauly 2015). It exhibits rapid growth, with females reaching sexual maturity at approximately 2 years of age and between 890 mm and 980 mm total length (TL) (Phelan & Errity 2008; Phelan *et al.* 2008b).

As part of a larger study, Black-spotted Croakers were collected from a number of locations across northern Australia (Figure 1; Table 1), primarily by line fishing by staff of both the Western Australian and Northern Territory Departments of Fisheries and Indigenous Marine Rangers, as well as by commercial fishers (collected under Northern Territory Fisheries Permit S17/2737). All the fishes were euthanased (Charles Darwin University Animal Ethics Approval A13014), placed on ice, and transported to the laboratory for processing; some were frozen whole prior to processing. Total length (in mm) and sex was recorded for most fish, with the exception of those from the Arafura Sea that were collected by a commercial trawler and were neither measured nor had their gonads collected, and fish collected from Peron Islands that were not measured. The internal organs were removed, and the stomach and intestinal tract was separated from the mesenteries and associated organs, and slit along its length for examination.

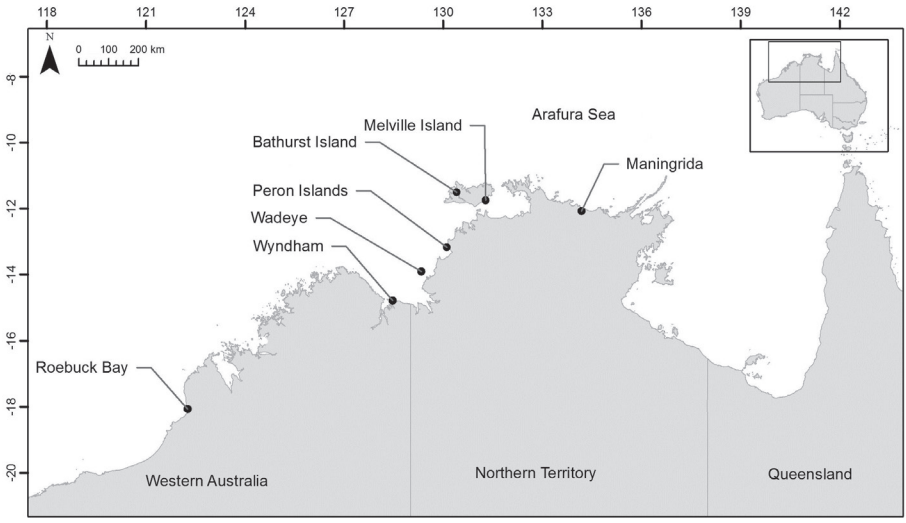

Figure 1. Map of collection localities for *Protonibea diacanthus* across northern Australia that were used in this study.

At the time of examination, it was noted whether the stomach was everted or not. For non-everted stomachs, whether the stomach was empty or contained food (that was not obviously bait items such as cut chunks of fish) was also noted. Stomach contents were classified broadly as crabs (whole crabs or segments of the carapace and/or claws), prawns (including stomatopods), or fishes (including whole fishes, skeletal remains, or flesh). As the main aim of the study was the collection of parasites and not a detailed examination of diet, weight and proportions of items were not recorded and identification of dietary item beyond the higher taxonomic levels was not usually attempted.

Results

A total of 223 *Protonibea diacanthus* had their stomach contents noted at the time of dissection (Table 1). A total of 60 (26.9%) stomachs were everted, either partially or completely. Of the remaining 163 stomachs, 74 (45.4%) contained food items.

The highest numbers of fish with everted stomachs were in the collections from Arafura Sea (17 of the 19 (90%) fish; no TL data), Wadeye (14 of 25 (56%); mean TL 699.5 (540–1090) mm) and Bathurst Island (12 of 28 (43%); mean TL (8 fish) 948.1 (510–1120) mm). Depth of collection for fish from these locations was generally over 20 m; fish collected from more shallow waters had higher numbers of non-everted stomachs (Table 1). There was no difference between male and female fish, with 21 males (773.5 (520–1120) mm) and 22 females (797.1 (405–1100) mm) having everted stomachs.

Table 1. Locations of fishes collected from along the coastlines of Western Australia (WA) and the Northern Territory (NT) examined in this study. Locations are listed in order from west to east. The number of fishes examined from each location is presented, with the mean Total Length (TL) in mm (range in parentheses), reported water depth at location of collection, and stomach contents (number of fish with relative percentage for each category in parentheses). N/A indicates fish where TL data was not obtained.

Location	No. fish	TL (mm)	Water depth (m)	Number everted	Number with food[a]	Crabs[b]	Prawns[b]	Fishes[b]
Western Australia								
Roebuck Bay	36	1018.5 (720–1199)	8–15	3 (8)	17 (47)	10 (18)	3 (18)	15 (88)
Wyndham	34	1067.1 (804–1300)	10–20	1 (3)	23 (68)	7 (4)	1 (4)	17 (74)
Northern Territory								
Wadeye	25	789.2 (540–1160)	20–25	14 (56)	1 (9)	0 (0)	0 (0)	1 (100)
Peron Islands	22	N/A	15	7 (32)	7 (47)	5 (71)	1 (14)	4 (57)
Bathurst Island	28	980.6 (387–1235)	8–35	12 (43)	2 (11)	1 (50)	0 (0)	2 (100)
Melville Island	30	646.3 (405–1170)	8–12	3 (10)	13 (48)	7 (54)	5 (39)	3 (23)
Maningrida	29	730.9 (420–1210)	3–5	3 (10)	11 (42)	5 (46)	5 (46)	3 (27)
Arafura Sea	19	N/A	60	17 (90)	0 (0)	0 (0)	0 (0)	0 (0)
TOTAL	223	879.1 (387–1300)		60 (27)	74 (45)	35 (47)	15 (20)	45 (61)

[a] Percent of fish calculated as percent of fish with food in stomach out of total number of fish with non-everted stomachs.

[b] Percent of fish calculated as percent of fish with that food type (alone or in combination) out of total number of fish with food in stomach.

Of the 74 stomachs with food items (Table 1), 35 (47.3%) contained crab remains (usually parts of the carapace or claws), 15 (20.3%) contained prawn (and/or stomatopod) remains, and 45 (60.8%) contained fish remains (usually skeletal remains). Of the stomachs with food items, 16 (21.6%) contained two types of food (usually crabs and fishes – 14 (87.5%)), and 2 (2.7%) contained elements of all three food types.

The mean TL of fish that contained only prawns was 734 (415–1171) mm, only crabs was 882 (420–1195) mm, and only fishes was 1067.1 (700–1300) mm (Figure 2). However, the distribution of fish with only crab remains was bimodal, with the smaller group 511.7 (420–610; 6 fish) and the larger 1128.9 (1010–1210; 9 fish); notes taken at the time of dissection did not indicate any difference in size of crabs ingested, with small crabs (<5 cm carapace width) dominating both groups. Fishes with two diet items had a mean TL of 940.7 (510–1162) mm; for the fish that contained a combination of prawns and fish TL was 520 mm, for the two fishes that contained prawns and crabs, mean TL was 525 (510–540) mm and for fishes containing crabs and fish (n = 14), mean TL was 1054.5 (984–1168) mm. For the fishes with three diet items, mean TL was 941 (870–1012) mm.

Of the total of 223 fishes, 115 were female (960.2 (405–1220) mm), 88 were male (770.8 (387–1300) mm), and 20 were undetermined (as explained in the Introduction, 19 of these were the Arafura Sea trawler samples from which gonads and TL were not collected; the other was a 1170 mm TL fish from Maningrida, Northern Territory, which contained only prawns in its stomach). Of the female fishes, 45 (13%) contained food,

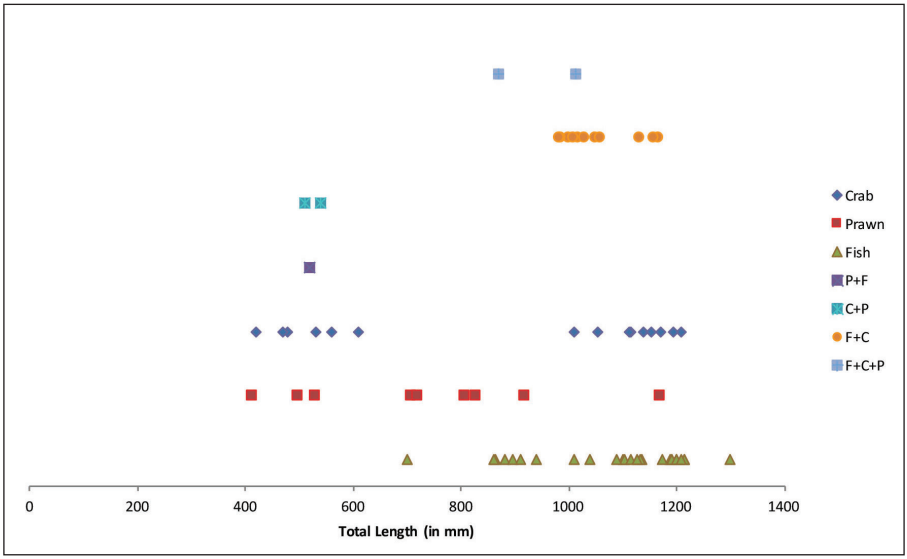

Figure 2. Stomach contents of *Protonibea diacanthus* related to Total Length of fish. C, Crabs; F, Fishes; P, Prawns.

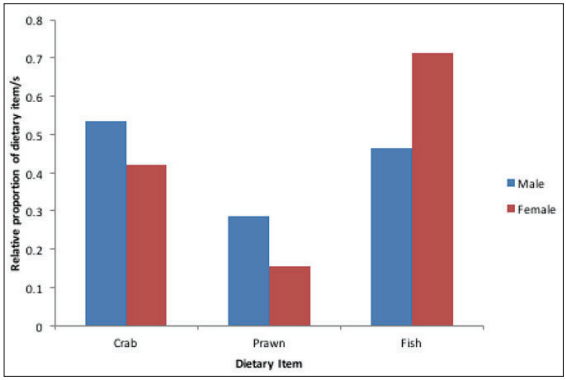

Figure 3. Relative proportions of male and female fishes with dietary items in their stomach contents. Relative proportion is the number of fishes of each sex that contained that food item, either alone or in combination.

of which 19 (42.2%) had crabs, 7 (15.6%) had prawns and 32 (71.1%) had fishes; 11 (24.4%) fish had two food items and 1 (2.2%) fish had three items; 22 (19.1%) fishes had everted stomachs (Figure 3). Of the male fishes, 28 (31.8%) contained food, of which 15 (53.6%) had crabs, 8 (28.6%) had prawns, 13 (46.4%) had fish; 6 (21.4%) fish had two food items and 1 (3.6%) fish had three; 21 (23.9%) had everted stomachs.

The month of collection may have an effect on dietary items found within the stomach contents (Figure 4; Table 2); however, not all months were sampled. Fish dominated the prey items for Black-spotted Croakers collected in May to July, whereas crabs were the dominant items in August (Figure 4; Table 2).

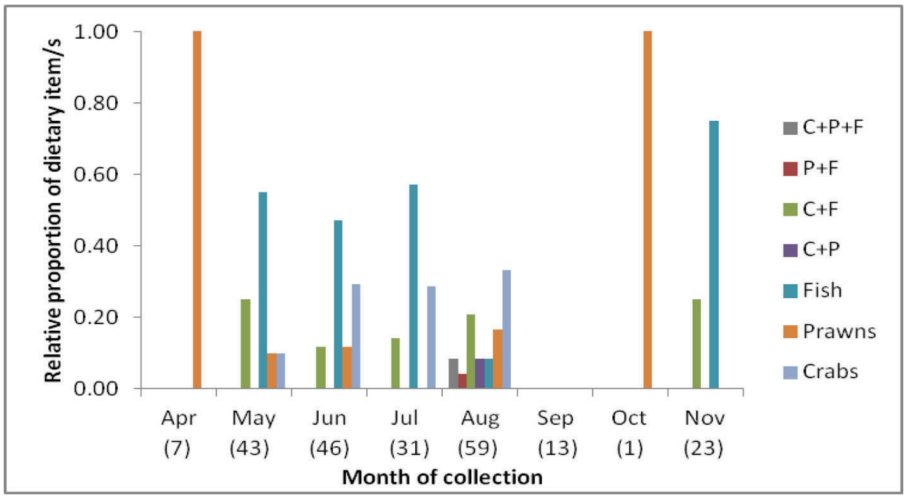

Figure 4. Stomach contents of *Protonibea diacanthus* by month of collection (relative proportion of fish collected for that month). Data combined for all fishes, independent of sex or location of collection. Sample size for each month of collection indicated by the number in parentheses under month of collection. C, Crabs; F, Fishes; P, Prawns.

Table 2. Months of collection for fishes caught from along the coastlines of Western Australia and the Northern Territory examined in this study. Numbers are combined across years of collection and across all sites of collection. Number of fishes examined per month (number of fishes with relative percentage for each category in parentheses; percentages calculated as per Table 1) is presented, with the mean Total Length (TL) in mm (range in parentheses).

Month	Number of fishes	TL (mm)	Number everted	Number with food	Crabs	Prawns	Fishes
April	7	708.6 (405–1170)	2 (29)	1 (20)	0 (0)	1 (100)	0 (0)
May	43	1042.1 (822–1215)	7 (16)	20 (56)	7 (35)	2 (10)	16 (80)
June	46	911.6 (540–1300)	14 (30)	17 (53)	7 (41)	2 (12)	10 (59)
July	31	1084.2 (899–1210)	19 (61)	7 (58)	3 (43)	0 (0)	5 (71)
August	59	723.9 (420–1199)	8 (14)	24 (69)	17 (71)	9 (38)	10 (42)
September	13	744.2 (540–1100)	6 (46)	0 (0)	0 (0)	0 (0)	0 (0)
October	1	720	0 (0)	1 (100)	0 (0)	1 (100)	0 (0)
November	23	1051.0 (387–1235)	4 (18)	4 (21)	1 (25)	0 (0)	4 (25)
TOTAL	223	879.1 (387–1300)	60 (27)	74 (45)	35 (47)	15 (20)	45 (61)

Discussion

Little is known of the biology of many of the commercial and recreationally important fish species of northern Australia. As the current status of the Black-spotted Croaker is overfished or undefined (Saunders *et al.* 2016), the requirement for more knowledge on its biology is paramount. Thus, aspects of the diet of the Black-spotted Croaker are presented here to provide baseline data on a previously unreported aspect of the biology of this species of fish in these waters. The only previous study to report on diet of the Black-spotted Croaker in Australian waters (Phelan *et al.* 2008b) was conducted off the northern tip of Cape York Peninsula, an area not included within this study. The data reported here were collected as an adjunct to a parasitological study primarily to assist with parasite life cycle determinations and, as such, were not recorded at a level required for in-depth dietary analysis. The results do show, however, that overall, the diet is similar to that recorded previously (Rao 1963; Thomas & Kunju 1981; Phelan *et al.* 2008b), with Black-spotted Croakers being opportunistic predators, feeding primarily on benthic organisms.

Everted stomachs affected a low number of Black-spotted Croakers in this study (27%) compared to previous studies. Rao (1963) found that 95% (of 679 fishes) collected from trawlers had everted stomachs. These fish were predominantly large (over 500 mm TL), whereas fish under 500 mm TL were usually caught by land-based nets and had a much lower frequency (<37%) of everted stomachs. Thomas & Kunju (1981) also recorded 95% (of 57 fishes) with everted stomachs; all of which were taken by trawlers. Phelan *et al.* (2008b) found 93% of the fish caught by handlines by indigenous subsistence and recreational fishers had everted stomachs; fish were caught in depths ranging from 10 to 25 m. High numbers of everted stomachs were found in this study into Black-spotted Croakers collected from Arafura Sea (trawler samples), and Wadeye and Bathurst Island (commercial fishermen) where collection occurred in water over 20 m in depth. This corresponded with the results of Phelan *et al.* (2008a), who found that 100% of fish

caught in waters over 15 m in depth had everted stomachs. Other collection localities still contained fish with everted stomachs, but at much lower levels which may be due to collection from shallower waters or slower ascent through the water column.

It is apparent that differently sized Black-spotted Croakers exhibit different diets. Rao (1963) divided his samples into big- and medium-sized fish (over 500 mm) and juveniles (below 500 mm). For the big Black-spotted Croakers, fishes and prawns were the major food items, but the percentage of prawns was not as high as in juveniles. Black-spotted Croakers reach sexual maturity at approximately 890–980 mm TL (Phelan *et al.* 2008a, 2008b), which corresponds with a shift in dietary items from prawns to fishes in this study (Figure 2). Similar results were found for *Argyrosomus japonicus*, a sciaenid found in waters off southern Australia, with a shift in diet from mysids, to prawns, to fishes corresponding with increasing size (Taylor *et al.* 2006). Crabs, however, had a split distribution with smaller and larger fish containing crabs in their diet. There were no apparent differences in the size of crabs targeted by these fishes, with notes taken at the time of dissection showing that small to medium crabs (less than 5 cm carapace width) were common across both groups of fish. Thus, the dominance of crabs in the diet of Black-spotted Croakers studied by Phelan *et al.* (2008b) could be due to a preference for crustaceans by smaller individuals. The size range of the fishes studied by Phelan *et al.* (2008b) was at the lower end of the size range (429–825 mm TL) compared to the fishes examined in this study (325–1300 mm TL).

Rao (1963) suggested that the Black-spotted Croaker can travel in separate sex-related shoals as there was a consistent difference in the number of female and male fishes collected in trawls across months. As in Rao's (1963) study, females dominated the samples overall, with 56.7% of fish (that were able to be determined) being female and 43.3% being male. Female Black-spotted Croakers in this study generally ate more fishes (70% of all females compared to 46% of males), whereas males ate more crabs and prawns (82% of all males compared to 58% of females). However, the size differences between males and females caught in this study (males mean TL 770.8 (387–1300) mm, females 960.2 (405–1235) mm) is likely to be a confounding factor. More research needs to be conducted on fishes across a wide size range, including juveniles, to determine if there is a relationship between the sex of the fish and dietary preferences.

Aggregations of Black-spotted Croakers are well known and are often targeted by fishermen, leading to overfishing of the species (Phelan *et al.* 2008a, 2008b; Saunders *et al.* 2016). The aggregations are suggested to be either breeding aggregations (Welch *et al.* 2014), or due to food availability (Thomas & Kunju 1981). Recent studies have shown, however, that Black-spotted Croakers show high levels of localised site fidelity (Semmens *et al.* 2010; Taillebois *et al.* 2017), with small scale seasonal migration from shallow to deeper waters, with individuals returning to the same location over time (Semmens *et al.* 2010). Although there is apparent seasonal variability in the diet of the Black-spotted Croakers examined in this study, the lack of samples over the spawning

season (peaking in December to January; Phelan & Errity 2008) prevents any conclusion regarding the relationship between aggregation and either diet or reproduction.

The majority of dietary items identified in this study were demersal in origin, indicating that the Black-spotted Croaker is a predominantly benthic feeder at all stages of its life cycle. The various crustaceans found are known to be associated with benthic structures, such as reefs; however a few portunid crabs were also found in stomachs, although, generally only in smaller Black-spotted Croakers. The fish that could be identified to either family (i.e. Ophichthidae) or genus (i.e. *Arius, Johnius, Ambassis*) were primarily associated with demersal habitats (Froese & Pauly 2015). The fish identified by Rao (1963) and the sole collected by Thomas and Kunju (1981) are also predominantly benthic.

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First record of tree-climbing behaviour in the Striated Mudcreeper (*Terebralia semistriata*) (Gastropoda: Potamididae)

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Abstract

Amongst the gastropod family Potamididae, only *Terebralia sulcata* and the genera *Cerithidea* and *Cerithideopsis* are presently known to climb trees in mangrove forests. Here, tree-climbing behaviour is reported in another potamidid, the Striated Mudcreeper (*Terebralia semistriata*), from mangrove forests in the Northern Territory and the southern Gulf of Carpentaria, Queensland. Both observations were made during spring tidal cycles. These are the first cases of tree-climbing behaviour reported for this species. Given a semi-arboreal habit is already known in a congeneric Australian species, *Terebralia sulcata*, these observations suggest that tree-climbing in *T. semistriata* is a behavioural response to rhythmic tidal inundation and is likely ubiquitous. However, without further detailed studies this remains unconfirmed.

Introduction

Within the Potamididae (variously known as longbums, mudsnails, mudcreepers, treecreepers), only members of the genera *Cerithidea* and *Cerithideopsis* are considered to display specialised tree-climbing habits (Reid *et al.* 2008). It is the tree-dwelling *Cerithidea* snails however, that are best known for their vertical migrations up and down the trunks of mangrove trees (e.g. McGuiness 1994; Ohtaki *et al.* 2002; Vannini *et al.* 2006). Another potamidid species that possesses a 'semi-arboreal' habit is the essentially ground-dwelling *Terebralia sulcata*. This comparatively thin-shelled species is common in mangrove forests of the Indo-West Pacific region (Houbrick 1991; Poutiers 1998), and throughout its range it is occasionally found attached to the stems (Poutiers 1998; Mujiono 2009), roots (Vermeij 1973; Houbrick 1991; Willan 2013), and pneumatophores (Wells 1980) of mangrove trees during low tide.

Here I report tree-climbing behaviour in another species of *Terebralia*, the Striated Mudcreeper (*Terebralia semistriata*), based on observations made within mangrove forests in Darwin Harbour, Northern Territory and Karumba, Queensland. Tree-climbing behaviour is undocumented in *Terebralia semistriata* within the literature, and to my knowledge, this is the first reported case of any form of arboreal behaviour in this species.

Observations

On the morning of 28 May 2017, approx. 1.5 hours after the peak of a 7.8 m high spring tide within a mid-tidal *Ceriops australis* mangal (mangrove forest) situated about 11 m from a rock wall on the eastern side of O'Ferrals Road, Bayview Marina Estate (12° 26.436'S, 130° 51.675'E), 14 individuals of the Striated Mudcreeper (*Terebralia semistriata*) were observed attached to the trunks of mangrove trees relatively high off the floor of the mangrove forest. The snails ranged in size from juveniles (approx. 30 mm in shell length) to large, mature adults measuring up to 71.3 mm in shell length (Figure 1). As the tide receded, most of the snails began creeping relatively rapidly backwards down the trees, shell apex first, with the head positioned perpendicular to the forest floor. Some individuals actively followed the ebbing tide (Figure 2), while others appeared to 'rest' in the trees after which they started to slowly glide down the trunks. To determine the climbing heights of snails, two methods were employed: (1) measurements of 'resting' individuals (i.e. inactive snails with no mucous trail evident above the animal) were taken from the uppermost part of the shell furthest from the mud surface; and (2) measurements of active snails (i.e. snails that were

Figure 1. A mature *Terebralia semistriata* (71.3 mm total shell length) attached 819 mm up the trunk of a *Ceriops australis* tree after a 7.8 m high spring tide in the mangrove forest opposite Bayview Marina Estate, Darwin, 28 May 2017. Bottom left insert shows a close-up of the same individual. (Adam Bourke)

Figure 2. *Terebralia semistriata* actively following the ebbing tide down the trunk of a *Bruguiera exaristata* tree in the mangrove forest opposite Bayview Marina Estate, Darwin, 28 May 2017. (Adam Bourke)

already creeping down the trunks during the receding tide) were taken from the highest visible part of the mucous trail above the animal. From the 14 snails measured, climbing heights ranged between 535–955 mm, with an average climbing height of 731.0 ± 143.5 mm. Within 10–15 minutes most snails were back on the mud surface. After the tide had completely left the forest it became apparent there were numerous *T. semistriata* on the forest floor away from trees, indicating that not all individuals at the site had climbed trees during that particular high tide.

One month later (on 26 June 2017), after a comparably high spring tide at the same location, the heights of 16 *T. semistriata* snails attached to the trunks of mangrove trees were recorded approx. 1.3 hours after the peak of a 7.7 m morning high tide (Figure 3). Slightly greater climbing heights were observed, ranging between 550–1195 mm, with an average height of 812.0 ± 207.2 mm. As on the previous occasion, not all the snails at the site had climbed trees.

Approximately two months later, on 23 August 2017 in a mid-tidal mangrove forest dominated by *Avicennia marina* located 7.3 km north-west of Karumba in the southern Gulf of Carpentaria, Queensland (17° 28.835'S, 140° 45.950'E), a single subadult

Figure 3. One of the 16 *Terebralia semistriata* observed in mangrove trees after the 7.7 m high spring tide in the mangrove forest opposite Bayview Marina Estate, Darwin, 26 June 2017. Note the conspicuous mucous trail left on the dry bark as the snail actively crept down the trunk. (Adam Bourke)

Figure 4. The single subadult *Terebralia semistriata* recorded on the trunk of an *Avicennia marina* tree after the 3.39 m high spring tide in a mangrove forest north-east of Karumba, Queensland, 23 August 2017. (Adam Bourke)

T. semistriata snail was observed attached to the trunk of an *A. marina* tree about 45 minutes after the ebbing turn of a 3.39 m high spring tide. The height to which it had climbed was estimated at 410 mm, as no mucous trail was visible above the snail due to the wetness of the trunk (Figure 4). A few other *T. semistriata* were present at the site, but none of these snails was recorded in the trees.

Discussion

Wells (1998; 2003) investigated *Terebralia semistriata* in the mangrove forests of north-western Australia, but made no reference to any form of arboreal behaviour. However, given the timing and nature of the observations presented here (i.e. field measurements made on ebbing tides in mid-tidal mangrove forests), plus the swiftness at which snails return to the forest floor, plus the fact that not all snails climb trees, it is not surprising that this climbing behaviour has gone unnoticed until now. As similar climbing behaviour was observed in both the Darwin and Karumba populations of *T. semistriata* – which are separated by over 1200 km and are subjected to very different tidal regimes (i.e. Darwin Harbour has a semi-diurnal, macrotidal range of about 8.0 m while Karumba is subjected to diurnal, micro-tides of approx. 4.0 m tidal amplitude [Bureau of Meteorology 2018]) – the climbing of mangrove trees during large spring tides is most likely a regular behavioural response to rhythmic tidal inundation rather than an isolated one-off event. Furthermore, given a semi-arboreal habit is already known in the congeneric species *T. sulcata*, the climbing behaviour observed in *T. semstriata* is likely ubiquitous. Without further detailed studies however, this remains unconfirmed.

Perhaps significantly, the third and largest member of the genus in tropical northern Australia, *Terebralia palustris*, apparently never climbs trees. *Terebralia palustris* has an open peristome at the base of its aperture, whereas both the other species close the peristome when adult into a short tubular siphon (Houbrick 1991). Perhaps the architecture of the aperture of *T. sulcata* and *T. semistriata* facilitates tree climbing in some way?

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