SHORT COMMUNICATION

A note on the Australian freshwater crocodiles inhabiting Tunnel Creek cave, West Kimberley

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INTRODUCTION

Tunnel Creek National Park, located 390 km east of Broome in the Kimberley region of Western Australia, is one of region's top tourist attractions. The 91 ha national park is positioned within the Napier Range which is composed of limestone, remnants of a Devonian barrier reef system formed around 350 million years ago (Goudie et al. 1990). The park contains a limestone cave system ~750 m in length (cave entrance at 51K 727683 8051871) (Figure 1). It is considered to be one of the oldest cave systems in Western Australia and also a nationally important wetland (Environment Australia 2001). The cave also has historical value as the Aboriginal freedom fighter Jandamarra, a member of the Bunuba group of the area, evaded the police and others for nearly three years using it as a hideout, until he was shot in April 1897 at the cave entrance (Pedersen and Woorunmurra 1995).

The cave is up to 20 m high and up to 20 m wide and contains permanent pools of freshwater throughout the year. Tunnel Creek generally flows during 4-5 months of the year (December to April), during which it is connected to a permanent, large freshwater pool located, ~15 m outside the southern entrance of the cave (Figures 1, 2A). Nearly halfway in, the roof of the cave has collapsed allowing sunlight to reach the banks of the cave in a ~ 30 m section. Other than this, sunlight does not penetrate the remainder of the cave, beyond the entrances. Two springs with warmer water, possibly created as a result of a perched water table passing through heated rocks outside the cave, flows into the cave creating ~ 1 m and ~ 2 m high waterfalls (Figure 1). Water within these two pools is warmer than the other pools within the cave.

While no detailed studies on the herpetofauna of the area have yet taken place, anecdotal information states the occasional presence of Australian freshwater crocodiles (*Crocodylus johnstoni*) inside the cave (Gueho 2003; Laurie 2010). Confirmed records of crocodilians inhabiting large caves are very rare and limited to a population each of the dwarf crocodile (*Osteolaemus* sp.) and the Nile crocodile (*C. niloticus*) (Handwerk 2003; IRD 2012). Hence in this short note, we provide more robust observational records of the population of *C. johnstoni* inhabiting the Tunnel Creek cave and discuss likely reasons for their occupation of the cave.

METHODS

During ongoing surveys by the Department of Parks and Wildlife of Western Australia for freshwater crocodiles in the West Kimberley region, Tunnel Creek cave was visited on eight occasions between May 2011 and September 2013 (Table 1). Spotlighting was conducted using headlamps and hand-held spotlights inside the cave (during daylight hours) and at the pool outside during night time (18:00-6:00). The outside pool was also searched for crocodiles and their signs more regularly during daytime. Once an eye shine was observed, attempts were made to approach the crocodile and estimate the size. Notes on the location and activity were made. On 9 June 2013, thermochron iButton data loggers [programmed to record temperature and relative humidity (in only those that were above water) at 20 min intervals over 17 hrs] were placed one per pool, ~20 cm underwater near the waterfall inflows at the two warm pools, two other pools inside the cave (cold pools 2 and 4), and the pool outside, while two loggers each were placed ~50 cm above ground level inside the cave (on ledges on the cave wall ~200 m from an entrance) and outside (suspended in air from trees ~50 m away from the two entrances). Those set above ground recorded both temperature and humidity. Additionally the air temperature was measured using a digital thermometer (CEM 4 in 1 Environment Meter DT-8820) outside the southern entrance and at the second warm pool inside the cave during visits (Table 1).

TABLE 1Observations of crocodiles made within the Tunnel Creek cave. Temperatures refer to those measured using a
hand-held thermometer at the outside pool and the second warm pool inside the cave.

Date	Time	Outside air temperature	Inside air temperature	Number of crocodiles	Observations
13 May 2011	11:30	24.7	21.6	2	 1. 120–150 cm animal on rocks directly under flowing spring in warm pool 1 2. Eye shine in deep water at a cold pool 2
14 May 2011	19:40	16.9	19.3	2	 Eye shine at water's edge in warm pool 1 Eye shine in deep water at warm pool 2
2 Sep 2011	8:10	24.3	20.1	3	 1. 150–180 cm animal at water's edge in cold pool 2 2. Eye shine in deep water at warm pool 1 3. Eye shine in deep water at warm pool 2
16 June 2012	13:20	31.7	21.9	4	 1. 150–180 cm at water's edge in warm pool 1 2. 120–150 cm in deep water at warm pool 2 3. Eye shine in deep water at cold pool 4 4. Yearling (37 cm) in shallow cold pool, ~60 m inside of the south entrance
16 June 2012	21:20	18.4	19.7	4	 1. 150–180 cm at water's edge in warm pool 1 2. 120–150 cm in deep water at warm pool 2 3. Two eye shines in deep water at cold pool 4
9 June 2013	8:00	27.6	23.4	2	 1. 120–150 cm animal on a rock directly under the flowing spring at warm pool 2 2. Eye shine in deep water at cold pool 2
10 June 2013	6:00	22.6	23.0	3	 1. 120–150 cm on a sand bank bordering warm pool 2 2. 120–150 cm at water's edge in warm pool 2 3. Eye shine in deep water at cold pool 4
26 Sep 2013	8:00	21.6		2	 1. 150–180 cm animal in shallow water directly under flowing springs in warm pool 1 2. Eye shine in deep water at cold pool 1

RESULTS

At least two crocodiles were observed within the cave during each survey with four individuals observed in June 2012 (Table 1). Six of the 11 observations were made at less than 5 m from the animal and all individuals observed closely were noticeably paler in colour relative to those observed at Windjana Gorge, ~30 km north-east, the closest other water body where surveys took place. Six observations were made at warm pool 1 and seven at warm pool 2, compared to nine observations in all other locations inside the cave, indicating a possible preference to warm pools (e.g. Figure 2B). The smallest individual encountered was a 37 cm (total length) hatchling in June 2012, which was estimated to be 7-8 months old. The largest, a 150-180 cm individual, was observed during four of the visits. Apart from one observation of a 120-150 cm crocodile on a sand bank (Figure 2C), all other observations were of animals in water. Numerous tracks were observed on the sand banks within the cave and those that lead to the pool outside (Figure 2D). Despite clear signs of crocodiles moving between the pools inside and outside, no crocodiles were observed in the outside pool during any of the surveys. The two warm springs inside the cave were flowing during all surveys except in September 2011 and September 2013, during the peak dry season. Tracks leading to the bank in the section where the roof has collapsed were observed in September 2013.

Data logger recordings on 9-10 June 2013 showed that the warmer pools maintained a temperature $\sim 0.5^{\circ}$ higher than the cold pools inside and were much more stable over the day (Figure 3). Contrastingly, the pool outside was cooler than the pools inside and the temperature gradually dropped through the night till the morning (being $\sim 1^{\circ}$ cooler than the warm pools at 13:20 to $\sim 1.5^{\circ}$ at 6:20). However it is noteworthy that these differences are small and within the error margins for iButtons. The air temperature inside the cave showed lower variation (4.1°C, ranging from 19.3-23.4°C) during the visits compared to 24.7°C (ranging from 16.9-41.6°C), ~50 m away but outside the cave (Table 1). Recordings from the data loggers show that the air temperature inside the cave remained largely stable for the 17 hour period on 9 June 2013 while the temperature outside dropped over the same time period (Figure 4). The Relative Humidity (RH) outside on the other hand, remained ~20% less than that inside throughout the 17 hr time period (Figure 4).



FIGURE 1 Relative positioning of the pools inside and outside the Tunnel Creek cave.



FIGURE 2 A, southern entrance of the Tunnel Creek cave; B, 120–150 cm crocodile directly under the spring at warm pool 2; C, 120–150 cm crocodile on sand bank inside the cave with the southern entrance in the background; D, tracks heading in and out of the cave. Photos A & D: Karen Bettink; B & C: Ruchira Somaweera.



FIGURE 3 Comparison of mean water temperature of the two warm pools and two of the cold pools (2 and 4) inside the cave and the pool outside over 17 hrs on 9–10 June 2013.



FIGURE 4 Comparison of mean air temperature (upper panel) and mean relative humidity (lower panel) inside and outside the cave over 17 hrs on 9–10 June 2013.

DISCUSSION

Among the few known examples of crocodilians inhabiting large caves is a population of dwarf crocodiles (*Osteolaemus* sp.) in karst caves of Abanda in Gabon (IRD 2012). This unique population is morphologically different, live in complete darkness, and depend on a diet of cave dwelling animals including bats and invertebrates. A population of Nile crocodiles (*C. niloticus*) is known to inhabit the labyrinth of caves beneath Madagascar's Ankarana Nature Reserve (Handwerk 2003). Steubing et al. (2004) found tracks of false gharials (*Tomistoma schlegelii*) entering caves in Bukit Sarang in Sarawak, Malaysia but no direct observations of individuals were made.

Nevertheless, use of smaller subterranean habitats by crocodilians is well documented. Caverns or burrows are often used by smaller crocodilians as hideouts during daytime (e.g. Chinese alligator, *Alligator sinensis*, African dwarf crocodile, *Ostolaemus tetraspis*, smooth-fronted caiman *Paleosuchus trigonatus*: Magnusson and Lima 1991; Brazaitis and Watanabe 2011); as refugia during the periods guarding nests and protecting hatchlings (e.g. mugger crocodile *C. palustris*, American crocodile *C. acutus*: Gupta and Bhardwaj 1995; Wasilewski and Enloe 2006); and also to avoid adverse environmental conditions such as drought and winter (e.g. Nile crocodile *C. niloticus*, American alligator *Alligator mississippiensis*: Cott 1961; Neill 1971). However, these burrows and tunnels are usually dug by the adults of the species, and in most instances are only used seasonally or as a hideout during part of the day.

Crocodylus johnstoni is endemic to mainland northern Australia and is widespread in the Kimberley region (Burbidge 1987), generally inhabiting upstream permanent freshwater habitats, although they may extends into tidal, brackish waters in a few river systems (Webb and Manolis 2010). Despite its wide range and occupation of a variety of aquatic habitats, there are no records of Australian freshwater crocodiles utilising subterranean habitats, other than using smaller caverns to aestivate during the dry season. Crocodylus johnstoni are known to seek refuge in subterranean shelters when water bodies dry entirely (Kennett and Christian 1993; Walsh 1989). Recaptures of C. johnstoni in the Northern Territory of Australia indicate high site fidelity to specific caverns for aestivation in the dry season. Potential advantages for C. johnstoni seeking shelter in caves to aestivate include predator avoidance, improved thermoregulation, and reduced rates of dehydration (Walsh 1989).

The occupation of Tunnel Creek cave by crocodiles may be based on thermal and foraging benefits. Observations show that crocodiles had a clear preference to warmer pools over cold pools. For example, the largest animal (150-180 cm) was always observed at a warm pool. Crocodilians, especially the dominant individuals, often seek the warmer water if available (Grigg and Seebacher 2001). In the dry season of September 2013, when one spring was not flowing, we observed clear signs of crocodiles coming up to the section with the collapsed roof, arguably for basking. However, it is likely that the crocodiles occupying the Tunnel Creek cave are mainly following a thermoconformity pattern where the body temperature equals water temperature (Seebacher and Grigg 1997), as the conditions inside the cave may not support active thermoregulation.

The cave may also provide foraging benefits for the crocodiles. *Crocodylus johnstoni* is an opportunistic predator having a wide breadth in prey items. Eel-tailed catfishes (*Anodontiglanis dahli* and *Neosilurus hyrtlii*), short-finned eels (*Anguilla bicolor*), spangled perch (*Leiopotherapon unicolor*) bony bream (*Nematalosa erebi*) and cherubin (*Macrobrachium rosenbergii*) are abundant in the much smaller pools within the cave (compared to the larger pool outside). Several species of bats (*Macroderma gigas, Vespadelus caurinus, Vespadelus douglasorum, Miniopterus schreibersii*,

Pteropus scapulatus; see McKenzie and Bullen 2012 for additional species), frogs (e.g. *Litoria caerulea*, *L. pallida*) and snakes (e.g. *Lialis olivaceus*, *Boiga irregularis*) were observed within the cave during the surveys and all these groups are known prey items of freshwater crocodiles (Tucker et al. 1996; Webb et al. 1982). Predator avoidance may not be a potential reason for inhabiting the cave as most animals observed were adults or sub-adults, those without a natural predator in the area.

The much paler colouration observed in the crocodiles at Tunnel Creek cave could have mainly been a result of the darker conditions within the cave, as crocodilians in darker environments tends to develop lighter body colours (Richardson et al. 2002; but see Kirshner 1985). However, animals with high growth rates also tend to be paler than their counterparts that are subordinate, probably due to hormonal influence (Richardson et al. 2002; C. Manolis, pers. comm., 2013). It is also possible that the lighter colour was an artefact of agitation/excitement due to us approaching the crocodiles (Kirshner 1985), although we did not observe similar colour changes in other sites where crocodiles were caught by us. The Osteolaemus sp. in karst caves of Abanda in Gabon has a lighter and a more orange body colour compared to those outside (IRD 2012), but the C. niloticus individuals in the caves at Ankarana Nature Reserve are of normal pigmentation (Wilson 1987).

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