Problem crocodiles (*Crocodylus porosus*) in the freshwater, Katherine River, Northern Territory, Australia

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ABSTRACT

Crocodylus porosus is a species that is potentially dangerous to humans and there are numerous records of fatal attacks by this species on humans. Since the Northern Territory population of *C. porosus* was declared a protected species in 1971, their populations have risen markedly, increasing the potential for conflict between people and crocodiles. In 1994 *C. porosus* was observed in the freshwater Katherine River for the first time in over twenty years. To reduce the risk of crocodile attacks, the Parks and Wildlife Service of the Northern Territory has operated a program to remove *C. porosus* from the Katherine River since 1995. Between 1994 and 2004, 53 males and 1 female were captured. The mean size of captured crocodiles was 313.9 cm total length. Crocodiles were captured in all months between March and November. The month with the highest rate of crocodile captures was June. The greatest number of crocodile captures were made in the years with the highest wet season rainfall. The results of this study indicate that removal programs need to be conducted throughout the year and highlight the necessity to collect quantitative data on crocodile capture effort.

Key words: *Crocodylus porosus,* wildlife management, human wildlife conflict, freshwater, saltwater crocodile

Introduction

Since *Crocodylus porosus* (saltwater crocodiles) was declared a protected species in the Northern Territory in 1971, their populations have increased in marine, estuarine and freshwater habitats (Stirrat *et al.* 2001; Nichols and Letnic 2008; Letnic and Connors 2006). During this period there have been 10 fatal attacks and at least 33 non-fatal attacks by crocodiles on people in the Northern Territory (Caldicott *et al.* 2005). In most instances where attacks have occurred, the victims have been in the water at the time of the attack, though in some cases the victims were located within 30 m of the waters edge.

The increase in *C. porosus* numbers in the upstream reaches (areas upstream of tidal influence) of freshwater rivers is a significant issue in the Northern Territory (Letnic and Connors 2006). In some river systems, *C. porosus* are being recorded in places where they have not been known to occur in living memory. Although *C. porosus* typically occur at very low densities in the upstream reaches of freshwater rivers (Messel *et al*. 1987; Letnic and Connors 2006) their presence has had or may have a significant impact on the use of rivers and riparian areas by people and livestock. The increased risk of crocodile attack is of particular significance to the tourism-industry, a major economic sector in the Top End of the Northern Territory, as swimming and other water-sports in rivers are an attraction for tourists visiting the region.

In 1994, *C. porosus* was recorded in the freshwater Katherine River, near the town of Katherine, for the first time in over twenty years. In response, the Parks and Wildlife Service of the Northern Territory initiated a program to remove all crocodiles from the waterways near Katherine in an operational area known as the "Katherine Crocodile Management Area". Similar programs operate in the marine waters surrounding the major urban centres of Darwin (Nichols and Letnic 2008) and Nhulunbuy (Walsh and Whitehead 1993). Any *C. porosus* that occur within the declared crocodile management areas around these urban areas are termed problem crocodiles. Because crocodiles demonstrate a strong homing instinct (Walsh and Whitehead 1993), the captured crocodiles are not relocated and are sold to crocodile farms. Crocodiles are also removed from other locations in the Northern Territory on a case by case basis.

In this paper we report on captures of *C. porosus* in the "Katherine Crocodile Management Area" between 1994 and 2004. The specific aims of this study were to: 1) report the number of crocodiles captured; 2) examine the size and sex ratio of the captured crocodiles; and 3) investigate the influence that month, river height and rainfall had on the capture rate of crocodiles in the Katherine Crocodile Management Area.

Methods

Study area

The study area was the Katherine Crocodile Management Area comprising parts of the Katherine River, Flora River and Daly River near the town of Katherine (Fig. 1). The Katherine Crocodile Management Area lies in the Daly River catchment. The climate of Katherine

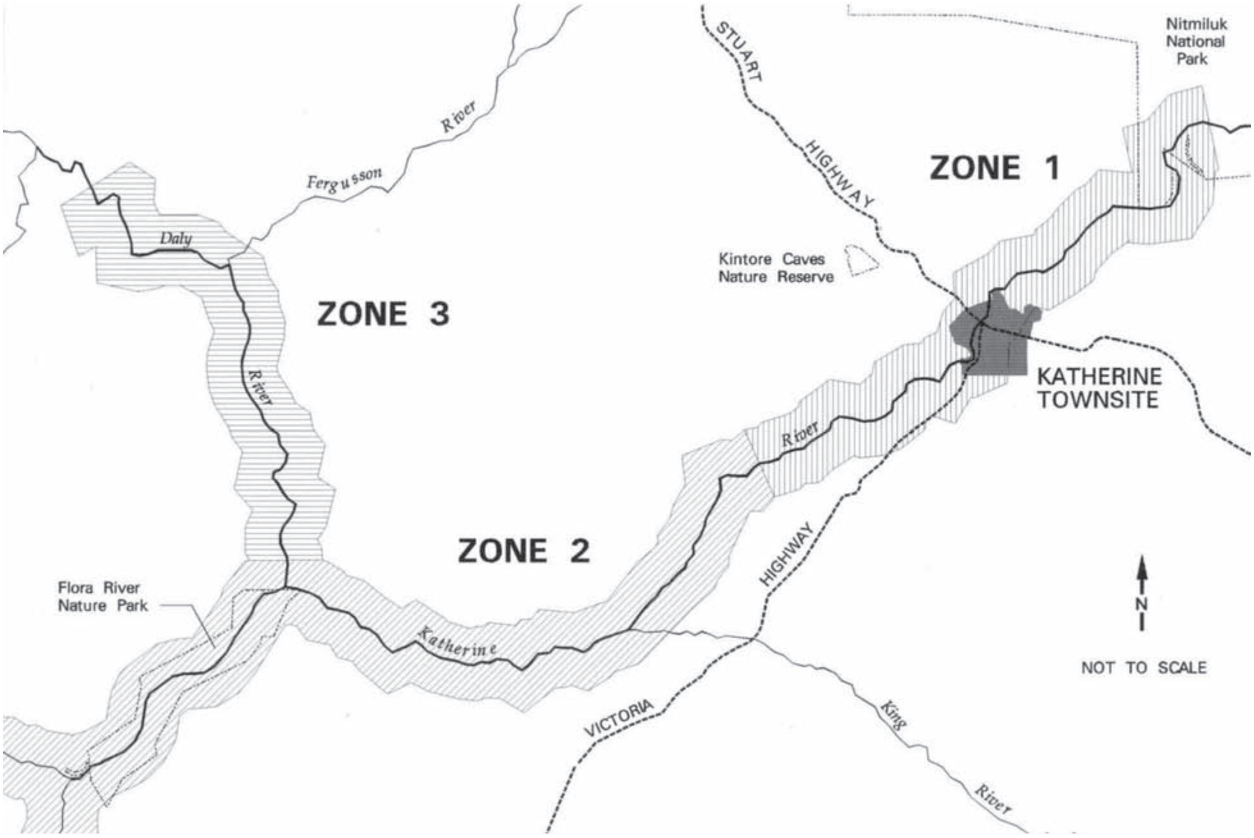

Figure 1. The Katherine Problem Crocodile Management Area, showing the locations of zones 1, 2 and 3.

is monsoonal and is characterised by a hot humid rainy season (December-February), a hot dry season (June-August) and two transitional seasons, the build-up (September-November) and late-wet (March-May). The average annual rainfall of Katherine is 1099.2 mm per annum (n=61). The elevation of Katherine is 120 m above sea level.

The Daly/Katherine/Flora Rivers have highly seasonal flow regimes, with peak flows during the wet season (January–March). The rivers are surrounded by pockets of monsoon rainforest and tropical savannah. In the late dry season, the river is 25–75 m wide and several centimetres to 3 m deep.

The Katherine Crocodile Management Area was declared in 1995 (Figure 1) due to the sighting and capture of a *C. porosus* in 1994. The individual captured in 1994 was the first recorded for many years. Since 1994 the number of traps deployed in the management area increased owing to an increase in crocodile sightings and captures. Only one trap was operational in 1994 compared to ten traps in 2004. The Management Area comprised three zones (Fig. 1) subject to varying levels of use by the public. The management zones and strategy for managing *C. porosus* in each zone are described below:

Zone 1. This section of river near Katherine is the one most utilised by people. Activities regularly conducted in this section of river include swimming, canoeing and fishing. Since 1995 at least four traps and up to eight crocodile traps were set during the dry season each year. The number of traps set was dependent upon the height of river and staff availability. Daytime helicopter patrols and night-time spotlighting patrols to locate and capture crocodiles were undertaken outside the wet-season months, and in response to crocodile sightings. The most intensive period for conducting patrols was at the end of the wet season when the height of the river decreases and it was possible to navigate the river.

Zone 2. This section of river included the Flora River National Park, which is used primarily for canoeing, fishing and camping during the dry season. Three traps were set during the dry season. Daytime helicopter patrols and night-time spotlight patrols were undertaken as required to locate and remove crocodiles.

Zone 3. This zone was located well downstream of Katherine and had less use by the public than the other zones. Aerial patrols were undertaken opportunistically and crocodiles removed when required.

Capture methods

The traps used to capture crocodiles were floating, galvanised mesh cages (4.5 m long, 1 m wide and 1 m high). Buoyancy for the traps was provided by pontoons attached to each side of the trap. The pontoons were attached so that approximately half of the trap was under-water, to allow captured crocodiles to submerge. The traps were placed in the river for as long as the water height would allow. The traps were baited with an animal carcass (normally a pig's head) which was replaced weekly. The bait was attached by rope to a door release mechanism that closed the door when the bait was taken by a crocodile.

Harpooning patrols to locate and capture crocodiles were usually conducted following sightings of crocodiles. Harpooning (Webb and Messel 1977) was undertaken at night when crocodiles can be easily located using a spotlight because of their reflective eyeshine. The harpoon consisted of a 3-m long pole and a two or three-pronged, barbed harpoon head that was attached to a cord. The harpoon head consists of straightened fish-hooks mounted on a broad base, designed so that the hooks do not penetrate far below the skin of the crocodile (Webb and Messel 1977). Crocodiles were usually harpooned in the muscles of the neck, although sometimes they were harpooned in the tail. Large crocodiles were sometimes harpooned several times to ensure they did not escape. Large crocodiles that are harpooned are susceptible to potentially fatal lactate build up (Seymour *et al.* 1987). Consequently it was standard procedure to inject crocodiles greater than 3 m total length with Flaxedil (gallemine triethiodide: Rhône-Poulenc Rorer Australia Pty Ltd.), a muscle relaxant, or a mixture of Flaxedil and Valium (diazepam: Roche Products Pty Ltd.) as soon as possible following capture.

Following capture, the sex and total length (TL) to the nearest centimetre of each crocodile was recorded. All captured animals were relocated to a crocodile farm. The date of capture, trap location, sex, total length and fate of each crocodile captured was entered into the Parks and Wildlife Service's Problem Crocodile database.

Environmental variables and crocodile capture rates

Charts were used in explore the relationship between the number of crocodiles captured in traps each year and environmental variables between 1995 and 2004. Because the data were not standardised for trap effort (the number of traps deployed and time that each trap was set was not documented and varied due to environmental and operational reasons) caution needs to be exercised when making inferences from the data. For example, some of the variation in annual crocodile capture rate that was observed may be an artifact of greater trapping effort in years when the perceived risk of crocodile attacks was greater. Despite this potential source of bias, we believe that patterns from these data may be useful for future crocodile management and highlight the need to keep quantitative data on capture effort.

Wet season rainfall was calculated as the rainfall received at the Katherine Airport during the months October-March. Peak river height was calculated as the highest recorded river height in each calendar year at the Katherine gauging station.

A number of river-height variables were calculated using different periods and trialled for exploratory charting against the number of crocodiles trapped each year. These included mean daily river height for the entire calendar year (Annual River Height), mean daily river height for the wet season (October-March), mean daily river height for the dry season (April-September), mean daily river height in the first 121 days of the calendar year (First third river height), mean daily river height between days 122-244 of the calendar year (Second third river height) and mean daily river height between days 245 and 365-366 of the calendar year (Last third river height). All rainfall and hydrology data were supplied by the Northern Territory Department of Infrastructure Planning and Environment.

Results

The sex ratio and size of captured crocodiles.

Of the 54 *C. porosus* captured between 1994 and 2004, 45 were caught in traps and 9 by harpooning (Table 1). Only 1 female was captured.

The largest *C. porosus* captured was a male that was 447 cm TL and the smallest was a male 180 cm TL (Fig. 2). The mean and median TL of male crocodiles were 313.9 cm and 313.5 cm, respectively. The only female crocodile captured was 222 cm TL.

Table 1. *Crocodylus porosus* captured in the Katherine Crocodile Management Area each month between January 1999 and December 2004 using all methods of capture. The number of animals trapped is presented in parentheses. No removals were conducted in the wet season months December-February. The mean represents the number of crocodiles trapped per year for each calendar month (n=11 years).

Year	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
1994	0	0	0	0	0	0	0	0	1 (1)	1 (1)
1995	0	0	1 (1)	0	3 (1)	3 (1)	1	0	0	8 (3)
1996	0	0	0	0	0	0	2 (1)	0	0	2 (1)
1997	0	1 (1)	0	1 (1)	0	0	0	0	0	2 (2)
1998	0	0	0	1 (1)	2 (2)	1 (1)	0	0	0	4 (4)
1999	1	1	0	0	0	2	2 (2)	2 (2)	0	8 (4)
2000	0	3 (3)	0	1 (1)	0	0	0	0	1 (1)	5 (5)
2001	1 (1)	0	0	3 (3)	0	1 (1)	2 (2)	2 (2)	0	9 (9)
2002	0	0	1 (1)	0	0	1 (1)	0	0	0	2 (2)
2003	0	0	0	2 (2)	1 (1)	0	0	0	0	3 (3)
2004	0	1 (1)	0	4 (4)	0	1 (1)	0	1 (1)	0	10 (10)
Mean	0.18 (0.09)	0.55 (0.55)	0.45 (0.45)	1.09 (1.09)	0.55 (0.27)	0.82 (0.82)	0.64 (0.36)	0.55 (0.55)	0.18 (0.18)	5 (4.09)

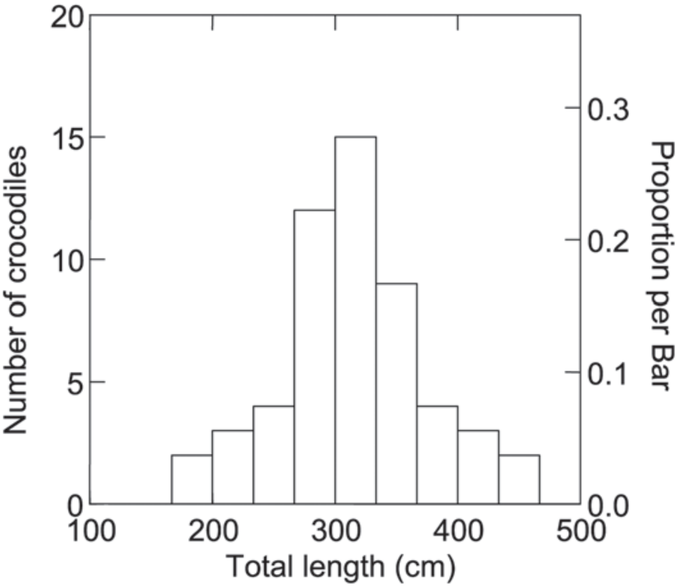

Figure 2. The size frequency distribution (total length cm) for all *Crocodylus porosus* captured in the Katherine Crocodile Management Area.

Month of capture and relationship with environmental variables

Crocodylus porosus were captured in all months between March and November. No attempts to capture crocodiles were made in the months December-February because of high water levels. June was the month with the highest average capture rate, followed by August and September respectively (Table 1). The lowest monthly capture rates were observed in March and November.

Values for environmental variables are presented in Table 2. Exploratory graphing of the data showed that the number of crocodiles trapped each year was greatest in the years when Wet season rainfall, Annual river height and First third river height were greatest (Fig. 3).

Discussion

The size range (1.8-4.47 m TL, mean = 3.13 m TL) and male bias of *C. porosus* captured in the Katherine Crocodile Management Area indicates that most of the animals were

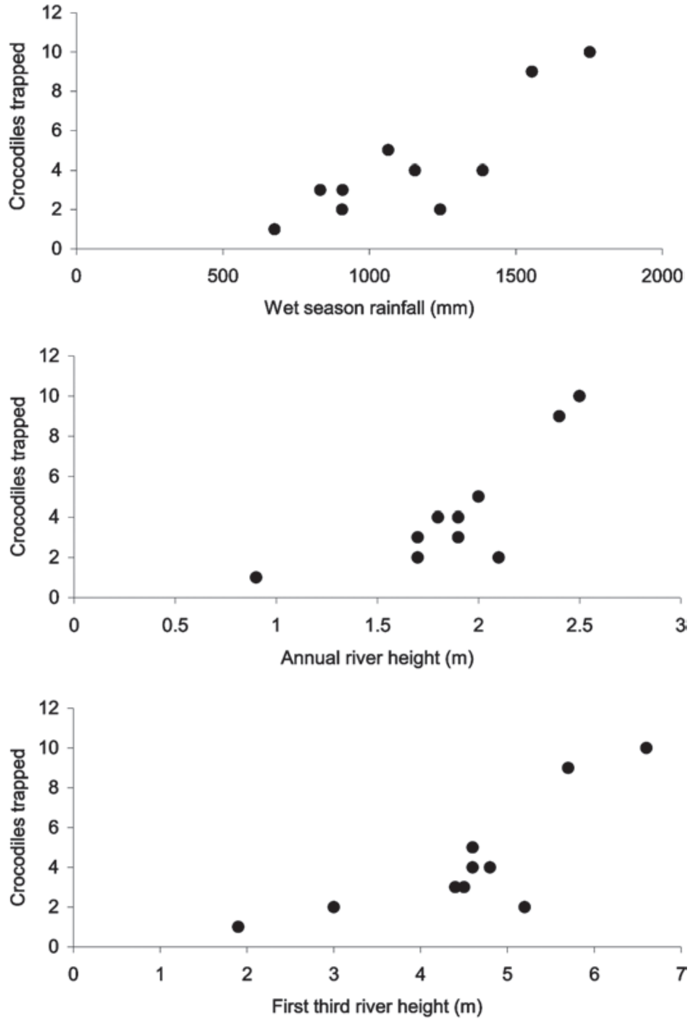

Figure 3. The number of *C. porosus* trapped each calendar year plotted against (A) rainfall in the preceding wet season (October-March), (B) Annual river height (mean daily height from January-December) and (C) First third river height (mean daily height from January-April) for the Katherine Crocodile Management Area between 1995 and 2004.

sub-adult or small adult males. The size-structure of *C. porosus* captured in the Katherine Crocodile Management Area, differed markedly from habitats with high crocodile

Table 2. Values for environmental variables between the 1993-1994 wet season and December 2004.

Year	Wet season Rainfall (mm)	Peak river height (m)	Annual river height (m)	First third river height (m)	Second third river height(m)	Last third river height (m)
1994	844.5	12.6	1.4	3.5	0.3	0.3
1995	833	10.8	1.7	4.4	0.4	0.4
1996	677	8.7	0.9	1.9	0.3	0.6
1997	1242	13.7	2.1	5.2	0.3	0.8
1998	1387	20.4	1.9	4.8	0.4	0.5
1999	1156	11.2	1.8	4.6	0.4	0.5
2000	1064.5	17.5	2.0	4.6	0.7	0.8
2001	1555	15.2	2.4	5.7	0.7	0.9
2002	907	17.0	1.7	3.0	0.4	0.5
2003	908.5	16.2	1.9	4.5	0.4	0.9
2004	1752.5	14.9	2.5	6.6	0.4	0.4

densities that are associated with nesting, such as tidal estuaries and floodplains (Webb *et al.* 1983). In areas where nesting occurs, hatchlings and sub-adults less than 2.1 m TL dominate populations (Messel and Vorliceck 1986; Read et al. 2004). Although there is little data available on the sex ratio of *C. porosus* populations in habitats associated with nesting, it would be reasonable to assume that the sex ratio would be closer to parity than was observed in the Katherine Crocodile Management Area

Nichols and Letnic (2008) invoked a "male dispersal" hypothesis to explain the strong male bias (approximately 70 % male) and size-structure (mean TL= 2.15 m) of *C. porosus* captured in the marine waters of Darwin Harbour. They suggested that sub-adult male *C. porosus* avoid aggressive interactions with larger males by dispersing from their preferred habitats that have high *C. porosus* densities, such as tidal estuaries and floodplain billabongs, to less favourable "peripheral habitats" which have low crocodile densities. The similarity in the size structure and sex ratio of *C. porosus* captured in the Katherine Crocodile Management Area and Darwin Harbour lends support to the hypothesis that the captured *C. porosus* had dispersed upstream to avoid intra-specific competition. This hypothesis is supported by observations that the density of *C. porosus* within the Katherine Crocodile Management Area is very low (0.11 *C. porosus*/km; Letnic and Connors 2006) when compared to the downstream, tidal reaches of the Daly River (2.88 *C. porosus*/km; Doody *et al.* 2007).

Rainfall in the wet season, mean annual river height and mean river height in the first third of the calendar year appear to be correlates of the number of crocodiles trapped each year, although we acknowledge that the crocodile capture data were not standardised for capture effort. These observations and anecdotal accounts suggest that movements by *C. porosus* into the management area may be contingent upon the height of the river and the duration of high flows, and occur mainly during the wet season. Presumably it is easier for crocodiles to negotiate rock-bars and other barriers when the river is flooded. The apparently positive relationship between crocodile captures, rainfall and river height highlight the need to maintain a register of capture effort so that the variables influencing the movements of *C. porosus* into the management area can be better understood.

The trapping of crocodiles throughout the year after initial post-wet season helicopter and spotlight patrols has important management implications. In particular, it highlights that helicopter and spotlight patrols cannot provide conclusive evidence of the absence of *C. porosus* because they cannot detect crocodiles that are concealed by vegetation or submerged (Bayliss *et al.* 1986). In an experimental mark-resight study conducted in an estuarine habitat with moderate crocodile density, Bayliss *et al.* (1986) sighted only 35-66% of the crocodiles present in spotlight population surveys. Similarly, Messel *et al.* (1981) working in estuarine habitats estimated that only 63% of the *C. porosus* present were sighted. The probability of sighting crocodiles during helicopter surveys is generally lower than during spotlight surveys (Bayliss et el. 1986; Stirrat *et al.* 2001).

The poor reliability of spotlight and helicopter surveys/patrols as a detection technique for crocodiles is further highlighted by differences in the sightability of different size classes. Large crocodiles are more wary than smaller animals and therefore are more difficult to detect during spotlight surveys (Webb and Messel 1979; Messel *et al.* 1981; Bayliss *et al.* 1986). This is of particular concern in freshwater areas such as the Katherine River, where the *C. porosus* present are mainly large (> 3 m TL) and potentially dangerous to people. Because of the relatively low probability of sighting crocodiles in any given patrol/survey, spotlight and helicopter patrols should be repeated regularly and removal efforts using trapping must be maintained for as long as the river height allows. An estimation of the number of surveys needed to give a specified (statistical) level of confidence of sighting crocodiles when they occur at low population densities may assist with the design of crocodile management programs (e.g. McKenzie *et al.* 2002).

Foam buoys are being used increasingly as a passive crocodile detection device (Parks Australia 2004). These devices consist of a foam float that has been anchored or attached securely to the river bank. Crocodiles find these buoys attractive, particularly when they have been baited, and frequently bite them leaving a tooth imprint indicative of the species and size of the crocodiles present. These buoys have the potential to be used routinely as an additional crocodile detection device in freshwater rivers.

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