NESTING ECOLOGY OF THE AUSTRALIAN FRESHWATER
CROCODILE, CROCODYLUS JOHNSTONI, ON THE MCKINLAY RIVER

Setting a Baseline for Assessing the Potential Impact of the Exotic
Cane Toad, *Bufo Marinus*

A thesis submitted to Charles Darwin University in partial fulfilment of the requirements for the degree of Master of Science
by
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December, 2003
DECLARATION

I declare that this thesis contains no material that has been presented for the award of any other degree or diploma in any university and, to the best of knowledge and belief, contains no material previously published or written by another person, except where duly acknowledged in the text.

I consent to the thesis being made available for photocopying and loan, should it be accepted for the award of the degree.

28 December 03

Amaral Machaculeha Chibeba
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SUMMARY

The nesting ecology of the Australian freshwater crocodile, *Crocodylus johnstoni*, was investigated in 2003 on the McKinlay River, Northern Territory of Australia. The study encompassed the period of time prior to nesting until hatching.

Altogether, 61 nests were laid in three weeks, from 16 August to 6 September 2003. Coarse sand was the most common substrate type (58.5%) followed by fine sand (30.2%). The majority of nests were laid less than 20 m away from permanent water (58.8%), though some nests were laid 200 m away from water (5.9%). It appeared that in selecting nesting sites the availability of friable substrates plays the major role with distance of nests from permanent water being determined by availability of suitable substrates in the landscape.

Analysis of clutch characteristics showed that larger clutches with larger eggs tended to be laid earlier. Larger clutches had wider eggs, suggesting that they were produced by larger females. There was no consistent variation in laying date or other clutch characteristics across sites, indicating that nesting time was synchronised across sites and clutch characteristics did not change with location.

A comparison of clutch sizes obtained this year to those from 1980, 1982-85 and 2002 showed that while clutch size did not vary significantly amongst years, egg breadth, egg length and egg mass, varied considerably from one year to another. This indicates that should cane toads have an impact on clutch characteristics, it may be difficult to ascertain, unless clutch size it affected.

Similarly, a comparison of time of nesting from 1980, 1982-85, 2002 and 2003 showed that commencement of nesting varies noticeably from one season to another. No significant correlation was found between time of nesting and the mean temperature experienced in the three months preceding the nesting season.
There was extremely high egg mortality during incubation. *Varanus panoptes* took 52 of the 61 nests (85.3%) found throughout the study. *Varanus mertensi* was also observed but was never found excavating or investigating *C. johnstoni* eggs. Water buffaloes, pigs, dingo, and horses were also observed but no evidence was found of pigs or dogs preying on nests, nor was any nest physically destroyed by pugging or trampling by buffaloes or horses.

A total of ten nests hatched in two weeks, from 4 November to 14 November 2003, 81.3 days after they were laid (N = 4, SD = 4.6, range 75 - 86). Hatching success was estimated at 1.68%, which can be used to derive an estimate of 476 nests laid in this season across the study site. The standard error was very high suggesting that unless large sample sizes, of at least 50 nests found before predation, are obtained, impacts of toads on the reproductive success of *C. johnstoni* may not be detected statistically.

There has been an increased invasion of saltwater crocodiles in the McKinlay River area. Saltwater crocodiles were observed in two Sites: in one Site the occurrence of saltwater crocodiles had been suspected yet never confirmed, while the other Site has just been invaded. The arrival of saltwater crocodile in the second Site appears to have displaced the once common and repeatedly observed population of freshwater crocodiles.

Recommendations for future studies are provided. In evaluating the impact of cane toads upon the nesting ecology of freshwater crocodiles, mark-recapture studies are suggested to ascertain changes in size, sex ratio and population structure attributable to the arrival of cane toads. Concomitantly, monitoring the invasion of saltwater crocodiles and examining the stomach contents of any varanid lizard or crocodile found dead is also suggested.

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*Nesting Ecology of the Australian Freshwater Crocodile on the McKinlay River: Baseline for Assessing the Impact of Cane Toads*

*Amaral M. Chibeba*
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I INTRODUCTION

The cane toad, *Bufo marinus*, has a pair of large parotoid glands that secrete a combination of highly toxic substances (Tyler, 1975; Freeland, 1986; Lever, 2001; van Dam *et al.*, 2002) known to be capable of killing a wide range of predators, including reptiles, which attempt to feed on them (Covacevich and Archer, 1975; Freeland, 1984, 1985, 1986; Jacklyn, 1992; Burnett, 1997; Catling *et al.*, 1999; Oakwood, 2002). A number of reliable anecdotal reports on the impact of *B. marinus* upon Australian native fauna have been published (Covacevich and Archer, 1975; Freeland, 1985, 1986; Jacklyn, 1992; Burnett, 1997; Catling *et al.*, 1999; Oakwood, 2002; van Dam *et al.*, 2002; Altman *et al.*, 2003). Some of these reports are summarised in Table 1.1.

The McKinlay River area has a large and discrete freshwater crocodile population and no *B. marinus* individuals have been observed thus far. However, it is believed that the arrival of *B. marinus* may occur within 12 months (Grahame Webb, Personal com.).

In this chapter, the biology and ecology of the Australian Freshwater Crocodile, *Crocodylus johnstoni*, and the Cane Toad, *Bufo marinus*, are reviewed. First, the population size, density, growth, movement, population structure, feeding, reproduction and survivorship of *C. johnstoni* are presented, with emphasis on how these attributes may potentially be influenced by the arrival of *B. marinus*. And second, the habitat, feeding habits, reproduction, toxicity and impact on fauna of *B. marinus* are discussed, with stress on how these attributes may influence the interaction between *B. marinus* and *C. johnstoni*.

Nesting Ecology of the Australian Freshwater Crocodile on the McKinlay River: Baseline for Assessing the Impact of Cane Toads

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Table 1.1: Susceptibility of Australian native fauna to *B. marinus*. Dead, means animals died as a result of consumption of cane toads. No ill, means animals presented no ill effects.

<table>
<thead>
<tr>
<th>Faunal group</th>
<th>Susceptibility</th>
<th>Source</th>
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<tbody>
<tr>
<td></td>
<td>Dead</td>
<td>No ill</td>
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<tr>
<td><strong>MAMMALS</strong></td>
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<tr>
<td>Quoll (<em>Dasyurus hallucatus</em>)</td>
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<td>(3), (5), (7), (8), (10)</td>
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<td>Dingo (<em>Canis familiaris dingo</em>)</td>
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<td>(6), (2), (8)</td>
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<tr>
<td>Feral Cat (<em>Felis catus</em>)</td>
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<td>(8)</td>
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<tr>
<td>Western Native Cat (<em>Dasyurus geoffroii</em>)</td>
<td>*</td>
<td>(1)</td>
</tr>
<tr>
<td>Tasmanian Devil (<em>Sarcophilus harrisii</em>)</td>
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<tr>
<td>Water Rat (<em>Hydromys chrysogaster</em>)</td>
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<td>Sand Goanna (<em>Varanus gouldii</em>)</td>
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<td>Mangrove Monitor (<em>Varanus indicus</em>)</td>
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<td>Northern Sand Monitor (<em>Varanus panoptes</em>)</td>
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<td>Land Mullet (<em>Egernia bungana</em>)</td>
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<tr>
<td>Spotted Tree Monitor (<em>Varanus scalaris</em>)</td>
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<td><strong>SNAKES</strong></td>
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<td>Northern Death Adder (<em>Acanthophis praelongus</em>)</td>
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<td>Slaty Grey Snake (<em>Stegonotus cucullatus</em>)</td>
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<td>Keelback Snake (<em>Tropidonophis mairii</em>)</td>
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<td>Crow (<em>Corvus sp.</em>)</td>
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<tr>
<td>Whistling Kite (<em>Haliastur sphenurus</em>)</td>
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<td>Long-necked Tortoise (<em>Chelodina sp.</em>)</td>
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<tr>
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<td>Krefft's River Turtle (<em>Emydura krefftii</em>)</td>
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<td><strong>CROCODILES</strong></td>
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<td>Saltwater Crocodile (<em>Crocodylus porosus</em>)</td>
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<td>(1), (4), (8)</td>
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<td>Freshwater Crocodile (<em>Crocodylus johnstoni</em>)</td>
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1.1 THE AUSTRALIAN FRESHWATER CROCODILE

Crocodylus johnstoni (KREFFT, 1873) is endemic to Australia and its distribution is restricted to the northern part of the continent between Rockhampton, on the east coast of Queensland, and Broome, on the west coast of Western Australia (Webb and Manolis, 1989). This relatively small crocodile (Webb and Manolis, 1989) occurs primarily in permanent freshwater streams, rivers and lagoons (Messel et al., 1979; Webb et al., 1983b, 1983e; Burbidge, 1987; Webb and Manolis, 1989), with small numbers inhabiting brackish water in estuarine or tidal rivers (Messel, et al., 1980a, 1980b, 1981; Webb et al., 1983e, 1983f; Webb et al., 1987b).

Whilst until relatively recently the biology of C. johnstoni was poorly known (Webb, 1982; Webb et al., 1983b), extensive research on its ecology has been completed. Most of the research has been undertaken in the McKinlay River area of the Northern Territory (Webb, 1982; Webb et al., 1982; Webb et al., 1983a, 1983b, 1983c, 1983d; Webb and Smith, 1984; Smith and Webb, 1985; Smith, 1987; Whitehead, 1987; Webb and Manolis, 1989; Webb, 1991; Britton, 2003). Reports of studies in Queensland have become available more recently (Tucker et al., 1996; Taplin, 1987; Tucker et al., 1997).

1.1.1 Population Size

Until the early 1960's, C. johnstoni was hunted for its skin to supply the export market (Smith and Webb, 1985; Burbidge, 1987; Taplin, 1987; Webb et al., 1987b; Webb and Manolis, 1989). Though the population size of C. johnstoni prior to the imposition of a total export ban on export of crocodile skins is unknown (Taplin, 1987; Webb et al., 1987), it is believed the population has increased remarkably since then (Webb, 1982; Smith and Webb, 1985; Taplin, 1987; Webb and Manolis, 1989). The population size of C. johnstoni in the Northern Territory has been estimated between 30,000 and 60,000 individuals (Webb et al., 1987b), whereas about 1,000 individuals (Webb et al., 1983c) and a natural population growth of 1.5% (Smith and Webb, 1985) have been reported for the McKinlay River area.
The extent to which the population size of *C. johnstoni* will be affected by *B. marinus* is difficult to predict. Given that *C. johnstoni* have been reported to die after consuming *B. marinus* (Jacklyn, 1992; van Dam *et al.*, 2002), the population size of *C. johnstoni* might be expected to decline through an increase in mortality. On the other hand, populations of varanid lizards, the main predators on *C. johnstoni* eggs (Section 1.1.6) have been reported to decline severely through high mortality through consuming *B. marinus* (Section 1.2.5). This would favour increase in the reproductive success of *C. johnstoni*. The extent to which the population of *C. johnstoni* will be affected by the arrival of *B. marinus* will ultimately depend on the relative magnitude of these critical influences on population dynamics.

1.1.2 Density

The density of *C. johnstoni* is determined by the seasonality of wetlands in which it lives (Webb, 1991). In the dry season *C. johnstoni* congregate non-randomly in the available waters, concentrating in deeper and larger pools (Webb and Smith, 1984; Webb, 1991). Of 505 crocodiles recorded in July 1979, 97.8% were in pools deeper than one meter and, of those, 77.7% were in pools greater than two meters deep (Webb and Smith, 1984). In the wet season, crocodiles follow the expanding water's edge out of their dry season limits and out of the surrounding floodplains (Webb and Manolis, 1989).

Intra-specific fighting is greater when animals are concentrated, judging by the frequency of fresh injuries (Webb, 1991). It is likely that mortality varies significantly with both density and season (Webb, 1991).

Given that *B. marinus* attains maximum densities close to available water in open areas (Section 1.2.1), it is likely that *C. johnstoni* and *B. marinus* may, to some extent, share the same habitats.
1.1.3 Diet and Feeding

*Crocodylus johnstoni* exhibit a remarkable seasonal variation in food intake. It has been observed that *C. johnstoni* eats appreciably more during the wet season than in the dry season (Webb, 1982; Webb *et al.*, 1982; Webb and Manolis, 1989; Webb, 1991), with most animals losing weight during the dry season (Webb and Manolis, 1989; Webb, 1991). Though the reason for seasonal variation in food intake has not been fully elucidated (Webb, 1991), lower prey availability in the dry season has been ascribed as the major factor (Webb *et al.*, 1982; Webb and Manolis, 1989; Webb, 1991).

Inspections of stomach contents of *C. johnstoni* on the McKinlay River indicate that it feeds primarily on aquatic and terrestrial insects, fish, crustaceans and frogs (Webb *et al.*, 1982; Webb and Manolis, 1989; Tucker *et al.*, 1996). Being an opportunistic predator, *C. johnstoni* preys on any suitable-sized animal present at the water's edge (Webb *et al.*, 1982). It was also noted that with increase in body size, crocodiles increase the diversity of prey and eat markedly fewer anurans (Tucker *et al.*, 1996).

Since frogs have been reported amongst the prey of *C. johnstoni* (Tucker *et al.*, 1996) and *C. johnstoni* has been reported to die from consuming cane toads (van Dam *et al.*, 2002), it is likely that a number of crocodiles will die after the arrival of *B. marinus* on the McKinlay River. Furthermore, given that younger crocodiles eat substantially more frogs than older ones (Tucker *et al.*, 1996), the mortality of *C. johnstoni*, from the consuming of cane toads, may be markedly higher in younger crocodiles.
1.1.4 Growth, Movement and Population Structure

(a) Growth

In the McKinlay River area, *C. johnstoni* grow almost exclusively in the wet season with downstream animals growing faster than upstream and males growing faster and attaining larger sizes than females (Webb *et al.*, 1983d). In their study, Webb and Manolis (1989) recorded a maximum length of 2.51 m for males, weighing 61.0 kg, and a maximum of 2.0 m in total length for females, weighing 29.8 kg.

The impact of cane toads upon *C. johnstoni* may vary with sex. Because adult crocodiles ingest substantially fewer anurans than younger ones (Section 1.1.3) and that the physiological effects of a given dose of cane toad toxins, it can be expected that the fast growing males (Webb *et al.*, 1983d) may be less affected than females. But if males grow faster because they eat more and so are more likely to ingest toads, then they may experience a correspondingly higher mortality that offsets advantages enjoyed by males through spending less time in vulnerable size classes (Section 1.1.3).

Not surprisingly, *C. johnstoni* growth takes place almost exclusively in the wet season (Webb and Manolis, 1989), which agrees with the markedly higher food intake in this season (Section 1.1.3). In the McKinlay River area, it has been found that *C. johnstoni* linear growth rate between June and November is negligible (Webb *et al.*, 1983d; Webb, 1991) and that at the commencement of the wet season, feeding increases dramatically and most annual growth takes place (Webb, 1991).

It is not clear whether this seasonal pattern in food intake is determined principally by season reduction in relatively available prey or is also influenced by physiological changes associated with lower dry season temperatures. Because *B. marinus* congregates in large numbers on the margins of remaining water bodies late in the dry...
season, should *C. johnstoni* lower food intake in the dry season be chiefly due to lack of other prey, then *C. johnstoni* mortality may be higher at this time.

(b) **Movement**

*C. johnstoni* has clearly demonstrated homing ability. Of 17 male and female crocodiles captured on the McKinlay River and released 30 km upstream in July 1979, seven were recaptured in September-October 1980 exactly in the pool where they were originally caught, and one between the two sites, 11.5 km from the site of release (Webb et al., 1983a).

In contrast, crocodiles captured and released at their site of capture travelled significantly lower distances and tended to travel in the opposite direction to relocated animals (Webb et al., 1983a). From a total of 254 annual records of capture-recapture surveys, 73.4% were recaptured within one kilometre of the pool they had been released a year before, and only 2.8%, most of which were sub-adults (Webb et al., 1983a), had moved beyond 10 km (Webb et al., 1983d). Moreover, amongst the crocodiles that showed movement, 73.9% moved in upstream direction (Webb et al., 1983a, Webb et al., 1983d).

*C. johnstoni* movement patterns are related to sex and maturity. In a 20-years mark-recapture study carried out in Queensland, a linear home range of 1.2 km for pubescent females, 30.3 km for pubescent males, 0.6 km for mature females and 1.6 km for adult males were estimated (Tucker et al., 1997). Nomadic tendencies of pubescent males are ascribed to unsuccessful attempts at entering local dominance hierarchies (Tucker et al., 1997).

Since *B. marinus* appears to prefer water bodies that are relatively open with sparse ground level vegetation on their margins (Section 1.2.1) crocodiles living in highly vegetated pools may encounter fewer toads, hence suffering less mortality. Thus, there can be expected to be variation in *C. johnstoni* mortalities attributable to toads in
different habitat types. Being remarkably more mobile than pubescent females and adults (Tucker et al., 1997), pubescent males are perhaps more likely to encounter cane toads and be the most negatively affected by its toxins. Hence, there may also be sex-related variation in mortalities that may offset advantages enjoyed by males through spending less time in vulnerable size classes.

(c) Population Age and Sex Structure

The population age and sex structure of C. johnstoni was investigated in 1979 and 1985 on the McKinlay River (Webb et al., 1983d; Smith and Webb, 1985). Adult sex ratio (expressed as the proportion of males) has been estimated at 0.17, whereas hatchling sex ratio is believed to be 0.36 (Webb et al., unpublished; Webb et al., 1983d; Webb et al., 1987b; Smith and Webb, 1985). The maximum age recorded on the McKinlay River in 1979 is estimated at least 45 years (Webb et al., 1983d).

The impact of the arrival of cane toads upon population age and sex structure of C. johnstoni is difficult to predict. Should nomadic pubescent males (Tucker et al., 1997) suffer noticeably higher mortality than females, the sex ratio will decrease. However, considering that younger crocodiles eat considerably more frogs than older ones (Section 1.1.3), the fast growing males (Section 1.1A) may be expected to suffer less mortality, if risk of dying is size-dependent, which would increase the sex ratio. C. johnstoni sex ratio after the arrival of cane toads will hence depend upon the relative magnitude of the two influences.

1.1.5 Reproduction

Crocodylus johnstoni is a hole-nester reptile that lays eggs at night, in sand or other friable substrates, in the proximity of permanent water (Webb et al. 1983b; Smith, 1987; Webb et al., 1987b; Webb and Manolis, 1989). The nesting season is preceded by a period of two to three weeks in which the female excavate holes without laying eggs (Webb and Manolis, 1989) and it is believed female is testing the substrate.
conditions, temperature and moisture, in which the embryo will develop (Smith, 1987; Webb and Manolis, 1989).

Laying eggs in easily recognised and relatively sparse patches of sand or other friable substrates makes C. johnstoni eggs a relatively easy target to varanid lizards. Additionally, given that B. marinus is also nocturnal (van Dam et al. 2002) and is often active close to water (section 1.2.1) it can be predicted that encounter between C. johnstoni and toads may be greater during nesting time and the preceding three weeks. Should significant female mortality occur during this period, C. johnstoni reproduction will be severely affected.

(a) Size and Age at Maturity

Crocodylus johnstoni males and females mature at different sizes and ages. Most females attain maturity at 11-14 years of age and approximately 1.5 m in total length, but males typically mature at 16-17 years of age and about 1.7 m in total length (Webb et al., 1983b; Webb et al., 1987b; Webb and Manolis, 1989). Reproductive senescence is possibly around 40-45 years of age and there are probably a few years between senescence and death (Webb and Smith, 1984; Webb et al., 1987b).

C. johnstoni nest once a year and in an average year 8% of females younger than 11 years of age and 84.4% of females older than 11 years of age lay eggs (Webb and Smith, 1984; Webb et al. 1987b).

Being less nomadic than males (Section 1.1.4) and maturing earlier (Webb et al., 1987b; Webb and Manolis, 1989), females, especially those living in pools with inherently lower concentration of cane toads, may have higher probability of survival until attaining maturity than males, which may influence effective sex ratios. However, sex differences in vulnerability seem likely to be too limited to grossly skew sex ratios to the point where this factor itself influences population dynamics.
(b) Timing of Nesting

Eggs are typically laid in a brief nesting period between August and September (Webb et al., 1987b; Webb, 1991). There is, however, a slight geographic variation in time of nesting. Nesting commences later on more southern rivers like the Victoria and the Roper River, than on northern rivers like the McKinlay River (Webb and Smith, 1984; Webb et al., 1987b). In the McKinlay River area, nesting occurs typically in three weeks between August and September (Webb, 1982; Webb et al., 1983b; Smith, 1987; Webb, 1991) with older females laying eggs earlier than younger ones (Webb et al., 1983b; Smith, 1987; Webb and Manolis, 1989).

Considering that older crocodiles tend to lay eggs earlier in the nesting season than younger ones (Webb et al., 1983b; Smith, 1987; Webb and Manolis, 1989) and that younger crocodiles are more likely to suffer higher toad-related mortality than older ones (Section 1.1.3), initial responses to presence of toads may be shorter nesting periods, with nests laid relatively earlier.

(c) Egg Measurements

Data from six nesting seasons (n = 147) indicate that on average *C. johnstoni* lay a clutch with 12.35 ± 3.36 eggs (±SD) and the egg measurements are: length 6.61 ± 0.06 cm, breadth 4.16 ± 0.05 cm and mass 67.60 ± 8.07 g (Smith, 1987). These data also indicate that older crocodiles tend to lay larger clutches with larger and heavier eggs (Webb et al., 1983b; Smith, 1987).

Since younger crocodiles may be expected to suffer higher mortality from consuming cane toads (Section 1.1.3), the clutch characteristics of *C. johnstoni* can be expected, in the short to medium term, to be more homogenous, with a great proportion of comparatively larger clutch sizes and egg sizes.
1.1.6 Survivorship

(a) Eggs

A large proportion of *C. johnstoni* eggs fail to develop for a number of reasons. In the McKinlay River area, predation, primarily by varanid lizards, is the key factor, accounting for 64% of egg losses (Webb *et al.*, 1983b). A more recent study has, however, revealed that egg predation can be as high as 93.5% (Britton, 2003). Other factors contributing to egg losses are flooding, overheating, infertility, trampling by feral stock, predation by pigs and excavation of nests by other nesting females (Webb, 1982; Webb *et al.*, 1983b; Smith, 1987; Webb *et al.*, 1987b; Webb and Manolis, 1989).

Egg survival has been estimated at 29.5% (Smith and Webb, 1985) but, giving that this figure was calculated assuming that loss to predators is only 64%, the average figure may be much lower.

On the arrival of cane toads, egg survivorship of *C. johnstoni* may vary depending upon the magnitude of impact of *B. marinus* on varanid lizards (Section 1.2.5). Should the magnitude be great, egg survivorship will be much higher.

(b) Hatchlings

Hatchlings suffer a remarkably high mortality primarily in the first year (Webb, 1982; Webb *et al.*, 1987b; Webb and Manolis, 1989). The agents of hatchling mortality are not fully known. It is, however, believed that the new hatchlings are predated by large fish, turtles and birds, or suffer cannibalism from older crocodiles (Webb, 1982). It has been estimated that only 10-20% hatchlings survive to the second year (Webb, 1982; Smith and Webb, 1985; Webb *et al.*, 1987b).
Considering that the reproduction of the cane toads takes place mostly in the wet season (van Dam et al., 2002), it can be expected that hatchlings may tend to eat this readily available prey, hence suffering greater mortality than the other age groups.

(e) **Sub-adults**

Hatchlings surviving to the second year have a greater chance to attain adulthood. The survival rate of hatchling from one to ten years of age is as much as 85% per year (Smith and Webb, 1985; Webb and Manolis, 1989).

Given that with increase in body size crocodiles increase their prey richness and eat markedly fewer frogs (Section 1.1.3), *C. johnstoni* sub-adults are likely to suffer lower mortality than hatchlings but they may suffer relatively higher mortality than adults.

(d) **Adults**

Adults from 11 years of age to 30 years of age are estimated to survive at the rate of 95% per annum (Webb and Manolis, 1989), whereas those between 31 and 50 years of age survive at an estimated rate of 85% per annum (Smith and Webb, 1985).

*C. johnstoni* adult survivorship may be less affected by the arrival of the cane toads given the relatively lower consumption of frogs at this age (Section 1.1.3). However, much will depend on encounter rates and hence the behaviour of the toads as well as the dose required to kill a large animal. Large animals that experience ill effects from cane toad ingestion but survive the experience may learn to avoid them (Section 1.2.5).
1.2 THE CANE TOAD

The cane toad, *Bufo marinus* (Linnaeus, 1758), is a feral frog deliberately introduced from Hawaii to Australia in 1935, in Queensland, as a means of controlling scarab beetles that were major pests of sugar cane (Freeland, 1986; Jacklyn, 1992; Pyers *et al.*, 1995; Speare, 1997; Cameron, 2002; CSIRO, 2003). *B. marinus* was not successful in controlling the cane beetles but it successfully established throughout Queensland and then spread southwards into New South Wales and westwards into the Northern Territory (Pyers *et al.*, 1995; Speare, 1997; Cameron, 2002; van Dam *et al.*, 2002). The natural spread rate of the cane toad is 25-35 km/year in the Northern Territory (Freeland, 1984; Freeland and Martin, 1985; Freeland, 1986; Jacklyn, 1992; Speare, 1997), and approximately 5 km/year in northern New South Wales (Speare, 1997).

1.2.1 Habitat

*Bufo marinus* has been reported in nearly every type of habitat in northern Australia except at high altitude and in very arid areas (van Dam *et al.*, 2002). It attains its highest densities in open disturbed habitats, close to available water (such as flood-prone river banks), areas cleared of vegetation (grazed paddocks, farm dams, roadsides), villages or communities (parklands, golf courses, roadsides) and other open areas (Freeland, 1984; Jacklyn, 1992; Lever, 2001; Cameron, 2002; van Dam *et al.*, 2002; Altman *et al.*, 2003).

The success of *B. marinus* as coloniser can be attributed to its broad environmental tolerance. It can withstand loss of up to 50% of its body water (Freeland, 1984, 1986; Cameron, 2002; van Dam *et al.*, 2002) and it can absorb moisture from soil or atmosphere (Freeland, 1984, 1986). Moreover, *B. marinus* can survive at temperatures ranging from 6 to 40°C (Tyler, 1975; Freeland, 1986; Lever, 2001; Cameron, 2002) and has been reported to tolerate up to 6% salinity, and a wide range of pH, from 4 to 9 (Freeland, 1984; Lever, 2001; van Dam *et al.*, 2002).

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*Nesting Ecology of the Australian Freshwater Crocodile on the McKinlay River: Baseline for Assessing the Impact of Cane Toads*

*Amaral M. Chibeba*
Cane toads exhibit seasonal distribution, to some extent, similar to that of crocodiles (Section 1.1.2). *B. marinus* disperse widely during the wet season but concentrate around permanent water in the dry season (van Dam *et al.*, 2002), with preference for pools located in open areas (Lever, 2001; Cameron, 2002; van Dam *et al.*, 2002). Hence, it can be predicted that crocodiles and cane toads are likely to share the same habitats throughout the year although probability of encounter is likely to vary seasonally, being lower in the wet season when both species are more widely dispersed and cane toads are able to make use of ephemeral water bodies.

### 1.2.2 Feeding Habits

*Bufo marinus* has wide taxonomic prey diversity (Tyler, 1975; Freeland, 1984, 1985, 1986; Lever, 2001). Though insects constitute the major proportion of the cane toad’s diet (Freeland, 1984; Cohen and Williams, 1992), they eat any small creature that fits in their mouth (Lever, 2001).

Crocodiles are unlikely to be consumed by cane toads. Though the adult cane toad is known to ingest prey up to half its own length (Freeland, 1984), crocodile hatchling are both too large and too mobile to be taken by cane toads.

### 1.2.3 Reproduction

In the tropics, *B. marinus* attains sexual maturity within a year, whereas in temperate Queensland it takes up to 18 months to reach sexual maturity (Cameron, 2002). Females lay as many as 8,000 to 35,000 eggs at a time and frequently breed twice per year (Tyler, 1975; Freeland, 1984; van Dam *et al.*, 2002). The eggs hatch into tadpoles within three days and the tadpole phase takes between 17 days and six months (Tyler, 1975).
Given that cane toad’s breeding occurs primarily in the wet season (van Dam, 2002), *C. johnstoni* feeding takes place largely in the wet season (Section 1.1.3) and younger crocodiles eat markedly more frogs than adults (section 1.1.3), it can be expected that younger crocodiles will be most at risk of mortality from consuming cane toads in this season.

1.2.4 Toxicity

*Bufo marinus* defends itself against predators with a powerful toxin secreted in two large parotoid glands on the back of its head (Tyler, 1975; Freeman, 1986; Jacklyn, 1992; Altman et al., 2003). When a predator molestes the toad, parotoid secretion may be released simultaneously from the numerous pores, affecting the eyes or the mucus membranes of the mouth (Tyler, 1975). Dogs consuming or attempting to consume cane toads have been reported to show symptoms of profuse salivation, prostration, cardiac arrhythmias and convulsion (Tyler, 1975; Freeland, 1984), with only 15 minutes elapsing between the onset of symptoms and death (Tyler, 1975; Freeland, 1984, 1986).

1.2.5 Impact upon Native Fauna

All the stages of the cane toad’s life cycle are believed to have sufficient toxins to be lethal to many frog-eating animals (Freeland, 1984). This is in contrast to native frogs that produce relatively mild toxins to defend themselves against predators (van Dam et al., 2002). Although it is commonly acknowledged that a range of predators may die when mouthing or ingesting toads (Jacklyn, 1992), there are differing opinions as to whether or not cane toads can cause long-term population decline of the predators (van Dam et al., 2002).

The impact of *B. marinus* on native fauna remains a controversy chiefly because most of the published reports on this issue are based on anecdotal evidence (Covacevich and Archer, 1975; Tyler, 1975; Freeland, 1984, 1986; Jacklyn, 1992; Burnett, 1997;
van Dam et al., 2002). Moreover, some of the dearth of published scientific reports on this topic are not conclusive. For example, research carried out in the Northern Territory on the short-term effects of cane toads on native fauna using five major fauna groups (wingless invertebrates, amphibians, reptiles, birds and mammals) found no evidence that B. marinus has significant adverse effect on species richness nor abundance (Catling et al., 1999). The dingo (Canis lupus dingo) and one order of insect (Coleoptera) appeared to be negatively affected (Catling et al., 1999). However, because the study was done over large areas and covered many taxa, it was not capable of detecting any but highly dramatic changes attributable to cane toads (that is, it lacked statistical power).

Another study conducted in the Northern Territory on the impact of cane toads upon native frogs found that of the 23 species monitored none suffered short-term detrimental effects attributable to cane toads (Grigg et al., 2001). Nonetheless, considering that this study was undertaken in only four years based on calls, activity of breeding adults only, and that adults of some species live for several years, any predation or less direct competitive effects of cane toads on tadpoles and/or sub-adults could not be ascertained (Grigg et al., 2001).

It appears that some Australian native predators can learn to avoid cane toads. Laboratory research found that Barramundi (Lates calcarifer) recognized and avoided toad tadpoles one day after the previous encounter (Crossland, 2001). A similar behaviour has been reported with varanid lizards. In a study with ten varanid lizards, two from Darwin, which had no experience of cane toads, and eight from toad-infested areas of Queensland, it was found that the Darwin varanids attacked the toads and died, whereas the other varanids left the toads alone and survived (Jacklyn, 1992). Nonetheless, the fact that populations of varanid lizards have been reported to decline upon arrival of cane toads (Covacevich and Archer, 1975; Burnett, 1997; van Dam et al., 2002) suggests that they may only learn in the medium to long term.
From the reports on learning to avoid toads (Jacklyn, 1992; Crossland, 2001) it can be deduced that the key factor is surviving the first encounter. Hence, the decline in the population of varanid lizards (Covacevich and Archer, 1975; Burnett, 1997; van Dam et al., 2002) possibly results from a relatively low varanid lizards’ survival of the first experience with cane toads.

There are contradictory reports about the impact of *B. marinus* upon *C. johnstoni*. Trials with captive *C. johnstoni* have indicated that animals die if forced to ingest whole toads but survive if allowed to capture the toads (Jacklyn, 1992; van Dam et al., 2002). It has been suggested that the habit of shredding that occurs during capture may dilute or remove the toxin (Jacklyn, 1992; van Dam et al., 2002). This contrasts with many convincing anecdotal reports of *C. johnstoni* dying from consuming cane toads (van Dam et al., 2002).

It is generally accepted that adverse impacts of *B. marinus* upon native fauna can be as follows (Freeland, 1984, 1985; Jacklyn, 1992; Lever, 2001; Altman et al., 2003):

1. Consumption of native fauna species;
2. Poisoning of native fauna species consuming or attempting to consume it;
3. Competition with native fauna for shelter and resting places;
4. Competition with native amphibians for breeding habitats.

The extent at which *B. marinus* will impact upon egg survival of *C. johnstoni* is difficult to predict quantitatively. Considering that varanid lizards, the principal egg predators of *C. johnstoni* (Webb et al., 1983b; Smith, 1987; Britton, 2003) are amongst the species whose population is reported to have declined on the arrival *B. marinus* (Covacevich and Archer, 1975; Burnett, 1997; van Dam et al., 2002), one can expect that the presence of *B. marinus* will, in the short term at least, lead to a substantially increase in the survival of *C. johnstoni* eggs. However, the presence of toads may also lead, in the short or longer term, to a reduction in the number of crocodiles surviving to produce nests.
While no *B. marinus* individuals have yet been noted on the McKinlay River area, it is predicted that arrival may occur within 12 months (Grahame Webb, personal comm.). This study intends to evaluate one of the key determinants of population dynamics in *C. johnstoni* so that the impact of *B. marinus* can be assessed.

### 1.3 AIM OF STUDY

The aim of this study is (i) to investigate the egg production, time of nesting and egg survivorship of the freshwater crocodile *C. johnstoni* in the absence of cane toad *B. marinus*; and (ii) to establish a baseline from which impacts of the arrival *B. marinus* upon the *C. johnstoni* population can be assessed.
II METHODS

In this chapter the location and climate of the study area are described, as well as a description of the sites selected within the study area. Following this, the methods used to locate \emph{C. johnstoni} nests, and to estimate laying date, nest predation and hatching success are presented.

II.1 THE STUDY AREA

Most of the research on the ecology of \emph{C. johnstoni} has been undertaken on the McKinlay River area (Webb, 1982; Webb \textit{et al.}, 1983a, 1983b, 1983c, 1983d; Webb and Smith, 1984; Smith and Webb, 1985; Smith, 1987; Whitehead, 1987; Britton, 2003). This area has been chosen because it supports a large and relatively discrete crocodile population, which is easy to study given the ready access and proximity to Darwin city.

II.1.1 Location

The McKinlay River is situated circa 130 km South-East of Darwin city, in the Northern Territory. The map of the study area is presented in Fig 2.1, with emphasis put on the position of the thirteen sites monitored throughout the study.

II.1.2 Climate

The study area's climatic information, mean daily temperature, relative humidity, mean rainfall and mean number of raindays, is summarised in Table 2.1. The climate of the area is monsoonal with 93.4% of the annual rainfall occurring between November and April (BOM, 2003). During this period, the McKinlay River flows and extensive flooding generally occurs (Webb \textit{et al.}, 1983b; 1983c). In the dry season (May – October), nonetheless, there is no flow in the main stream (Webb \textit{et al.}, 1983d; Webb and Smith, 1984; Smith and Webb, 1985; Smith, 1987; Whitehead, 1987; Britton, 2003).
1983c) and water is restricted to isolated mainstream pools and floodplain billabongs (Webb et al., 1983b).

Table 2.1. Meteorological data recorded at Middle Point, 50 km Northwest of the study area. Data accumulated from 1957 to 2003 (BOM, 2003)

<table>
<thead>
<tr>
<th>Month</th>
<th>Mean daily temperature (°C)</th>
<th>Relative humidity At 9 a.m. (%)</th>
<th>Mean monthly rainfall (mm)</th>
<th>Mean number of raindays</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max.</td>
<td>Min.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jan.</td>
<td>32.6</td>
<td>23.8</td>
<td>84</td>
<td>339.6</td>
</tr>
<tr>
<td>Feb.</td>
<td>32.0</td>
<td>23.8</td>
<td>86</td>
<td>271.9</td>
</tr>
<tr>
<td>Mar.</td>
<td>32.4</td>
<td>23.6</td>
<td>85</td>
<td>259.2</td>
</tr>
<tr>
<td>Apr.</td>
<td>33.1</td>
<td>22.1</td>
<td>78</td>
<td>82.8</td>
</tr>
<tr>
<td>May</td>
<td>32.6</td>
<td>19.5</td>
<td>72</td>
<td>18.9</td>
</tr>
<tr>
<td>Jun.</td>
<td>31.3</td>
<td>16.1</td>
<td>67</td>
<td>1.6</td>
</tr>
<tr>
<td>Jul.</td>
<td>31.3</td>
<td>14.9</td>
<td>64</td>
<td>0.8</td>
</tr>
<tr>
<td>Aug.</td>
<td>32.9</td>
<td>16.9</td>
<td>67</td>
<td>2.5</td>
</tr>
<tr>
<td>Sep.</td>
<td>34.7</td>
<td>20.1</td>
<td>69</td>
<td>10.8</td>
</tr>
<tr>
<td>Oct.</td>
<td>35.6</td>
<td>22.7</td>
<td>69</td>
<td>57.8</td>
</tr>
<tr>
<td>Nov.</td>
<td>35.2</td>
<td>23.7</td>
<td>74</td>
<td>128.2</td>
</tr>
<tr>
<td>Dec.</td>
<td>33.8</td>
<td>23.9</td>
<td>80</td>
<td>219.8</td>
</tr>
</tbody>
</table>

II.1.3 Site Description

All of the thirteen Sites used in this study are within 500 m of the McKinlay River main stream, and are within 18 river km of the McKinlay River and Mary River junction. The estimated pool size and crocodile populations as at late August 2003, for each Site, are summarised in Table 2.2.

The Sites are numbered northwards (Figure 2.1) and the names used by the Wildlife Management International in previous studies are given in brackets.
Figure 2.1. The location of the study area in the Northern Territory of Australia. On the right side, the position of the thirteen study sites and their proximity to the McKinlay River is shown. Most crocodiles and nesting sites are associated with water bodies at varying distances from the main river channel rather than the river itself, which is mostly dry for much of the dry season.

* Nesting Ecology of the Australian Freshwater Crocodile on the McKinlay River: Baseline for Assessing the Impact of Cane Toads

* Amaral M. Chibeba
(a)  **Site 1 (Big Stockyard)**

This Site is situated on the west bank of the McKinlay River and the pool associated with it is the largest one but has the smallest freshwater crocodile population (Table 2.2). The pool is known to support saltwater crocodiles (Charles Manolis, personal com.) and this explains the small counts of freshwater crocodiles sighted during the spotlight surveys (Table, 2.2).

The majority of the area encircling the pool has a muddy dried substrate, possibly inappropriate for nesting. There is, however, a small sandy nesting bank on the northeast end of the pool. Another possible nesting area for this Site is the creek with friable substrate that joins the pool with the main stream of the McKinlay River.

(b)  **Site 2 (Little Stockyard)**

Site two is an oval pool located on the west bank of the McKinlay River and situated at less than 500 m from Site one. There are two nesting areas related to this pool. One is a creek situated at 50 m, which connects Site one to the main stream - crocodiles from both Site one and Site two may use this area. The other nesting area, with a coarse sand substrate, is located at 200 m from the pool and is the main stream of the McKinlay River.

(c)  **Site 3 (Many Croc Pool)**

Site three is associated with two pools. The first is a long pool situated on the main stream with large sandy areas on both ends. The other pool is positioned to the east, within 20 m from the main stream. Given that the majority of the area surrounding this pool has a very hard substrate, possibly inappropriate for nesting, crocodiles from this pool probably nest in the main stream.
(d) **Site 4 (Heather Bong)**

This is a small circular pool situated on the west at about 500 m from the McKinlay River main stream. Given its size, this pool has a very high *C. johnstoni* population density (Table 2.2). The nesting areas associated with this Site primarily consist of coarse sand substrate and are within 12 m of the pool.

There is another pool to the south, located at less than 100 m from the main billabong, but the surrounding area has a muddy dried substrate, unsuitable for nesting.

(e) **Site 5 (Many Catfish – G1)**

This Site is situated on the main stream of McKinlay River and has a small nesting area on the southern end of the pool. The main substrate of the nesting area is fine sand. Given the size of the pool, this Site has a low crocodile population density (Table 2.2).

(f) **Site 6 (Many Catfish - G2)**

Site six is located on the main stream at less than 500 m from Site five. The pool associated with this Site has a much higher crocodile population (Table 2.2) and has also a larger nesting area than Site five. The nesting area, most of which with a coarse sand substrate, is within 20 m from the pool.

(g) **Site 7 (Webb Bong)**

The pool associated with this Site is on the west side of the McKinlay River main stream, at a distance of about 50 m. Most of the area surrounding the pool has a muddy dried or pebbled substrate, but the main stream has a large sandy substrate. Two areas on the main stream with high crocodile activity (test holes and signs of crocodiles moving on the bank) were selected and monitored throughout the study.
(h) Site 8 (Many Bony)

Site eight is situated on the main stream of the McKinlay River and has two areas with friable nesting substrates. The first area, predominantly with a coarse sand substrate, is on the southern end of the pool. The other area is linked to the first by a narrow dried channel, at about 50 m, and also has a coarse sand substrate. Considering its size, this pool has a low-density crocodile population (Table 2.2).

(i) Site 9 (Big Bony)

Big Bony is at approximately 50 m on the east of the main stream of the McKinlay River. This is the second largest pool and has the highest crocodile population (Table 2.2). Whilst the substrates encircling the pool at the time of nesting are dried mud, the main stream has a very large sandy nesting bank. Two areas in which there was noticeable crocodile activity before the commencement of the nesting season were selected and monitored throughout the study. One area is located at 100 m from the pool, whereas the other is circa 200 m of the pool.

(j) Site 10 (3.7 C2)

Site ten is on the main stream of the McKinlay River and the pool associated with it has two large sandy nesting banks on both the southern and northern ends. However, crocodile activity was almost exclusively on the southern side of the pool. This is one of the most populated pools (Table 2.2).

There is a larger pool on the west side at about 40 m of the main stream but the area surrounding it has a very hard substrate, probably unsuitable for nesting, so crocodiles from this pool probably nest in the main stream of the river.
(k) Site 11 (3.7 C3)

This Site is on the main stream of the McKinlay River and is located at approximately 100 m from Site ten. It has an immense coarse sandy nesting bank. The pool directly associated with this Site is very small (Table 2.2), but it had a remarkably high crocodile activity at the commencement of the nesting season and a total of 10 nests were recorded in this Site in 2002 (Britton, 2003).

(l) Site 12 (3.7 C1)

Site twelve is situated on west of the McKinlay River and there are three neighbouring pools in its proximity. It is located within approximately 150 m of Site 10 and has a large sandy nesting bank. Though no crocodiles were sighted on the pools associated with this Site, crocodile activity was observed at the commencement of the nesting season. Moreover, two nests were recorded in this Site in 2002 (Britton, 2003).

(m) Site 13 (3.7 A1)

Site thirteen is on west on the McKinlay River main stream, at about 150 m, and the principal nesting bank consists of a coarse sandy substrate situated on the west end of the pool. There is an unconfirmed sighting of a saltwater crocodile in this pool.
Table 2.2 Approximate pool size and number of crocodiles sighted during a spotlight survey in thirteen sites on the McKinlay River in 2003. In such surveys the entire population is rarely recorded and counts are best treated as an index of relative abundance (Webb et al., 1983c).

<table>
<thead>
<tr>
<th>Location</th>
<th>Approximate pool size (m²)</th>
<th>N° of crocodiles spotlighted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>9,600</td>
<td>4</td>
</tr>
<tr>
<td>Site 2</td>
<td>2,800</td>
<td>16</td>
</tr>
<tr>
<td>Site 3 (1)</td>
<td>850</td>
<td>14</td>
</tr>
<tr>
<td>Site 3 (2)</td>
<td>1,000</td>
<td>12</td>
</tr>
<tr>
<td>Site 4</td>
<td>200</td>
<td>13</td>
</tr>
<tr>
<td>Site 5</td>
<td>1,400</td>
<td>9</td>
</tr>
<tr>
<td>Site 6</td>
<td>2,100</td>
<td>16</td>
</tr>
<tr>
<td>Site 7</td>
<td>1,100</td>
<td>9</td>
</tr>
<tr>
<td>Site 8</td>
<td>5,050</td>
<td>7</td>
</tr>
<tr>
<td>Site 9</td>
<td>6,000</td>
<td>17</td>
</tr>
<tr>
<td>Site 10</td>
<td>900</td>
<td>16</td>
</tr>
<tr>
<td>Site 11</td>
<td>&lt;100</td>
<td>1</td>
</tr>
<tr>
<td>Site 12</td>
<td>250</td>
<td>0</td>
</tr>
<tr>
<td>Site 13</td>
<td>5,000</td>
<td>3</td>
</tr>
</tbody>
</table>

(1) Pool located on the main stream.
(2) Pool located on East of the mean stream.

II.2 LOCATION OF NESTS

In identifying the nesting sites, the areas covered in previous studies (Webb et al., 1983b; Smith, 1987; Whitehead, 1987; Britton, 2003) were visited on 26-27 July 2003. The sites were inspected daily from 9 August 2003 until 6 September 2003 for: (a) crocodile tracks and digging, and (b) remains of eggshells of nests first found through predators. Following this period, the nesting banks were surveyed in two-days visits on 11-12 September and 18-19 September 2003. And finally, the areas were visited weekly until the hatching period.

Where it appeared crocodiles had been digging, the substrate was probed with a stainless steel rod approximately 60 cm long and 0.3 cm in diameter (Webb et al., 1983b; Smith, 1987; Whitehead, 1987). Whenever a nest was found a number of details were recorded including:

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*Nesting Ecology of the Australian Freshwater Crocodile on the McKinlay River: Baseline for Assessing the Impact of Cane Toads*

*Amaral M. Chibeba*
1. Substrate type, assigned to one of 5 categories (Whitehead, 1987): coarse sand and gravel; medium grain sand; fine sand; fine sand and humus; and clay and humus.

2. Temperature (°C) at the depth of the top egg, using a calibrated mercury thermometer (Webb et al., 1983b; Smith, 1987; Whitehead, 1987).

3. Depth to the top egg (0.5 cm) (Webb et al., 1983b; Smith, 1987; Whitehead, 1987).

4. The extent of opaque band development on the eggs, from which the age of the nest was estimated (Section II.3).

5. Clutch size (number of eggs).

6. Egg measurements, taken from five eggs randomly chosen: egg width (0.1 mm; by callipers); egg length (0.1 mm; by callipers); and egg mass (0.1 g by spring balance) (Webb et al., 1983b; Whitehead, 1987).

In addition to these details, the occurrence of test holes and the distance of the nest to permanent water were recorded. The occurrence of test holes was recorded as presence of at least one test hole on the nesting bank on a given day. The distance to permanent water was recorded, using a tape measure, so as to evaluate how far females moved in search of a nesting site. In recording this information the minimum distance between the nest and the edge of the pool was considered, although a crocodile may use a longer route.

Limited records were taken from nests first found through predators. Where two or more eggs remained in the nest, egg measurements were taken. Because nests were partly excavated, temperature of the nest and the depth to the top egg were not recorded. Clutch size was not estimated in predated nests because predators usually ate some of the eggs far from the nests and some of the eggs were entirely swallowed.

After all the records had been taken, crocodile tracks were swept so that, on following visits, areas needing probing were easily identifiable (Webb et al., 1983b). Then, the substrate on and around the nest, approximately one meter in diameter, was sprayed.
with air freshener as an odour neutraliser to mask the smells of both the turned soil and mucus on the eggs, which could otherwise attract predators (Smith, 1987).

II.3 ESTIMATION OF LAYING DATE

The laying date was estimated based on the extent of opaque banding. Clutches whose opaque banding did not entirely encircle the egg were aged as follows (Smith, 1987; Webb et al., 1987): less than one day, spot or band 1/10 complete; 1 day, band 2/10 – 3/10 complete; 2 days, band 4/10 – 5/10 complete; 3 days, band 6/10 to just complete (Webb et al., 1987a). In clutches found with complete opaque banding it was not possible to estimate the laying date with any consistency and nests were categorised as ≥ seven days old (Webb et al. 1987a).

In estimating laying date, intact eggs from non-predated nests and partly broken eggs from predated nests were considered. Eggs from predated nests were considered only when predated within the previous 24h (Charles Manolis, personal comm.) and sufficient eggshell remain to enable the development of the opaque band to be determined.

In some cases it was not possible to estimate the laying date. This occurred in nests found predated in which all eggs had been taken or the opaque banding was not clear.

II.4 ESTIMATION OF NEST PREDATION

Predation was estimated by visiting the nests found through probing and by inspecting the nesting banks for remains of eggshells from nests first found through predators. The main sites and potential nesting sites were inspected during the observations, as described in Section II.2. Whenever a nest was found predated it was excavated to ascertain whether there were any remaining eggs. Then the eggs, if found, were buried to the original depth and air freshener was used as described earlier.

Nesting Ecology of the Australian Freshwater Crocodile on the McKinlay River: Baseline for Assessing the Impact of Cane Toads

Amaral M. Chibeba
Given that during the nesting season the nesting banks were surveyed daily, nests found in this period were regarded as predated on the day they were found. However, nests found after the nesting season, when nesting banks were visited weekly, were estimated as predated on the middle day between visits (Mayfield, 1961).

II.5 ESTIMATION OF REGIONAL HATCHING SUCCESS

To provide an independent estimate of hatching success, all the pools included in the study were spotlight-surveyed at weekly intervals from 6–28 November 2003. Whenever a crèche was sighted, records were taken on number of hatchling present, mobility and presence of adults in their company.

Concomitantly, the 13 Sites were checked for signs of hatching from nests known to have survived predation and from nests never found before, whether through probing or exposure by predators. Whenever a nest was found excavated, tracks of crocodiles and predators were searched for to ascertain whether the nest had hatched or was predated.

II.6 STATISTICAL ANALYSIS

Assumptions of analysis of variance (ANOVA) where checked using Cochran’s test for homogeneity of variances and data were transformed, where necessary, using log transformation for ordinal data.

Variations amongst locations in relation to laying date, clutch size, egg length, egg breadth and egg mass were analysed using parametric one-way ANOVA. Likewise, the variations in depth to the top egg amongst the substrates were examined using parametric one-way ANOVA. The homogeneity of variances was checked prior to any analysis using Cochran’s test (Fowler et al., 1998).
Correlation analyses, Spearman Rank, involving laying date, depth to the top egg, clutch size, egg breadth, egg length and egg mass were performed to ascertain associations among variables.

To investigate whether digging up nests to record clutch characteristics did influence predation, one test was performed. One-way ANOVA was employed comparing nests found through predators and nests found through probing in terms of the time elapsed before predation since the day the nests were laid. The hypothesis examined was that should digging exacerbate predation, the time elapsed before predation in nests found through probing would be shorter than in nests found by predators without the extra disturbance created by observers.

In estimating regional hatching success three models were compared. The first model is the Naive Method which estimates hatching rate as a percentage of nests that hatch in an observed sample (Mayfield 1961; Klett and Johnson, 1982; Pollock and Cornelius, 1988). The second model is the Mayfield Method, which estimates hatching success considering the time of exposure, the total number of days the nests are exposed to the risk of predation (Mayfield, 1961; Klett and Johnson, 1982; Pollock and Cornelius, 1988; Johnson and Shaffer, 1990). Mayfield Method assumes constant mortality of nests throughout the observation period (Mayfield, 1961; Klett and Johnson, 1982; Pollock and Cornelius, 1988; Johnson and Shaffer, 1990). The last model, the Product Method, is a modification of the Mayfield Method (Klett and Johnson, 1982) and calculates hatching rates as the product of age-class survival rates whenever significant age-related differences in mortality can be recognised (Klett and Johnson, 1982).

The success rate was used to provide an indirect estimate the total number of nests laid across the study area. This was obtained dividing the number of hatched nests by hatching rate.
III RESULTS

This chapter presents the findings of the study. This includes a description of sites that *C. johnstoni* selected for nesting, a description of nest characteristics, a comparison of sites with respect to laying date and clutch characteristics, results of hatching timing and hatching success. Observations regarding occurrence of feral animals and saltwater crocodiles are also reported because these have the potential to influence *C. johnstoni* populations.

III.1 SITE SELECTION

*Crocodylus johnstoni* excavated holes without laying eggs since at least three weeks before the commencement of the nesting season, on sand or other friable substrates located in the proximity of permanent water. Crocodiles often used the same sandy and/or other friable substrates to nest in during the nesting season.

III.1.1 Substrates Types

A summary of the substrate types of the nests is given in Table 3.1. Coarse sand was the most common substrate type (58.5%) followed by fine sand (30.2%), and medium grain sand was the least common substrate type (3.8%). These results are in broad accordance to the commonness of nesting substrates in the study area.

<table>
<thead>
<tr>
<th>Substrate type</th>
<th>Number of samples</th>
<th>Occurrence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse sand</td>
<td>31</td>
<td>58.5</td>
</tr>
<tr>
<td>Clay and humus</td>
<td>4</td>
<td>7.5</td>
</tr>
<tr>
<td>Fine sand</td>
<td>16</td>
<td>30.2</td>
</tr>
<tr>
<td>Medium grain sand</td>
<td>2</td>
<td>3.8</td>
</tr>
</tbody>
</table>

Nesting Ecology of the Australian Freshwater Crocodile on the McKinlay River: Baseline for Assessing the Impact of Cane Toads

Amaral M. Chibeba
111.1.2 Distance To Water

The proximity of the nests to permanent water was measured for 51 nests and is summarised in Figure 3.1. Crocodiles nested far from permanent water only where there were no friable substrates nearby. Of the 51 nests, whose distance ranged from 3.0 to 212 m, 30 (58.8%) nests were laid within 20 m, compared to only three nests (5.9%) situated beyond 200 m of permanent water. The distance of the nests from permanent water strongly reflected the distance at which friable substrates were from permanent water.

![Figure 3.1. Distance to permanent water measured in 51 nests in the McKinlay River area in 2003. Bars represent frequencies (left vertical axis) in individual classes and the line cumulative frequencies (right vertical axis). Nests were laid on the closest nesting banks to permanent water.](image)

III.2 THE NESTS

III.2.1 Number of Nests

A total of 61 nests were located in the thirteen sites monitored during the nesting, incubation and hatching periods (Table 3.2). Twenty-six nests were located through

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probing, whereas predators found 29 nests before researchers detected their presence. A total of six nests were located only after hatching. Site six was the most important nesting Site, with twelve nests recorded, while no nests were found in Site one.

Table 3.2. Number and method of location of nests in each of the pools monitored in the McKinlay area River in 2003

<table>
<thead>
<tr>
<th>Site</th>
<th>Nests located through</th>
<th></th>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Probing</td>
<td>Predator</td>
<td>Hatching</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>5</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>11</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Big Crossing*</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>26</td>
<td>29</td>
<td>6</td>
<td>61</td>
</tr>
</tbody>
</table>

* This area was not amongst the monitored sites because of the very small size of the pool associated with it.

III.2.2 Time of Nesting

The nesting timing is shown in Figure 3.1. The nests were laid in three weeks, between 16 August and 6 September 2003. It has been assumed that the nesting season commenced on 16 August 2003 based on the location of a predated nest on that day. Given that no remaining eggs were found in the nest, the exact laying date could not be determined. None of the nests subsequently found with opaque banding that permitted estimates of age returned an early date.

The nesting season was estimated based on 36 nests. In 15 nests there was no ambiguity in determining the laying date because mucous was covering the eggs and

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_Amaral M. Chiebeba_
the eggs showed no development of opaque bands. They were regarded as having
being laid during the night preceding the survey visit. Of the remaining 22 nests, 14
had uncompleted opaque banding and hence were able to be aged with some
accuracy, whereas eight had complete opaque banding and could not be reliably aged
although it was possible to specify a minimum age (Section II.3). In 19 out of the 55
nests recorded it was not possible to estimate the laying date because predators had
eaten all the eggs leaving only small eggshell pieces. The last nest for which age
could be accurately determined was laid on 6 September 2003.
Figure 3.1. Estimated laying dates of *C. johnstoni* in 2003, by reference to opaque banding (Webb *et al.* 1987) of the eggs at the time of measurements. Not banded: Nests whose eggs were covered with mucus and showed no development of opaque bands. Banded: Nests whose eggs showed opaque banding. Unknown: The first nest was found predated but its age could not be determined because all the eggs had been taken.

### III.2.3 Clutch Characteristics

Mean clutch characteristics, clutch size (number of eggs), egg length, egg breadth and egg mass for 30 nests, from which at least two eggs were sampled, is summarised in Table 3.3. One unusually large egg was recorded on 26 August 2003 in Site ten. This egg was found in a nest with 15 eggs and its dimensions were as follows: length 8.98 cm, breadth 5.03 cm and mass 139.5 g. All the other eggs were normal.
Table 3.3. Clutch size and average egg measurements samples of five eggs of 30 C. johnstoni nests located on the McKinlay River in 2003. Egg measurement was undertaken in all non-predated nests and in some predated nests where at least two eggs remained intact.

<table>
<thead>
<tr>
<th>Nest n°</th>
<th>Site</th>
<th>Clutch size (Mean ± SD)</th>
<th>Egg length (Mean ± SD cm)</th>
<th>Egg breadth (Mean ± SD cm)</th>
<th>Egg mass (Mean ± SD g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>#</td>
<td>6.55 ± 0.01*</td>
<td>4.29 ± 0.01*</td>
<td>71.00 ± 2.12*</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>14</td>
<td>6.93 ± 0.17</td>
<td>4.41 ± 0.05</td>
<td>79.90 ± 2.07</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>12</td>
<td>7.01 ± 0.08</td>
<td>4.31 ± 0.09</td>
<td>76.90 ± 2.51</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>8</td>
<td>7.15 ± 0.09</td>
<td>4.15 ± 0.07</td>
<td>74.50 ± 2.74</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>14</td>
<td>6.54 ± 0.24</td>
<td>4.35 ± 0.04</td>
<td>73.90 ± 3.36</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>14</td>
<td>7.07 ± 0.18</td>
<td>4.44 ± 0.05</td>
<td>81.50 ± 1.87</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>14</td>
<td>6.93 ± 0.18</td>
<td>4.32 ± 0.07</td>
<td>76.10 ± 2.41</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>12</td>
<td>7.21 ± 0.16</td>
<td>4.35 ± 0.05</td>
<td>80.50 ± 1.87</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>#</td>
<td>6.74 ± 0.11**</td>
<td>4.22 ± 0.05**</td>
<td>70.25 ± 1.50**</td>
</tr>
<tr>
<td>10</td>
<td>6</td>
<td>16</td>
<td>7.06 ± 0.26</td>
<td>4.38 ± 0.08</td>
<td>80.10 ± 2.19</td>
</tr>
<tr>
<td>11</td>
<td>6</td>
<td>13</td>
<td>6.98 ± 0.18</td>
<td>4.16 ± 0.04</td>
<td>72.10 ± 1.14</td>
</tr>
<tr>
<td>12</td>
<td>6</td>
<td>12</td>
<td>6.91 ± 0.11</td>
<td>4.28 ± 0.06</td>
<td>74.10 ± 1.14</td>
</tr>
<tr>
<td>13</td>
<td>6</td>
<td>11</td>
<td>6.73 ± 0.08</td>
<td>4.22 ± 0.07</td>
<td>71.90 ± 1.82</td>
</tr>
<tr>
<td>14</td>
<td>6</td>
<td>13</td>
<td>6.84 ± 0.13</td>
<td>4.23 ± 0.04</td>
<td>71.50 ± 2.24</td>
</tr>
<tr>
<td>15</td>
<td>6</td>
<td>10</td>
<td>7.04 ± 0.13</td>
<td>4.31 ± 0.11</td>
<td>81.10 ± 3.91</td>
</tr>
<tr>
<td>16</td>
<td>6</td>
<td>#</td>
<td>6.74 ± 0.08</td>
<td>4.05 ± 0.09</td>
<td>67.30 ± 1.48</td>
</tr>
<tr>
<td>17</td>
<td>6</td>
<td>#</td>
<td>6.72 ± 0.03</td>
<td>4.34 ± 0.04</td>
<td>72.50 ± 1.87</td>
</tr>
<tr>
<td>18</td>
<td>7</td>
<td>14</td>
<td>7.03 ± 0.16</td>
<td>4.38 ± 0.03</td>
<td>79.50 ± 1.58</td>
</tr>
<tr>
<td>19</td>
<td>7</td>
<td>15</td>
<td>6.86 ± 0.11</td>
<td>4.38 ± 0.05</td>
<td>78.50 ± 2.55</td>
</tr>
<tr>
<td>20</td>
<td>7</td>
<td>15</td>
<td>6.68 ± 0.12</td>
<td>4.34 ± 0.07</td>
<td>74.50 ± 1.87</td>
</tr>
<tr>
<td>21</td>
<td>7</td>
<td>13</td>
<td>6.95 ± 0.15</td>
<td>4.47 ± 0.04</td>
<td>81.30 ± 1.79</td>
</tr>
<tr>
<td>22</td>
<td>9</td>
<td>15</td>
<td>7.18 ± 0.14</td>
<td>4.52 ± 0.04</td>
<td>86.50 ± 1.58</td>
</tr>
<tr>
<td>23</td>
<td>9</td>
<td>9</td>
<td>6.92 ± 0.20</td>
<td>4.17 ± 0.05</td>
<td>71.10 ± 2.21</td>
</tr>
<tr>
<td>24</td>
<td>10</td>
<td>11</td>
<td>6.78 ± 0.14</td>
<td>4.28 ± 0.03</td>
<td>74.50 ± 2.35</td>
</tr>
<tr>
<td>25</td>
<td>10</td>
<td>15</td>
<td>7.23 ± 0.15</td>
<td>4.38 ± 0.12</td>
<td>78.90 ± 4.04</td>
</tr>
<tr>
<td>26</td>
<td>10</td>
<td>14</td>
<td>6.98 ± 0.15</td>
<td>4.25 ± 0.05</td>
<td>73.70 ± 2.17</td>
</tr>
<tr>
<td>27</td>
<td>10</td>
<td>15</td>
<td>6.79 ± 0.13</td>
<td>4.53 ± 0.05</td>
<td>81.10 ± 3.13</td>
</tr>
<tr>
<td>28</td>
<td>10</td>
<td>11</td>
<td>6.69 ± 0.06</td>
<td>4.06 ± 0.04</td>
<td>67.30 ± 1.10</td>
</tr>
<tr>
<td>29</td>
<td>12</td>
<td>12</td>
<td>6.72 ± 0.24</td>
<td>4.16 ± 0.10</td>
<td>71.30 ± 2.39</td>
</tr>
<tr>
<td>30</td>
<td>13</td>
<td>9</td>
<td>6.84 ± 0.10</td>
<td>4.20 ± 0.04</td>
<td>70.90 ± 1.82</td>
</tr>
<tr>
<td>Mean</td>
<td>-</td>
<td>12.7 ± 2.1</td>
<td>6.90 ± 0.22</td>
<td>4.30 ± 0.13</td>
<td>75.60 ± 5.14</td>
</tr>
</tbody>
</table>

The egg measurements of nests indicated with * and ** were calculated with two and four eggs respectively. Nests whose clutch size is indicated with # were found predated thus the total number of eggs could not be accurately determined. Mean egg length, egg breadth and egg mass shown at the bottom of the table were obtained from all measured eggs.

Correlation analyses - Spearman Rank Order - were performed among laying date, depth to the top egg, clutch size, egg breadth, egg length and egg mass (Table 3.4). Egg mass declined with laying date (\( r = -0.38, \text{df} = 28, P<0.05 \)) indicating that

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clutches with large eggs tended to be laid earlier. Egg mass was positively correlated with clutch size (r = 0.51, df = 28, P < 0.05), egg breadth (r = 0.85, df = 28, P < 0.05) and egg length (r = 0.67, df = 28, P < 0.05), indicating that heavy eggs were found in clutches with a large number of long and/or wide eggs. Clutch size was positively correlated with egg breadth (r = 0.74, df = 28, P < 0.05), indicating wider eggs were found in clutches with a large number of eggs.

Table 3.4. Spearman Rank Order Correlation results between pairs of factors laying date, depth, clutch size, egg breadth and egg length from nests recorded on McKinlay River in 2003

<table>
<thead>
<tr>
<th>Variable</th>
<th>Laying date</th>
<th>Depth</th>
<th>Clutch size</th>
<th>Egg breadth</th>
<th>Egg length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laying date</td>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth</td>
<td>0.1369&lt;sup&gt;ns&lt;/sup&gt;</td>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clutch size</td>
<td>-0.3547&lt;sup&gt;ns&lt;/sup&gt;</td>
<td>0.3511&lt;sup&gt;m&lt;/sup&gt;</td>
<td>1.0000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Egg breadth</td>
<td>-0.3336&lt;sup&gt;ns&lt;/sup&gt;</td>
<td>0.1511&lt;sup&gt;ns&lt;/sup&gt;</td>
<td>0.7408&lt;sup&gt;*&lt;/sup&gt;</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Egg length</td>
<td>-0.2509&lt;sup&gt;ns&lt;/sup&gt;</td>
<td>-0.0769&lt;sup&gt;ns&lt;/sup&gt;</td>
<td>0.1422&lt;sup&gt;ns&lt;/sup&gt;</td>
<td>0.3568&lt;sup&gt;ns&lt;/sup&gt;</td>
<td>1.0000</td>
</tr>
<tr>
<td>Egg mass</td>
<td>-0.3820&lt;sup&gt;*&lt;/sup&gt;</td>
<td>0.0144&lt;sup&gt;ns&lt;/sup&gt;</td>
<td>0.5067&lt;sup&gt;ns&lt;/sup&gt;</td>
<td>0.8489&lt;sup&gt;*&lt;/sup&gt;</td>
<td>0.6689&lt;sup&gt;*&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>ns</sup> Not significant at α=0.05. <sup>*</sup> Significant at α=0.05.

A comparison of clutch characteristics recorded in this study and in the previous six studies carried out on the McKinlay River is given in (Table 4.2). Contrary to the other years, in the years 1982-1985 egg breadth and egg length were the only measurements recorded, egg mass being deduced through formula (Smith, 1987). Because of this, egg mass was compared for the years 1980, 2002 and 2003. Egg mass was significantly different amongst the three years (ANOVA, F<sub>2,78</sub> = 32.66, P<0.001) and eggs recorded in 2003 are significantly heavier than those recorded in 1980 but are significantly lighter compared to those sampled in 2002 (Tukey HSD test, MS = 37.696, df = 78, P < 0.05).

One-Way ANOVA was also employed for all the nesting data to investigate whether there was significant difference amongst years in terms of clutch size, egg length and egg breadth. There was no significant difference in clutch size (ANOVA, F<sub>6,136</sub> = 1.759, P > 0.05). There was a significant difference in egg length amongst years (ANOVA, F<sub>6,148</sub> = 10.8, P<0.001). Eggs recorded in 2003 were significantly longer

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than those recorded in previous years, except 2002, whereas egg length recorded in 2002 was significantly higher than 1980 and 1985 (Tukey HSD test, MS = 0.3655, df = 148, P < 0.05). Similarly, there was a significantly difference in egg breadth recorded amongst the seven years (ANOVA, F_{6,148} = 6.5, P < 0.001). Mean egg breadth recorded in 2002 and 2003 was significantly higher than 1980 and 1985, and there was no significant difference between egg breadth recorded in 2002 and 2003 (Tukey HSD, MS = 0.01917, df = 148, P < 0.05).

Table 3.5. Descriptive statistics of the distribution of *C. johnstoni* mean clutch size, egg length, egg breadth and egg mass for the years 1979-80, 1982-85 and 2002-03

<table>
<thead>
<tr>
<th>Year</th>
<th>Clutch size (Mean ± SD)</th>
<th>Egg length (Mean ± SD cm)</th>
<th>Egg breadth (Mean ± SD cm)</th>
<th>Egg mass (Mean ± SD g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>13.38 ± 2.87 (29)</td>
<td>6.57 ± 0.20 (29)</td>
<td>4.12 ± 0.38 (29)</td>
<td>66.00 ± 8.20 (29)</td>
</tr>
<tr>
<td>1982</td>
<td>12.67 ± 3.11 (27)</td>
<td>6.68 ± 0.18 (27)</td>
<td>4.19 ± 0.42 (27)</td>
<td>69.22 ± 8.41 (27)</td>
</tr>
<tr>
<td>1983</td>
<td>12.60 ± 4.32 (12)</td>
<td>6.68 ± 0.20 (12)</td>
<td>4.21 ± 0.27 (12)</td>
<td>69.87 ± 6.65 (12)</td>
</tr>
<tr>
<td>1984</td>
<td>12.28 ± 3.75 (15)</td>
<td>6.65 ± 0.18 (15)</td>
<td>4.19 ± 0.38 (15)</td>
<td>68.84 ± 9.41 (15)</td>
</tr>
<tr>
<td>1985</td>
<td>10.48 ± 2.87 (20)</td>
<td>6.55 ± 0.19 (20)</td>
<td>4.11 ± 0.34 (20)</td>
<td>65.56 ± 6.60 (20)</td>
</tr>
<tr>
<td>2002</td>
<td>10.93 ± 3.17 (14)</td>
<td>6.80 ± 0.22 (21)</td>
<td>4.29 ± 0.14 (21)</td>
<td>81.14 ± 7.28 (21)</td>
</tr>
<tr>
<td>2003</td>
<td>12.73 ± 2.15 (26)</td>
<td>6.89 ± 0.18 (30)</td>
<td>4.31 ± 0.12 (30)</td>
<td>76.28 ± 4.56 (30)</td>
</tr>
<tr>
<td>Total</td>
<td>12.42 ± 2.87 (143)</td>
<td>6.70 ± 0.22 (155)</td>
<td>4.21 ± 0.15 (155)</td>
<td>71.15 ± 7.91 (155)</td>
</tr>
</tbody>
</table>


On the basis of these results, it can be inferred that clutch characteristics, except for clutch size, may vary substantially from one year to another.

### III.2.4 Nesting Substrates

The substrate on which the nests were found has been presented previously (Section III.1.1). Here the depth at which the eggs were laid in each substrate is investigated. The average depths to the top egg recorded from the most common substrate types are presented in Table 3.4. There was a significant difference in the depth at which the eggs were laid in the three substrates (F_{2,22} = 3.79, 0.05 < P < 0.025). Eggs laid in clay and humus were at a significantly shallower depth than the ones laid in other

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_Nesting Ecology of the Australian Freshwater Crocodile on the McKinlay River: Baseline for Assessing the Impact of Cane Toads_

_Amaral M. Chibeba_
substrates (Tukey HSD Test MS = 13.22, df = 22, P < 0.05). There was no significant difference in depth of eggs laid in coarse sand and fine sand substrate (Tukey HSD Test MS = 13.22, df = 22, P > 0.05).

Table 3.6. Mean depth to the top egg recorded across all the substrates surveyed on the McKinlay River in 2003. Depth to the top egg was only recorded in non-predated nests.

<table>
<thead>
<tr>
<th>Substrate type</th>
<th>Number of samples</th>
<th>Depth (mean ± SD cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse sand</td>
<td>17</td>
<td>17.65 ± 3.50</td>
</tr>
<tr>
<td>Clay and humus</td>
<td>2</td>
<td>10.50 ± 2.12</td>
</tr>
<tr>
<td>Fine sand</td>
<td>6</td>
<td>15.50 ± 4.62</td>
</tr>
</tbody>
</table>

III.2.5 Nest Predation

Predation timing is presented in Figure 3.2. Of 61 nests recorded throughout the study, 52 nests were predated (85.2%), most of them (69.2%) during the nesting season. It should be noted that these estimates of predation rates included a large proportion of nests found easily because they had been predated and so cannot be treated as a robust estimate. There was an increase in predation during the nesting season (that is, the period during which laying was concentrated), with the peak occurring around the end of the nesting season. Though the maximum number of predated nests was recorded for 9 September 2003 this should be interpreted cautiously since this is likely be to a cumulative figure for the preceding days (Section II.4).
Figure 3.2. Dates of location and predation of *C. johnstoni* nests in 2003. Nest location and predation was recorded daily from 16 August to 6 September 2003, but after this period data was recorded in intervals of five to seven days (Section 11.4). Located: new nests located through probing or predators. Predated: new and old nests found predated.

The proportion of nests predated in three-days intervals since laying date is shown in Figure 3.3. Predation was seemingly age-dependent; predation was substantially higher in nests eight days or less (78.8%) than in older ones. Further, nests younger than 14 days of age were markedly more predated (91%) than older ones. Interestingly, one nest was predated one month after its laying date.

It can be concluded than though predation was particularly high in the first two weeks after laying, it also continued to occur at low levels in nests older than three weeks.
Figure 3.3. Percentage of nests predated and accumulated percentage of nests predated in different time intervals on the McKinlay River in 2003, based on 33 nests whose laying and predated dates were known.

A summary of predation events, percentage of eggs taken and the number of eggs left in each of the nests inspected is shown in Table 3.3. The calculations were made from a sample of 36 nests, ten first found through predators and 26 first found through probing. All eggs were taken from four of ten nests first found by predators, and 16 nests of 26 nests found through probing. Of 13 nests in which only a portion of eggs were taken initially and researchers refilled the nest cavity, seven nests were dug up by predators within five days, when all of the remaining eggs were taken. Three nests were never dug up again by predators throughout the incubation period and the eggs remaining in five nests, which had been predated previously, survived until the hatching period.
The potential for the researcher's interference with nests to enhance predation was investigated by comparing nests found through predators and nests found through probing in terms of the time elapsed before predation since the day the nests were laid. Should digging exacerbate predation, the time elapsed before predation in nests found through probing would be shorter than in nests found through predators. The time elapsed before predation since laying date in nests found through probing was not significantly different to the nests found through predators (ANOVA, $F_{1,31} = 0.75$, $P > 0.05$). It can be inferred that should observer's impact exist, it does not appear to be large.

The nests appeared to be predated exclusively by varanid lizards. Varanid lizards' tracks were observed before the commencement of the nesting season and continued to be found until the end of September. During the nesting season, varanid lizards were repeatedly observed searching the areas where the nests were located, excavating the nests and taking $C. johnstoni$ eggs. An analysis of a number of photos revealed $Varanus panoptes$ as the key $C. johnstoni$ egg predator. $Varanus mertensi$ was also observed on nesting areas, though to a lesser extent, but it was never found excavating or investigating $C. johnstoni$ nests.

Two $V. panoptes$ were found dead during the study, one in early September and the other in late September. The first one was in Site nine, and the last one was in Site eight. Stomach contents of the last animal were examined and no evidences of toad-related death were found. Both animals were very emaciated and may have starved. Emaciated $V. panoptes$ were observed in four Sites (6, 8, 9, 10 and 11). Interestingly, healthy animals were also observed in the same Sites.
Table 3.7. Summary of predation events, percentage of eggs taken and number of eggs left in each of the nests inspected on the McKinlay River in 2003. This includes only 36 nests from which laying date could be estimated. In the status column PREDATED indicates that the nest was found predated, while OK indicates that the nest was found intact.

<table>
<thead>
<tr>
<th>Site</th>
<th># Days elapsed before 1st predation</th>
<th>Status</th>
<th>Cutch size</th>
<th># Eggs remaining</th>
<th>% of eggs taken</th>
<th># Days elapsed from 1st to 2nd predation</th>
<th># Eggs remaining</th>
<th>% of eggs taken</th>
<th># Days elapsed from 2nd to 3rd predation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0</td>
<td>Predated</td>
<td>7</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
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<td>14</td>
<td>0</td>
<td></td>
</tr>
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<td>12</td>
<td>0</td>
<td>100.0</td>
</tr>
</tbody>
</table>
III.3 SITE COMPARISONS

Comparisons amongst Sites were made in relation to laying date and clutch characteristics. There was no significant difference amongst Sites in terms of laying date (ANOVA, $F_{5,22} = 1.09$, $P > 0.05$), clutch size (ANOVA, $F_{5,17} = 0.92$, $P > 0.05$), egg length (ANOVA, $F_{5,19} = 0.55$, $P > 0.05$), egg breadth (ANOVA, $F_{5,19} = 0.72$, $P > 0.05$) and egg mass (ANOVA, $F_{5,19} = 0.71$, $P > 0.05$).

III.4 HATCHING

A total of ten nests hatched in the period 4 to 14 November 2003. The nests for which laying dates were known showed an average incubation period of 81.3 days ($N = 4$, $SD = 4.6$, range 75 – 86).

The location and history of hatched nests is summarized in Table 3.8. Of the ten-hatched nests, six had not been located prior to hatching, while the other four were located through probing during the nesting season. Of the nests found by probing, two were partially predated (Section II.2) and the other two were never predated.

For hatching analysis it was considered that only eight nests hatched because the other two had been re-buried, thus increasing their chance of survival.

Table 3.8. Location and nest history of hatched nests. PP: partly predated nest; I: intact nest (nest found through probing and never predated); H: hatched (nest only found after hatching).

<table>
<thead>
<tr>
<th>Site</th>
<th>PP</th>
<th>I</th>
<th>H</th>
<th>Total hatched</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
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<tr>
<td>6</td>
<td>1</td>
<td>0</td>
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<td>2</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>2</td>
<td>2</td>
<td>6</td>
<td>10</td>
</tr>
</tbody>
</table>

Surprisingly, of the five nests that were predated at least once and reburied, two appeared to have hatched. Eggs from the remaining nests died, probably through overheating during the period of exposure after predation events.
In hatched nests, characteristically large holes, remaining eggshells and crocodile tracks associated with the nests were observed. Holes excavated, presumably by female crocodiles, were in average 105 cm in diameter \( (N = 4, \ SD = 10.4, \ range \ 95 - 115 \ cm) \) in coarse sandy substrates, compared to 30 cm \( (N = 1) \) in fine sand.

### III.4.1 Hatching Success

A comparison of hatching success rates obtained from three models, *Naive*, *Mayfield* and *Product* methods, and an estimate of the total number of nests laid across the study area that can be derived from them is shown in Table 3.9. Hatching success was estimated considering the 26 nests found through probing and monitored until the hatching period. Since only two of these hatched, hatching success with the *Naive* Method (Section II.6) is 7.69%.

<table>
<thead>
<tr>
<th>Model</th>
<th>Hatching success (%)</th>
<th>Standard error (%)</th>
<th>Number of nests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naive</td>
<td>7.69</td>
<td>5.23</td>
<td>104</td>
</tr>
<tr>
<td>Mayfield</td>
<td>0.39</td>
<td>1.14</td>
<td>2,051</td>
</tr>
<tr>
<td>Product Method (1)</td>
<td>0.98</td>
<td>1.45</td>
<td>816</td>
</tr>
<tr>
<td>Product Method (2)</td>
<td>1.68</td>
<td>1.40</td>
<td>476</td>
</tr>
</tbody>
</table>

Product Method was used considering two segments, eight days of age or younger and nine to 81 days of age \(1\), and 14 days of age or younger and 15 to 81 days of age \(2\). Standard error for the *Naive* Method was estimated with the Binomial test, whereas for *Mayfield* and *Product* Methods the standard error was estimated with Bart and Robson test.

However, when the time of exposure (Section II.6) of the 26 nests is considered, hatching success is much lower. When constant mortality of the nests throughout the incubation period is assumed, and the *Mayfield* Method applied (Section II.6), the hatching rate is estimated at 0.39%. Given that nest predation appeared to be age-dependent (Section III.2.5) the *Product* Method was also employed. *Product Method 1* considers two sets of ages: eight days of age or younger and nine to 81 days of age (a

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*Amaral M. Chibeba*
74 day period to an approximation of the average incubation period), whereas product
Method 2 considers 14 days of age or younger and 15 to 81 days of age.

If it is assumed that these predation rates are representative of the entire population,
the estimate of nests laid across the study area derived from the three methods differs
substantially. The Naive Method returned the lowest estimate, 104 nests, whereas the
Mayfield Method returned as high as 2,051 nests. The Product Method returned 476 –
816 nests, which is a more moderate estimate.

III.4.2 Hatchling Surveys

Only few hatchlings were observed during the spotlight surveys. Though three nests
hatched in both Sites four and nine (Table 3.8), only three and two hatchlings were
recorded respectively in Sites four and nine. No hatchlings were recorded from Site
three in spite of the three-hatched nests.

However, in Site six a crèche of twenty-one hatchlings was found. In the following
week, no hatchlings were found and, surprisingly, no adult eye-shines were seen,
contrasting with the fifteen crocodiles recorded in the previous spotlight survey. A
week later, a saltwater crocodile at least three meters in length was seen near the pool
associated with this Site. Another large crocodile was also observed on this occasion
but it was seen from a considerable distance so it could not be confirmed whether it
was another saltwater crocodile. Apart from these two large reptiles, no other
crocodiles were spotlighted.

Apart from the saltwater crocodile, the other potential hatchling predator surveyed is
long-necked turtle. Two large long-necked turtles were spotlighted in the pool in site
four.

Hatchlings were commonly spotlighted on the edge of pools with no adult crocodile
obviously accompanying them.

Nesting Ecology of the Australian Freshwater Crocodile on the McKinlay River: Baseline
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Amaral M. Chibeba
III.5 OCCURRENCE OF FERAL ANIMALS

Feral animals were seen throughout the study period. Water buffaloes were by far the most common animals, having been seen in almost each visit. Pigs were the second most common having been recorded in about one third of the visits. Horses were recorded in three consecutive visits, whereas only one dingo was seen in a single visit in early September.

In spite of the occurrence of feral animals, no evidence was found of pigs or dogs preying on nests, nor were any nests physically destroyed by pugging or trampling by buffaloes or horses.

III.6 OCCURRENCE OF SALTWATER CROCODILES

There appears to have been a recent substantial invasion of saltwater crocodiles into the McKinlay River area. Whilst no *C. porosus* individuals had been recorded in the area by the mid eighties (Smith, 1987), in 2002 saltwater crocodiles were reported from Sites three, nine and 13 (Britton, 2003). Site one was suspected to support a large saltwater crocodile (Britton, 2003) and this was confirmed in the course of this study (Adam Britton, personal comm.). During this study, a large crocodile was seen twice in September in Site 13 (personal observation) but it rapidly went into the water so it could not be ascertained whether or not it was a saltwater crocodile. Additionally, in site six a saltwater crocodile was observed on 21 November 2003 (personal observation).
IV DISCUSSION

This chapter compares the results found in this study to those obtained previously in similar studies, especially the ones undertaken in the McKinlay River area.

IV.1 SITE SELECTION

In nest sites used by Crocodylus niloticus, another a hole-nester, the main requirements are shade, suitable soil, proximity of water and the degree of slope (Cott, 1961; Modha, 1967). Not attending its nest during incubation (Webb et al., 1983b; Smith, 1987; Webb et al., 1987b; Webb and Manolis, 1989), C. johnstoni may be less constrained in selecting nesting sites (Smith, 1987). Shade, proximity to water and slope are believed to relate to the comfort of the female rather than the ecology of the eggs (Smith, 1987).

That females excavated test holes at least three weeks prior to the nesting season agrees with previous findings. In the McKinlay River, C. johnstoni has been reported to excavate holes without laying eggs two to three weeks before the nesting period (Webb et al., 1983b; Smith, 1987; Webb and Manolis, 1989). It is presumed that females are testing the substrate conditions, temperature and moisture, in which the embryo will develop (Smith, 1987; Webb and Manolis, 1989).

With C. johnstoni, it appears that the availability of friable substrate is the key factor used in site selection. In this study, C. johnstoni nested near permanent water whenever a friable substrate was available near the pool. It was not surprising that though 58.8% of the nests were situated at less than 20 m of permanent water, 35.3% of the nests were laid beyond 50 m of water because these were the nearest areas of favourable substrate. Furthermore, the majority of nests were located in coarse sand (58.5%) or fine sand (30.2%) substrate, and these are by far the most common substrate types in the nesting banks surveyed.
Nests were laid in a period of three weeks, from 16 August to 6 September 2003, and despite the characteristic variation in nesting timing of _C. johnstoni_ amongst years (Smith, 1987), this nesting season overlaps with all the previous ones recorded in the McKinlay River area (Fig. 4.1). One-way ANOVA showed a statistical difference in nesting timing amongst years (ANOVA, $F_{6,224} = 27.67$, $P < 0.05$). Nesting commenced significantly earlier in 1980 than 1982, 1985 and 2002 (Tukey HSD Test, $MS = 29.57$, $df = 224$, $P < 0.05$). On the other hand, nesting commenced later in 1983 than all the other years except for 2002 (Tukey HSD Test, $MS = 29.57$, $df = 224$, $P < 0.05$).

Nesting data from this year showed no significant difference in nesting timing amongst Sites (ANOVA, $F_{5,22} = 1.09$, $P > 0.05$) indicating that the nesting timing was fairly synchronised across the Sites in the study area.

The variation in timing of initial nesting amongst years remains to be explained. In _Alligator mississippiensis_ the time of nesting is strongly correlated with the mean temperature experienced in the proceeding tree months (Joanen and McNease, 1989; Kushlan and Jacobsen, 1990). Based upon the similarities that exist amongst crocodilians (Lance, 1987), it has been predicted that _C. johnstoni_ may exhibit the same pattern (Smith, 1987). Nonetheless, a comparison of seven nesting seasons showed that the mean temperature experienced three months prior to nesting was neither significantly correlated with the first nesting date ($r = -0.2752$, $df = 5$, $P > 0.05$) nor with median nesting date ($r = -0.0367$, $df = 5$, $P > 0.05$) of _C. johnstoni_. In these seven seasons, the earliest nesting occurred in 1980 though this was not a particularly hot year and nesting commencement had a difference of 15 days between 1983 and 1984 despite experiencing exactly the same mean temperature (Table 4.1). Further study is, therefore, needed to clarify the variability of nesting timing among years in _C. johnstoni_.

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*Nesting Ecology of the Australian Freshwater Crocodile on the McKinlay River: Baseline for Assessing the Impact of Cane Toads*

*Amaral M. Chibeba*
Figure 4.1. Laying date of *C. johnstoni* in the McKinlay River area for the period 1980, 1982-85, 2002 and 2003. 1983 was a very dry year with an early wet season (Smith, 1987).


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Table 4.1 Summary of first nesting date, median nesting date and mean temperature experienced in the three months (May–July) that proceeded the nesting period of *C. johnstoni* in seven years (1980, 1982–85, 2002 and 2003) on the McKinlay River. Nesting date for each year is counted commencing from July 31st.

<table>
<thead>
<tr>
<th>Year</th>
<th>First nesting date</th>
<th>Median nesting date</th>
<th>May–July mean Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980 (1)</td>
<td>07</td>
<td>21</td>
<td>32.3</td>
</tr>
<tr>
<td>1982 (2)</td>
<td>16</td>
<td>19</td>
<td>31.5</td>
</tr>
<tr>
<td>1983 (2)</td>
<td>25</td>
<td>31</td>
<td>31.1</td>
</tr>
<tr>
<td>1984 (2)</td>
<td>10</td>
<td>21</td>
<td>31.1</td>
</tr>
<tr>
<td>1985 (2)</td>
<td>18</td>
<td>26</td>
<td>30.5</td>
</tr>
<tr>
<td>2002 (3)</td>
<td>18</td>
<td>31</td>
<td>33.0</td>
</tr>
<tr>
<td>2003 (4)</td>
<td>16</td>
<td>25</td>
<td>33.9</td>
</tr>
</tbody>
</table>

Sources: (1) Webb *et al.*, (1983b); (2) Smith (1987); (3) Britton (2003); (4) This study; (5) BOM (2003).

### IV.3 CLUTCH CHARACTERISTICS

That clutch size declined with time of egg-laying is not surprising. This relationship has been established previously in the McKinlay River area (Webb *et al.*, 1983b; Smith, 1987; Webb *et al.*, 1987b; Webb and Manolis, 1989). This trend has been ascribed to large females with bigger clutches (Smith, 1987; Webb *et al.*, 1987b; Thorbjarnarson, 1996) nesting prior to small females (Webb *et al.*, 1983b; Webb *et al.*, 1987b; Webb and Manolis, 1989), which have smaller clutches of small eggs (Smith, 1987; Webb *et al.*, 1987b; Thorbjarnarson, 1996). Consistent with this was a capture of two small gravid females late in the nesting season, after 28 August (Webb *et al.*, 1983b) on the McKinlay River.

### IV.4 THE INCUBATION PERIOD

#### IV.4.1 Duration

That nests took 81.3 days after being laid (N = 4, SD = 4.6, range 75 – 86) to hatch is consistent with earlier studies. In the McKinlay River area, the incubation period is known to take between 75 and 90 days (Webb, 1982).
IV.4.2 Egg Mortality

Of 61 nest recorded throughout the study 52 (85.2%) were predated exclusively by *V. panoptes*. Varanid lizards have been reported as the key predator on the eggs of *Crocodylus niloticus* (Cott, 1961; Modha, 1967; Kofron, 1989) and *C. johnstoni* (Webb et al., 1983b, Smith, 1987; Webb and Manolis, 1989; Whitehead, 1987; Britton, 2003). Though *V. mertensi*, another varanid lizard, was also observed during this study, it was far less common and it was never found excavating or investigating *C. johnstoni* eggs. These observations agree with previous findings for the McKinlay River area (Webb et al., 1983b; Smith, 1987; Britton, 2003).

Although loss of eggs to feral animals has been reported in the area (Webb et al., 1983b), such mortality did no occur during this study. Webb et al (1983b) reported egg predation of 6% of nests (n = 5) to wild pigs, *Sus scrofa*, and in one nest, 11 of 19 eggs were crushed after being walked by a water buffalo. Water buffalo was by far the most common feral animal recorded during this study, followed by wild pigs, but they were never seen in the proximity of the nests.

The extent to which observers' interference to nests exacerbates predation remains to be elucidated. Working in the McKinlay River area, Webb et al. (1983b) observed that 64% of the nests are lost to varanid lizards. This initial estimate was regarded as inflated by research activities and a 50% loss of eggs to varanid lizards was suggested as a more realistic mean estimate (Smith and Webb, 1985). Believing that the smells of both the turned soil and the mucus of the eggs may attract predators, Smith (1987) employed deodoriser after eggs sampling in a four years study undertaken on the McKinlay River. Given that the nests were actively protected against predators, using wire nesting, the overall predation rate of 43% could be an underestimate. Britton (2003), also working in the McKinlay River area, used air freshener and did not protect the nests. The predation rate, exclusively ascribed to *V. panoptes*, was as high as 93.5%. In this study, air freshener was equally employed and in spite of care in not leaving excavated nest soil, nest loss due to *V. panoptes* was 82.5%. Although the test
of the influence of nest excavation on subsequent risks of predation showed no significant effect, it must be acknowledged that it was a relatively indirect and weak one.

The predation behaviour of varanid lizards is not well understood. The fact that varanid lizards heavily predate nests at the time of egg-laying (Section III.3.2; Webb and Manolis, 1989, Britton, 2003) has been attributed to their keen sense of smell and a related ability to detect recently laid eggs (Webb and Manolis, 1989). However, it was noted that, on several occasions, varanid lizards moved across recently laid nests without excavating them and on one occasion one *V. panoptes* was observed excavating a sand bank, missing a nest less than 30 cm away. *V. panoptes* was also observed excavating holes that no longer had eggs. In a colonial nesting area, varanid lizards predated, on the same day, two nests at least two meters apart but left untouched a nest less than 30 cm from a predated nest. The three nests had an age difference of less than three days and had been located through probing on consecutive days. Interestingly, varanid lizards successfully found old nests, including one aged one month, without any evidence of failed excavation attempts. This agrees with a previous finding, equally from the McKinlay River area, of *Varanus gouldii* (probably actually *V. panoptes*), predating 15 nests aged between 61 and 90 days after laying date (Smith, 1987).

Observations of partially predated nests were similarly intriguing. Of 13 partially predated and re-covered nests, nine nests were revisited by predators within four days but four nests were never predated again, though tracks of varanid lizards were repeatedly seen over the nests. Seven eggs, which survived the first predation event, survived throughout the incubation period and hatched even though there was one rotten egg in the nest.
IV.5 HATCHING

IV.5.2 Timing

Nests hatched between 4 – 14 November 2003 and this is in accordance with previous findings. In the McKinlay River area, most nests hatch from 6 to 26 November (Webb et al. 1983b; Webb et al. unpublished).

IV.5.2 Success

The estimates of hatching success from the Naïve, Mayfield and Product method were very different and it is difficult to ascertain which provides the most robust estimate. However, by not considering the time of exposure, the Naïve Method normally returns higher hatching estimates (biased upwards) (Mayfield, 1961; Pollock and Cornelius, 1988; Johnson, 1990; Johnson and Shaffer, 1990). Hence, the estimates from the Naïve Method are unlikely to be correct.

Mayfield Method, on the other hand, returned a very low estimate of nest survival that, if applied across the entire population, would generate a correspondingly high estimate of nests laid across the study area. Given that the crocodile population of the McKinlay River area has been estimated at 1,500 individuals, the resultant estimate of 2,051 nests is very unlikely to be correct. Moreover, the Mayfield Method performs well with samples of at least 50 nests (Klett and Johnson, 1982), and when egg mortality is constant throughout the observation period (Mayfield, 1961; Pollock and Cornelius, 1988; Johnson, 1990; Johnson and Shaffer, 1990). Hence, the poor performance of the Mayfield Method can be ascribed to the relatively low sample size, only 26 nests, and to the seemingly age-related predation of nests.

Though the Product Method also performs well with samples of at least 50 nests (Klett and Johnson, 1982), given variation in nest predation rates during incubation, it is very likely that the Product Method provides the most robust estimate of hatching.
success. And subdividing the incubation period in two periods of 14 and 67 days of age appeared to better reflect age-related predation and returned an apparently better estimate of nets laid across the study area. Considering than the current crocodile population has been estimated at 1,500 individuals (Smith and Webb, 1985) and adult sex ratio has been estimated at 0.17 (Webb et al. 1983b; Smith and Webb, 1985; Webb et al. 1987b), then, the number of females can be estimated at 1,245 individuals. Because of these animals only 35% may be beyond 11 years of age (Smith and Webb, 1985) and 84% of females of this age nest per year (Webb et al. 1987b), then, the number of nests from females of this age structure can be estimated at 366 nests. Further, since only 8% of females younger than 11 years of age nest per year (Webb et al. 1987b), then, the nesting contribution of females from this age segment can be estimated at 64 nests. Hence, the total number of nests laid per year can be estimated at 430, which is relatively close to 476 nests estimated through the Product Method 2.

Interestingly, none of the three methods returned a hatching rate greater than 8%. This is a clear reflection of the high egg mortality due to predation by *V. panoptes*. Should cane toads have a substantial impact on the population of *V. panoptes*, this will favour an increase in the reproductive success of *C. johnstonii*.

However, considering that with the sample size of 26 nests the three methods returned very high standard errors, it can be predicted that impacts of cane toads may be difficult to detect statistically using these standard methods, unless larger sample sizes are obtained.

**IV.5.2 Hatchling Surveys**

The dearth sighting of hatchlings can be ascribed to predation. In the McKinlay River area, about 80 – 90% of hatchlings die during the first wet season (Webb, 1982; Smith and Webb, 1985; Webb and Manolis, 1989) primarily due to predation immediately after the hatching period (Webb and Manolis, 1989). Fish, python, large crocodiles and sea eagles have been confirmed as hatchlings predators (Webb and Manolis,
1989), whereas fresh water turtles are suspected predators (Webb and Manolis, 1989). Though hatchling predators were noted during the hatching period, they were never observed capturing young freshwater crocodiles.

In this study no adult-sized crocodiles have been observed near a crèche. A previous research found that in most cases adult crocodiles were not obvious with a crèche and it suggested that they may have dived when searchers approached the pool.
V RECOMMENDATIONS

In this chapter, relevant aspects to be considered in assessing the impact of cane toads upon nesting ecology of *C. johnstoni* are presented.

In future studies, after the arrival of cane toads, Varanid lizards’ activity and mortality, especially *Varanus panoptes*, should be closely monitored. Stomach contents of any varanid lizard found dead should be examined to ascertain whether its death is due to consumption of cane toads.

Mark-and-recapture studies of crocodiles should be undertaken over at least three years after the arrival of cane toads to ascertain short and mid-term changes in size, sex ratio and population structure attributable to cane toads. These data would be compared with similar studies done during 2001 and 2002, which drew on marking studies conducted from the early 1980s. Concomitantly, stomach contents of any crocodile found dead should be examined to ascertain whether deaths are toad-related. Capture-and-recapture studies will also enable monitoring of the progressive invasion of saltwater crocodiles in the McKinlay River area and help to explain short and mid-term changes on the population and nesting ecology of *C. johnstoni*.

Clutch characteristics and nesting timing have proved to vary considerably from one year to another. However, should cane toads have a large impact on the crocodile population, significant change in these variables may occur as outlined elsewhere in this study. Monitoring clutch characteristics and nesting timing should continue to be monitored over a period of time after the arrival of cane toads, to ensure that the full range of effects and hence the likely cumulative impacts can be explored.

The most significant changes can be predicted in regard to nest survival. Given that the with the sample size of 26 nests all the hatching success methods returned very high standard errors, in future studies efforts should be made to record at least 50 nests before predators find them. This can be achieved with a team of at least two researchers surveying the study area every day during the brief nesting season.  

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Inference may also be strengthened by examining associated variables, including evidence of varanid activity which, although not presented in detail here, could be compared quantitatively to provide an index of varanid presence at nest sites. Copies of all data have been lodged with the Charles Darwin University to permit a wide range of direct post-toad comparisons.
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