Management of Human-Crocodile Conflict in the Northern Territory, Australia: Review of Crocodile Attacks and Removal of Problem Crocodiles

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Abstract

Rebuilding of depleted crocodilian populations leads to increased Human-Crocodile Conflict (HCC), and the focus of management changes from conservation to mitigation of HCC. As the largest and most aggressive extant crocodilian species, saltwater crocodiles (\textit{Crocodylus porosus}) are of particular concern, although they are an important natural resource for commercial harvesting, tourism, and customary use. We quantified HCC in the Northern Territory of Australia by reviewing the historical records of saltwater crocodile attacks and the removal of saltwater crocodiles. Between 1977 and 2013, a total of 5792 problem crocodiles were caught, of which 69.04\% were males. The most common size class was 150-200 cm and their mean size did not change significantly over years. Between 1971 and 2013, 18 fatal attacks and 45 non-fatal attacks occurred. About 60\% of these attacks occurred around human population centers including remote communities. The number of attacks, particularly non-fatal cases increased over years. This increase was strongly related to the increase in both human and crocodile populations, and the increasing proportion of larger (>180 cm) crocodiles. The peak of problem crocodile capturing and crocodile attacks was in the beginning (Sep.-Dec.) and end (Mar.-Apr.) of the wet season. However, fatal attacks occurred almost all year around. Attacks by >400 cm crocodiles often resulted in death of the victim (73.33\%). Crocodiles in 300-350 cm class were more responsible for attacks than any other sizes. Proportions of indigenous and non-indigenous victims did not differ greatly. Local and male victims were much more common than visitors and females, respectively. The most common activity of victims was swimming and wading. It is essential that the public receive messages about crocodile awareness and risks through education programs.

Introduction

Depleted populations of large carnivores represent a particularly difficult conservation challenge, because success in increasing wild populations can come with the social, political and economic cost of increased conflict with people (Treves and Karanth 2003; Treves \textit{et al.} 2006; Dickman 2010). The rebuilding of wild crocodilian populations has often resulted in increased Human-Crocodile Conflict (HCC) (Stuebing 1983; Conover and Dubow 1997; Aust \textit{et al.} 2009; Gopi and Pandav 2009; Wallace \textit{et al.} 2011; Webb 2012), and with larger and more aggressive crocodilians, conflict involves people being severely injured or killed (Nekisic and Wardill 1992; Scott and Scott...
Saltwater crocodiles (Crocodylus porosus) are of particular concern, because 1) they are the largest of extant crocodilians and can exceed 6 m in length and 1000 kg in weight (Britton et al. 2012), 2) they feed on large prey items including people and domestic stock (e.g., cattle, horses, and water buffalo), 3) they are widely distributed in the Indo-Pacific region (Webb and Manolis 1989; Webb et al. 2010), and 4) they occupy a variety of water bodies, including marine and freshwater wetlands critical to the livelihoods of many people.

The Northern Territory of Australia represents the southern part of the range of saltwater crocodiles. Wild populations in the Northern Territory were severely depleted by unregulated commercial harvesting (1945-70), were eventually protected (1971), and have increased in abundance and biomass since then (Messel et al. 1981; Webb et al. 1984). They are now considered almost fully recovered in the core habitats of tidal rivers and associated floodplains (Webb et al. 2000; Fukuda et al. 2011), but are still expanding into upstream sections of rivers (Letnic and Connors 2006) and the sea (Nichols and Letnic 2008). In some of these areas there is no institutional memory of crocodiles being present and their re-appearance poses a risk to public safety where the types of recreational water activities undertaken assume the absence of crocodiles. Crocodiles that appear in or near human settlement are considered a risk to people and/or livestock and defined as problem crocodiles (Leach et al. 2009).

Despite the risk to public safety, saltwater crocodiles are an important and valuable natural resource in the Northern Territory, exploited through commercial farming and ranching (Leach et al. 2009), tourism (Ryan 1998) and customary use (Lanhupuy 1987). Crocodiles and their eggs are harvested in a sustainable manner for commercial use and land owners receive royalties for these harvests (Leach et al. 2009). This incentive-driven conservation system adds economic value to the species and motivates the community to tolerate and conserve wild populations of crocodiles (Webb and Manolis 1993; Hutton et al. 2002). Consequently, management goals are somewhat diametrically opposed, improving public safety by removing problem animals and educating the public about the risk, while encouraging crocodile population growth to support ongoing commercial uses by people.

In this study, we describe 1) HCC with a particular reference to the dynamics of human and crocodile populations, 2) the development of public safety programs including education and the removal of problem crocodiles, and 3) patterns and trends in problem crocodiles and attacks on humans in the Northern Territory of Australia. After quantifying HCC and its relationship with human and crocodile populations, we provide a series of recommendations to guide the management programs to reduce HCC.
Study area

The study area was the northern, coastal regions of the Northern Territory, Australia (Fig. 1), encompassing the natural historical distribution of *C. porosus* in the Northern Territory, where it inhabits a range of freshwater and saline water bodies, including beaches, billabongs, floodplains, lagoons, lakes, mangroves, rivers, swamps, and waterholes (Webb and Manolis 1989; Fukuda *et al.* 2007). The climate is monsoonal with distinct wet (Nov.-Apr.) and dry (May-Oct.) seasons. The dry season is characterised by the coldest (May-Aug.) and the hottest (Aug.-Nov.) periods of the year (Webb 1991). The mean minimum and maximum temperature typically ranges between 22 and 32°C and the annual rainfall is around 1700 mm (Station Number 14015, Darwin Airport; Bureau of Meteorology 2014). During the wet season, heavy rainfalls flood water bodies and floodplains, enabling more extensive movement of saltwater crocodiles (Webb 1991; Campbell *et al.* 2013). Courtship and mating for saltwater crocodiles begin in the late dry season, and nesting occurs during the wet season (Webb and Manolis 1989; Fukuda and Cuff 2013). During the cooler times of the dry season, the activity of saltwater crocodiles may be reduced, but they will continue to feed to some degree throughout the year (Webb *et al.* 1978; Taylor 1979).

The study area covers several townships (Table 1), including the state capital, Darwin, and many large and small indigenous communities. The main land use is indigenous use (any land uses by indigenous or Aboriginal groups in their lands to which access is controlled by authorities or land councils), pastoralism, conservation (national parks and reserves), and tourism (Fig. 1). Local communities, including indigenous and non-indigenous groups, hold diverse perceptions towards crocodiles as a culturally or ecologically significant species, natural resource, and predator of humans and livestock (Lanhupuy 1987; Webb and Manolis 1989; Fijn 2013).

Australian freshwater crocodiles (*Crocodylus johnstoni*) also inhabit the study area, mainly in freshwater bodies upstream of tidal influence (Webb *et al.* 1983; Webb and Manolis 1989). We did not include *C. johnstoni* in this study because this smaller species poses few HCC issues (Webb and Manolis 1989; Delaney *et al.* 2010) and its attacks on humans are rare and reported elsewhere (Hines and Skroblin 2010; Somaweera 2011).
Figure 1. Study area in the Northern Territory, Australia, with approximate locations of saltwater crocodile attacks between 1979 and 2013 (N = 63).

Table 1. Population centers in the study area of the Northern Territory, Australia, and their human population size, the number of saltwater crocodile attacks between 1979 and 2013, and estimated saltwater crocodile breeding habitat within 50 km buffer around each of the population centers. Note that the three attacks in Oenpelli were also contained within the 50 km proximity of Jabiru.

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Methods

Human population

The Northern Territory has a relatively small human population (approximately 234,800 in 2012), concentrated within the Greater Darwin Region (approximately 131,900 people in 2012) that includes, Darwin, Darwin Harbour, and its surrounding urban and rural residential areas (ABS 2013). Towns and communities in the study area have different human population sizes (Table 1) and approximately 30% of the entire population in the Northern Territory are indigenous (ABS 2006). The human population in the Northern Territory has been constantly increasing and the increase is expected to continue (ABS 2013). We derived the human population in the Greater Darwin Region from ABS (2013) and described the trend by fitting a linear regression to the mean population in five-year periods for 1979-2013 with 1971-1978 grouped as one period.

Crocodile population

At the time of protection in 1971, saltwater crocodiles in the Northern Territory were considered commercially extinct due to uncontrolled hunting, and the population was estimated to be between 3000-5000 non-hatchlings (Webb et al. 1984; Richardson et al. 2002). Extensive monitoring programs since protection showed consistent increases in crocodile populations across the Northern Territory (Messel et al. 1981; Webb et al. 2000; Fukuda et al. 2011). Although the degree of recovery differs between sub-populations due to intrinsic habitat quality (Fukuda et al. 2007, 2011), the overall population, now estimated to be 80,000-100,000 non-hatchlings (Y. Fukuda, Northern Territory Department of Land Resource Management, unpublished data), is considered to be approaching carrying capacity and the abundance level that existed in 1945, before the period of uncontrolled hunting (Leach et al. 2009; Fukuda et al. 2011). The monitoring surveys of crocodile populations showed that as the number of crocodiles recovered, the mean individual size of individuals in the population also increased (Fukuda et al. 2011). Using data derived from Fukuda et al. (2011) and the historical surveys of crocodile populations in twelve tidal rivers monitored...
between 1971 and 2013, we described the trends in the relative density of saltwater crocodiles (sighting/km of river) and the proportion of crocodiles >180 cm total length (TL) by fitting linear regressions to the mean of these indices in five-year periods, except for 1971-1978 which was grouped as one period.

Public safety program

Public safety is one of the priorities in the management of saltwater crocodiles in the Northern Territory (Leach et al. 2009; Fukuda et al. 2012). The Northern Territory Government’s public safety program consists of two major components, education for safety awareness and the removal of problem crocodiles.

The public education program for crocodiles started in the late 1970s with the goal of raising the awareness of the risk of crocodile attack (Butler 1987), and was sustained at different levels of intensity depending on the public concern triggered by occasional crocodile attacks (G. Webb, Wildlife Management International, unpublished data). It also involved the installation and maintenance of warning signs in crocodile habitats with frequent human access, providing information exhibits and talks at local events and schools, and advertizing public notices in a variety of media (eg television, radio, newspaper, and website). During the 1990s less effort was expended on media and school outreach, but in the last decade, government revitalized the public education program (“Be CROCWISE”) with dedicated staff and funding to deliver the message about crocodiles and efforts to maintain public safety in the Northern Territory (Leach et al. 2009; PWCNT 2014).

The removal of problem crocodiles began in the late 1970s as government started receiving reports from the public about crocodiles considered a risk to people, livestock or domestic animals. As the crocodile population continued to recover, the concern spread across the Northern Territory, and the removal of problem crocodiles, especially around human settlements, became a permanent feature of the crocodile management program. Since the inception of the problem crocodile program in the early 1980s, the removal of problem crocodiles has concentrated on Darwin and its environs. This area was defined as the Darwin Crocodile Management Zone (DCMZ; Fig. 2) in 2009 as a management response to increasing crocodile populations and HCC around the urban areas (Leach et al. 2009; Fukuda et al. 2012). The DCMZ encompasses the Greater Darwin Region that contains approximately 56% of the human population in the Northern Territory (ABS 2013), and around 70% of the population in the study area (TNRM 2013). Captured problem crocodiles are not returned to the wild, because *C. porosus*, particularly males, have a strong homing instinct (Walsh and Whitehead 1993; Read et al. 2007; Campbell et al. 2010). Instead, they are transported to crocodile farms in most cases to be utilized as stock (Leach et al. 2009). Outcomes of the problem crocodile management such as the location and number of problem crocodiles removed are reported regularly to the public through the media and government reports (Leach et al. 2009; Fukuda et al. 2012; PWCNT 2014).
We compiled the historical data for saltwater crocodiles caught as problem crocodiles between 1977 and 2013 from internal government databases. We did not include the data for crocodiles captured 1) primarily for commercial or traditional use, 2) in Kakadu National Park, because they were relocated within the park rather than removed (Lindner 2004; G. Linder, Parks Australia, unpublished data), and 3) by non-government staff, because these crocodiles were also used for commercial purposes and the distinction between problem crocodile and commercial use was not clear. We excluded data for 1998 from the analysis because they were incomplete. We also excluded hatchlings (<0.6 m) that were rarely captured as problem crocodiles. The detail of each problem crocodile record included the date and location of the capture, and the species, sex, and TL of the crocodile.

We analysed the historical data on problem saltwater crocodiles with respect to 1) numbers caught annually and mean total length in each year over time, using ANOVA, 2) TL distribution in 50 cm categories using chi-square test, 3) sex difference in the size distribution, using chi-square test, 4)
seasonal (monthly, Jan.-Dec.) distribution of captures, using chi-square test, and 5) correlation between number of problem crocodiles and mean rainfall in each month [rainfall data derived from Weather Station Number 14015, Darwin Airport (Bureau of Meteorology 2014) nearest to the DCMZ where most problem crocodiles were captured]. We did not test the correlation between the number of problem crocodiles and the rainfall in each year because the capture effort was not standardised, but rather has been increasing over time [eg the number of traps used to catch problem crocodiles in the DCMZ increased from 33 in 2009 to 65 in 2012 (T. Nichols, Northern Territory Department of Land Resource Management, unpublished data)].

**Crocodile attacks**

We compiled historical records of crocodile attacks in the Northern Territory since 1971 by 1) collating the internal reports and databases kept by the Northern Territory government agencies and police, 2) interviewing victims, witnesses, police officers, or rangers involved in the incidents, 3) searching the media such as archived newspapers and websites, and 4) consulting with an independent database (C. Manolis, Wildlife Management International, unpublished data). We excluded attacks 1) involving escapees from crocodile farms, 2) that occurred on people working with crocodiles (eg handling crocodiles or collecting eggs), 3) that did not result in any injury or death of humans, and 4) which were not confirmed as crocodile attacks (eg victims went missing without witnesses or evidence). Details collected for each incident included 1) the date, time, location, and severity of attack, 2) TL of the crocodile, and 3) age, sex, origin (local or visitor), race (indigenous or non-indigenous), and activity of the victim at the time of the incident.

We grouped crocodile attacks into five-year periods between 1971 and 2013, but 1971-1978 was grouped as one because there were no crocodile attacks during that period. We then calculated the mean number of attacks (fatal, non-fatal and combined) in each period and compared the means between periods using ANOVA. Where there was a significant effect, a linear regression was fitted to further examine the trend.

We examined the seasonal distribution of crocodile attacks by dividing the crocodile attack data into months (Jan.-Dec.) and performing a chi-square test. We also tested the similarity of the monthly distribution between crocodile attacks and problem crocodiles, using chi-square test.

To examine trends with regard to the size of crocodile involved in attacks, we grouped the TL data into 50 cm increments and examined their distribution using a chi-square test. We summarised the detail of the victims (age, sex, local or visitor, indigenous or non-indigenous, day or night, activity, and position) to identify patterns and trends.
To explore potentially important areas for future HCC management in the study area, we performed a spatial analysis, in which we identified the human population centers in the Northern Territory and drew a 50 km buffer around each center to calculate the number of the historical crocodile attacks and the total area of the habitat predicted suitable for *C. porosus* within each buffer. We obtained the human population size from ABS (2013) and the spatial data for the breeding habitat from Fukuda *et al.* (2007).

To examine the relationships between the frequency of crocodile attacks and the human and crocodile populations, and the proportion of large individuals in the crocodile population, we fitted Generalized Linear Models (GLM). We used the number of crocodile attacks (fatal and non-fatal combined) as the response variable, and the densities of human and crocodile populations and the proportion of crocodiles >180 cm TL as a single explanatory variable in each model. All the variables were grouped at every five years between 1971 and 2013, except for 1971-1978 that was grouped as one period, as in the other analyses. We used the log link function in the Poisson family for GLM because the response variable was count data and the data showed non-linear relationship (Fig. 3). We compared the model fit by calculating the deviance explained by each model (1-residual deviance/null deviance) and Akaike Information Criteria corrected for small sample size (AICc).

We used ArcGIS (version 10.0, Esri) for the spatial analysis and producing maps, and R (version 2.12.0, CRAN) and Microsoft Excel 2010 for all the statistical analyses.

**Results**

The density of the human population in the Greater Darwin Region increased constantly between 1971 and 2013 ($r^2 = 0.99$, $P<0.01$; Fig. 3A). On the other hand, a logistic regression was the best fit for the crocodile population density (residual standard error= 0.05, df= 5; Fig. 3B) and the proportion of >180 cm long crocodiles (residual standard error= 0.05, df= 5; Fig. 3C).
Figure 3. Changes since protection (1971) in A) human population density in the Greater Darwin Region of the Northern Territory, Australia, B) saltwater crocodile density in the 12 monitored rivers, C) proportion of saltwater crocodiles larger than 180 cm in the 12 monitored rivers, and changes in the number of crocodile attacks against D) human population density, E) saltwater crocodile density, F) proportion of saltwater crocodiles larger than 180 cm. Linear regression was fitted in A, logistic regression was fitted in B and C, and generalized linear model (Poisson family with log link) was fitted in D, E, and F.

Between 1977 and 2013, 5792 non-hatchling *C. porosus* were recorded as being caught as problem crocodiles in the Northern Territory, mostly (4910 crocodiles, 83.01%) in the DCMZ. The actual number of crocodiles caught in 1998 remains unknown (thus, excluded from the analysis), but it is estimated that an additional 32 crocodiles may have been caught. For capturing method, trapping accounted for 71.22% of all captures, harpoon for 24.04%, hand catch for 2.21%, and others for...
2.52%. Of total problem crocodiles, 69.04% (3,999 crocodiles) were male, while 27.92% (1617 crocodiles) and 3.04% (176 crocodiles) were females and unknown sex, respectively. The total number of problem crocodiles increased from 2 in 1977 to 317 in 2013. The mean TL for each year ranged from 149.0 to 240.19 cm, but it did not change significantly over years \([F(1, 5790)= 2.664, P= 0.10]\) (Fig. 4).

**Figure 4.** Number of problem saltwater crocodiles caught between 1977 and 2013 \((N= 5792)\), and the mean TL for each year in the Northern Territory, Australia. Bars on mean total length show standard errors.

The TL of males ranged from 70 to 541 cm, and for females from 95 to 370 cm. The proportion in each TL class was not equally distributed between males and females \((\chi^2 = 443.98, \text{df}= 9, P<0.01)\), although the most common TL class was 150-200 cm for both males and females (Fig. 5). When males and females were combined, the TL classes were not equally distributed \((\chi^2 = 6,164.53, \text{df}= 9, P<0.01)\).
The number of problem crocodiles also differed between months ($\chi^2 = 215.60$, df= 11, P<0.01), with the highest number in April and the lowest number in January (Fig. 6). There was no significant correlation between the number of problem crocodiles caught in each month and the mean monthly rainfall ($r = -0.25$, P= 0.36). However, the monthly distribution of problem crocodiles showed significant correlation with the monthly rainfall two months earlier ($r = 0.82$, P<0.01) (eg problem crocodile numbers in April were related to the mean rainfall in February).

Figure 5. Number of male and female problem saltwater crocodiles in different total length classes caught between 1977 and 2013 in the Northern Territory, Australia (N= 3999 for male and N= 1617 for female).

Figure 6. The number of problem saltwater crocodiles caught in each month ($N = 5,763$), and mean monthly rainfall at Darwin (closed symbols with solid line) between 1977 and 2013 in the Northern Territory, Australia. The open symbols with dashed line are the mean monthly rainfall shifted later by two months. Bars show standard errors.
The first crocodile attack in the Northern Territory after protection of the species occurred in 1979. Between 1971 and 2013, a total of 63 attacks on humans by wild *C. porosus* were recorded, of which 28.57% (18 attacks) were fatal and 71.43% (45 attacks) were non-fatal. The mean number of crocodile attacks (fatal and non-fatal combined) was significantly different between the five-year groups \[F(1, 41)= 32.35, P<0.01\] (Fig. 7) and showed a linear increase over year-groups at a rate of 0.36 \( (r^2 = 0.76, P<0.01) \). There was a more profound difference between year-groups for the mean number of non-fatal attacks \[F(1, 41) = 20.53, P<0.01\] than fatal attacks \[F(1, 41)= 6.46, P=0.01\], and the mean of non-fatal attacks showed a linear increase over year-groups at a rate of 0.27 \( (r^2 = 0.67, P<0.01) \).

**Figure 7.** The number of fatal and non-fatal saltwater crocodile attacks in the Northern Territory, Australia divided into five-year periods between 1979 and 2013 (N= 63); 1971-1978 was grouped as one because there were no attacks. In brackets is the mean annual number of total crocodile attacks (± standard error).

Although there was apparent variation between months in the number of crocodile attacks (fatal and non-fatal combined) (Fig. 8), the difference between months was not statistically significant \( (x^2 = 17.19, df= 11, P=0.11) \). The difference in monthly distribution between crocodile attacks and problem crocodiles captured was not significant \( (x^2 = 17.22, df= 11, P=0.10) \).
The TL of 54 crocodiles, representing 85.71% of all attacks, was known (Fig. 9). The proportion of attacks differed significantly between TL classes ($\chi^2 = 26.96$, df= 9, P<0.01) with the most common TL in the 300-350 cm class (Fig. 9). The most common TL for non-fatal attacks was also 300-350 cm, while for fatal attacks it was 400-450 cm. Attacks by very large (>400 cm) crocodiles were mostly fatal (73.33%). The TL of crocodiles responsible for non-fatal attacks ranged from 80 to 450 cm, but ranged from 320 to 510 cm for fatal attacks. In the case of two non-fatal attacks involving 4.0 m long crocodiles, the victims were able to escape due to assistance from other people, and the result of the attack would have been different otherwise.

Figure 8. Number of saltwater crocodile attacks between 1979 and 2013 (N= 63) and the number of problem saltwater crocodiles captured between 1977 and 2013 (N= 5763) by month in the Northern Territory, Australia.

Figure 9. Number of fatal and non-fatal saltwater crocodile attacks in the Northern Territory, Australia between 1979 and 2013 in different total length classes (N= 54).
Most attacks (56 attacks; 88.89%) occurred while victims were in the water or on land at the water’s edge; two attacks (3.17%) involved crocodiles leaving the water and walking on land to attack people, in one case even entering a tent in which occupants were sleeping, and five attacks (7.94%) were directed at people sitting in boats. Fatal attacks mainly occurred in deep water (>0.5 m depth; 83.33%), but non-fatal attacks were more common in shallow water (<0.5 m; 42.22%) (Table 2). Both fatal and non-fatal attacks occurred more commonly in daytime (61.11% for fatal and 66.67% for non-fatal). The most common activities at the time of fatal attacks were swimming and wading (77.78%), diving (16.67%), and fishing (5.56%). The most common activities at the time of non-fatal attacks were swimming and wading (37.78%), fishing (20.0%), and hunting (20.0%) (Table 2).

For both fatal and non-fatal attacks, male victims were more common than female, and local people were much more common than visitors (Table 3). The number of indigenous victims was slightly lower than non-indigenous victims in non-fatal attacks, but the proportions were equal in fatal attacks. The age of victims ranged widely (7-55 years for fatal attacks and 5-75 years for non-fatal attacks) with a mean of 26.28 years for fatal attacks and 32.98 years for non-fatal attacks.

Within the study area, 12 major population centers were identified (Table 1). Within the 50 km buffer of these centers, 38 crocodile attacks (60.32% of total attacks) occurred between 1971 and 2013. Darwin, Katherine, and Nhulunbuy had the largest human populations, while Nhulunbuy, Jabiru, and Darwin had the highest number of attacks. The largest amounts of breeding habitat were predicted in Ramingining, Jabiru, and Oenpelli.

The number of crocodile attacks showed an exponential increase as a function of the density of human population, the density of crocodile population, and the proportion of >180 cm crocodiles (Fig. 3). The models showed similar support for these variables (difference in deviance explained <0.08 and ΔAICc <2.18), but the fit did not improve greatly when these variables were combined in one model (deviance explained= 0.79, AICc= 55.01).

**Discussion**

Despite the current population size of saltwater crocodiles being similar to that estimated before 1945 (Webb *et al.* 2000; Fukuda *et al.* 2011), our results showed a higher frequency of attacks in recent years (3.20 attacks/year for 2009-2013; Fig. 7) than was estimated by Manolis and Webb (2013) for northern Australia between 1855 and 1945 (2.38 attacks/year). The greatly increased human population relative to pre-1945 is considered to be a key factor contributing to this difference. Improved communication may also contribute to a higher number of crocodile attacks reported in recent years.
The increasing frequency of crocodile attacks in the Northern Territory since 1971, as the *C. porosus* population has increased, is also evident in other countries such as Timor Leste, Malaysia, and Solomon Islands where protection and conservation actions have led to depleted *C. porosus* populations recovering (Lading 2013; Sideleau and Britton 2012; C. Manolis, Wildlife Management International, unpublished data). In these cases, as with other successful crocodilian programmes, the focus of management changes from conservation to mitigation of HCC (CSG 2014).

Crocodile attacks occurred across the study area, but there were concentrations of attacks around or near remote communities such as Daly River, Jabiru, and Nhulunbuy (Table 1). Given that these rural communities contain a high proportion of indigenous residents (ABS 2006) and their traditional livelihood requires access to water bodies (eg fishing and hunting), public education may need to focus more attention on this segment of the population. However, the proportions of indigenous and non-indigenous victims did not differ significantly (Table 3), suggesting that both groups conduct the risk-associated activities (Table 2) at similar rates and public education should be applied to both sectors. A strikingly high proportion of attacks involved local residents (Table 3), and in view of the highly transient nature of the human population in the study area (Morgan 2011), public education should be maintained as a continuous process.

Despite the extremely large size of human population in the DCMZ (>56% of the Northern Territory), that only six attacks (one fatal and five non-fatal) have occurred since 1971 is considered to reflect to a large degree the effectiveness of the public safety programs including education and the removal of problem crocodiles. Given that the frequency of crocodile attacks is strongly related to the increasing human population (Fig. 3) there could have been more crocodile attacks taking place without the intensive removal of crocodiles within the DCMZ.

The most common class of problem crocodiles were 150-250 cm males (Fig. 5), and the mean TL of captured crocodiles did not significantly change over years (Fig. 4). Thus, these immature juvenile males have always been the major contributor to the problem crocodile issue within the DCMZ where most problem crocodiles were caught (83%). This is consistent with observations that smaller male *C. porosus* show greater range of movement than larger, more dominant males (Campbell et al. 2013). The crocodiles caught in the DCMZ are migrants from adjacent rivers, because *C. porosus* are highly mobile (Read et al. 2007, Campbell et al. 2010) and there is no major breeding habitat within the zone (Table 1, Fig. 2) to account for their origin. Likewise, in areas outside the DCMZ (e.g., Flora and Katherine Rivers), problem *C. porosus* have migrated from downstream habitats into upstream freshwater areas with no breeding habitat. However, the average TL of problem saltwater crocodiles in the Katherine River is remarkably large (eg >3.1 m; Letnic et al. 2011).

The peaks in problem crocodile capture and crocodile attacks in Mar.-Apr. and Sep.-Dec. (Fig. 8) mark the beginning and end of the wet season (Fig. 6) and coincide with the species’ nesting season (Nov.-Apr.). Early rains in Nov.-Dec. fill up rivers and associated freshwater floodplains, triggering increased dispersal of crocodiles (Webb 1991; Campbell *et al*. 2013). Crocodiles move back to permanent water bodies as the floodplains dry out in Mar.-Apr. A number of other factors may also contribute to higher encounter rates with crocodiles in these periods, such as seasonal human activities (eg swimming in hotter months of Oct. and Nov., and recreational fishing when fish flush into the floodplains in Nov. and Dec.). The effort put into catching problem crocodiles also increases in these months (D. Best, Northern Territory Department of Land Resource Management, unpublished data). Lower numbers of problem crocodile captures and crocodile attacks in May-
Aug. may relate to decreased activity of crocodiles during the coolest time of the year (eg reduced appetite and feeding), although this period also coincides with the peak of tourist visitation and associated human activities around water (Tourism NT 2012).

It is unclear why there was no significant change in the number of fatal attacks over years, whereas there was a steady increase in the number of non-fatal attacks (Fig. 7). The increase in the latter is strongly related to key factors for which our models show similar support (Fig. 3), namely the increasing human and crocodile populations and the increasing size of individuals in the crocodile population. The rate of crocodile attacks may continue to increase, as both human and crocodile populations are expected to keep increasing although the rate of increase in both may slow over time (Fukuda et al. 2011; ABS 2013). This is consistent with the number of non-fatal attacks by American alligators (*Alligator mississippiensis*) being higher in Florida, USA, where the populations of humans and alligators are much larger than those of humans and *C. porosus* in Australia (Langley 2005, 2010), and where there is greater encroachment of urban expansion into alligator habitats. However, fatal attack by *A. mississippiensis* is much less common than that by *C. porosus*, due to the less aggressive behaviour and smaller size of the former (Harding and Wolf 2006; Langley 2010; Brien et al. 2013).

In *C. porosus*, 73.33% of attacks by very large (>400 cm) individuals resulted in death (Fig. 9). Combining fatal and non-fatal, the 300-350 cm TL class was responsible for more crocodile attacks than any other size classes. According to the size-age relationships derived for wild *C. porosus* in the Northern Territory (Webb and Messel 1978), 300-350 cm crocodiles most likely born after protection in 1971. These post-protection crocodiles may be less wary of humans than the survivors of intensive hunting that hatched before protection (Webb and Messel 1979). For crocodiles less than 300 cm TL, an adult human may represent a prey size that is simply too large to handle.

Fatal attacks commonly occurred in deeper water (Table 2), possibly reflecting the habitat preference of very large crocodiles (>400 cm TL), but also the greater difficulty of escape for victims. In contrast, non-fatal attacks associated with smaller crocodiles occurred more commonly in shallow water or at the water’s edge, where crocodilians catch most of their prey (Webb and Manolis 1989). In only a few cases were victims not in direct contact with the water (eg fishing on a boat, sleeping on beach, or camping near the water’s edge). Crocodiles also attack people for self-defence or to exclude intruders from their territory (Caldicott et al. 2005).

Swimming and wading in crocodile habitats clearly poses a high risk of attack (Table 2), and were also the most common activity of victims of attacks by *A. mississippiensis* (Langley 2005, 2010) in the USA and Nile crocodiles (*C. niloticus*) in Africa (Fergusson 2004; CSG 2014). Consumption of alcohol by victims is noted as a factor contributing to crocodile attacks (Caldicott et al. 2005) as it may cause people to undertake activities that they would not otherwise have done. In this study, of 44 adult victims outside of Aboriginal lands where alcohol is largely prohibited, 10 (22.73%) were known to have been drinking alcohol prior to the attack. These numbers are likely to be underestimated as intoxication status was not often reported. Non-fatal attacks happened more commonly in daytime (Table 2), presumably because some activities such as fishing and hunting were more commonly conducted during daylight hours. Also, a higher rate of fatal attacks than non-fatal attacks at night may indicate that crocodiles generally feed more actively at night (Webb and Manolis 1989).

**Management implications**
We provide the following recommendations to reduce HCC. Given that most problem crocodiles are relatively young males migrating from other river systems, the management of problem crocodiles can be more strategic and efficient by examining their movement patterns and concentrating capture effort in areas where crocodiles enter and exit the management zones. The removal of problem crocodiles and safety awareness education should be maintained year round. Increasing management effort in areas with a high number of crocodile attacks such as Jabiru, Nhulunbuy, and Daly River may be beneficial. Attacks occur throughout the year and caution should be exercised at all times whilst in crocodile habitats. Increasing number of crocodile attacks is strongly related to the increasing human and crocodile populations, and the increasing proportion of >1.8 m crocodiles. This indicates that the management of problem crocodiles 1) should continue to incorporate components on both human (eg public education and safety awareness) and crocodile (eg population monitoring, removal of problem crocodiles) and 2) may be most effective if 300-350 cm TL crocodiles are strategically targeted as the most likely perpetrator. Public education through a range of the media is the most effective means of informing the public about the potential danger of water-related activities in crocodile habitats, particularly swimming and wading that should be avoided where a safety sign is not present. Public education programs need to apply to both indigenous and non-indigenous sectors. However, cultural values of crocodiles as a totem to some indigenous people should be taken into consideration. In the long-term the ability of authorities to conserve and maintain large populations of a predator such as the saltwater crocodile will rely on the ability to create positive incentives (eg through sustainable use and tourism) for conservation.

Acknowledgements

This study was conducted as part of crocodile management programs by the Northern Territory Government. All the crocodiles in this study were treated in accordance to the Animal Welfare Act (Northern Territory of Australia 2013) and the Code of Practice on the Humane Treatment of Wild and Farmed Australian Crocodiles (NRMMC 2009). We thank T. Nichols and D. Best at the Parks and Wildlife Commission of the Northern Territory, G. Lindner at Parks Australia, K. Boddington, S. Bradley and M. Casey at the Northern Territory Police, Fire and Emergency Services (NTPFES), and many others from various organisations for providing the data and associated information on historical crocodile attacks. We also appreciate the contribution of numerous rangers across the Northern Territory for capturing problem crocodiles and providing the data. A. Fisher, G. Edwards, K. Saalfeld, A. Walters, G. Webb, H. Campbell and B. Crase provided helpful comments on this study.

References


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Table 2. Activity and position of fatal and non-fatal crocodile attacks in the Northern Territory, Australia, between 1979 and 2013.

<table>
<thead>
<tr>
<th>Activity and Position</th>
<th>Activity</th>
<th>Activity</th>
<th>Activity</th>
<th>Activity</th>
<th>Activity</th>
<th>Activity</th>
<th>Activity</th>
<th>Activity</th>
<th>Activity</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Attacking</td>
<td>Position</td>
<td>Position</td>
<td>Position</td>
<td>Position</td>
<td>Position</td>
<td>Position</td>
<td>Position</td>
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<td>Position</td>
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<tr>
<td></td>
<td>Swimming</td>
<td>Fishing</td>
<td>Hunting</td>
<td>Diving</td>
<td>Other</td>
<td>Deep</td>
<td>Shallow</td>
<td>Water's</td>
<td>On boat</td>
<td>Other</td>
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<tr>
<td></td>
<td>and wading</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>water</td>
<td>water</td>
<td>edge</td>
<td></td>
<td></td>
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<tr>
<td>Fatal (N=18)</td>
<td></td>
<td>14</td>
<td>1</td>
<td>3</td>
<td>15</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(77.78%)</td>
<td>(5.56%)</td>
<td>(16.67%)</td>
<td>(83.33%)</td>
<td>(11.11%)</td>
<td>(5.56%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-fatal (N=45)</td>
<td>17</td>
<td>9</td>
<td>9</td>
<td>3</td>
<td>7</td>
<td>14</td>
<td>19</td>
<td>5</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>(37.78%)</td>
<td>(20.0%)</td>
<td>(20.0%)</td>
<td>(6.67%)</td>
<td>(15.56%)</td>
<td>(31.33%)</td>
<td>(42.22%)</td>
<td>(11.11%)</td>
<td>(11.11%)</td>
<td>(4.44%)</td>
</tr>
</tbody>
</table>

Table 3. Detail of the victims of fatal and non-fatal crocodile attacks in the Northern Territory, Australia, between 1979 and 2013.

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Sex</th>
<th>Origin</th>
<th>Race</th>
<th>Non- indigenous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attack</td>
<td>Range</td>
<td>Mean</td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>Fatal (N=18)</td>
<td>7-55</td>
<td>26.28 ± 3.08</td>
<td>(72.22%)</td>
<td>(27.78%)</td>
</tr>
<tr>
<td>Non-fatal (N=45)</td>
<td>5-75</td>
<td>32.98 ± 2.59</td>
<td>(80.0%)</td>
<td>(20.0%)</td>
</tr>
</tbody>
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