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Patterns of human–crocodile conflict in Queensland: a review of historical estuarine crocodile (*Crocodylus porosus*) management

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Abstract

Context. In Queensland, the management of estuarine crocodiles (*Crocodylus porosus*) by the government is important for ensuring public safety, especially along the populated east coast, where there is a large human population.

Aims. The present study aimed to determine historical, temporal and spatial patterns of human–crocodile conflict in Queensland.

Methods. The study used Queensland Government records of estuarine crocodile attacks (1971–2015), sightings by the general public (2003–2015), and removals and relocations for management purposes (1985–2015) to develop General Linear Models describing historical, temporal and spatial patterns.

Key results. The highest number of attacks, sightings, removals and relocations occurred along the populated east coast between Townsville and the Daintree during wet season months (November–February). There have been 35 crocodile attacks in Queensland since 1971 (total 0.8 per year; fatal 0.3 per year), mostly involving local people or regular visitors (77.1%), specifically adult males (71.4%; mean age 44). There has been an increase in the rate of crocodile attacks over time, with an average of 1.3 per year since 1996, most of which were non-fatal (84%). The number of crocodile sightings has been increasing annually (with a mean of 348 per year since 2011), while the number of crocodiles removed or relocated for management purposes ($n = 608$) has fluctuating widely each year (range 1–57).

Conclusions. The level of human–crocodile conflict in Queensland is increasing, and this is likely to be a consequence of increasing human and crocodile populations. While conflict is highest during the wet season, estuarine crocodiles pose a threat to public safety year round.

Implications. With the increase in conflict, the ongoing management of estuarine crocodiles, through targeted removals in and around areas of higher human habitation and through education, is essential for ensuring public safety into the future.

Additional keywords: attacks, removals, sightings.

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Introduction

The estuarine crocodile (*Crocodylus porosus*) is the largest (up to 6 m) and most widely distributed crocodilian, and is found in coastal waterways from Sri Lanka in the west, throughout south-east Asia to the Caroline Islands in the east, and down to northern Australia (Webb and Manolis 1989). This species is considered the most territorial and least tolerant of conspecifics (Lang 1987; Brien *et al*. 2013*a*), and along with the Nile crocodile (*C. niloticus*), accounts for the highest number of crocodilian attacks on humans each year (Caldicott *et al*. 2005; CrocBITE – The Worldwide Crocodilian Attack Data-Base, available at http://www.crocodile-attack.info, accessed 12 September 2015). As such, effective management of estuarine crocodile populations is critical in places where range and habitat use overlap.

The worldwide status of estuarine crocodiles is listed as Low Risk and of Least Concern (2009 IUCN Red List), with large stable populations in Australia, Papua New Guinea and Indonesia (Webb *et al*. 2010). In Australia, populations in the Northern Territory and Western Australia are large and increasing, while recovery in Queensland has been more modest and patchy since implementation of protective measures (Webb *et al*. 2010). Densities in Queensland are generally low but variable across the state when compared with the Northern Territory, with the highest densities in rivers along north-west Cape York Peninsula and Lakefield National Park (Taplin 1987; Read *et al*. 2004).

Estuarine crocodiles are found in coastal waterways and associated wetlands throughout north Queensland, including

offshore islands and up to 100 km inland (Taplin 1987). Breeding populations are known from the Fitzroy River, south of Rockhampton, on the east coast, north to the Torres Strait and into the Gulf of Carpentaria (Taplin 1987; Messel *et al.* 1981). However, individuals are also known in waterways as far south as the Mary River on the east coast, and are not uncommon on offshore islands (Miller and Bell 1997). Along the populated east coast, significant habitat alteration for agriculture and urban development has occurred, and it is here where most human–crocodile conflict occurs (Taplin 1987; Kofron 2004).

Management of estuarine crocodiles in Queensland is the responsibility of the Government (currently Department of Environment and Heritage Protection) under the *Nature Conservation Act of 1992* and currently the *Nature Conservation* (*Estuarine Crocodile*) *Plan of 2007*. Historically, unregulated hunting of estuarine crocodiles occurred until they were protected in 1974 (Taplin 1987), with the species currently state listed as Vulnerable, due to the impacts of threatening processes such as urban and rural development. Estuarine crocodiles that pose a threat to human safety have been captured and removed by the Government since the mid-late 1980s. However, crocodile management policies in Queensland have changed over time in response to both changes of government and community and political pressure resulting from increased crocodile sightings and/or attacks.

In this study, we reviewed historical records of estuarine crocodile attacks, sightings, removals and relocations for management purposes to determine patterns of human–crocodile conflict in Queensland. The main objective was to determine the effect of time, location and season on the frequency of estuarine crocodile attacks, sightings, removals and relocations to inform management programs.

Materials and methods

Distribution and habitat

The study area included all coastal waterways estuarine crocodiles are known to inhabit in Queensland, from the Mary River near Bundaberg on the south-east coast (25°30′43.19″S 152°45′28.50″E), north to the tip of Cape York Peninsula, including the Torres Strait (10°11′57.06″S 142°16′2.14″E), and down through the Gulf of Carpentaria to the Northern Territory border (16°32′33.30″S 137°59′41.00″E), including all offshore islands (Fig. 1). However, breeding populations are only known as far south on the east coast as the Fitzroy River near Rockhampton (Taplin 1987; Fig. 1). For the purposes of analysis, the coast of Queensland north of the Mary River

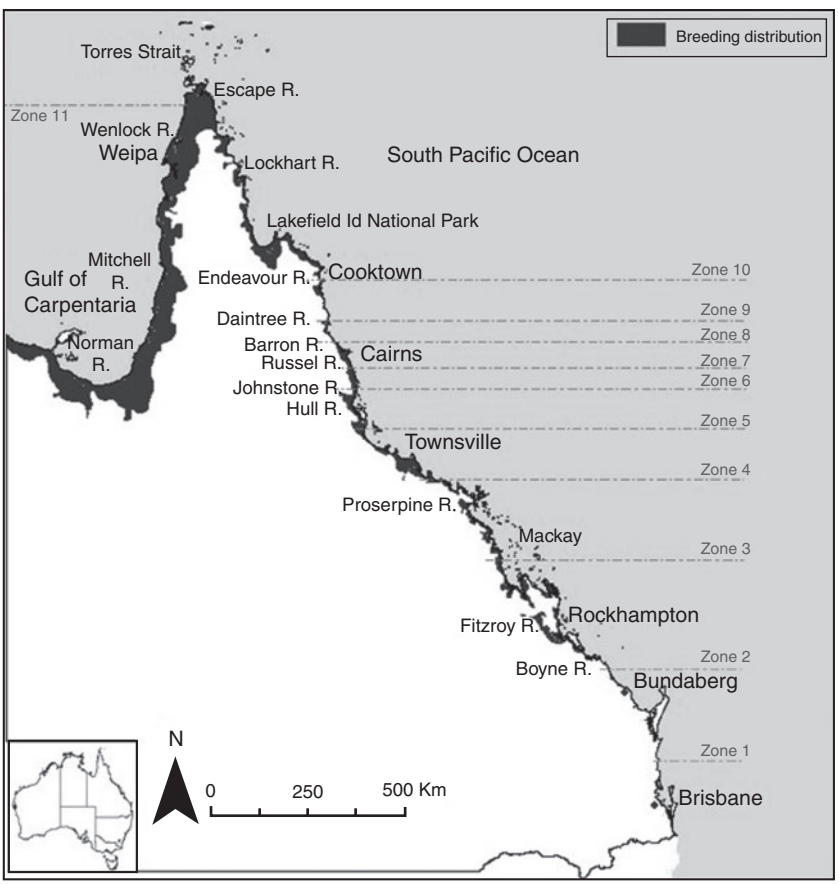

Fig. 1. Breeding distribution of estuarine crocodiles in Queensland (Taplin 1987). The state is divided into 11 broadly defined management zones.

around to the Northern Territory border was divided into 11 broadly defined management areas, based on the main estuarial river systems and associated urban centres (Fig. 1). Historically, this is also how the coastline has broadly been delineated with regards to crocodile management. These distances refer to approximate linear coastline and do not include lengths of inland waterways. However, management of crocodiles extends inland, generally up to 20 m above sea level where the majority of the crocodile populations exist.

Area 1: Wide Bay (Fraser Island, Mary River, Maryborough, Great Sandy Strait, Hervey Bay, Bundaberg) 150 km.
Area 2: Fitzroy (Benaraby, Tannum Sands, Gladstone, Rockhampton, Emu Park, Yeppoon, Byfield) 140 km.
Area 3: Mackay (Carmila, Sarina, Mackay, Eimeo, Seaforth, Lethebrook, Proserpine, Airlie Beach, Bowen) 330 km.
Area 4: Townsville (Home Hill, Giru, Barrata Creek, Alligator Creek, Magnetic Island, Ross River, Bohle River, Bushland beach, Toolakea, Bluewater, Toomulla, Balgal Beach) 200 km.
Area 5: Hinchinbrook (Forrest Beach, Taylors Beach, Halifax, Macknade, Lucinda, Hinchinbrook, Cardwell, Edmund Kennedy NP) 80 km.
Area 6: Innisfail (Tully, Mission Beach, Wongaling, Bingil bay, Garners Beach, Kurrimine Beach, Cowley Beach, Mourilyan, Etty Bay, Johnstone, Flying Fish Point) 70 km.
Area 7: Cairns (Bramston Beach, Eubanangee Swamp, Babinda, Deeral, Russel/Mulgrave, Edmonton, Cairns, Northern beaches, Ellis Beach) 100 km.
Area 8: Port Douglas (Mowbray, Port Douglas, Cooya Beach, Newell Beach, Wonga beach, Mossman, Daintree, Cow Bay) 50 km.
Area 9: Cape Tribulation-Cooktown (Cape Tribulation, Wujal, Bloomfield, Archer Point, Cooktown, Hopevale) 80 km.
Area 10: East Cape-Torres Strait (Hopevale-Crystal Creek including the Torres Strait) 1100 km.
Area 11: West Cape-Gulf (Skardon River-Northern Territory border) 1000 km.

Within the broad latitudinal range that encompasses estuarine crocodile habitat in Queensland, eight separate bioregions have been identified (Taplin 1987). These include the low-lying, arid Gulf Plains (Southern and Northern), hot and wet Cape York Peninsula (North-west and North-east), large wetland systems of Lakefield National Park, coastal fringes of the East Coast Plains, from the tropical northern reaches (Cape Melville to Cooktown and Cooktown to Ayr), to the sub-tropical and arid areas in the south (Ayr–Gladstone). All of these regions are characterised by a winter dry season (April–October), defined by low rainfall and cooler temperatures and a summer wet season (November–March), during which conditions are hot, humid and most precipitation occurs. Annual rainfall is highly variable, ranging from 700–1000 mm in parts of the south-western Gulf to 3000–4000 mm in tropical areas of the East Coast Plains (e.g. Innisfail). The summer wet season also corresponds with the breeding season for *C. porosus*, with nesting triggered by large rainfall events (Webb *et al*. 1977).

Human population

Although there are large tracts of pristine coastal habitat north of Cooktown and around the Cape into the Gulf, there has been intensive urban and agricultural (e.g. sugarcane) development along the East Coast Plains south of Cooktown. According to the Queensland Government Statisticians Office (http://statistics.qgso.qld.gov.au/qld-regional-profiles?; accessed 30 June 2016), populations in the major local government areas along the East Coast Plains in 2015 are estimated as (from south to north): Bundaberg (94 453); Rockhampton (81 589); Mackay (117 703); Townsville (192 058); Hinchinbrook (10 990); Cassowary Coast (29 396); Cairns (162 451); Douglas (11 997); and Cook (4 424). A few studies have suggested that human disturbance in catchment areas may be the dominant factor limiting crocodile population recovery along the east coast (Taplin 1987; Kofron and Smith 2001; Read *et al*. 2004). However, Fukuda *et al*. (2007) concluded that habitat availability was the dominant influence on successful recovery of the species in Queensland from the impact of commercial hunting (protection began in 1974). Queensland essentially has far less suitable nesting habitat available for estuarine crocodiles than the Northern Territory (Fukuda *et al*. 2007).

Cultural attitudes to crocodiles in Queensland vary among Aboriginal and Torres Strait Islander groups, with some traditionally hunting crocodiles and their eggs for food while others regard the crocodile as a totem animal or a spirit of ancestors. The rights of indigenous people to continue to hunt or use estuarine crocodiles as they have traditionally done so are recognised. With regards to managing problem crocodiles, cultural beliefs are taken into consideration when making decisions. For example, if a problem crocodile is captured that is larger than 4 m, it is recognised as an 'icon' crocodile and the department is required to formally consult with the traditional owners and enter into an agreement as to the fate of the animal.

Estuarine crocodile population

The population of estuarine crocodiles in Queensland has increased since protection in 1974, but this increase has been lower than in the Northern Territory and Western Australia (Taplin 1987; Read *et al*. 2004). The most recent comprehensive survey of the state occurred 1994–2000 and included 103 waterways (4174.3 km) between Gladstone, Rockhampton and the Northern Territory border (Read *et al*. 2004). The results indicated that crocodile numbers were generally low and highly variable across the state, with 91% of all animals sighted being less than the minimum breeding size for the species (Read *et al*. 2004). The population had undergone a limited recovery, with the highest numbers recorded from waterways in north-west Cape York Peninsula and Lakefield National Park, and low densities along the populated east coast. However, trends in population abundance and biomass since these surveys in the late 1990s and early 2000s are not well understood due to a lack of survey data. Freshwater crocodiles (*C. johnstoni*) also inhabit many of the same river systems as *C. porosus* in Queensland, although they are often found further inland (Taplin 1987), and considered a consequence of interspecific aggression with *C. porosus* (Brien *et al*. 2013*b*). Freshwater crocodiles were not

included in this study. Due to their smaller size, they pose little threat to humans, with very few attacks recorded.

History of estuarine crocodile management

Crocodile management in Queensland has generally involved the removal of crocodiles (>2 m) deemed to be a threat to safety of humans, livestock or working dogs. Crocodiles have been captured using either a trap (floating, gate) or with a harpoon, and either removed and placed at a suitable facility (farm, zoo) for breeding stock, or translocated to other sections of the river or to other systems such as Lakefield National Park (1995–97). However, this practice was discontinued in 1999 because estuarine crocodiles are known to 'home' back to their capture site, often travelling long distances (Walsh and Whitehead 1993; Kay 2004; Read *et al*. 2007). Intensive removal programs have also been in place along the populated east coast from: 1987–1991; 1998–2006; and 2012–15.

In late 1987, the East Coast Crocodile Management Program (ECCMP: 1987–1991) was introduced state-wide in response to community concerns that there had been an increase in crocodile sightings, along with several attacks (1980–1986: five fatal, one non-fatal). Three zones were established that dictated the type of management response: (1) all crocodiles removed; (2) all crocodiles >1.2 m removed; and (3) removed if posing a threat. During this period private contractors were also called on by the government to remove crocodiles in designated areas.

In 1998, the Trial Intense Management Area for Crocodiles (TIMAC) (Read *et al*. 2004) was established in the Cairns region (Trinity Inlet north to Wonga beach), again in response to community concerns about an increase in crocodile sightings, along with several attacks (1993–97: one fatal, two non-fatal). All crocodiles and crocodile eggs found in the designated TIMAC waterways were removed during the trial (1998–2001). The plan also included the removal of all crocodiles from areas of the Russell, Mulgrave, North Johnstone and South Johnstone rivers west of the Bruce Highway. In 2001, the program was extended as the Intensive Management Area for Crocodiles (IMAC) program (2001–06). The 'Croc-wise' educational campaign was also introduced by the Government in 2001, which involved the delivery of educational talks to the public, with a focus on schools.

In 2007, the Nature Conservation (Estuarine Crocodile) Conservation Plan 2007 and Management program 2007–17 came into effect. In 2009, it was also decided that any crocodiles south of the Boyne River should be removed. In 2011, the Government began reporting all crocodile sightings and declared 'crocodiles of concern' on its website (www.ehp.qld.gov.au), which was regularly updated. In 2012, Crocodile Urban Management Areas (CUMAs) were introduced in Gladstone, Mackay, and Rockhampton, in which all crocodiles >2 m in length were to be removed. In 2013, trial Crocodile Management Plans (CMPs) were introduced for the Cairns, Townsville, Hinchinbrook and Cassowary Coast local government areas. These areas were chosen because they experience a higher level of potential crocodile–human conflict (sightings, removals, attacks) than other population centres on the east coast, due to the larger size of both the human and crocodile populations. The plans set out a risk-based approach to crocodile management consisting of three different zones: Zone 1: prevent crocodiles from entering the zone and remove all crocodiles that enter into it; Zone 2: remove all crocodiles ≥2 m or any crocodile displaying aggressive behaviour; and Zone 3: remove crocodiles of concern.

This current approach to crocodile management in Queensland was largely derived from the Northern Territory model, in which crocodiles are more intensively managed and actively targeted for removal in and around urban centres (e.g. Darwin harbour). Along the populated east coast of Queensland between Cairns and Rockhampton, crocodiles ≥2 m are targeted for removal in and around several urban centres, with all crocodiles proactively removed from the Cairns area. The main difference between the Northern Territory and Queensland is the larger human population located in areas with healthy populations of crocodiles (Kofron 2004).

Data reduction and analyses

We used Queensland Government records to develop General Linear Models describing historical, temporal and spatial patterns of recorded crocodile attacks, sightings, removals and relocations in Queensland. We assigned each record to one of 11 management areas based on location of observation (Fig. 1) and collated data for year, month, sex (if known), crocodile body size (estimated from sightings, measured for captures), and crocodile attack outcome (fatal or non-fatal attack). As time of day was difficult to determine accurately for the majority of attacks, we did not attempt to examine or report on it. In comparing sex ratios of captured crocodiles we used chi-square tests. Recorded estuarine crocodile attacks on humans (non-fatal and fatal) have been reliably recorded by the government since 1971, and analyses included all recorded attacks from 1971 to 2015. We also confirmed records and cross-referenced information on attacks from The Worldwide Crocodilian Attack Data Base, CrocBITE. Estuarine crocodile sightings have been reported to the government since the 1980s, but before 2003 reports were not always filed and the facility for the public to report sightings was limited. Therefore, only sighting data from 2003 to 2015 were included in the analyses. Crocodile removals (including euthanised animals) and relocations have been recorded by the government since 1985, and analyses included all data from 1985 to 2015. Minimum monthly air temperature data for Cairns (Cairns AERO station 031011; 16.87S; 145.75E; Bureau of Meteorology 2016) was compared with monthly attack, sighting and capture data.

Results

Attacks

There have been 35 crocodile attacks recorded in Queensland since 1971 (mean 0.8 per year), 12 of which were fatal (34.3%; 0.3 per year). In one instance, a second person was also injured by the crocodile attempting to help the victim. Total length was recorded for 24 of the 35 attacking crocodiles (68.6%), with the mean size of crocodiles involved in fatal attacks (4.1 ± 0.22 m s.e.; range 2.7–5.0 m; $n = 9$) being significantly larger ($F_{1,21} = 23.14$; $P = 0.0001$) than those involved in non-fatal attacks (2.5 ± 0.21 m s.e.; range 1.2–4.2 m; $n = 15$; Fig. 2*a*).

Most attacks involved local people or people from north Queensland who regularly visited the area ($n = 27$; 77.1%), with two non-locals and six unknown. Adult males (mean age 44.2 ± 3.33 s.e.; range 24–75; $n = 25$) were the most common victims (71.4%), with four attacks on children (two males, two females; ages 5–11), three on teenagers (all males; ages 15–19), and three on adult females (ages 31–48; Fig. 2*b*). Only two victims were identified as aboriginal, although race was not identified for seven victims. Most victims were attacked in the water or on the edge (88.6%), with two attacks on people in canoes and two on people in tents. Most people were engaged in some form of recreational activity at the time. Attacks occurred between Innisfail on the east coast through to Normanton in the Gulf. The highest number of attacks occurred in and around rivers on the populated east coast between Cairns ($n = 7$; 1 fatal) and the Port Douglas area ($n = 6$; 2 fatal; Fig. 3). Several attacks also occurred in Weipa ($n = 4$; 1 fatal) and on offshore islands, including the Torres Strait ($n = 4$; non-fatal; Mt Adolphus Island 2006, 2007, MacArthur Islands 1999 and Thursday Island 2004) and Lizard Island near Cooktown ($n = 2$; 2009, 2015).

There has been a significant increase ($r^2 = 0.61$; $P < 0.0001$) in the overall rate of crocodile attacks recorded over time with a mean of 1.3 per year since 1996, most of which were non-fatal (84%; Fig. 4). Prior to 1996, the mean rate of attack was 0.4 per year (1971–1995), with most attacks being fatal (80%; Fig. 4). The mean size of crocodiles responsible for attacks has not changed significantly over time ($r^2 = 0.48$; $P = 0.47$).

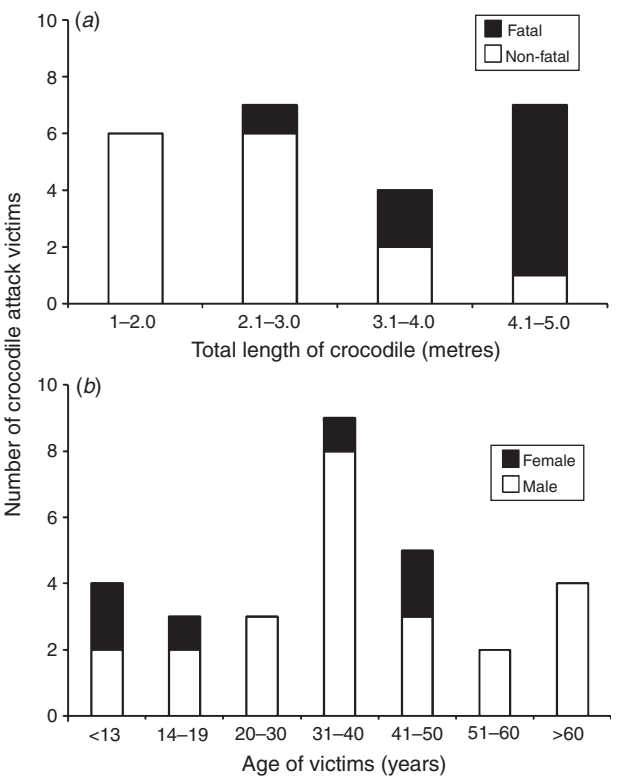

Fig. 2. Size of estuarine crocodiles involved in attacks on people in Queensland, and the age and sex of victims (1971–2015). The number of victims according to (*a*) total length of estuarine crocodiles (metres) involved in non-fatal and fatal attacks and (*b*) age and sex of victims of crocodile attack.

The distribution of attacks was not significantly different across months ($\chi^2 = 8.30$; d.f. = 10; $P = 0.60$), but attacks were more frequent December through February (Fig. 5*a*). The mean size of crocodiles responsible for attacks was not different across months of the year ($F_{10,12} = 0.88$; $P = 0.57$).

Sightings

In total, 3419 crocodile sightings were reported to the government from 2003 to 2015, with location recorded for 3223. Most sightings originated from the populated east coast between Ayr and Cape Tribulation (Areas 4–8: 73.6%; Fig. 3). The number of reports differed significantly among areas ($F_{10,995} = 33.4$; $P < 0.0001$) and was highest for Cairns (Area 7: 888; 27.6%; 68 per year), Innisfail (Area 6: 428; 13.3%; 33 per year), Port Douglas (Area 8: 394; 12.2%; 30 per year), Townsville (Area 4: 371; 11.5%; 29 per year) and Hinchinbrook (Area 5: 290; 9.0%; 22 per year), with 90 reports from offshore islands (Fig. 3).

Along the east coast, estuarine crocodiles have been reported as far south as Inskip Point, south of Fraser Island (Fig. 3). However, the southern-most sightings, confirmed by the government, were from the Mary River, Maryborough (Fig. 3). Some individuals have been reported up to 300 km inland near Georgetown, and at elevations up to 200 m in the upper reaches of the Burdekin and North Johnstone Rivers. However, the highest confirmed sighting of an estuarine crocodile (~2 m) is from Adeline Creek near the Daintree at 470 m above sea level (16°9′21.40″S 145°4′57.25″E; 15 May 2012; C. Hoskins). To travel to this location, the crocodile had to traverse several steep sections of river, including waterfalls.

The number of crocodile sightings has been increasing significantly each year ($F_{1,11} = 29.44$; $r^2 = 0.72$; $P = 0.0002$), with a mean of 347.6 ± 12.6 s.e. since 2011, and a maximum of 426 in 2015 (Fig. 6). Despite high variability, this trend was consistent across most locations, with the greatest increase in sightings occurring from around Cairns (Area 7).

Sightings have been reported throughout the year with significant differences among months ($F_{11,995} = 2.51$; $P = 0.004$). Sightings were highest during wet season months (October–February), when mean air temperatures were warmer, and lowest during dry season months (May–August; Fig. 5*b*).

Removals and relocations

In total, 608 estuarine crocodiles have been captured and either removed and placed at a facility ($n = 552$), relocated or released in-situ ($n = 46$) or euthanised ($n = 10$) since 1985. Crocodiles were captured from coastal areas from the Mary River in the south along the populated east coast and Cape York through to Normanton in the Gulf, including the Torres Strait (Fig. 2). However, the number of crocodiles captured differed significantly among areas ($F_{10,135} = 2.61$; $P = 0.006$; location recorded for 597), with most captured from waterways between Hinchinbrook and Port Douglas (Areas 5–8; 75%; Fig. 2). Crocodile captures were highest for Cairns (Area 7: 181; 5.8 per year; 30.3%), Innisfail (Area 6: 116; 3.7 per year; 19.4%), Hinchinbrook (Area 5: 85; 2.7 per year; 14.2%), and Port Douglas (Area 8: 66; 2.1 per year; 11.1%; Fig. 2).

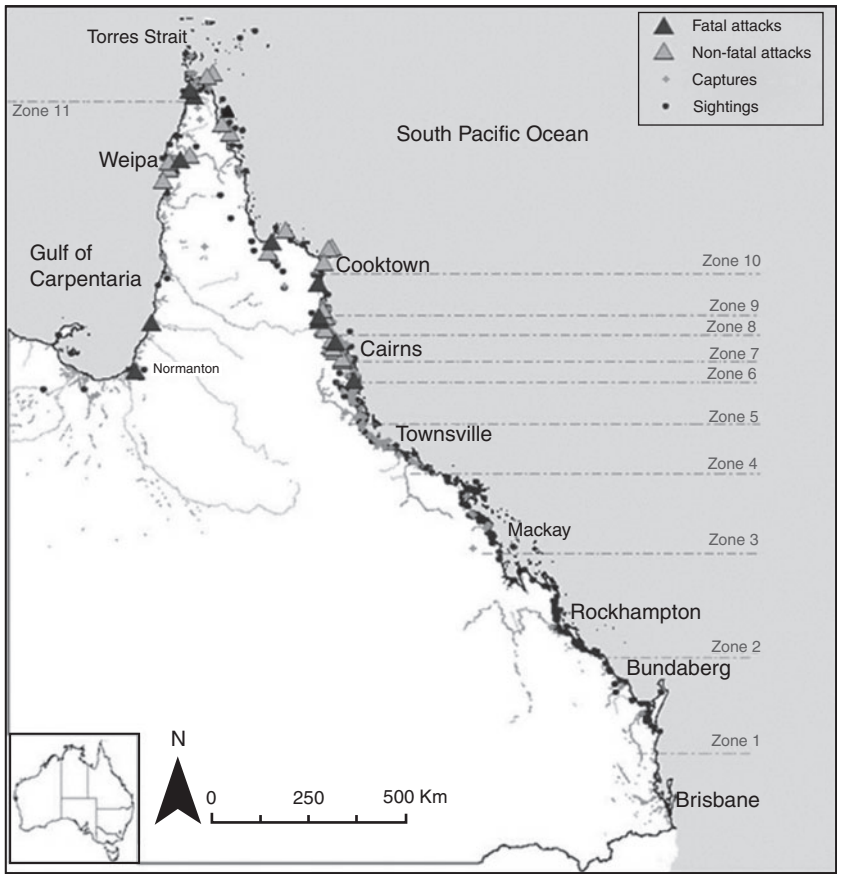

Fig. 3. Distribution of recorded estuarine crocodile attacks, sightings and removals and relocations in Queensland. Attacks: 1971–2015, sightings: 2003–15, and removals and relocations: 1985–2015.

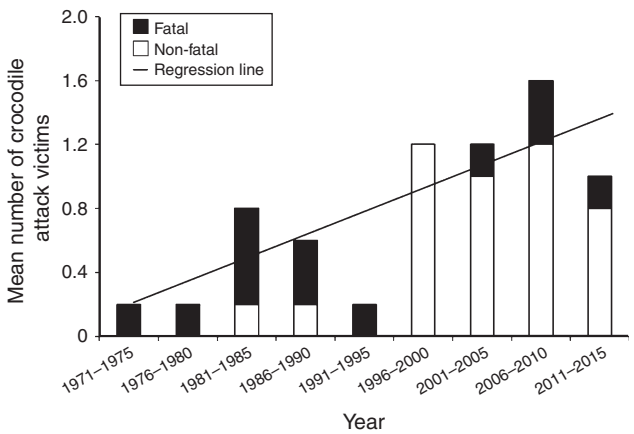

Fig. 4. Mean number of crocodile attacks (fatal and non-fatal) recorded in Queensland (1971–2015). Attacks are grouped into 5-year intervals. Regression line refers to all attacks.

A mean of 19.6 ± 2.3 s.e. crocodiles have been captured per year but this has been highly variable, fluctuating between one per year (1993) up to 57 per year (2014; Fig. 7). However, capture rates did not differ significantly among years ($F_{30,115} = 0.87$; $P = 0.65$).

The mean number of crocodiles removed and relocated did not differ significantly across months of the year ($F_{11,325} = 0.84$; $P = 0.60$), but the highest numbers were recorded between November–January (breeding or wet season), when mean air temperatures were warmer, with fewer captures in July and August (non-breeding or dry season) (Fig. 5*c*).

Of the total number of crocodiles captured ($n = 608$), sex was determined for 455 individuals (74.8%), with a significantly ($\chi^2 = 20.12$; $P = 0.043$) higher proportion of males captured (75.6%). However, the percentage of crocodiles for which sex was determined has declined over time from 95.3% (1985–2003) to 50% (2004–15). The mean size of males captured (mean 2948.6 ± 46.94 mm TL; range 890–4800 mm TL; $n = 344$) was significantly larger than for females captured (mean 2124.1 ± 53.51 mm TL; range 310–3400 mm TL; $n = 111$; $F_{1,362} = 48.71$; $P < 0.0001$). Of the crocodiles captured, 32.6% of females were of breeding size (>2.3 m) (Webb and Manolis 1989), 39.2% of males were of breeding size (>3.3 m; Webb and Manolis 1989) and only 13.1% were >4 m in length.

Discussion

Most recorded estuarine crocodile attacks, sightings and captures for management purposes have occurred on the populated east coast of Queensland between Townsville and

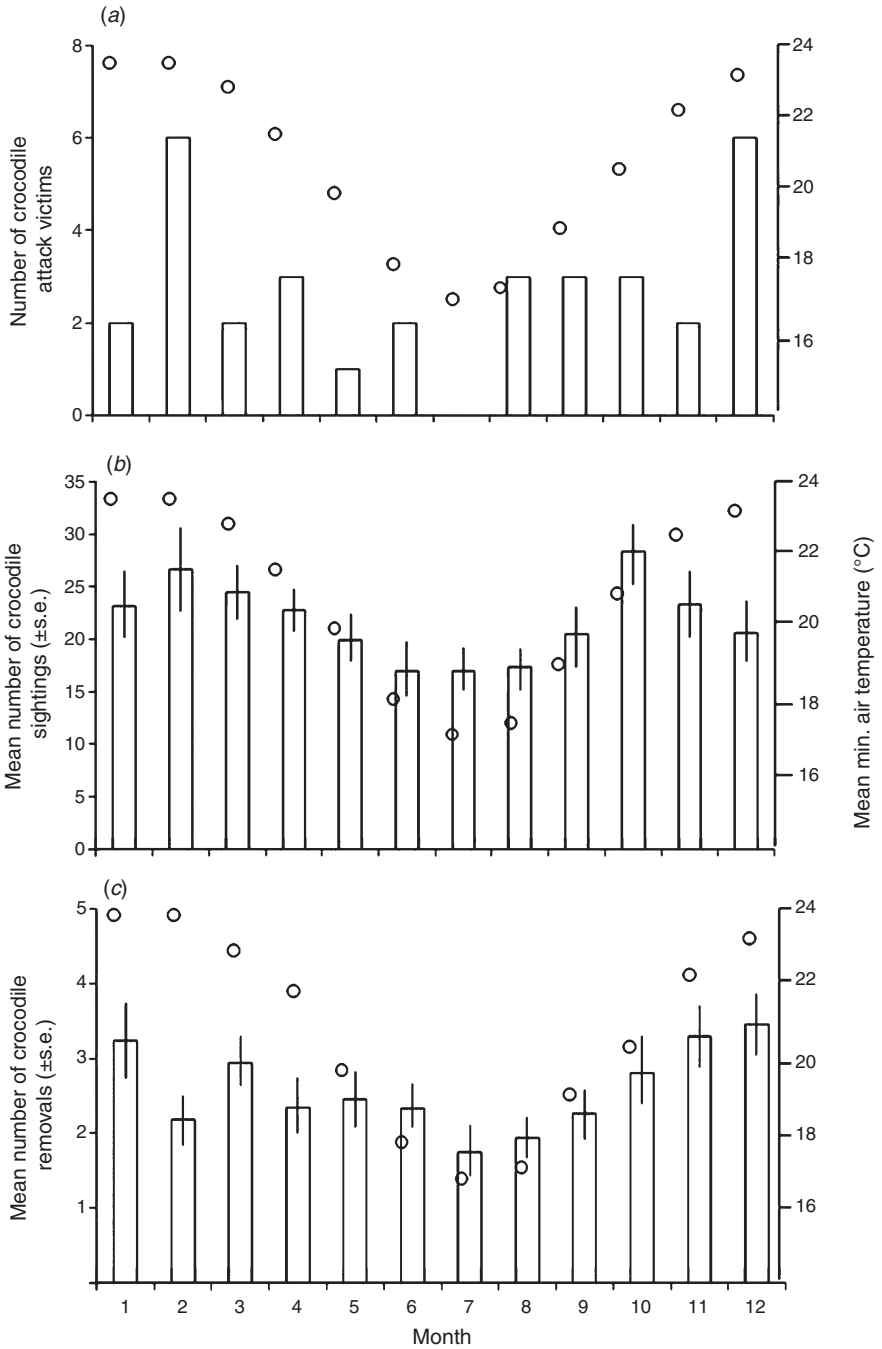

Fig. 5. Recorded estuarine crocodile attacks, sightings and removals and relocations throughout the year in Queensland. Monthly estuarine crocodile (*a*) attacks (1971–2015), (*b*) mean sightings (±s.e.; 2003–15) and (*c*) mean captures (±s.e.; 1985–2015) in Queensland compared with mean minimum air temperature for Cairns, Queensland (Bureau of Meteorology 2016).

the Port Douglas area. These locations have large human populations (e.g. Cairns: 160 285; Queensland Government Statisticians Office 2016) in the middle of known crocodile habitat, which is why management efforts have been focused in these areas. In Florida (USA), a similar situation exists where the highest number of complaints and bites from American alligators (*Alligator mississippiensis*) occurs in areas where the highest human populations exist (Woodward *et al*. 2014).

The highest number of recorded estuarine crocodile attacks, sightings and captures occurred during the summer wet season (November–February), which also corresponds with the breeding season for estuarine crocodiles (Webb *et al*. 1977; Webb and Manolis 1989). During summer months, ambient temperatures

are warmer, water levels are higher and individuals are dispersing out onto flood plains hunting prey (Webb *et al.* 1977; Webb and Manolis 1989). It is also a time when adults tend to be more mobile in pursuit of breeding partners, and can also become more aggressive, especially females in defence of a nest or young (Webb and Manolis 1989). During the summer wet season, people are coincidentally frequenting waterways for the purposes of cooling off, or for other recreational activities such as boating and fishing, bringing them into closer proximity with crocodiles.

In Florida, alligator attacks also increase during the warmer summer months when recreational water use is highest (Woodward *et al.* 2014), while alligator complaints and removals in Louisiana (USA) also peak during spring–summer and decline considerably in winter (Hines and Woodward 1980; Boundy 2004). In South Africa and Swaziland, 90% of attacks by Nile crocodiles have also occurred during the summer breeding season (1949–2014; Pooley 2014). In the Northern Territory the pattern is slightly different, with most crocodiles captured and removed during the beginning (September–December) and end (March–April) of the wet season, which is also when most attacks occur (Fukuda et al. 2014).

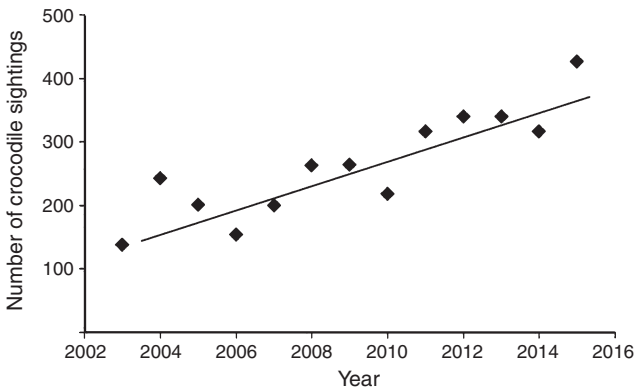

Fig. 6. Estuarine crocodile sightings reported to the government each year (2003–15).

There have been 35 crocodile attacks recorded in Queensland since 1971 (0.8 per year), with 34.3% fatal (0.3 per year) and the mean size of crocodiles responsible for fatal attacks (4.1 m) larger than that for non-fatal (2.5 m). This proportion of fatalities is consistent with what has been reported for *C. porosus* throughout the rest of Australia, but much lower than has been reported between 2007–14 in Timor-Leste (83% fatal), Papua New Guinea (76% fatal) and Solomon Islands (73% fatal; Manolis and Webb 2014). While this could be a consequence of higher water use for essential daily activities (e.g. washing), putting human residents at greater risk, it could also be that non-fatal attacks are under-reported or undocumented in these countries (Manolis and Webb 2014).

Most attacks in Queensland have involved local people or people from north Queensland who regularly visited the area (77.1%), specifically adult men (mean age 44), and almost all occurred in the water or on the edge (88.6%). Local adult men have also been the most common victims of estuarine crocodile attacks recorded in the Northern Territory (Fukuda *et al.* 2014), and of alligator bites in Florida (81.8%) (Woodward *et al.* 2014). The predominance of local adult male victims in Australia and the USA is likely related to higher recreational water use and risk-taking behaviour. Males also account for the highest number of drownings in Australia each year (~80%), mostly between the ages of 18–54 (Royal Life Saving Society Australia 2014). In contrast, the most common victim of Nile crocodile (*C. niloticus*) attacks in South Africa and Swaziland have been children and teens <20 years old (1949–2014; Pooley 2014).

There has been an increase in the rate of crocodile attacks recorded in Queensland over time, with an average of 1.3 per year since 1996, most of which were non-fatal (84%). In the Northern Territory, the rate of attacks has also increased over time, particularly non-fatal cases (1971–2013: 18 fatal and 45 non-fatal) with an average of 1.5 per year (Fukuda *et al.* 2014). This increase in the Northern Territory has been related

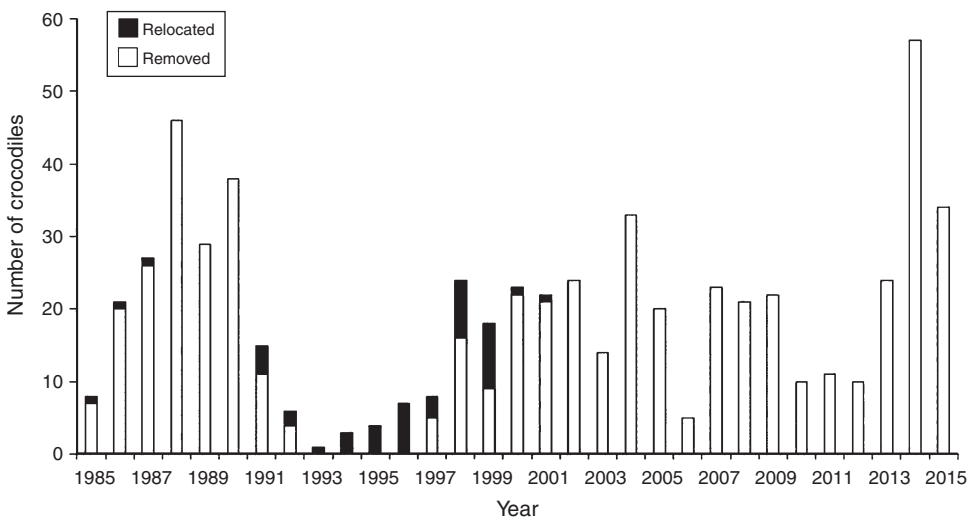

Fig. 7. Number of crocodiles removed (captured, euthanised) and relocated each year by the government (1985–2015).

to the increasing crocodile and human populations, and to the size of individual crocodiles capable of attack (Fukuda *et al*. 2014).

In Queensland, while crocodile numbers are lower and the rate of recovery slower than in the Northern Territory, the human population is considerably larger and steadily increasing, with human populations in the two largest cities in northern Queensland (Townsville: 193 946; Cairns: 160 285) increasing by 25% between 2005 and 2015 (Queensland Government Statisticians Office 2016). People in both Queensland and the Northern Territory are also increasingly able to access remote areas for the purposes of recreation. Increases in the human population, recreational water use and access to remote areas have also been attributed to the recent increase in non-fatal shark attacks in Australia (1990–2000: 6.5 per year; 2001–11: 15 per year; West 2011).

It is important to put the number of deaths by crocodiles in Australia each year into perspective. Most recorded crocodile attacks have occurred in the Northern Territory (63%), followed by Queensland (24%) and Western Australia (13%), with a national increase in non-fatal cases from 0.1 per year (1971–1980) to 3.3 per year (2001–04) but no increase in fatal cases, which have remained at 0.5 per year (Caldicott *et al*. 2005). This is relatively low when compared with the number of shark attacks in Australia per year (15 per year; 1.1 per year fatal: 2001–10) (West 2011) and the number of deaths through beach drownings in Australia each year (48 per year nationally; nine per year in Queensland: 2003–13; Royal Life Saving Society Australia 2014). Regardless, fear of being eaten tends to drive public concerns and attitudes towards species such as crocodiles.

Confirmed sightings of estuarine crocodiles have been reported as far south as the Mary River near Hervey Bay on the east coast and as early as the 1990s, with unconfirmed sightings further south in the Great Sandy Strait down to Tin Can Bay (~50 km south). This area represents the southern extent for the species, with historical records indicating crocodiles have always been present here but in low numbers, probably due to climate constraints.

The presence of large estuarine crocodiles (2–4 m) in upper freshwater sections of rivers (up to 470 m above sea level) along the north-east coast and on or near offshore islands, where there have been six recorded attacks, is of particular concern for management. These areas are considered marginal habitat for crocodiles, but are commonly used by people for swimming and other water-based recreational activities, some of whom may be unaware that estuarine crocodiles can be present.

While upstream movements by estuarine crocodiles have been linked to social pressure from an increasing crocodile population in the Northern Territory (Letnic and Connors 2006), the population of estuarine crocodiles along the east coast of Queensland remains low. Therefore, it is unclear why some individuals venture this far upstream in Queensland (up to 470 m above sea level) as it requires significant energy expenditure to navigate the shallow, rocky and steep sections of river, temperatures are cooler, food is limited and the clear water can hinder hunting success. Estuarine crocodiles in the Northern Territory have only been reported up to 126 m above sea level (Letnic and Connors 2006).

The increase in crocodile sightings in Queensland over time may indicate an increase in either human or crocodile populations, or both. However, the situation is complicated by several factors: improved reporting and data management by the government; the location of the sighting; whether it is a public place; the size of the crocodile reported; and the level and type of media coverage. Sightings cannot, therefore, be considered a good indicator of population size or change, and as a consequence, it is not possible to draw any conclusions as to whether there has been a change in crocodile numbers across the state, whether more crocodiles are occurring on offshore islands, or if the population is increasing or expanding further south.

In total, 562 estuarine crocodiles have been removed (captured, euthanised) from Queensland waterways for management purposes since 1985, most coming from the populated east coast. This is a relatively low number of crocodiles removed each year (18 per year), which appears to have been easily compensated by recruitment in most areas. In comparison, 5792 estuarine crocodiles were removed from the Northern Territory between 1977 and 2013 (Fukuda *et al*. 2014), ~161 per year, with most removed from Darwin Harbour. This difference reflects the larger crocodile population in the Northern Territory, which is considered to be at or above carrying capacity (Fukuda *et al*. 2014).

The majority of Queensland crocodiles removed between 1985 and 2015 were male (75.6%), and most of these were less than breeding size (<3.3 m: 60.8%) with only 13.1% larger than 4 m. Similarly, in the Northern Territory, 69% of problem estuarine crocodiles removed were male (1977–2013; Fukuda *et al*. 2014), and in the USA, ~75% of problem *A. mississippiensis* removals and attacks involved males (King and Elsey 2014; Woodward *et al*. 2014). Subadult male crocodilians are often nomadic, highly mobile (Tucker *et al*. 1998; Campbell *et al*. 2013) and more likely to come into conflict with people. As female crocodilians are known to mate with multiple partners and store sperm (Lewis *et al*. 2013), the removal of subadult males is unlikely to be a significant threat to the overall breeding potential of most crocodilian populations.

The aim of any management program involving estuarine crocodiles is to strike a balance between conservation and management. The overall purpose is to minimise the chance of human–crocodile conflict while not negatively impacting upon the crocodile population as a whole. This is achieved by reducing the number of crocodiles in and around areas where there are high human populations, while at the same time preserving crocodile numbers in sparsely populated remote areas, coupled with public education. The current program in Queensland largely achieves this goal.

Conflicts of interest

The authors declare no conflicts of interest.

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References

Boundy, J. (2004). Louisiana Department of Wildlife and Fisheries Report. p. 15. Louisiana Nuisance Alligator Program, Department of Wildlife and Fisheries, Baton Rouge, LA.

Brien, M. L., Lang, J. W., Webb, G. J., Stevenson, C., and Christian, K. A. (2013*a*). The good, the bad, and the ugly: agonistic behaviour in juvenile crocodilians. *PLoS One* **8**, doi:10.1371/journal.pone.0080872

Brien, M. L., Webb, G. J., Lang, J. W., and Christian, K. A. (2013*b*). Intra- and interspecific agonistic behaviour in hatchling Australian freshwater crocodiles (*Crocodylus johnstoni*) and saltwater crocodiles (*Crocodylus porosus*). *Australian Journal of Zoology* **61**, 196–205. doi:10.1071/ZO13035

Bureau of Meteorology (2016). Climate statistics for Australian locations. Cairns AERO station 031011; 16.87S; 145.75E. Commonwealth of Australia. Available at http://www.bom.gov.au/climate/averages/tables/cw_031011.shtml [verified 12 September 2015].

Caldicott, D. G., Croser, D., Manolis, C., Webb, G., and Britton, A. (2005). Crocodile attack in Australia: an analysis of its incidence and review of the pathology and management of crocodilian attacks in general. *Wilderness & Environmental Medicine* **16**, 143–159. doi:10.1580/1080-6032(2005)16[143:CAIAAA]2.0.CO;2

Campbell, H. A., Dwyer, R. G., Irwin, T. R., and Franklin, C. E. (2013). Home range utilisation and long-range movement of estuarine crocodiles during the breeding and nesting season. *PLoS One* **8**, doi:10.1371/journal.pone.0062127

Fukuda, Y., Whitehead, P., and Boggs, G. (2007). Broad-scale environmental influences on the abundance of saltwater crocodiles (*Crocodylus porosus*) in Australia. *Wildlife Research* **34**, 167–176. doi:10.1071/WR06110

Fukuda, Y., Manolis, C., and Appel, K. (2014). Management of human–crocodile conflict in the Northern Territory, Australia: review of crocodile attacks and removal of problem crocodiles. *The Journal of Wildlife Management* **78**, 1239–1249. doi:10.1002/jwmg.767

Hines, T. C., and Woodward, A. R. (1980). Nuisance alligator control in Florida. *Wildlife Society Bulletin* **8**, 234–241.

Kay, W. R. (2004). Movements and home ranges of radio-tracked *Crocodylus porosus* in the Cambridge Gulf region of Western Australia. *Wildlife Research* **31**, 495–508. doi:10.1071/WR04037

King, R., and Elsey, R. (2014). Louisiana's nuisance alligator program. In 'Proceedings of the 23rd Working Meeting of the Crocodile Specialist Group', Louisiana, USA, 26–30 May 2014. pp. 163–181. (IUCN – The World Conservation Union: Gland, Switzerland.)

Kofron, C. P. (2004). The trial intensive management area for crocodiles: a crocodile removal zone in Queensland, Australia. *Coastal Management* **32**, 319–330. doi:10.1080/08920750490448424

Kofron, C. P., and Smith, R. (2001). Status of estuarine crocodiles in the populated coast of north-east Queensland. *Memoirs of the Queensland Museum* **46**, 603–610.

Lang, J. W. (1987). Crocodilian behaviour: implications for management. In 'Wildlife Management: Crocodiles and Alligators'. (Eds G. J. W. Webb, S. C. Manolis and P. J. Whitehead.) pp. 273–294. (Surrey Beatty and Sons: Sydney.)

Letnic, M., and Connors, G. (2006). Changes in the distribution and abundance of saltwater crocodiles (*Crocodylus porosus*) in the upstream, freshwater reaches of rivers in the Northern Territory, Australia. *Wildlife Research* **33**, 529–538. doi:10.1071/WR05090

Lewis, J. L., FitzSimmons, N. N., Jamerlan, M. L., Buchan, J. C., and Grigg, G. C. (2013). Mating systems and multiple paternity in the estuarine crocodile (*Crocodylus porosus*). *Journal of Herpetology* **47**, 24–33. doi:10.1670/10-303

Manolis, S. C., and Webb, G. J. (2014). Human–crocodile conflict in the Australia and Oceania region. In 'Proceedings of the 23rd Working Meeting of the Crocodile Specialist Group', Louisiana, USA, 26–30 May 2014. pp. 200–208. (IUCN – The World Conservation Union: Gland, Switzerland.)

Messel, H., Vorlicek, G. C., Wells, A. G., and Green, W. J. (1981). Surveys of tidal river systems in the Northern Territory of Australia and their crocodile populations. Monograph 1. (Pergamon Press: Sydney.)

Miller, J. D., and Bell, I. P. (1997). Crocodiles in the Great Barrier Reef World Heritage area. In 'State of the Great Barrier Reef World Heritage Area. Workshop Series 23'. pp. 248–255. (Queensland Department of Environment, Townsville, Queensland, Australia).

Pooley, S. (2014). An historical overview of human crocodile conflict in South Africa and Swaziland, 1949–2014. In 'Proceedings of the 23rd Working Meeting of the Crocodile Specialist Group', Louisiana, USA, 26–30 May 2014. pp. 236–245. (IUCN – The World Conservation Union: Gland, Switzerland.)

Read, M. A., Miller, J. D., Bell, I. P., and Felton, A. (2004). The distribution and abundance of the estuarine crocodile, *Crocodylus porosus*, in Queensland. *Wildlife Research* **31**, 527–534. doi:10.1071/WR02025

Read, M. A., Grigg, G. C., Irwin, S. R., Shanahan, D., and Franklin, C. E. (2007). Satellite tracking reveals long distance coastal travel and homing by translocated estuarine crocodiles, *Crocodylus porosus*. *PLoS One* **2**, doi:10.1371/journal.pone.0000949

Royal Life Saving Society Australia (2014). Royal Life Saving National Drowning Report. Available at http://www.mq.edu.au/__data/assets/pdf_file/0014/120074/RLS-National-Drowning-Report-2015.pdf [accessed 12 September 2016].

Taplin, L. E. (1987). The management of crocodiles in Queensland, Australia. In 'Wildlife Management: Crocodiles and Alligators'. (Eds G. J. W. Webb, S. C. Manolis and P. J. Whitehead.) pp. 129–140. (Surrey Beatty and Sons: Sydney.)

Tucker, A. D., McCallum, H. I., Limpus, C. J., and McDonald, K. R. (1998). Sex-biased dispersal in a long-lived polygynous reptile (*Crocodylus johnstoni*). *Behavioral Ecology and Sociobiology* **44**, 85–90. doi:10.1007/s002650050519

Walsh, B., and Whitehead, P. J. (1993). Problem crocodiles, *Crocodylus porosus*, at Nhulunbuy, Northern Territory: an assessment of relocation as a management strategy. *Wildlife Research* **20**, 127–135. doi:10.1071/WR9930127

Webb, G., and Manolis, S. C. (1989). 'Crocodiles of Australia.' (Reed Books: Sydney.)

Webb, G. J. W., Messel, H., and Magnusson, W. E. (1977). The nesting biology of *Crocodylus porosus* in Arnhem Land, northern Australia. *Copeia* **1977**, 238–249. doi:10.2307/1443905

Webb, G. J., Manolis, S. C., and Brien, M. L. (2010). Saltwater crocodile, *Crocodylus porosus*. In 'Status Survey and Conservation Action Plan', 3rd edn. pp. 99–113. (Eds S. C. Manolis and C. Stevenson.) (Crocodile Specialist Group: Darwin.)

West, J. G. (2011). Changing patterns of shark attacks in Australian waters. *Marine and Freshwater Research* **62**, 744–754. doi:10.1071/MF10181

Woodward, A. R., Leone, E. H., Dutton, H. J., Hord, L., and Waller, J. E. (2014). Human alligator conflict in Florida. In 'Proceedings of the 23rd Working Meeting of the Crocodile Specialist Group', Louisiana, USA, 26–30 May 2014. pp. 182–199. (IUCN – The World Conservation Union: Gland, Switzerland.)