Survey of a Pristine Population of Freshwater Crocodiles in the Liverpool River, Arnhem Land, Australia

Grant Recipient: Grahame J. W. Webb, School of Zoology, University of New South Wales, Kensington, New South Wales, Australia.

Grant 2052: For helicopter transportation to remote areas along the Liverpool River, Arnhem Land, Australia, to conduct night surveys of a pristine population of freshwater crocodiles.

Crocodiles are being studied throughout the world. Most populations under study have been hunted in the past and are in a recovery phase. Populations that have never been hunted, and may reflect the pristine condition, are certainly rare, if they exist at all.

In the upper reaches of the Liverpool River, Arnhem Land, Australia, the populations of *Crocodylus johnstoni* are probably as close to pristine as those anywhere in Australia and possibly anywhere in the world. The area has been essentially uninhabited for some 30 years. Tribal aboriginals used part of the area during the dry seasons (from May to November) prior to 1950, but even they rarely ventured into the very upper reaches, upstream of Cuthbertson Falls (Figure 1).

The broad aims of this study were to determine the general habitat types of *C. johnstoni,* the relative density of crocodiles by spotlight counting, the size distribution of individuals, and the upper limit of *C. porosus* penetration, their distribution downstream already being known (Messel et al., 1979).

The major finding of the expedition was that the crocodiles in the upper reaches of the Liverpool River are stunted. This finding has a number of important ramifications, which are discussed in detail.

Location of Study Areas

The Liverpool River has its headwaters in the Arnhem Land plateau (lat. 133° 41′E, long. 12° 58′S) and runs some 180 km north to the sea (Figure 1). The course of the river from its mouth (134° 14′E, 11° 51′S) to 70 km

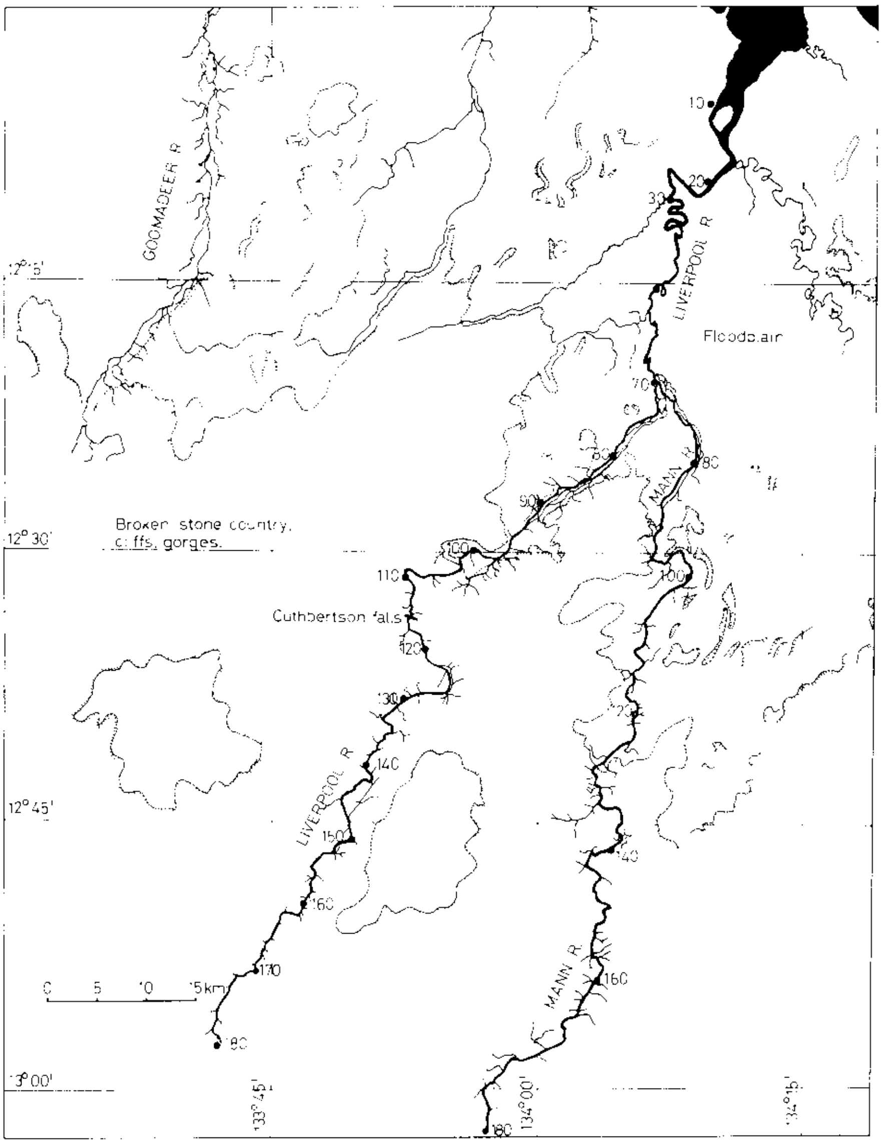

FIGURE 1. Liverpool and Mann Rivers. Numbers indicate river-kilometers from the mouth.

upstream (134° 7'E, 12° 21'S) is highly sinuous, meandering over a floodplain. The banks are muddy and lined with mangroves; the water is turbid, saline, and influenced by tides. This area contains only *C. porosus* (Messel et al., 1979; Webb, pers. obs.).

Beginning 70 km upstream there are a variety of habitats, with substrates of sand and rock and fresh, clear water.

The Liverpool River has two waterfalls, both approximately 20 m high, Cuthbertson Falls (115 km upstream at 133° 53'E, 12° 34'S) and Havelock Falls (135 km upstream at 133° 52'E, 12° 40'S). In this area *C. johnstoni* are found.

The headwaters of the Mann River (133° 21'E, 13° 23'S) are some 275 river-km from the sea. The Mann merges with the Liverpool River 70 km from the sea (134° 14'E, 11° 51'S; Figure 1), and does not have steep waterfalls. The headwaters of the East Alligator River (133° 5'E, 13° 18'S) are close to those of the Mann River, some 225 km from the sea (132° 35'E, 12° 8'S); tidal influence extends for about 85 km.

Methods

Surveys

Survey areas were reached by means of a Bell 206 helicopter. The surveys themselves were conducted from inflatable 3.7- and 5.2-m canoes (Metzler), using "Big Jim" hand lanterns (Eveready). When located, crocodiles were approached and their size estimated in 30-cm units of total length. Accuracy of the method was checked by catching and measuring crocodiles whose size had been previously estimated.

Navigation

The Australian 1:100,000 Topographic Survey Sheets were used for all navigation. Specific survey sections or points are referred to using the Universal Grid Reference, in which two letters refer to the 100,000 square in which a point lies, the next three numbers to the vertical lines and the last three to the horizontal lines. For convenience, each reference in this report is prefixed by the map sheet number, e.g., "5672-LF562889." Distances upstream were determined with a "Sukurai" map measurer.

Results

Habitats

The locations of areas surveyed are listed in Table 1, and general habitat descriptions of these areas are given in Table 2. On the basis of substrate type, pool size, and edge vegetation the following broad habitat types were recognized, although intermediates were also common.

TABLE 1. Locations of Survey Areas

Survey Area	Distance Upstream (km)*	Latitude; Longitude*	Downstream Limit†	Upstream Limit†	Survey Date (1979)
Liverpool River					
1	90	134°00′E; 12°28′S	5773 – LG 916217	5773 – LG 919222	11 Oct.
2	92	133°59′E; 12°29′S	5673 – LG 907210	5673 – LG 893197	10 Oct.
3	96	133°58′E; 12°30′S	5672 – LG 880174	5672 – LG 874169	10 Oct.
4	105	133°55′E; 12°32′S	5672 – LG 825153	5672 – LG 801152	7 Oct.
5	107	133°53′E; 12°32′S	5672 – LG 799149	5672 – LG 789151	2 Oct.
6	109	133°53′E; 12°32′S	5672 – LG 789151	5672 – LG 784135	2 Oct.
		(Cuthbertson Falls)			
7	123	133°55′E; 12°37′S	5672 – LG 798066	5672 – LG 823048	3 Oct.
8	139	133°51′E; 12°42′S	5672 – LF 752981	5672 – LF 729938	4 Oct.
9	148	133°49′E; 12°45′S	5672 – LF 721891	5672 – LF 720900	5 Oct.
10	153	133°48′E; 12°47′S	5672 – LF 708868	5672 – LF 697867	5 Oct.
11	172	133°44′E; 12°54′S	5672 – LF 616743	5672 – LF 605737	4 Oct.
Mann River					
12	140	134°04′E; 12°46′S	5772 – LF 999885	5772 – LF 976868	17 Oct.
13	183	133°58′E; 13°02′S	5671 – LF 874603	5671 – LF 888581	16 Oct.
East Alligator River					
14	164	133°25′E; 12°53′S	5572 – LF 278760	5572 – LF 277749	18 Oct.

* *Designations refer to midpoint of survey area.*
† *Map references refer to Australian 1:100,000 Topographic Survey Sheets.*

1. Sandy, broad (>100 m) riverbed divided into channels (from two to four). *Pandanus* and *Melaleuca* are common. Most channels are dry by October.
2. Long (0.5- to 2-km) discrete pools or billabongs within Type 1 habitats, with no rock.
3. Like Type 2, except the ends of pools consist of rocky rapids, shelves of rock (as in Type 5), or banks of boulders.
4. Areas of mainstream river similar to those of Type 3, except pools are surrounded by rock shelves, cliffs, or banks of rubble.
5. Shallow (<2 m) exposed pools, seldom more than 100 m long, on rock shelves and separated by rapids and boulders.

Surveys of Crocodile Densities

Surveys were restricted to bodies of water where canoes could be paddled and to areas where the bank could be walked (Types 2 to 5). Survey results are summarized in Table 3.

TABLE 2. Habitats in Specific Survey Areas

Survey Area	Distance Upstream (km)	Description*
Liverpool River		
1	90	Single main pool with numerous small isolated pools. Heavy *Pandanus* cover. No rock. "Mundakardi." (2)
2	92	Single main pool with four side pools. Heavy *Pandanus* cover with areas of white sand. No rock. "Djarbell." (2)
3	96	Single main pool with smaller pool downstream. Heavy *Pandanus* cover. Some rock on the edges. "Lotlollman." (2)
4	105	Single main pool with rocky rapids at the downstream end. Banks sandy with *Pandanus* and *Melaleuca*. Upstream merges into heavy *Pandanus*. "Gorerarlling." (3)
5	107	Single main pool. Heavy *Pandanus* at downstream end and rocks, rapids, and cliffs at upstream end. Banks are rock or sand with *Pandanus* and *Melaleuca*. "Gorerarlling." (3)
6	109	Large rocky pools separated by rapids within steep gorges. Little edge vegetation. Patches of white sand. "Djereyeyeh." (4, 5)
7	123	Pools separated by rock bars and rapids. Banks mostly sandy with heavy *Pandanus* cover in front of *Melaleuca*. Steep cliffs to the sides of the mainstream. (3, 5)
8	139	Like areas 6 and 7 above. (3, 4, 5)
9	148	Single pool with extremely heavy *Pandanus* edge cover. No rock. (2)
10	153	Rock and waterfall at upstream end and major pool with sandy banks and *Pandanus* downstream. (3)
11	172	Rock and sand at upstream end, with little vegetation. Downstream areas sandy, with isolated pools. Much *Melaleuca* debris blocking stream bed. (3)
Mann River		
12	140	Like Area 6. One pool with *Pandanus* and *Melaleuca* on sandy bank. (4, 5)
13	183	Like Area 7, but without dense *Pandanus* and *Melaleuca* vegetation at edge. Many buffalo in this area. (3, 5)
East Alligator River		
14	164	Like Area 6. (4, 5)

**Names in quotes are aboriginal. Numbers in parentheses refer to habitat type as discussed in the text.*

In the Liverpool River downstream of Cuthbertson Falls, crocodile densities ranged from 3.0 to 7.0 individuals/km, with a mean value of 4.6±1.8. Upstream of the falls, densities ranged from 5.6 to 13.3, with a mean of 9.2±3.2. These densities were significantly different at the 5% level (with nonoverlap of two SEs). In the Liverpool River, crocodiles were more dense upstream than downstream of Cuthbertson Falls.

TABLE 3. Number and Size of Crocodiles in Survey Areas

Survey Area	Upstream River (km)	Distance Surveyed (km)	No. Crocodiles Sighted	Population Size Index*	Density (Crocodiles /km)
Liverpool River					
1	90	0.6	4	na†	6.7
2	92	2.9	9	1:2	3.1
3	96	1.0	3	na†	3.0
4	105	1.9	7	1:1	3.7‡
5	107	1.0	7	3:4	7.0
6	109	4.0	16	7:6	4.0
		(Cuthbertson Falls)			
7	123	3.9	51	38:0	12.9
8	139	6.6	45	11:3	6.8
9	148	0.9	5	5:0	5.6
10	153	1.4	17	17:0	12.1
11	172	1.8	15	15:0	8.3
Mann River					
12	140	3.1	24	18:2	7.7
13	183	3.6	50	30:7	13.9
East Alligator River					
14	164	2.0	14	11:1	7.0
Totals	—	34.7	267	157:26	7.3±3.5 (SD)

**Ratio of crocodiles less than 120 cm long to number greater than 120 cm long.*
†Not applicable. Only one animal sighted whose size could be estimated.
‡This area was burning at the time of survey and crocodiles sighted were away from the edges, whereas under normal conditions they might have been hidden by tree roots, etc.

In the Mann and East Alligator Rivers (Table 3), *C. johnstoni* were found in similar densities as in the Liverpool River. In the Mann River, density was lower downstream than it was upstream. With only two areas surveyed, however, no significance is attached to this finding.

The mean crocodile density for all areas was 7.3±3.5 individuals/km. The mean value taking into account total survey distance (total crocodiles sighted/total distance surveyed, or 268 individuals/34.7 km) is 7.7 individuals/km.

The only obvious association between density and habitat type was the tendency of Type 2 and Type 3 habitats to have lower densities (Tables 2 and 3). This is thought to reflect the downstream locations of Type 2 habitats.

Behavioral Observations

Most crocodiles were not wary. During the surveys, they could be approached to within 1 to 2 m before they dived or swam off, although approach distance (see Webb and Messel, 1979) was not formally measured. Crocodiles often displayed to the survey canoes, typically with an "inflated posture" or "head emergent tail arch posture" (Garrick and Lang, 1977), both often accompanied by a loud grunting sound. Crocodiles approaching the canoes while displaying and grunting on occasion collided with them before diving. It was common for crocodiles to vocalize in response to any loud noise. For example, in reply to the report of a .22-caliber revolver on the Mann River, six *C. johnstoni* vocalized for a few seconds.

Estimating Crocodile Size

Capture and measurement of a small number of individuals after their length had been estimated gave an indication of the magnitude of error of size estimates made during the surveys. A crocodile estimated at 60 cm actually measured 84 cm; one at 90 cm, measured 99 cm; six at 120 cm, from 100 to 122 cm (with a mean of 111 cm), and two at 150 cm, 142 and 171 cm.

The number of crocodiles we estimated to be longer than 120 cm compared to the number equal to or shorter than 120 cm was assumed to be an index of population size structure. This proportion did not vary significantly for the three river systems. Within the Liverpool River system, however, there was a striking difference in the sizes of crocodiles upstream and downstream of Cuthbertson Falls. Upstream of the falls, 3% ($n = 89$) were estimated to be longer than 120 cm, whereas downstream of the falls 48% were ($n = 27$). The difference in these proportions is highly significant (Fisher's test; $P = 0.001$), and thus the Liverpool River populations are heterogeneous with regard to size structure.

Further comparison indicated that downstream of Cuthbertson Falls there was a significantly higher proportion of *C. johnstoni* greater than 120 cm than in either the Mann ($P = 0.002$) or East Alligator Rivers ($P = 0.014$). The proportion of *C. johnstoni* greater than 120 cm in the upstream Liverpool River was significantly lower than that in the Mann River ($P = 0.008$) but was not significantly different from that in the East Alligator River.

The apparent homogeneity of populations in the East Alligator and upper Liverpool Rivers could in part reflect disparity in sample sizes.

C. johnstoni Upstream of Cuthbertson Falls

In the McKinlay River region, outside Arnhem Land, *C. johnstoni* females reach maturity at about 1.5 m TL (8 to 10 kg) and attain a maximum

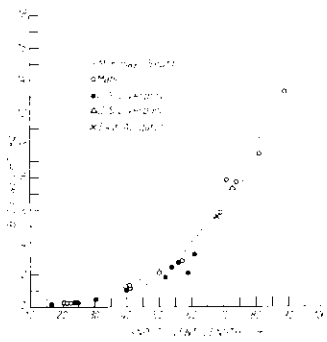

FIGURE 2. Comparison of the length-to-weight relations of *C. johnstoni* in different rivers. U/S = upstream; D/S = downstream.

size of about 2 m (35 kg); males mature at 1.6 to 2 m (12 to 20 kg) and attain a maximum size of about 2.5 m (60 kg) (Webb et al., 1983). *C. johnstoni* downstream of Cuthbertson Falls are thus of similar size, but not those upstream of the falls. Upstream, 97% of the crocodiles sighted were smaller than the size at which maturity is reached in the McKinlay River.

A sample of 10 *C. johnstoni* was collected from a pool upstream of Cuthbertson Falls (121 km upstream; Figure 2), including examples of the biggest crocodiles seen. This sample was composed of 2 males (62 and 118 cm) and 8 females (36, 51, 52, 81, 100, 107, 108, and 112 cm).

The three largest females had wide oviducts and their ovaries contained corpus lutea; they were mature. Histological examination of the gonads of the large male (112 cm) indicated that both testes were degenerated.

A striking feature of the upstream sample was that the larger animals were in poor condition (see Figure 2). The large male and the 100- and 107-cm females were very thin, and the largest female (112 cm) was extremely emaciated. At least one more extremely emaciated crocodile was seen but not caught.

The emaciated female had worn and eroded scutes on the back, an indistinct scute pattern on the snout, and a striking yellow eye. In the McKinlay River, these features, when combined with maximal size, are interpreted as indicating old age (Webb et al., 1983).

UPSTREAM LIMIT OF *C. POROSUS*

During the surveys, no crocodiles were positively identified as *C. porosus*, although at survey Areas 2 and 3, the tracks of *C. porosus* (crocodiles approximately 3.5, 4.0, and 3.5 m long) were present. These areas were 92 and 96 km from the sea, 22 to 24 km upstream of tidal influence. Tracks indicated three *C. porosus* of adult size in 3.9 km, approximately 0.8 individuals/km. The large rock shelves 100 km upstream may act as a barrier to this crocodile's upstream movement.

Discussion

The habitats of *C. johnstoni* in the present study are widespread in northern Australia. The mean relative density value we obtained, 7.3± 3.5 crocodiles/km (with a range of 3.0 to 13.9 crocodiles/km), can probably be used as a first estimate of densities in these similar habitats.

The mean density value is lowered (Table 3) by the low densities measured in some Liverpool River survey areas, especially in those downstream of the first rock bars. If the data from these surveys (of Areas 1, 2, and 3) are left out of the analysis, along with that from the survey of Area 4 because of its disturbance by fire (Table 3), mean density becomes 8.5±3.3 (n = 10), which is applicable to areas where a river is passing through a sandstone plateau, for example, at the headwaters of most northern rivers.

Crocodiles that have been disturbed by humans learn to dive on the approach of a boat (Bustard, 1968; Webb and Messel, 1979) and thus are not seen in surveys. Similarly, in swamps or areas where there are physical obstructions in the water (plants, logs, etc.), crocodiles' eyes may be shielded from the searchlight and missed in the survey. In the areas surveyed in this study, both these factors would seem to be reasonably constant, and the effect of edge cover was probably the same as in similar habitats outside Arnhem Land. The wariness of crocodiles, however, could be expected to vary markedly in areas outside Arnhem Land, depending on prior interactions of the crocodiles with humans (Webb and Messel, 1979). Thus, spotlight counts of areas within and outside Arnhem Land may not always be comparable.

A measure of absolute density is ideal for comparisons but is difficult to obtain. Data from the McKinlay River study allow a first estimate of the relationship between measures of absolute and relative densities in areas where wariness and edge cover have a negligible effect. In four billabongs, surveys had revealed 72% (n = 61), 79% (n = 14), 87% (n = 14), and 90% (n = 10) of those in the billabong; the average value was thus 82%.

Using these figures, absolute density in this study would be calculated at about 8.9±4.3 individuals/km for all habitats, and 10.4±4.0 individuals/km upstream of the first rocky bars; maximum absolute density would be about 17 individuals/km (in Area 13).

In the Liverpool River, Cuthbertson Falls appears to be a major geographic barrier. In the field, this barrier was particularly noticeable with regard to black bream *(Hephaestus fuliginosus)* and saratoga *(Scleropages leichardti)*: Both were common downstream, but nonexistent upstream. Midgley (1979) has commented on the major reduction in fish species above waterfalls in other Northern Territory rivers.

The small C. *johnstoni* may be more widespread in the Northern Territory, and perhaps in Western Australia. Two former crocodile hunters described the same small crocodile in the same type of habitat in the upper reaches of the Wilton and Limmen Bight Rivers; both described its having "paper-thin" skin without knowing our sample was so characterized. Storr and Smith (1975) describe a 95-cm C. *johnstoni* from the Prince Regent River that had six oviducal eggs. Unfortunately, there is uncertainty about the measurement of this specimen, and it may be longer; however, the eggs are 12% smaller than the smallest eggs from the McKinlay River, and the clutch size (six) is smaller than average (13.2±3.2; Webb et al., 1983).

Why the densities of C. *johnstoni* below Cuthbertson Falls were so low is far from clear. In some areas C. *porosus* were present, and they could be predators, but they themselves were observed in low numbers. One striking characteristic of the downstream Liverpool River waterways was the abundance of black bream *(H. fuliginosus)* and saratoga *(S. leichardti)*, which attacked any surface disturbance. Although not known to be predators of C. *johnstoni*, they could be attracted by hatchling movements. These fish do not occur above the falls.

The upstream limit of C. *porosus* seemed to be the start of the rocky country, and the rock itself may be a barrier. They were observed in very low densities, yet had been undisturbed for perhaps 30 years. C. *porosus* is known to have mound nests in the wet season (Webb et al., 1977). It seems likely that if nests were constructed in this area, they would be completely flooded during the wet season.

The stunted C. *johnstoni* upstream of Cuthbertson Falls were in poor condition. Lack of food may have been the factor responsible. The most important questions in this context are how long have the populations been separated, and how much have they diverged from one another? Could the small C. *johnstoni* physically mate successfully with the larger ones? These questions remain for future research.

One ramification of finding the small crocodiles is that one set of growth curves will obviously not be applicable to C. *johnstoni* in all habitats. Is this true for all crocodilians? Do growth curves reflect the "richness" of particular habitats?

Such variability is consistent with Graham's (1968) findings on the Lake Rudolph C. *niloticus* population. Three marked juveniles (78 to 88 cm) grew 0.4, 0.8, and 2.6 cm in eight to nine months, whereas animals of the same size raised in captivity grew 30 cm in a year. Clutch size, and common maximum size of this population in the field were less than those of C. *niloticus* from Uganda and Zambia (Cott, 1961). The percentage of empty stomachs found in the three populations (Lake Rudolph, 48.4%; Uganda and Zambia, 5.1% to 20.2%, depending on specimen length; Cott, 1961) indicated the Lake Rudolph habitat was energetically poor compared to the Ugandan and Zambian sites.

There appear to be few other records in the literature of "stunted" wild crocodiles, though the report of *Caiman crocodilus fuscus* maturing at 1.08 cm (Chirivi-Gallego, 1973; see Staton and Dixon, 1977) could reflect a similar situation.

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GRAHAME J. W. WEBB