CHAPTER 18

A Population Model for *Crocodylus porosus* in the Tidal Waterways of Northern Australia: Management Implications

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THE saltwater or estuarine crocodile *Crocodylus porosus*, reaches the southernmost limit of its range in Australia, where it is restricted to the coastal regions of the far north in Western Australia, the Northern Territory and Queensland (Cogger 1975). It occurs primarily in rivers as far upstream as tidal influence extends, but it is also found in swamps (freshwater and saline), billabongs, lakes and non-tidal rivers up to 150 km or more from the sea. As a consequence of very intense exploitation for skins during the 1950's and 1960's, the Australian population of *C. porosus* at the start of the 1970's was severely depleted (Bustard 1970; Messel, pers. obs.). A total import-export ban on crocodile skins and products, imposed by the Federal Government in 1972, effectively ended the exploitation, although this had already happened in many areas due to numbers being too low for economically viable hunting.

In 1971, the Crocodile Research Group of the University of Sydney commenced an extensive and long-term study of *C. porosus* in northern Australia. Published results to date address physiology, nesting, growth, movement, mortality and the population structure among other things. However, one of the most important aspects of the work was the development of a systematic spotlight surveying method. This enabled the numbers of *C. porosus* in some 100 tidal river and creek systems to be estimated, and allowed the changes in population size with time to be monitored during the period 1974 to 1984. This in turn has allowed an assessment of the species' "status" over much of the north Australian coastline.

The majority of results pertaining to the population aspect of the study have been published in a series of monographs (numbers 1-18; Messel *et al.* 1979-1984), which for convenience will be referred to here by their number rather than by author. Additional results are in Messel *et al.* (1977) and Burbidge and Messel (1979) (from Western Australia rivers), and the latest overview summaries are in Messel *et al.* (1984a) and Messel and Vorlicek (1985, 1986). The survey methods and the statistical basis for estimating absolute numbers from spotlight counts are in Monograph 1. Altogether, data have been obtained for 3998 km of tidal waterways in the Northern Territory, 527 km in Western Australia and 643 km in Queensland.

Fig. 1. A typical boat and crew used to survey *Crocodylus porosus* numbers across northern Australia.

The results of these surveys and of the various other studies that have been undertaken, have allowed a picture of the population dynamics of *C. porosus* in northern Australia to be developed (see particularly Monographs 1 and 18). It is this functional model that we describe in some detail here. It enables us to account in a consistent fashion for the results of surveys carried out to date and it allows us to predict with confidence an "expected" result of future surveys. In formulating the model, repeat surveys from two regions have been particularly significant:

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Pages 189-98 *in* WILDLIFE MANAGEMENT: CROCODILES AND ALLIGATORS ed by Grahame J. W. Webb, S. Charlie Manolis and Peter J. Whitehead. Surrey Beatty and Sons Pty Limited in association with the Conservation Commission of the Northern Territory.

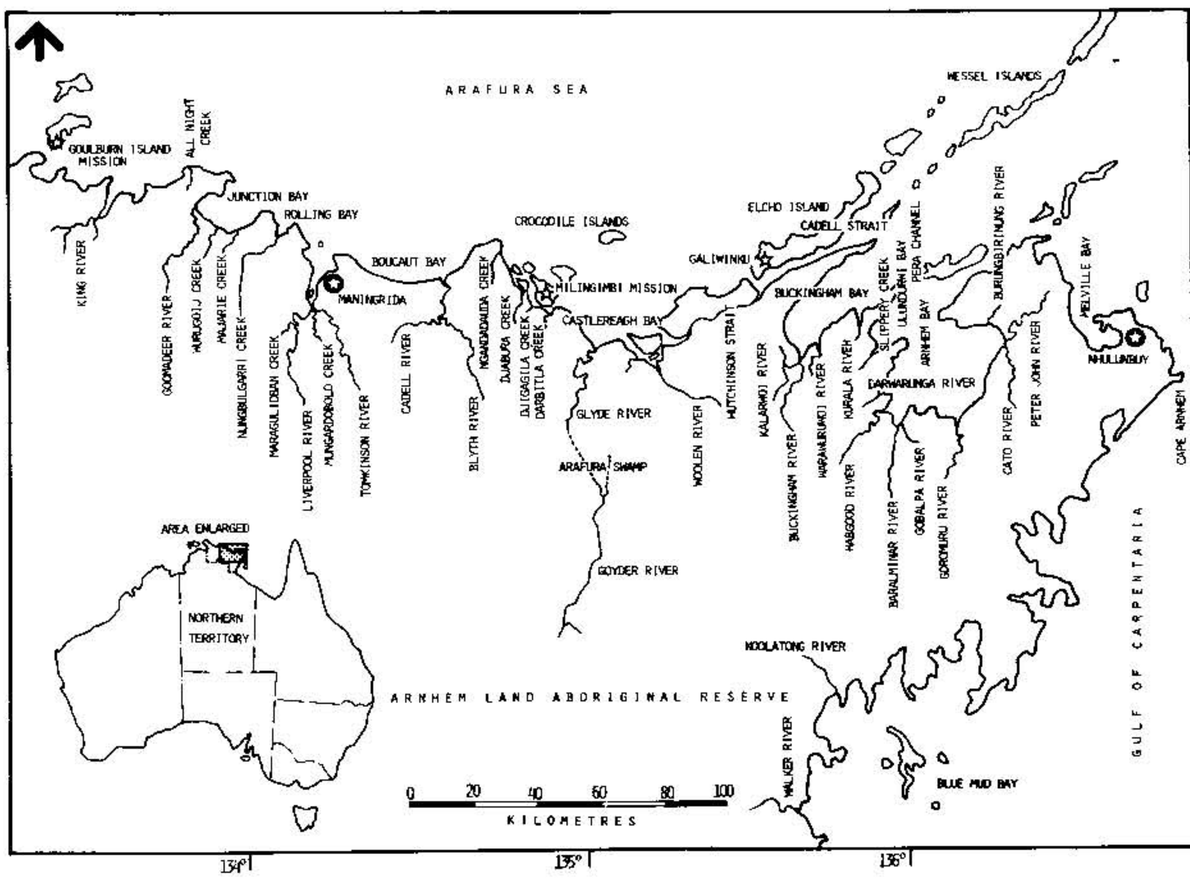

Fig. 2. Part of the Northern Territory coast showing the location of the main monitoring area around Maningrida (Junction Bay to the Blyth River); the Glyde River and Arafura Swamp; and other rivers and creeks which have been surveyed.

1. The Maningrida area, on the north Arnhem Land coast (Fig. 2), centred on the Liverpool-Tomkinson and Blyth-Cadell Rivers, but including creeks and rivers between and on each side of them, and the extensive Arafura Swamp upstream of tidal influence in the Glyde River. This part of the Arnhem Land coast was the main monitoring area and consequently results from here were heavily implicated in formulating the model; and,

2. The Van Diemen Gulf area (Fig. 3), including the Adelaide River to the west, the Alligator and Wildman Rivers to the east, and Murgenella and Saltwater Creeks plus the Ilamaryi and Minimini complexes to the north-west.

One implication of the model is that recovery of the crocodile populations should occur most rapidly in areas where *Type 1* rivers (see below) are closely associated with extensive freshwater wetlands. One of the best such areas remaining in northern Australia is the Alligator Rivers Region, in Van Diemen Gulf. In contrast, the model predicts recovery in *Type 3* river systems (see below) should be markedly different from that in *Type 1* rivers — the Ilamaryi and Minimini Complexes (and Saltwater Creek), on the north-west of Van Diemen Gulf, represents the largest assemblage of *Type 3* waterways in northern Australia. Recovery will also proceed differently in *Type 1* systems that have no associated freshwater habitat.

The model and the results as a whole have implications for the present and future management of *C. porosus* in northern Australia. These are discussed, along with an experiment that could have particular management significance.

THE POPULATION MODEL

1. The tidal waterways of northern Australia have been classified according to the dry season salinity profiles along their length. In essence, three salinity "signatures" can be recognized (Fig. 4), *Type 1*,

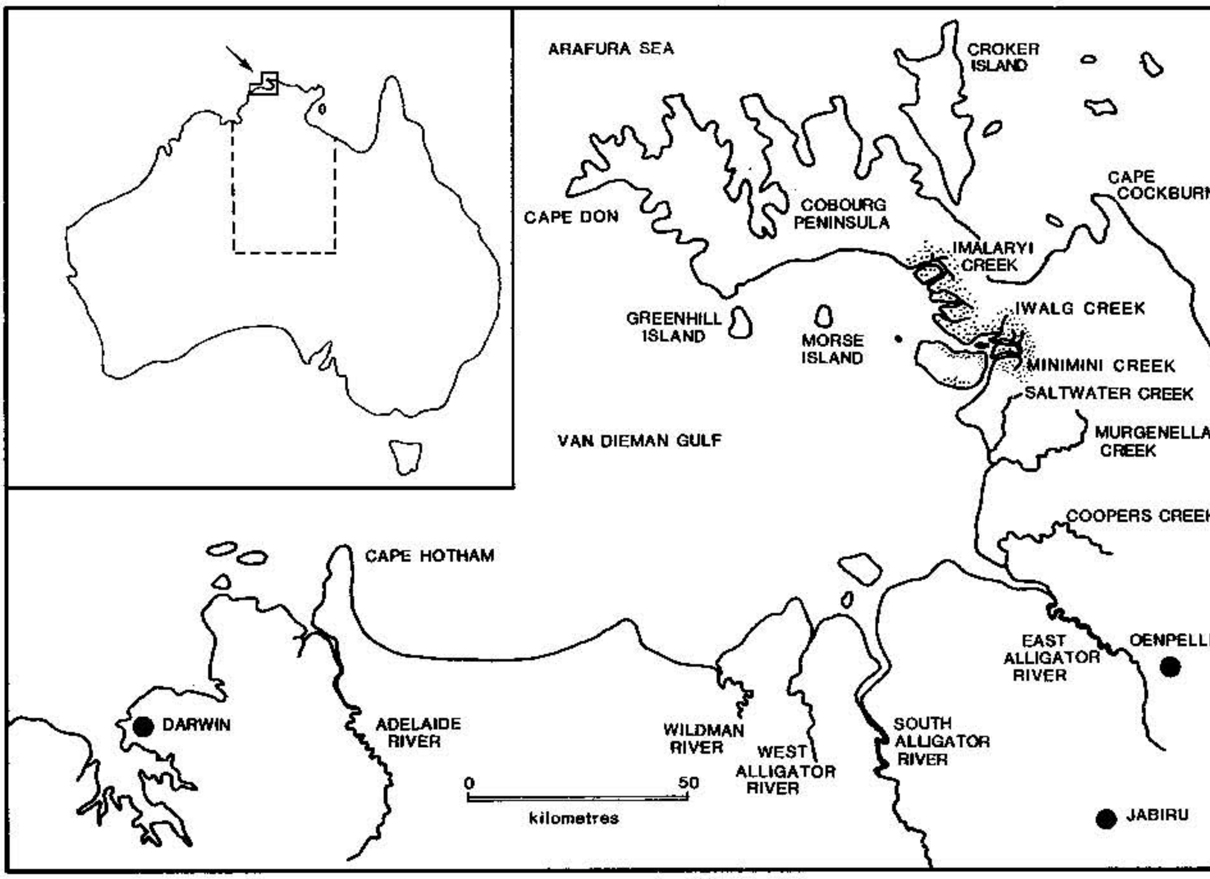

Fig. 3. Part of the Northern Territory coast showing the rivers in Van Diemen Gulf and the location of the Cobourg complex (in square) of *Type 3* waterways.

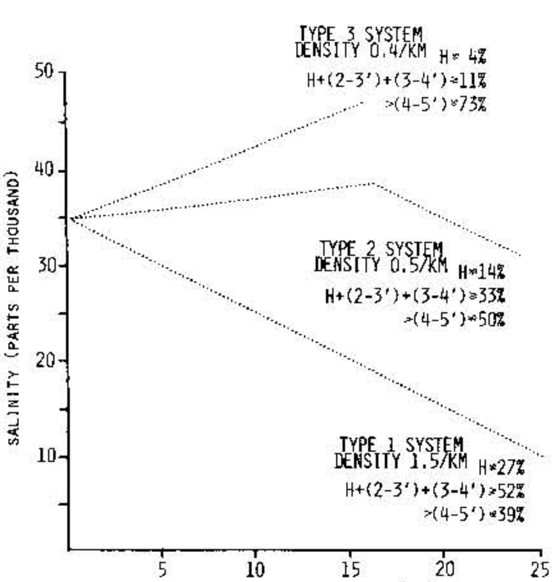

Fig. 4. Salinity profiles with distance upstream in *Types 1, 2* and *3* tidal rivers. Numbers refer to the distribution of different sized *Crocodylus porosus* in 1978-79: H = hatchlings.

Type 2 and *Type 3* (Monograph 1: 100-1). These indirectly reflect the amount of fresh water that flows into tidal rivers during the dry season. *Type 1* systems have the greatest input of fresh water, and most *C. porosus* breeding takes place in them. *Type 2* and *Type 3* systems are partially hypersaline or hypersaline in the dry season, and they typically support poor or no breeding. As a consequence, it is the *Type 1* systems and their associated freshwater billabongs and swamps which account for the major recruitment of *C. porosus*. The *Type 2* and *Type 3* systems may contribute a little (they sometimes have small freshwater swamp complexes associated with them), but they depend largely upon *Type 1* systems and their associated freshwater complexes for recruitment.

2. The size of crocodiles within *Type 1*, *Type 2* and *Type 3* systems varies (Fig. 4) (Monograph 1: 419). In 1978-1979, some 27% of the crocodiles sighted in *Type 1* systems were hatchlings, whereas about 14% of those in *Type 2* systems and 4% of those in *Type 3* systems were hatchlings. The same trend was apparent in crocodiles sighted that were less than 4′ long (including hatchlings: *Type 1*, 52%; *Type 2*, 33%; *Type 3*, 11%). The opposite trend existed with crocodiles > 4′ (*Type 1*, 39%; *Type 2*, 50%; *Type 3*, 73%), however, the majority of all crocodiles sighted are in *Type 1* systems (79% of non-hatchling; Monograph 1: 419).

3. The size of the non-hatchling *C. porosus* population in freshwater habitats with perennial water is largely unknown; such areas are limited, perhaps

less than 400 km^2. From many casual observations made we estimated the non-hatchling population in freshwater swamps in 1979 to be less than 20% (800-900 animals) of that in the tidal systems; we now believe that to be an overestimate for 1979, as our estimate of the tidal population was inflated by an unusually "dry" wet season.

4. It appears that a large fraction of the subadults in *Type 1* systems (and associated freshwater complexes) are excluded from those systems, and that it is these individuals which populate *Type 2* and *Type 3* systems. Adult crocodiles appear generally to tolerate animals up to 3′ and perhaps 3-4′ in their vicinity [but not always — they sometimes kill them (Monograph 1: 334) and may eat them (Monographs 14: 43)] but not larger crocodiles. Once a crocodile reaches 3-5′, it is likely to be challenged increasingly by crocodiles its own size class (Monograph 1: 454-8) and larger, and to be excluded from areas it was able to occupy when it was smaller (Fig. 5). A very dynamic situtation prevails with both adults and subadults being forced to move between various components of a system and between systems.

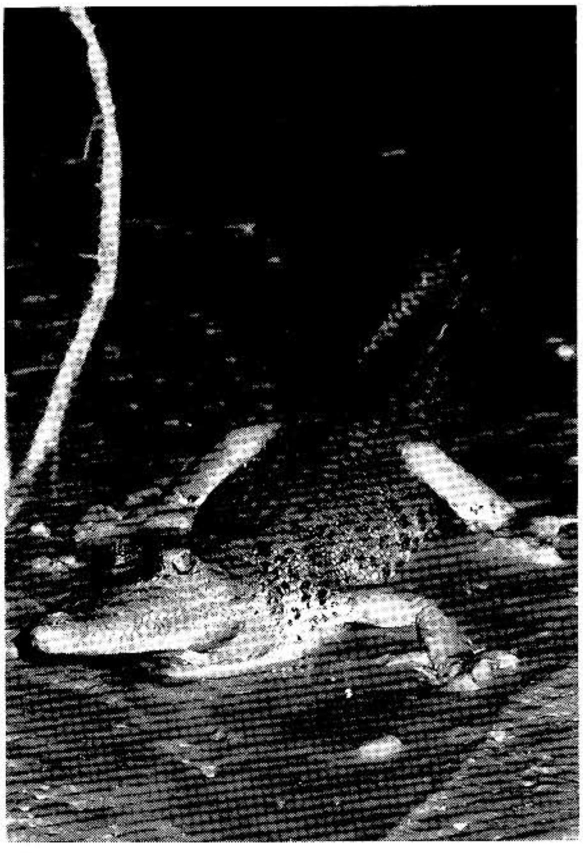

Fig. 5. When *Crocodylus porosus* reach 3-5′ long it is likely that they will be challenged increasingly by crocodiles their own size or larger.

Aggressive behaviour between crocodiles of all sizes increases around September-October, at the start of the breeding season (Monograph 1: 445; Monograph 18: 109). Exclusions, if any, normally occur around this period but may occur throughout the wet season (to April-May).

A substantial fraction (around 80%) of subadults, mostly 3-6′ long but some >6′, are either excluded from *Type 1* rivers or are killed in them by larger crocodiles.

5. Excluded crocodiles may take refuge in freshwater swamps, billabongs or "non-breeding" side creeks (*Types 2* and *3*) associated with a *Type 1* system, or they may leave the system altogether. Some may go out to sea, but others travel along the coast and find *Type 2* or *Type 3* refuges; perhaps after further exclusion from other *Type 1* systems.

The refuges (*Type 2* and *Type 3* systems and the freshwater complexes) act as rearing "stockyards" for excluded subadults ≥3′, and individuals may remain there until sexual maturity is attained (Monograph 1: 431). They then return to *Type 1* systems, perhaps using a homing instinct, and attempt to establish territories in either the mainstream or in associated freshwater complexes. Some 60-70% of subadults simply disappear and are presumed to die, although more recent data (Monograph 18) suggests this figure may be in excess of 70%. Animals that travel out to sea could be expected to starve (*C. porosus* are essentially "shallow-water-at-edge" feeders) or be eaten by sharks.

6. Freshwater complexes (swamps and/or billabongs) associated with tidal systems, are normally at the upstream limit of tidal creeks or at the terminal sections of the mainstream(s). The "alternative" habitat they provide is usually very limited, although it may be used for nesting. There are, however, several areas where extensive freshwater complexes are associated with *Type* 1 tidal systems, and these provide important rearing stockyards and breeding sites (just as the *Type 1* mainstreams themselves do). Examples are the Glyde River with the Arafura Swamp (Monograph 9), the Alligator Rivers region (Monographs 4 and 14), and the Daly, Finniss, Reynolds and Moyle Rivers (Monograph 2).

The loss of subadults which appears to occur during the exclusion stage, can be expected to be lower for movements between *Type* 1 rivers and closely associated swamps, than between *Type 1* rivers and other coastal streams (*Types 2* and *3*). Nests in freshwater swamps also appear to be less prone to flooding than *Type 1* mainstreams — we have observed nests made on floating cane grass mats in the Daly River region.

Thus recovery of *C. porosus* populations in *Type 1* tidal waterways that have substantial freshwater complexes associated with them, could be expected to be faster than on other systems (Monograph 1: 445; Monograph 14: 98).

7. Because of exclusion and an estimated 70% plus subadult mortality, there has been no significant increase in the numbers of non-hatchlings in the tidal waterways around Maningrida on the central Arnhem Land coast between 1974 and 1983 (some 500 km of stream; Monograph 18). With the exception of the Glyde River, these waterways have only minor freshwater complexes associated with them.

8. If the results from this area applied elsewhere, significant increases in non-hatchling *C. porosus* within tidal waterways of northern Australia could take decades. However, as discussed in (6) above, on tidal systems with associated freshwater complexes, the recovery could be expected to be more rapid.

9. Although numbers of non-hatchlings in the Maningrida area have not increased between 1974 and 1983, the size structure of the population has been changing slowly. The ratios of small to large animals sighted, either 2-6′: ≥6′ or 3-6′: ≥6′, has been decreasing slowly in the monitoring area as a whole (although perhaps not in the Liverpool-Tomkinson system), indicating a slow recovery.

However, for the 861 km of tidal waterways surveyed in Van Diemen Gulf, which includes the Alligator Rivers region and the Adelaide River, both with substantial freshwater complexes, there is strong evidence of both increasing numbers and sizes, indicating a faster recovery.

10. It appears that as the numbers of large (≥6′) crocodiles in a tidal waterway increase, the numbers of small subadults (3-6′) decrease or increase only marginally. It appears that the 4-6′ size classes, in particular, represent something of a "bottleneck" in the population. The total numbers of 3-6′ and ≥6′ animals sighted during surveys appears rather constant, as though there were a set number of territories or "slots" in a river system for them to occupy. Crocodiles themselves appear to be primarily responsible for the 70% plus subadult mortality that occurs during the processes involved in either securing these slots or expanding the number of them.

11. When a steady state is reached in a fully recovered population, the ratio of 3-6′: ≥6′ animals may be considerably less than 1.0.

12. Any influx or return of larger animals appears to occur mainly in the early dry season (April-June), but may continue up until September.

13. If a wet season is characterized by relatively little rain, there may be a substantial influx of ≥6′ animals and sometimes 3-6′ animals, into the tidal mainstreams. These are forced out of freshwater complexes and are sighted during June-July spotlight surveys. However, by October-November of the same year, numbers of 3-6′ and ≥6′ animals may be markedly reduced, although the numbers of ≥6′ animals may still be higher than on "normal" years. A number of the new large animals do not return from whence they came and are apparently successful in establishing territories.

A further ramification of a "dry" wet season is that more nests on the tidal waterways are successful (reduced flooding); in contrast, there appears to be greatly reduced nest success in the freshwater swamps.

CASE HISTORIES

Because of the movements which appear to occur within and between rivers, survey results from any one system often need to be interpreted in terms of broad groups of associated tidal and non-tidal waterways, and even geographic regions (Monographs 1, 9 and 11). We deal here mainly with the changes in spotlight counts that have occurred over time in two regions, and use data from them to exemplify trends in the population; all raw counts, which have been corrected to absolute numbers using the method derived in Monograph 1, are summarized by Messel and Vorlicek (Tables 1a, b; 1986) (see also Monographs 1 and 18).

In order to interpret the results, certain aspects of the methodology and of the areas surveyed need to be clarified:

1. Although a river's mainstream is usually assignable to *Types 1, 2* or *3*, which we use as the "signature" for that river, the mainstream and side-creeks may be different. Type 1 mainstreams may have *Type 2* and *Type 3* side-creeks associated with them.

2. Crocodiles which could not be assigned to 1-foot size classes during a survey were reported as "eyes only" (EO). We needed to account for these individuals in the size class structure here, so they have been subdivided as follows: 50% to the 3-6′ counts (equally distributed among the 3-4′, 4-5′ and 5-6′ size classes), and 50% to the >6′ counts (33.3% to 6-7′, and 66.7% to >7′) (Monograph 1: 308).

3. When examining changes over time, variation in the hatchling size class can swamp more subtle trends in the data as a whole. This variation itself reflects the extent of annual nest success and the time of the survey relative to the time of hatching; the hatchling size class experiences about 50% mortality between June of the first and second years (Monograph 1: 390-4). Accordingly, most trends discussed here refer only to the non-hatchling size classes.

4. Because of the apparent effect of season on "exclusions", surveys from one period of the year should be compared with those from the same period in other years, although even here additional variation can be attributed to the extent of the previous wet season. In the comparisons made here,

only those data from equivalent survey month are included, although a considerable amount of data from other months is available (Messel and Vorlicek 1986).

5. For a variety of logistic reasons the exact length of each stream surveyed sometimes varied a little, particularly at the upstream limit to which the survey boats could be taken. This variation at most involved a few kilometres of low density habitat and can be largely ignored.

6. The data presented here refer only to the tidal mainstreams that could be travelled by boat. In 1982 and 1983, patches of "alternative" habitat (small coastal creeks, upstream pools and billabongs) were surveyed (Monograph 18). Such areas provide some important rearing stockyards for both large and small animals, but the total population is small compared to the hundreds of subadults "missing" from the regularly surveyed mainstreams. Parts of the Arafura Swamp were also examined (Monograph 18), and yielded high densities of *C. porosus* in the larger pools surveyed.

1. *The Main Maningrida Monitoring Area*

The very extensive results from this area are summarized in Table 1. The Blyth-Cadell (<94.5 km surveyed) and Liverpool-Tomkinson (<152.5 km surveyed) are essentially *Type 1* mainstreams with some *Type 2* and *Type 3* side-creeks. Rolling Bay contains a short *Type 1* stream (Nungbulgarri Creek; <15.0 km surveyed) and Junction Bay contains a long *Type 1* stream (Goomadeer River; <45.3 km surveyed) and two *Type 3* streams (Majarie and Wurugoij Creeks; <24.1 km and <16.4 km surveyed respectively). In these survey results, the "eyes only" sightings have been allocated to size classes, and the size classes themselves have been merged into four meaningful ones: hatchlings, 2-6′, 3-6′ and ≥6′.

The number of ≥6′ and 3-6′ crocodiles sighted in the complete area during 1976 was 83 and 340 respectively. These numbers remained fairly constant up to June-July 1979, when there was a dramatic increase, especially in those ≥6′ (83 in 1976 to 162 in 1979). The 1978-79 wet season was one of the driest on record, and we believe (Monograph 18) that this influx of animals came primarily from the freshwater Arafura Swamp, upstream in the Glyde River (Fig. 1). This extensive swamp is believed to be both a rearing stockyard and a breeding system, which would have been placed under unusual pressures when the breeding season occurred with perennial waters at a much reduced level.

The following year (1980) numbers had returned to previous levels, and by June-July 1981 the numbers of 3-6′ animals sighted in the surveys (347) was almost identical to the number in 1976 (340). The numbers of ≥6′ animals had increased from 83 to 113, suggesting some new animals were successfully establishing territories, perhaps in the very waterways from which they had been excluded. However, the extent of recruitment into the system

Table 1. Numbers and sizes of *Crocodylus porosus* sighted during spotlight surveys in three subsections of the main Maningrida monitoring area: H = hatchlings; * = some animals (in brackets) removed before the survey; ** count adjusted for longer area surveyed; "***" no comparable data available; [1] = two *Type 3* creeks in Junction Bay not surveyed, which means totals of 3-6′ and ≥6′ are a little low and size ratios a little high. [2] = totals should be increased by a maximum of about 40 hatchlings, 80 2-6′, 66 3-6′, 33 ≥6′ and 99 ≥3′ animals to account for areas not surveyed.

		Blyth-Cadell System				Liverpool-Tomkinson System				Rolling and Junction Bays				Totals						
		H	2-6′	3-6′	≥6′	H	2-6′	3-6′	≥6′	H	2-6′	3-6′	≥6′	H	2-6′	3-6′	≥6′	≥3′	2-6′/≥6′	3-6′/≥6′
Aug/Nov	75	50	289	183	14			***		1	78	46	12							
								Major Flooding												
July/Sept	76	82	240	177	26	19	169	130	40**	20	38	33	17	121	447	340	83	423	5.4	4.1
May/June	77	108	232	196	25	40	166	160	39	4	51[1]	40[1]	9[1]	152	449[1]	396[1]	73[1]	469[1]	6.2[1]	5.4[1]
October	77	112	226	158	22	56	147	140	25			***		168	373	298	47	345	7.9	6.3[2]
Sept	78	155	221	161	23	37	156	138	40			***		192	377	299	63	362	6.0	4.7[2]
								No Flooding — Driest Wet on Record												
June/July	79	123	287	196	55	289	152	141	74	39	80	66	33	451	519	403	162	565	3.2	2.5
October	80	119	249	160	32	71	173	122	51			***		190	422	282	83	365	5.1	3.4[2]
								Heavy Flooding												
June/July	81	76	253	167	37	26	176	124	54	8	65(7)*	56(4)*	22	110	494(7)*	347(4)*	113	460	4.4	3.1
October	81	72	204	127	39	34	166	132	54	17	66	60	12	123	436	320	105	425	4.2	3.0
								Dry Wet — Minor Flooding Only												
June/July	82	136	205	163	67	193	207	178	67	20	59	51	29	349	471	392	163	555	2.9	2.4
Oct/Nov	82	111	197	154	39	144	171	155	69	10	69	61	24	265	437	370	132	502	3.3	2.8
								Dry Wet — Minor Flooding Only												
June/July	83	157	258	160	50	121	257	174	54	62	65	57	21	340	580	391	125	516	4.6	3.1
October	83	73	246	151	35	63	219	142	45	48	67	57	26	184	532	350	106	456	5.0	3.3

over the 1976-81 period was certainly not being reflected in increased total numbers; most subadults had disappeared and were probably dead.

The 1981-82 and 1982-83 wet seasons were again very dry. In 1982, as in 1979, there was an influx of both 3-6′ and ≥6′ animals. The increase relative to the previous October (1981) count was 72 and 58 animals respectively, giving totals (392 and 163 respectively) that were amazingly similar to the counts obtained in 1979 (403 and 162 respectively). Again a substantial fraction of this increase, especially of ≥6′ animals, could have come from the Arafura Swamp. In June of both years (1979 and 1982), concentrations of large animals were sighted at the mouth of the Blyth River, showing that they were either entering or leaving the system through the mouth.

Surveys in June-July 1983 followed an unusually late and "dry" wet season. The numbers of 3-6′ animals remained constant, whereas the number of animals ≥6′ (125) was seven less than the previous October (1982) count, and 38 less than the previous June-July (1982) count. As in all years for which there are data, numbers in both size classes decreased between the June-July and October surveys in any one year.

In any overview, only a relatively small number of additional 3-6′ animals have established territories during the eight year period. The results are consistent with available territories being limiting for them, although we know little about what constitutes a territory. Superimposed upon this is the seasonal reduction in counts of 3-6′ animals which we believe reflects the more aggressive behaviour of larger crocodiles to them as the breeding season approaches.

The ≥6′ animals showed an increase of 83 to 125 between 1976 and 1983, suggesting that additional territories are being established. The majority of these larger crocodiles were sighted in the *Type 1* systems within the total survey area, particularly in the Blyth-Cadell and Liverpool-Tomkinson River mainstreams, which are the major breeding areas. The reduction in ≥6′ counts between June-July 1983 and October 1983 (125 to 106) could indicate that even these larger animals have difficulty maintaining territories when breeding activity starts.

The results as a whole are best explained by a highly dynamic situation in which animals are continually interacting in their attempts to secure territories, as has been documented for many other species. The mortality involved during the process with *C. porosus* seems to be startlingly high, and includes individuals in the largest size classes.

2. *Van Diemen Gulf*

The areas surveyed within this region (Fig. 3) include a series of major *Type 1* rivers and creeks (Adelaide River <231.6 km; Wildman River 33.5 km; East Alligator River <119.2 km; South Alligator River <114.0 km; West Alligator River <42.2 km and Murgenella Creek 45.9 km), a *Type 3* creek (Saltwater Creek 14.1 km) and two *Type 3* complexes (Minimini Complex 125.8 km; Ilamaryi Complex 135.2 km). Survey results are summarized in Table 2, and attention is drawn to the following points.

1. Between 1979 and 1984, on 861.2 km of tidal waterway surveyed, numbers of animals sighted that were 3-6′ long increased from 610 to 870 and numbers ≥6′ from 569 to 747.

2. As a result of an excellent breeding season in the "dry" wet season of 1981-82, there were unusually large numbers of 3-4′ animals sighted in 1984. This transient fluctuation is a significant seasonal bias in the 3-6′data and in the 3-6′:≥6′ ratios. There is no real evidence for a significant sustained increase in the numbers of 3-6′ animals.

3. In contrast, the increase in numbers of ≥6′ animals is not the result of one "good" season. Together, the results are consistent with a bottleneck existing in the 3-6′ size classes; once animals pass through it, they appear to have a greater chance of surviving and establishing territories.

4. Significant numbers of large *C. porosus* are known to be drowned annually in barramundi nets set in the tidal waterways of Kakadu National Park. An index of the impact of these losses may be gained by comparing the change in numbers of animals ≥6′ in Murgenella Creek, where net-fishing is not allowed (32 in 1977 to 95 in 1984), to that in the West Alligator River, where it is allowed (25 in 1977 to 24 in 1984). If commercial net-fishing was halted in the tidal waterways of Kakadu National Park, one could be confident that the 3-6′:≥6′ ratio would continue to fall.

5. Within the complete survey area the density of non-hatchlings sighted has increased significantly (>99% confidence level) from 1.5 per km in 1979 to 2.1 per km in 1984. Most important, the increase is not restricted to 3-6′ animals but includes animals ≥6′.

6. We believe that recruitment in the freshwater complexes associated with the tidal streams surveyed must have played an important role in the recovery that has occurred in the Alligator Rivers region. Along the tidal waterways themselves, especially in the South Alligator River, there has been much destruction of *C. porosus* riverine nesting habitat by feral water buffalo; there was minimal hatchling recruitment in the South Alligator River.

7. The total number of *C. porosus* sighted on the 261.0 km of the Cobourg Complex surveyed increased from 67 to 76 between 1979 and 1984 (0.26 to 0.29 per km), which is not statistically significant.

Table 2. Numbers and sizes of *Crocodylus porosus* sighted during spotlight surveys in the tidal waterways of Van Diemen Gulf. "*" excludes Wildman River data.

Survey	Totals	Hatchlings	2-3′	3-6′	≥6′	*3-6′ / ≥6′
ADELAIDE						
July 77	417	48	24	264	81	3.26
Sept 78	381	62	24	217	78	2.78
Sept 79	374	53	8	190	123	1.54
July 84	602	60	36	278	228	1.22
MURGENELLA						
Oct 77	95	1	1	61	32	1.91
June 78	173	48	16	50	59	0.85
Aug 79	198	47	24	66	61	1.08
July 84	236	7	17	117	95	1.23
EAST ALLIGATOR						
Oct 77	318	53	18	154	93	1.66
June 78	329	39	14	175	101	1.73
Aug 79	393	53	30	159	151	1.05
July 84	411	22	51	181	157	1.15
SOUTH ALLIGATOR						
Oct 77	142	—	—	73	69	1.06
June 78	157	6	3	73	75	0.97
Aug 79	164	4	1	58	101	0.57
July 84	279	39	15	78	147	0.53
WEST ALLIGATOR						
Oct 77	83	9	2	47	25	1.88
June 78	85	23	5	37	20	1.85
Aug 79	96	12	9	41	34	1.21
June 84	120	17	2	77	24	3.21
WILDMAN						
Sept 78	118	53	16	28	21	1.33
Aug 79	155	21	34	44	56	0.79
June 84	226	26	60	96	44	2.18
SALTWATER						
Aug 79	29	—	1	12	16	0.75
July 84	25	6	—	11	8	1.38
MINIMINI COMPLEX						
Aug 79	27	—	—	18	9	2.00
July 84	44	—	—	23	21	1.10
ILAMARYI COMPLEX						
Aug 79	40	—	—	20	20	1.00
July 84	32	—	—	8	24	0.33
TOTAL — ADELAIDE, WILDMAN, MURGENELLA AND ALLIGATOR RIVERS *(Type 1)*						
July-Oct 77*	1055*	111*	45*	600*	299*	2.01*
June-Sept 78	1243	231	78	582	352	1.65
Aug-Sept 79	1380	190	106	559	525	1.06
July 84	1874	171	181	827	695	1.19
TOTAL COBOURG COMPLEX —						
MINIMINI, ILAMARYI AND SALTWATER CREEK *(Type 3)*						
Aug 79	96	—	1	50	45	1.11
July 84	101	6	—	43	52	0.83
TOTAL — ALL AREAS SURVEYED						
Aug 79	1476	190	107	610	569	1.07
July 84	1975	177	181	870	747	1.16

These results support the view that a sustainable recovery in the *C. porosus* population is in progress in the Adelaide River System and in the tidal waterways of the Alligator Rivers region, as could be predicted from our model. The recovery is much more pronounced than in the tidal waterways of the Maningrida area (Table 1).

The explanation for the difference is straightforward. Freshwater complexes associated with the *Type 1* waterways in the Maningrida area are scant. Most excluded animals have little choice but to leave the tidal systems completely, with corresponding high losses among the 3-6′ and >6′ animals. In contrast, in the Alligator Rivers region, there are substantial freshwater complexes associated with the *Type 1* tidal waterways. Many of the excluded animals take refuge in them; they are used both as rearing stockyards and as breeding systems. The losses in this case are for some reason lower, and the recovery rates on the systems as a whole are faster.

For the overall waterways in the Alligator Region we found that the exclusion (and/or loss factor) varied between 47 and 82% — the 82% can probably be attributed largely to the losses in fishing nets. Were it not for this, the recovery would have been more spectacular.

For the Adelaide River System, there appears to be two important factors. Many of the former freshwater complexes associated with the mainstream have been destroyed by feral water buffalo, but there are extensive (101.8 km) of mostly *Type 3* waterways on its downstream section. Animals excluded from the breeding sections can take refuge in these without having to leave the system. The exclusion and/or loss factor for the Adelaide River system was 31-45%, compared to the 80-90% or more in the Maningrida monitoring area (Monograph 18: 127, 134, 155). The increase from 81 to 228 animals ≥6′ long sighted (in 1977 and 1984 respectively) is a consequence of these smaller losses. Given another decade or two of protection, the population of saltwater crocodiles in the Adelaide River System may begin to approach its former self.

MANAGEMENT OF THE *CROCODYLUS POROSUS* POPULATION

What are the management implications of our results? We are not management authorities, but are aware that a multitude of factors — some of them political — must be taken into consideration. For example, for reasons based on public safety, Australian society could decide that all waterways utilized for business and/or pleasure, or which had settlements near them, should be cleared of *C. porosus*. Their recovery could be restricted to designated parks and reserves used for tourism and scientific purposes (we have suggested some suitable areas; Monograph 1: 439).

Such a decision could have far reaching ecological consequences, although they are difficult to predict with the current state of our knowledge. Based on examples from elsewhere in the world, we know that the removal of a predator from the top of a complex food chain cannot occur without other major consequences.

The Australian people would have to decide whether the unhindered enjoyment of the waterways of northern Australia is worth the risk of possibly disastrous consequences to the ecology of those waterways. The fishing industry is one group that readily springs to mind as a possible sufferer.

It might also be decided to encourage a commercial *C. porosus* skin industry based directly upon harvesting the wild population. Since some 70% of the 3-6′ animals are lost — and these are the most valuable ones commercially — it may appear that their removal beforehand would yield a valuable harvest without harming the resource. But the exclusion and/or loss of some 80% of the 3-6′ animals is an integral part of the vital process of sorting out the successful from the less successful individuals — the strong from the weak. Removing a given fraction of the population might very well remove the stronger component and thus over the long-term set the population on a declining course. We simply do not know.

In 1981 we proposed (Monograph 1: 15) an experiment to test the effect of removing 25-40% of the 3-6′ in the downstream section of the Adelaide River annually, over a 4-5 year period. Although this was not proceeded with, such experiments could have important ramifications for the management and ranching of the *C. porosus* resource.

Two important factors affecting the recovery of *C. porosus* populations could be influenced by correct management. The first is the prevention of habitat destruction by the feral water buffalo, with a programme to rehabilitate habitats already damaged. The second is action to overcome the drowning of hundreds of large crocodiles per year in legally and illegally set fishing nets (Monograph 1: 437-8). Our results show that there is great and continuing movement of *C. porosus* into and out of the river systems. Net-fishing in or at the mouths of rivers, especially *Type 1* rivers, is certain to remove an important component of the large animals; it could restrict recovery and/or cause a decline in local populations, as appears to have occurred in the West Alligator and Wildman Rivers.

Undoubtedly economic and political considerations are involved in arriving at a reasonable compromise in relation to the matter of commercial net-fishing in tidal waterways. However, at the very minimum, net-fishing within the rivers of national parks (it is still legal to set nets in the tidal waterways of Kakadu National Park) should be phased out as a matter of priority.

Crocodile farming should be encouraged and the removal of eggs from wild nests which become flooded during the January-March period might have little impact on the populations. However, early November and March-April nests often hatch and should not be collected.

Because of the heavy losses of hatchlings and 3-6′ animals, restocking with smaller animals into *Type 1* systems would more than likely be cosmetic (unless the resident population was severely depleted). If restocking were to be considered, then only animals

$\geq 4'$ should be released, and then into *Type 2* or *3* systems or into freshwater complexes. Even then, many uncertainties would remain about the success of any such restocking programme.

Finally, the situation in the Gulf of Carpentaria is in need of clarification. In 1979, particularly low densities of *C. porosus* were found in many rivers and recent results (1985) show no significant change in this situation during the intervening 6.5 years.

ACKNOWLEDGEMENTS

The authors wish to thank the Science Foundation for Physics and the Univsrsity of Sydney for their continued financial support. We also wish to thank A. G. Wells, W. J. Green and I. C. Onley for their continued participation in the onerous field work necessary to obtain the results presented in this chapter. Many other individuals, too numerous to acknowledge separately here, have contributed to the programme over the years and are acknowledged in the appropriate Monographs. We thank Kim Mawhinnew for typing the manuscript.

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