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The Status of the Salt-Water Crocodile in some River Systems of the North-West Kimberley, Western Australia

BY

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PERTH
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Department of Fisheries and Wildlife

108 Adelaide Terrace

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CONTENTS

FIGURES

TABLES

PLATES

Dept. Fish. Wildl. West. Aust. Rept. No.24, 1977, 1-50.

THE STATUS OF THE SALT-WATER CROCODILE IN SOME RIVER SYSTEMS OF THE NORTH-WEST KIMBERLEY, WESTERN AUSTRALIA.

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ABSTRACT

Counts were made of Salt-water Crocodiles (Crocodylus porosus) in the estuarine portions of four river systems in the north-west Kimberley, Western Australia - the Lawley, Mitchell, Roe-Hunter and Prince Regent. During the ten day survey 463 crocodiles were spotted, including 109 hatchlings. The maximum number of non-hatchling crocodiles present in the four systems is estimated at 697. Very few large crocodiles were seen.

Populations were particularly small in the Lawley and Mitchell Rivers and the potential for recovery in this area is also small. Prospects for recovery in the Roe-Hunter and Prince Regent were a little better but further surveys will be necessary to show population trends.

Brief descriptions of each river system are given.

I INTRODUCTION

The Salt-water Crocodile *(Crocodylus porosus)* has suffered a drastic decline in numbers throughout its range due to extreme over-harvesting for the skin trade.

In Western Australia hunting pressure on *C. porosus* was particularly high during the early 1960's and by 1969 the species had become rare (Bustard 1970). *C. porosus* was not protected until April 1970, by which time commercial hunting had become uneconomic. Protection followed in the Northern Territory in 1972 and a total export-import ban on crocodile products was declared by the Commonwealth Government later the same year. It was this ban that effectively stopped hunting throughout Australia.

In 1971 a major research programme on *C. porosus* was initiated in Arnhem Land under the auspices of the University

of Sydney and the Department of the Northern Territory. In 1976 it was felt that data from Western Australia and Queensland would be of considerable value in making assessments of the Australia-wide status of the species. Following negotiations between the University of Sydney and the Western Australian Government a contract was let by the Western Australian Department of Fisheries and Wildlife to the School of Physics, University of Sydney, for surveys of crocodile numbers and population structure in some river systems in the north-west Kimberley. These surveys took place between 18 July and 28 July 1977 and the results form the basis of this report.

Surveys were conducted in the estuarine portions of the Lawley and Mitchell Rivers (which flow into Admiralty Gulf), the Roe and Hunter Rivers (Prince Frederick Harbour) and the Prince Regent River and St George Basin. These particular rivers were chosen because:

1. The Prince Regent and Roe Rivers are part of the Prince Regent River Nature Reserve.

2. The Lawley River system and part of the Mitchell River are in a proposed National Park (Conservation Through Reserves Committee Report - System 7, in press).

3. The Lawley and Mitchell Rivers lie adjacent to the Mitchell Plateau, an area which will receive a large human population influx when bauxite deposits which occur there are mined.

4. The Admiralty Gulf area once held large populations of crocodiles.

5. The river systems are different from those in Arnhem Land on which the crocodile research programme had concentrated hitherto - see Plates. Whereas rivers of Arnhem Land usually meander through low lying flood plains the Kimberley rivers usually follow straight but rugged fault lines formed in the ancient sandstones.

Mangroves form the dominant vegetation communities within the habitat of *C. porosus*. Structurally, mangrove communities within the Kimberley comprise low closed-forests rarely exceeding 10 metres in height. Thirteen mangrove species which were found during the study (Table 1) occurred in all the river systems examined. The Kimberley mangroves, like all Australian mangrove communities, are depauperate extensions of the Indo-Malaysian mangrove flora.

Macnae (1966) working along the eastern Australian coastline, identified habitat zones by their dominant mangrove species because plant species making up mangrove vegetation show

zonal tendencies. Six zones were identified as follows:

1. The landward fringe

1a. The landward *Avicennia* zone

2. *Ceriops* thickets

3. *Bruguiera* forests

4. *Rhizophora* forests

5. The seaward fringe

TABLE 1. MANGROVES RECORDED DURING THE SURVEY

Avicennia marina (Forsk.) Vierh.
Camptostemon schultzii Masters
Lumnitzera racemosa Willd.
Excoecaria agallocha L.
Xylocarpus moluccensis (Lamk.) Roem.
Aegiceras corniculatum (L.) Blanco.
Osbornia octodonta F. Muell.
Aegialitis annulata R. Br.
Bruguiera exaristata Ding Hou.
Bruguiera parviflora (Roxb.) Wright and Arn ex Griff.
Ceriops tagal (Perr.) C.B. Robinson var *australis* C.T. White
Rhizophora stylosa Griff.
Sonneratia alba J.E. Smith

Within the Kimberley area studied, all of these habitat zones were found with the exception of zone 3. Brief notes on the riverine mangrove habitats, from floristic and environmental viewpoints, are included in the descriptions of the individual river systems.

The work reported here was carried out from the University of Sydney's 21 m research vessel "The Harry Messel". Personnel were: H. Messel, A.G. Wells, W.J. Green (Department of Environmental Physics, the University of Sydney), A.A. Burbidge, P.J. Fuller (Western Australian Wildlife Research Centre, Department of Fisheries and Wildlife), B.R. Wilson (Western Australian Museum, a member of the Western Australian Wildlife Authority) and A.J. Watson (Wildlife Branch, Northern Territory). The vessel was crewed by Commander S.R. Schofield (R.A.N. Retd.) (Captain), I. Onley (Engineer) and W. Gill.

It should be noted that the survey techniques and interpretation of results from the present surveys rely upon the previous work of the University of Sydney's Crocodile Research Group (headed

by one of us - H.M.) carried out over the past six years. Much of this work is in the course of preparation for publication. We draw freely upon these preliminary findings without further justification.

II METHODS

A detailed description of crocodile survey methods is given by Messel (1977). Spotlight counts were conducted from two specially modified 5.5 m work boats, each with three staff members. These boats travelled a total of 2600 km during the 10 day survey. Counts were restricted to periods of the tide when 50 cm or more of exposed bank was visible below the base of the mangroves lining the river, creek or bay being surveyed (Fig. 1). Since most crocodiles are spotted in the shallow water on the river edge, this procedure ensures that few are missed because of screening by vegetation.

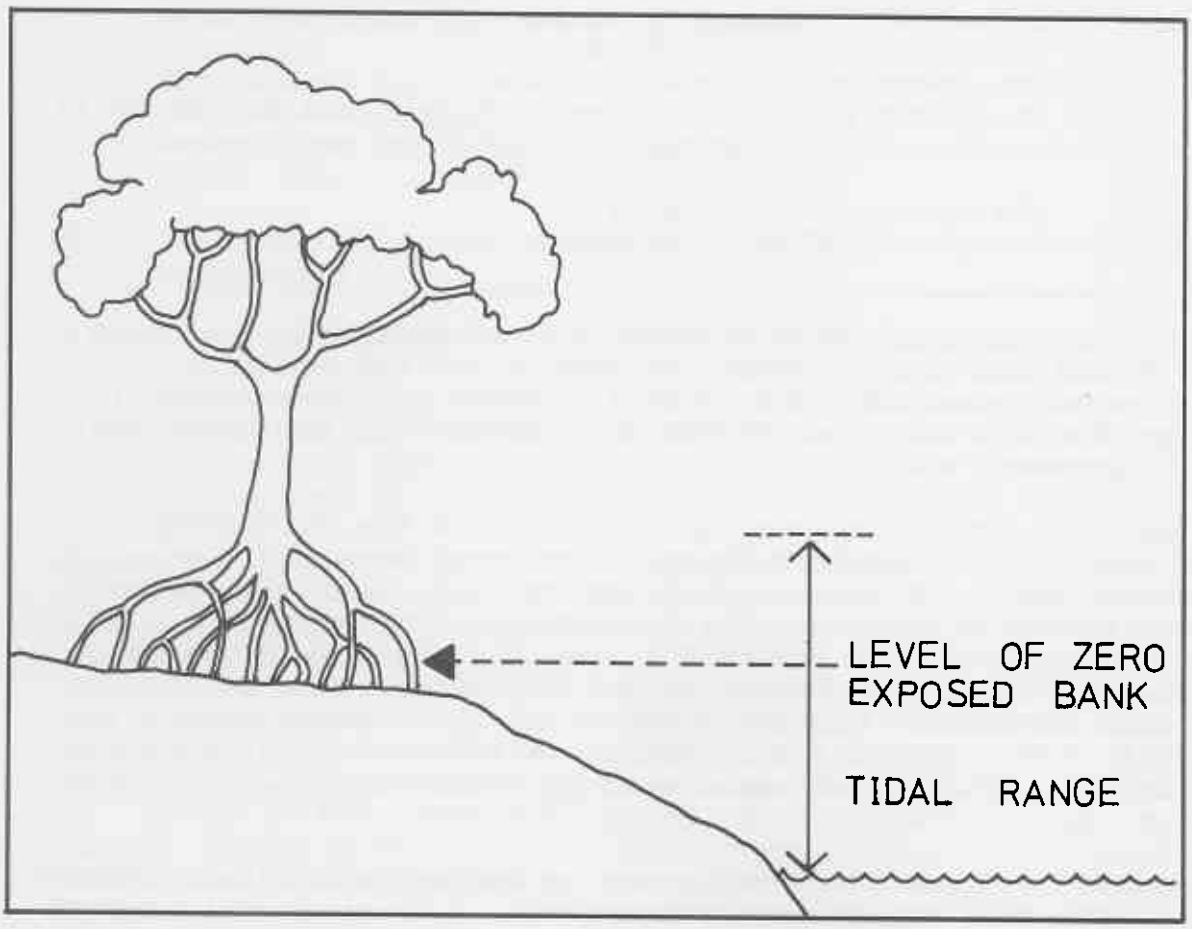

Figure 1. Method of measuring exposed bank.

The location (± 0.1 km) of each crocodile spotted was determined, using maps previously prepared from air photographs. When possible, each crocodile was approached to within 6 m and its size estimated by an experienced observer. Its situation on the bank or in the water was also recorded.

During each survey, at approximately every 5 km along a river or creek (corresponding to a time interval of 10 to 30 minutes), the following environmental parameters were recorded:

1. air, water and substrate (exposed mud) temperatures (± 0.5°C, using a Comark temperature gauge),

2. surface, midwater and bottom salinity (using a salinity-temperature bridge - Autolab Model 602),

3. height of exposed bank,

4. windspeed, state of the tide, and time interval before or after closest low tide,

5. moon phase and age, illumination in foot candles (using an International Light IL700 research radiometer),

6. time after sunset.

These data are required for detailed interpretation of the general river surveys and are available on request. In addition to the measurements in 1., a Grant multipoint temperature recorder was used to obtain a general 24 hour air and water temperature profile for each river system at this time of year.

Two consecutive surveys were made of the Lawley River System (see below) as a rough check on the repeatability of survey results.

Results from calibration surveys conducted on the Blyth River in Arnhem Land (Messel 1977) indicate that at least 60% of the crocodile present at this time of year were counted. There is some bias in the spot-light survey technique against sighting large crocodiles. Crocodiles

longer than 2 metres are survivors from the period of intense hunting pressure and are usually shy of outboard motors and spot-lights. Few of these animals were seen during surveys but some evidence of their number was obtained from tracks and slides observed on the mud-banks at low tide.

The density of crocodiles in a river system was calculated by dividing the total number of crocodiles seen by the number of midstream kilometres of the river and creeks surveyed.

Crocodiles spotted were grouped in size classes as follows: hatchlings, 2 to 3 feet (60 to 90 cms) 3 to 4 feet (90 to 120 cms), 4 to 5 feet (1.2 to 1.5 m), 5 to 6 feet (1.5 to 1.8 m), 6 to 7 feet (1.8 m to 2.1 m) and greater than 7 feet (2.1 m).

Crocodiles whose size could not be estimated were grouped into the category of "eyes only" - EO. The relationship between these size categories and age has been discussed by Webb and Messel (in press). 60 to 90 cm crocodiles are one year olds and females are known to breed at 1.8 to 2.1 m. The time from hatching to maturity is variable but is about 8 to 15 years.

During the daytime low tide general surveys were made to familiarise ourselves with the area to be surveyed that night and to obtain salinity readings at roughly 2.5 km intervals. High tide salinity measurements were also made and the mangrove communities surveyed. The salinity measurements were summarized in salinity profiles plotted for each river system. Detailed information on the mangrove communities will be published separately.

Observations were made on birds utilising the river shore vegetation, mudflats, sandbars, bays and general waterways. When possible, further surveys were made of birds in adjacent terrestrial ecosystems. The observations on the birds of the Lawley and Mitchell Rivers have been submitted to Western Australian Museum personnel who are preparing a paper on the birds of the Mitchell Plateau area. Records from the Roe and Prince Regent Rivers will be published elsewhere. All bird sightings have been submitted to the Royal Australian Ornithologists' Union Australian Bird Atlas.

III THE LAWLEY RIVER

A. DESCRIPTION

The Lawley River proper enters Port Warrender at its south-east corner (Fig. 2). The salinity (Fig. 3) in the mouth-bay area (5 to 11 km, Fig. 2) shows that the low water salinity values are higher than those recorded at high water at this time of year. From 11 km, which we deem to be the mouth of the river proper, the salinity profile is typical of a river with fresh water entering upstream.

Two tidal arms enter the bay, the middle arm (Creek A) and the western arm (Creek B). The salinity profiles of both these arms are shown in Fig. 3. In Creek A the low water salinity values increase by a small amount from 11 to 15 km, then decrease to 19 km, suggesting a small fresh water input. However, the high water values increase as one goes upstream, suggesting that this tidal arm could become a hyper-saline system as the season progresses. In Creek B low water salinity decreases slightly upstream. High water values dropped as one proceeded upstream, suggesting that the incoming tide pushed a pocket of fresh water upstream.

Water and air temperatures measured at the research vessel (anchored at 5.3 km, Fig 2) are given in Fig. 3. Water temperatures measured during the spotlight surveys varied from 20.6° to 23.1°C while air temperatures taken at the same time varied from 14.7° to 23.5°C. It is not known whether these temperatures are 'normal' or not, for the Lawley River at this time of year, however they are low compared to temperatures measured in Arnhem Land river systems in previous years, at this time of year.

The dominant riverside mangrove community is a mixed low closed-forest of *Avicennia marina* and *Rhizophora stylosa*. Thickets of *Ceriops tagal* var. *australis* form the more landward extension of the mangrove community. Extensive mudbanks with fringing mangroves occur throughout the Lawley River.

Creeks A and B are short tidal arms in which the dominant riverside vegetation is a mixed low closed-forest of *Avicennia marina*, *Camptostemon schultzii* and *Rhizophora stylosa*. Pioneer communities of *Sonneratia alba*, *Avicennia marina* and *Camptostemon schultzii* are located in the mouth of the two creeks on extensive shelving mudbanks.

B. CROCODILE NUMBERS AND SIZE CLASSES

During the first survey, on the night of 18 July 1977, 38 crocodiles were spotted (Table 2). Twenty-two were

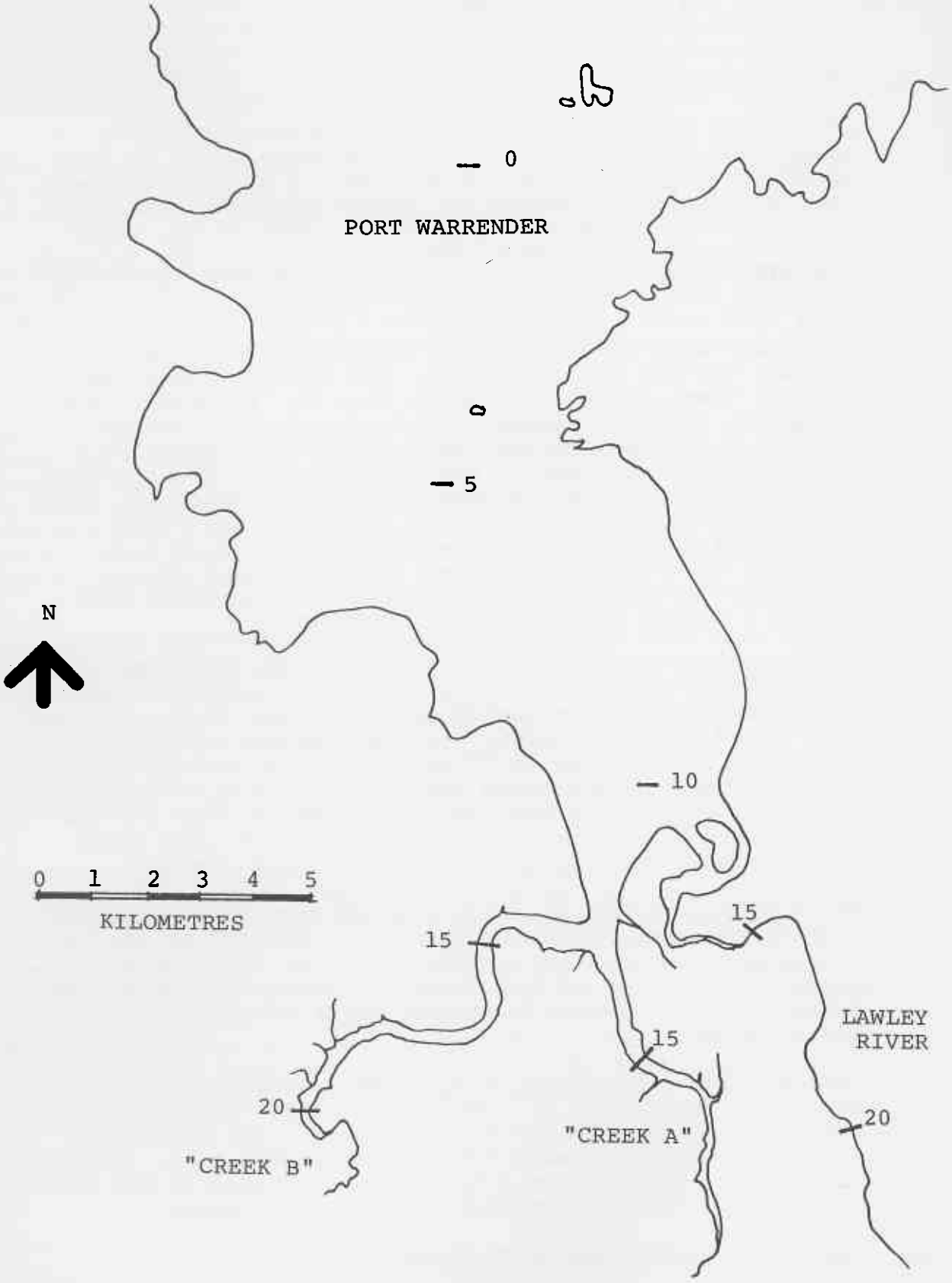

Figure 2. The Lawley River system.

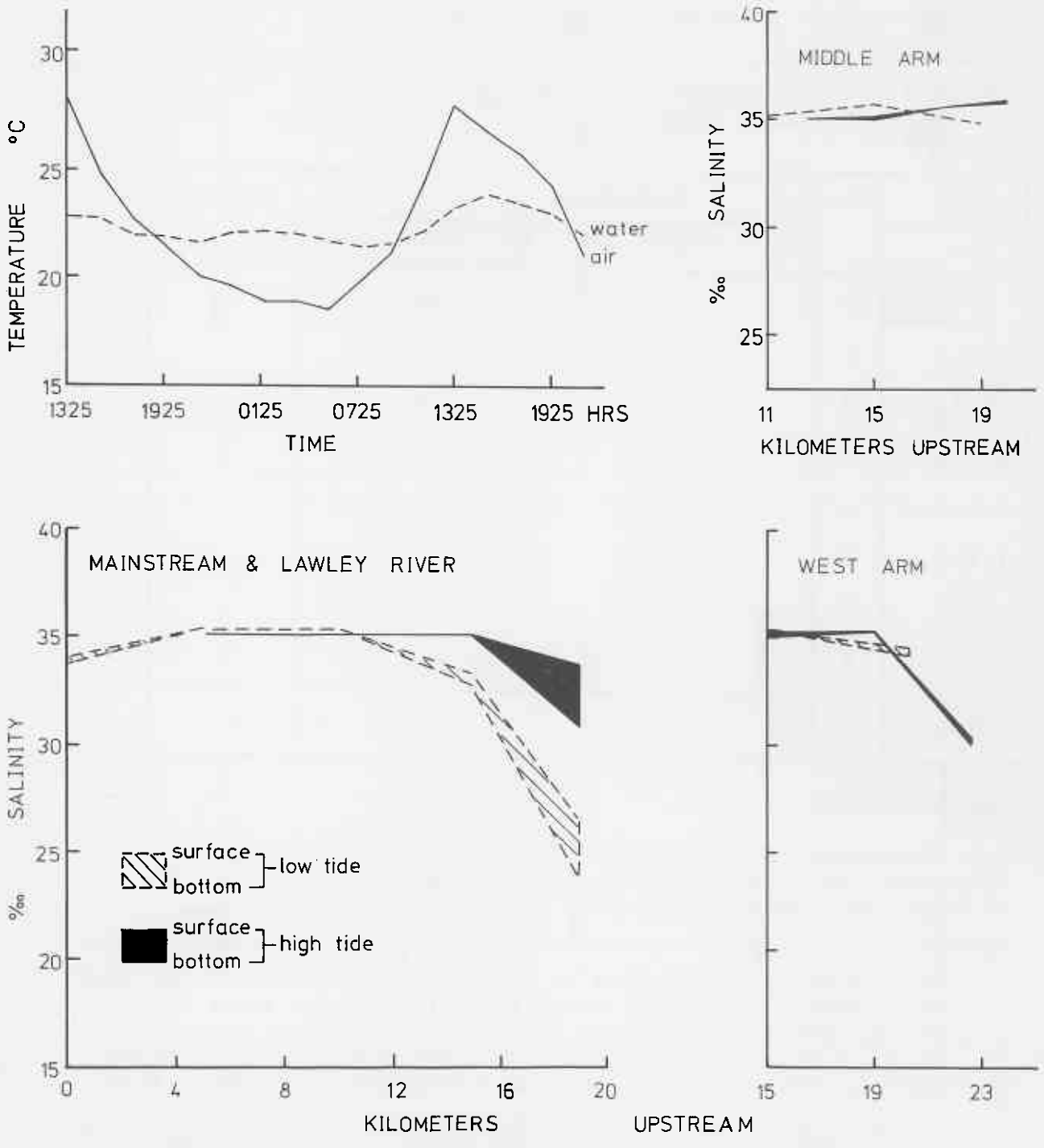

Figure 3. Temperature and salinity measurements in the Lawley River system.

in the Lawley River and of these 9 were hatchlings. This indicates that there was at least one successful nest during the last wet season. One hatchling was spotted in each of Creeks A and B, again indicating a possible successful nest in the creeks.

TABLE 2. CROCODILE NUMBERS AND SITUATION LAWLEY RIVER SYSTEM. 18 JULY 1977.

SIZE (Metres)	No.	SITUATION						FEEDING
		IV	IVIW	OM	IM	SWOE	MS	
H	11					11		
.6-.9	1					1		
.9-1.2	3			1		2		
1.2-1.5	6					6		
1.5-1.8	6					6		
1.8-2.1	2		1			1		
> 2.1	5					4	1	
EO	4			1		3		
TOTAL	38	0	1	2	0	34	1	0

Abbreviations:

H - hatchling, IV - in vegetation, IVIW - in vegetation in water, OM - on mud, IM - in mud, SWOE - shallow water on edge, MS - midstream, EO - eyes only.

The survey was repeated on 19 July and 44 crocodiles were seen (Table 3). Only seven hatchlings were seen in the Lawley and five in Creek A - all near a tiny sub-creek at 17.2 km. This further indicates a recent successful nest in this area, as well as heavy hatchling mortality.

The figure of 38 for the first night can be compared with the 44 crocodiles spotted during the second survey. It should be noted, however, that two crocodiles were spotted during the second survey in an area which had to be omitted on the first survey because of high tide.

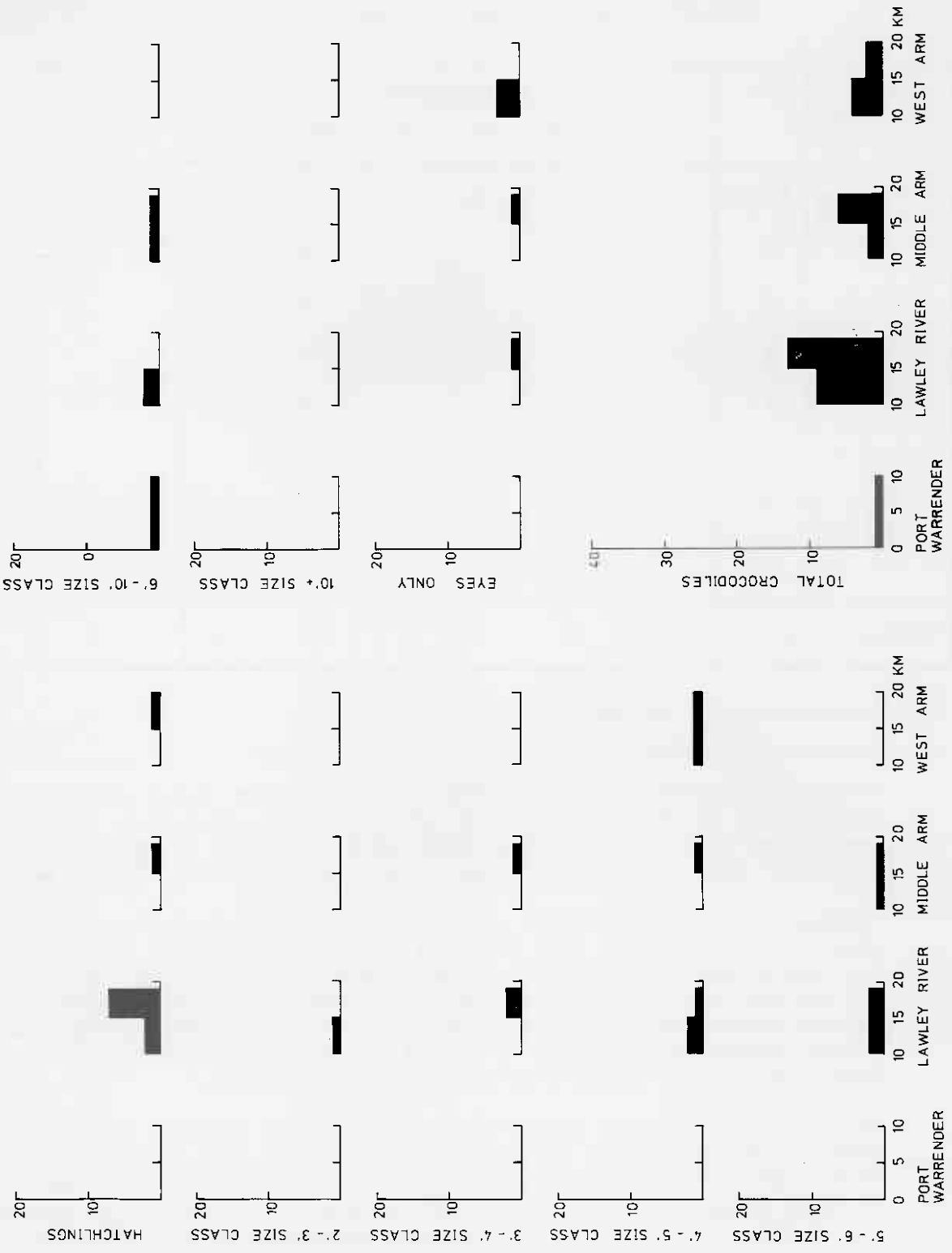

Figure 4. Crocodile distribution, Lawley River, 1st Survey. Size classes are in feet (one foot = 30.48 cm).

TABLE 3. CROCODILE NUMBERS AND SITUATION
LAWLEY RIVER SYSTEM. 19 JULY 1977.

SIZE (Metres)	No.	SITUATION						FEEDING
		IV	IVIW	OM	IM	SWOE	MS	
H	13			1		12		
.6-.9	1					1		
.9-1.2	4			1		3		
1.2-1.5	6			1	1	4		
1.5-1.8	8					7	1	
1.8-2.1	5					5		
> 2.1	3				1	2		
EO	4					3	1	
TOTAL	44	0	0	3	2	37	2	0

Abbreviations as in Table 2.

Port Warrender includes many broad shallow bays which were difficult to survey because of extensive shallows at or near low tide. As is the case with similar areas elsewhere we only spotted a few large size class crocodiles in these.

Tables 2 and 3 show the size classes and situation of the crocodiles spotted and Figs. 4 and 5 show their distribution in the river system. The low number of 60 to 90 cm and 90 to 120 cm crocodiles indicates few recent successful nests and/or high juvenile mortality. The remaining size class distribution appears similar to that observed in badly depleted river systems in Arnhem Land.

Our surveys showed that the Lawley River system has a small population of *Crocodylus porosus*. The potential for significant recruitment appears low and it will be a long time - if at all - before the few small size class crocodiles mature and add to the reproductive potential.

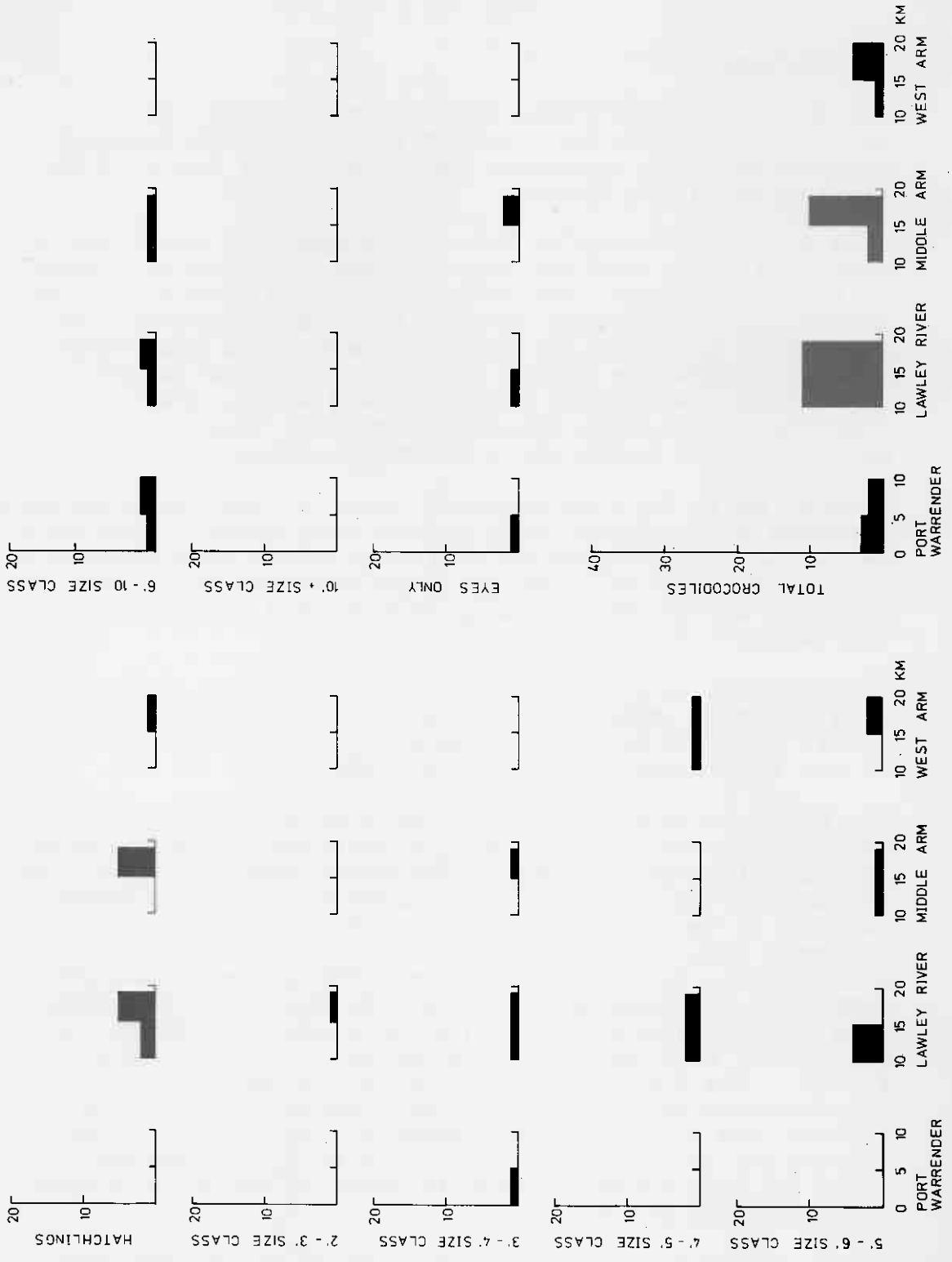

Figure 5. Crocodile distribution, Lawley River, 2nd Survey.

IV THE MITCHELL RIVER

A. DESCRIPTION

The Mitchell River flows into Admiralty Gulf via Walmsley Bay (Fig. 6). Extremely rugged King Leopold Sandstones occur on either bank. Walmsley Bay is 8 km wide at Pickering Point.

From Pickering Point to about 8 km upstream there are a number of wide, shallow bays. Creeks running into some of these bays were inadequately surveyed because of the difficulty in entering them at low tide. However, our experience with similar creeks elsewhere is that very few crocodiles are missed because only a few larger crocodiles are usually found in such areas, and at low tide they often move downstream and are thus usually near the creek mouth where their eye-shine can be seen.

From 20 km to 26.5 km upstream (Fig. 6) the river contains a series of sandbars, some strewn with rocks. From 26.5 km to the tidal rapids at 36 km the river runs through a gorge. From 15 km to about 34 km upstream the river contains extensive gradually sloping mud banks below the mangrove fringe.

The salinity profile (Fig. 7) demonstrates a sizeable flow of fresh water into the estuarine portion of the river. The air and water temperature profiles measured at the ship anchored at 9 km are also given in Fig. 7.

The Mitchell River appears to be a drowned river valley. Mangrove communities are more widespread along the side-creeks, although a fringing mangrove community does line the mainstream channel to the limit of tidal influence (around 36 km upstream). Extensive gently sloping mudbanks occur throughout the entire river system particularly in the first 20 km. The pioneer mangrove community on these mudbanks is a mixture of *Sonneratia alba* and *Avicennia marina*. A low closed-forest of *Rhizophora stylosa* occurs behind this riverine mangrove fringe. The more landward forests are comprised of *Camptostemon schultzii*, *Avicennia marina*, *Rhizophora stylosa* and *Xylocarpus moluccensis*. Isolated thickets of *Ceriops tagal* var. *australis* up to 5 m in height occur in this landward zone on areas of slightly higher physiographic relief.

Along approximately the upper 10 km of the mainstream under tidal influence the riverside mangrove vegetation changes to a mixed low closed-forest of *Avicennia marina*, *Rhizophora stylosa* and *Camptostemon schultzii* often having an understorey of *Aegiceras corniculatum*. *Avicennia marina* is the dominant mangrove species in this area and grows to 10 metres in height.

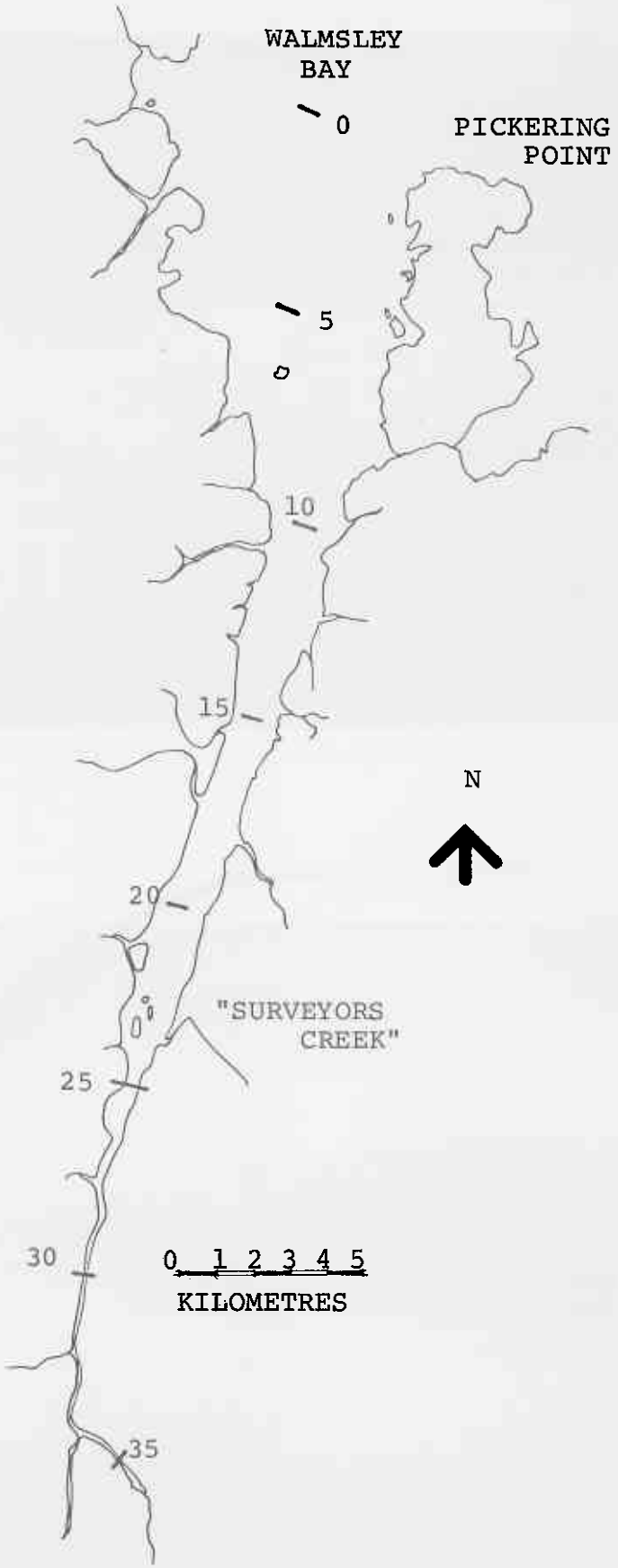

Figure 6. The Mitchell River system.

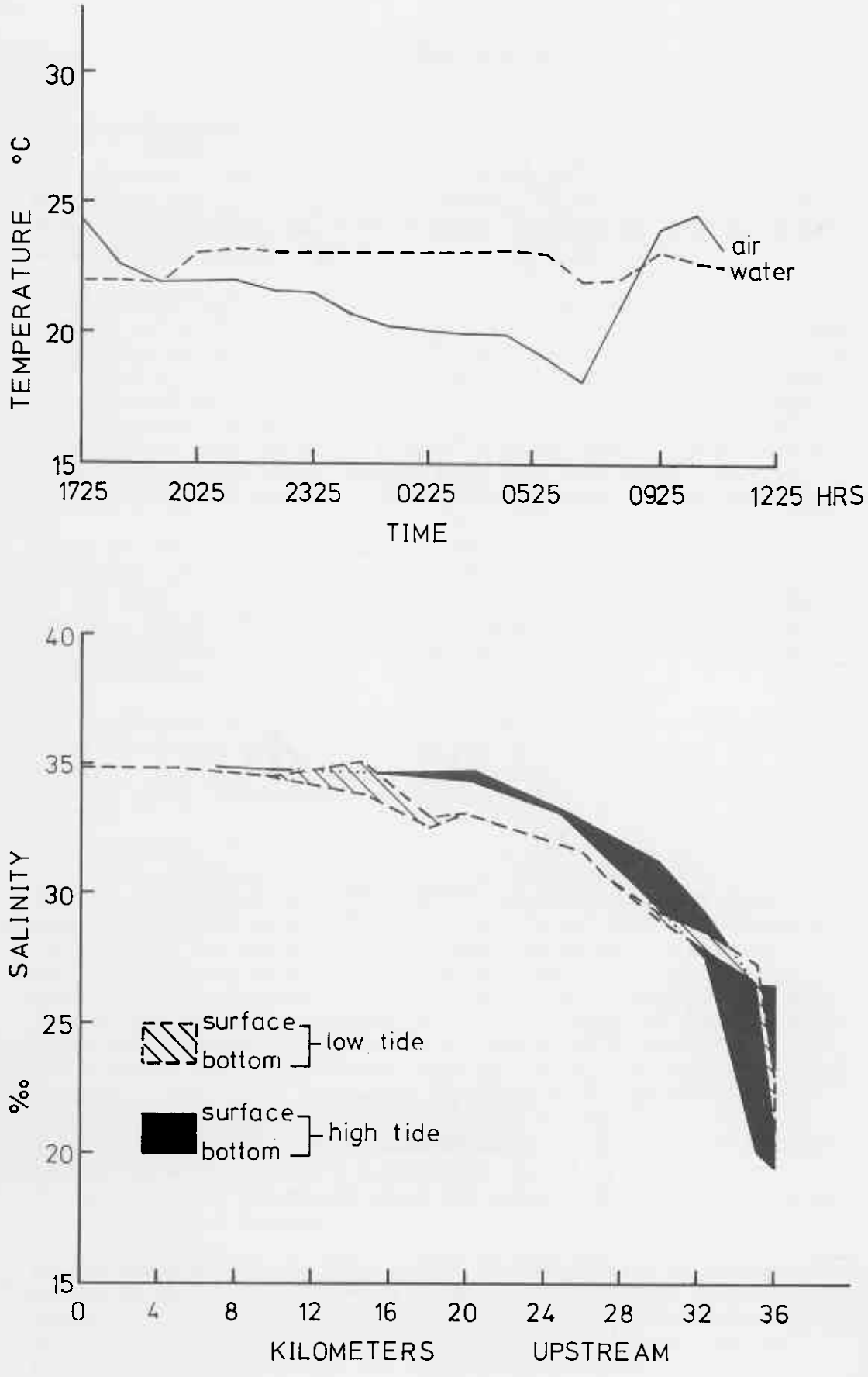

Figure 7. Temperature and salinity measurements in the Mitchell River system.

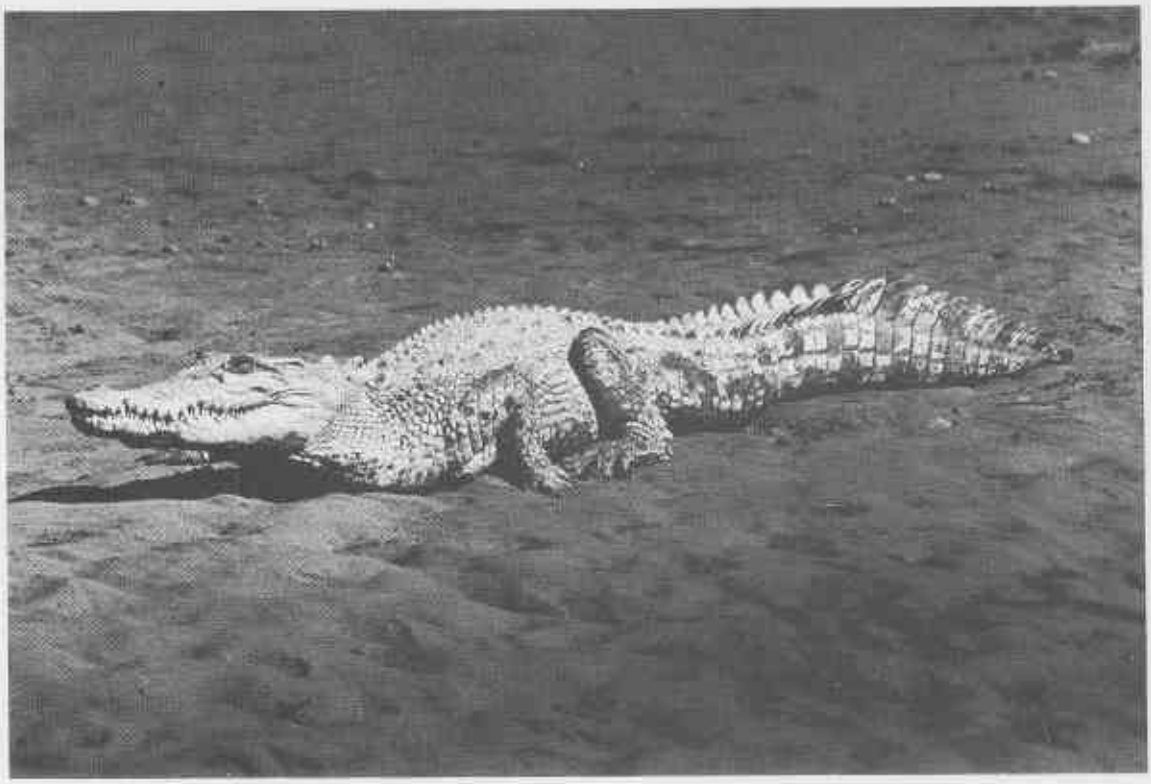

Plate 1. A 2 metre *Crocodylus porosus* on a mudbank in the Hunter River.

Plate 2. Mudbank near the mouth of the Lawley River. The pioneer mangrove community is a low closed-forest of *Avicennia marina* and *Sonneratia alba*.

Plate 3. Near the entrance of the western arm of the Lawley River system. The fringing mangroves are *Avicennia marina* with an understorey of *Aegiceras corniculatum*. A dark band of *Rhizophora stylosa* can be seen behind the fringing mangroves. Basalt cliffs rise toward the Mitchell Plateau.

Plate 4. The upper tidal region of Surveyors Creek, a tributary of the Mitchell River, at low tide.

Plate 5. The Roe River near its mouth at low tide. Behind the mudbank is a low closed-forest of *Avicennia marina*.

Plate 6. The gorge of the Roe River at low tide.

Plate 7. Mangroves in "Porosus Creek", Hunter River system at low tide. *Rhizophora stylosa* is shown with aerial roots at the left and without aerial roots at the right. *Avicennia marina* is in the centre and seedlings of *Aegialitis annulata* occur in the foreground.

Plate 8. The Prince Regent River showing the small extent of mudbanks and fringing mangroves.

B. CROCODILE NUMBERS AND SIZE CLASSES

The river system was surveyed over two nights, the lower reaches and creeks being spotted on the night of 20 July 1977 and the upper reaches and creeks on 21 July 1977. Table 4 gives the size class distribution and the situation of the 50 crocodiles spotted and Fig. 8 shows their location in the river system.

TABLE 4. CROCODILE NUMBERS AND SITUATION MITCHELL RIVER SYSTEM.20-21 JULY 1977.

SIZE (Metres)	No.	SITUATION						FEEDING
		IV	IVIW	OM	IM	SWOE	MS	
H	8		1			7		
.6-.9	1					1		
.9-1.2	9		1	1		6	1	
1.2-1.5	12	1				11		
1.5-1.8	8		2			5	1	1
1.8-2.1	3		1			2		
> 2.1	6			1		5		
EO	3					1	2	
TOTAL	50	1	5	2	0	38	4	1

Abbreviations as in Table 2.

The size class distribution, as well as the distribution along the river, again appears to be that of a badly depleted system. Eight hatchlings were spotted, showing that there was at least one successful nest during the last wet season. However, considering that an average nest produces between 40 and 50 hatchlings (Webb *et al.* 1977), mortality appears very heavy, as it did in the Lawley system.

Subjectively, the Mitchell appears to provide excellent Salt-water Crocodile habitat and there is little doubt that it once held large numbers of crocodiles. The "Australia Pilot" Volume 5, 1972, reports that during the 1918 survey of the Mitchell "The River swarmed with alligators, over 100 having been seen in one day".

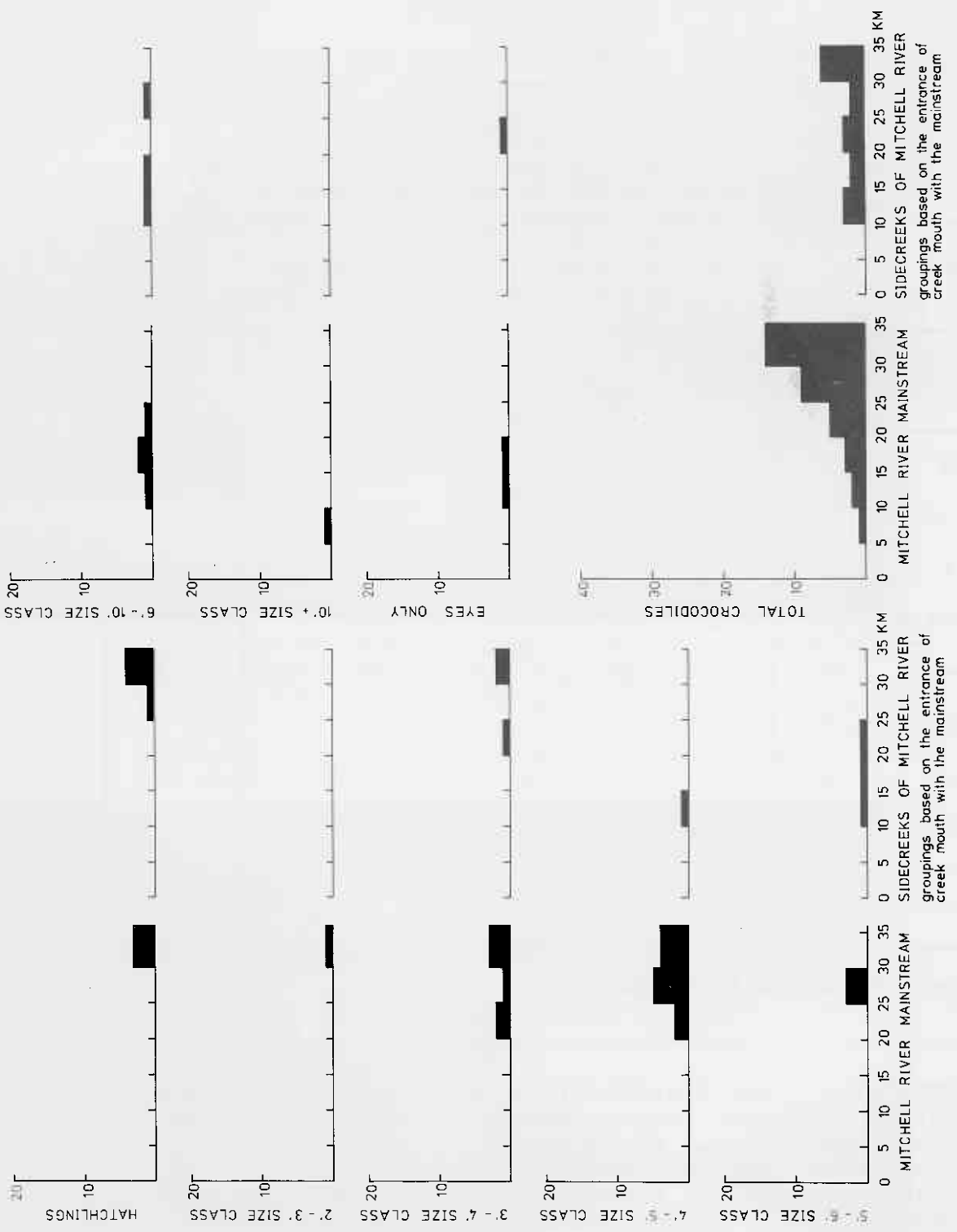

Figure 8. Crocodile distribution, Mitchell River.

Bustard (1970) quotes Father Sanz of Kalumburu Mission as describing the shooting of 35 crocodiles in four days *in daytime* in Admiralty Gulf, six or seven of which exceeded 14 feet (4.3 m) in length. Father Sanz said that shooting in this area started about 1963 and that in two years over 3 000 were shot between Bigge Island and Cape Londonderry, most coming from Admiralty Gulf. The present situation is in stark contrast - only 50 crocodiles being present, over seven years after the species was legally protected, and possibly twelve years since the period of maximum shooting pressure. There seems little doubt that a very high proportion of those crocodiles present in the Mitchell were shot.

As is the case with the Lawley there was little evidence of large crocodiles in the river, other than those we saw during our survey. One slide, estimated to have been made by a 3.3 to 3.7 m crocodile was seen at about 26.8 km.

The Mitchell River crocodile population appears to have been recruiting at a very low rate and if this trend continues there is little potential for a significant recovery in the immediate future. Based upon our experience with Arnhem Land rivers, it is in fact likely that the crocodile numbers are still falling on the Mitchell River.

V THE ROE RIVER

A. DESCRIPTION

The Roe River with its numerous side creeks flows into Prince Frederick Harbour at its south-east corner. To the north of the entrance is a large bay with three creeks and three further creeks enter the Harbour to the west of the river mouth (Fig. 9). The river is under tidal influence for about 33 km.

From 9 km to 13.5 km upstream are several large mangrove islands and there are numerous sand bars, exposed at low tide, from 13.5 km to 21.5 km. Upstream from here, the river runs through a scenic gorge. Above 30 km the river bed dries at low tide except for a small fresh water flow. The Moran River, which enters the Roe at 31.5 km is navigable for only a few hundred metres. A small tidal bore was observed in the upper reaches of the Roe.

The salinity profile is given in Fig. 10 and is similar to other systems with a freshwater input. Several of the side creeks were found to have significant fresh water inputs. Temperature measurements made on the vessel at anchor at 9.2 km are also given in Fig. 10.

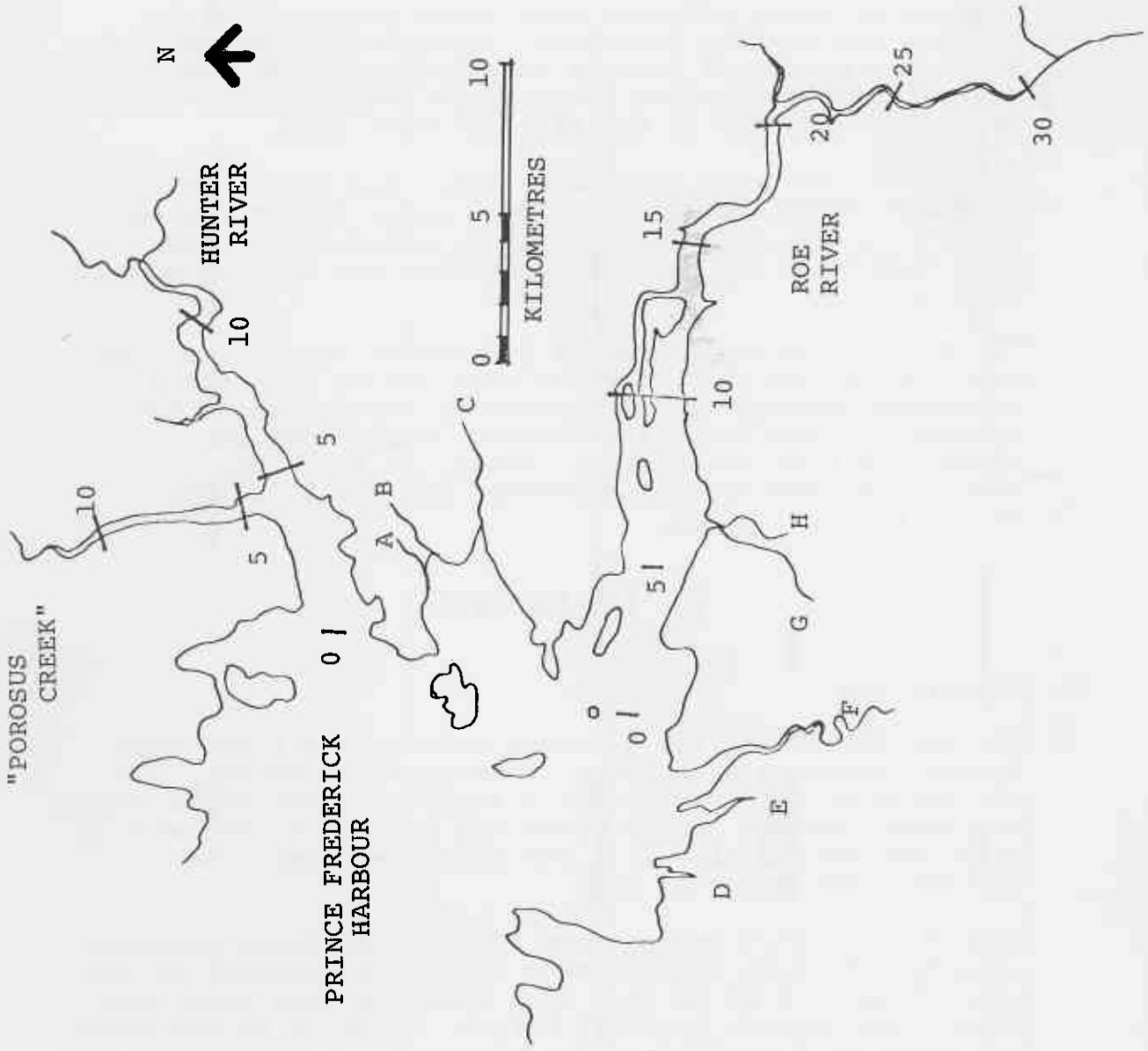

Figure 9. The Roe and Hunter River systems.

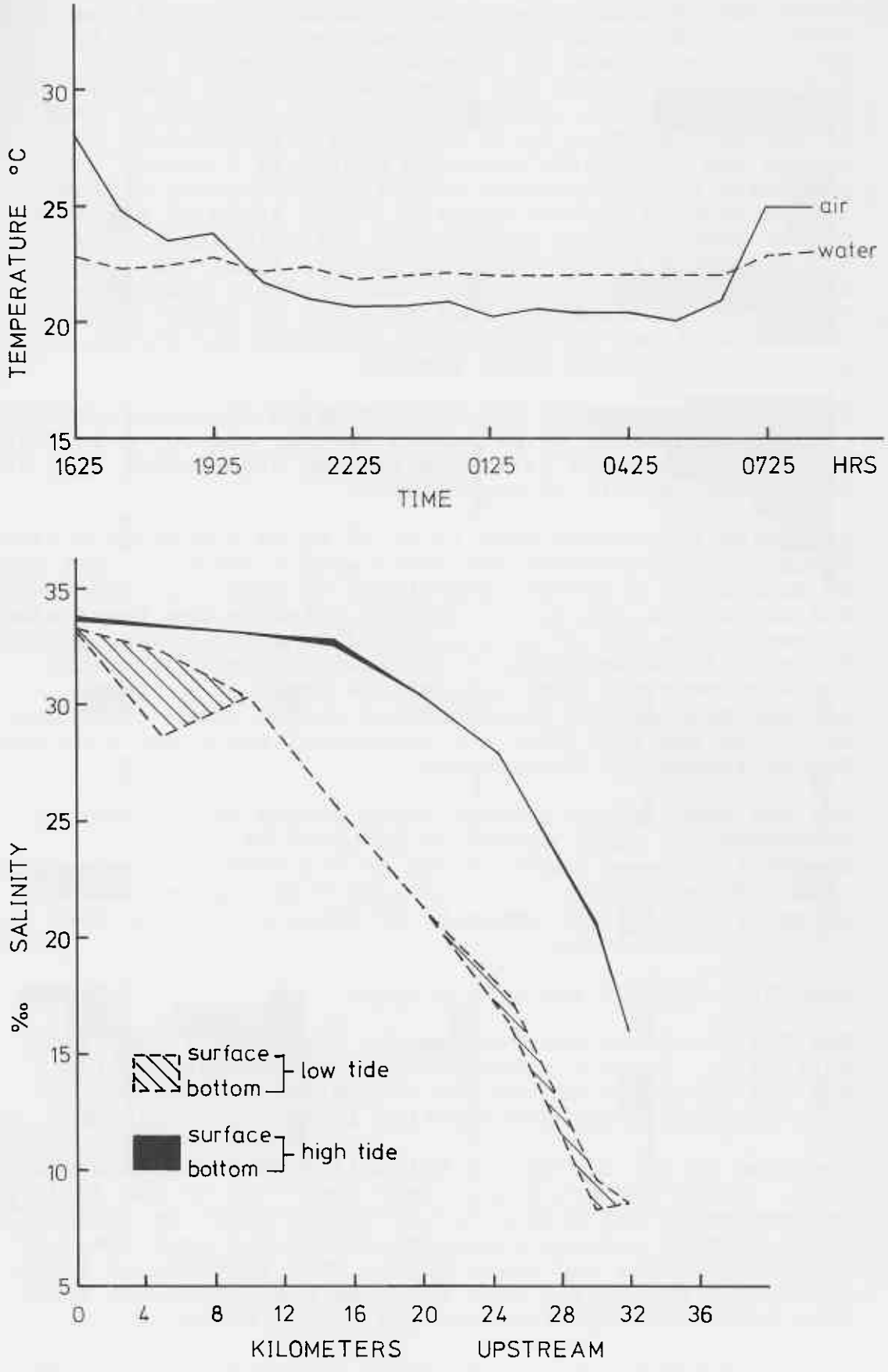

Figure 10. Temperature and salinity measurements in the Roe River system.

There are extensive low gradient mudbanks around the entrance and in the estuarine embayments adjacent to the river mouth and in these areas *Sonneratia alba* and *Avicennia marina* are established as the seaward pioneer community. *Rhizophora stylosa* occupies a band of variable width - up to 80 metres - immediately behind the *Sonneratia* zone and behind it a mixed community of *Camptostemon schultzii*, *Avicennia marina* and *Rhizophora stylosa* occurs. Where areas of slightly higher physiographic relief with suitable substrates are present a further zone of *Ceriops tagal* var. *australis* and *Avicennia marina* exists. Such *Ceriops* zones are generally low thickets, less than 5 m in height, with occasional trees of *Excoecaria agallocha* and shrubs of *Aegialitis annulata* being present.

This zone merges into the most landward mangrove community comprised entirely of *Avicennia marina*, about 5 m in height. There are extensive salt pans in some areas which are, in most cases, devoid of vegetation.

Riverside vegetation from 15 to 27 km is a mixed low closed-forest of *Camptostemon/Avicennia* with a canopy height around 10 metres and a sparse understorey of *Aegiceras corniculatum* and *Aegialitis annulata*. *Ceriops* thickets are found along cutaway banks and at points inland from the riverside fringe forest. A low woodland of *Avicennia* occupies the more landward mangrove zone and fringes areas of saltpan. Saltpan development is of limited extent above 17 km due mainly to the fact that the geological structure does not favour floodplain development.

The Roe River winds through steep gorges of Precambrian sandstone but quite extensive mudbanks still occur, especially around convex bends on the river. The dominant riverside vegetation over the last 8 km changes fairly abruptly to a mixed community of *Avicennia marina* and *Excoecaria agallocha*.

B. CROCODILE NUMBERS AND SIZE CLASSES

The Roe River was surveyed on the nights of 23 and 24 July 1977. Table 5 gives the size class distribution and the situation of the 176 crocodiles spotted and Fig. 11 shows their distribution in the river system.

Compared to the Lawley and Mitchell Rivers, numbers were high. Fifty-two hatchlings were seen - 22 on the 26-32 km section of the main river, 5 on the 21-26 km section, 14 in Creek F and the remainder spread out over the remaining creeks and river bank. This suggests at least one recent successful nest on Creek F and possible more than one on the upstream section of the river.

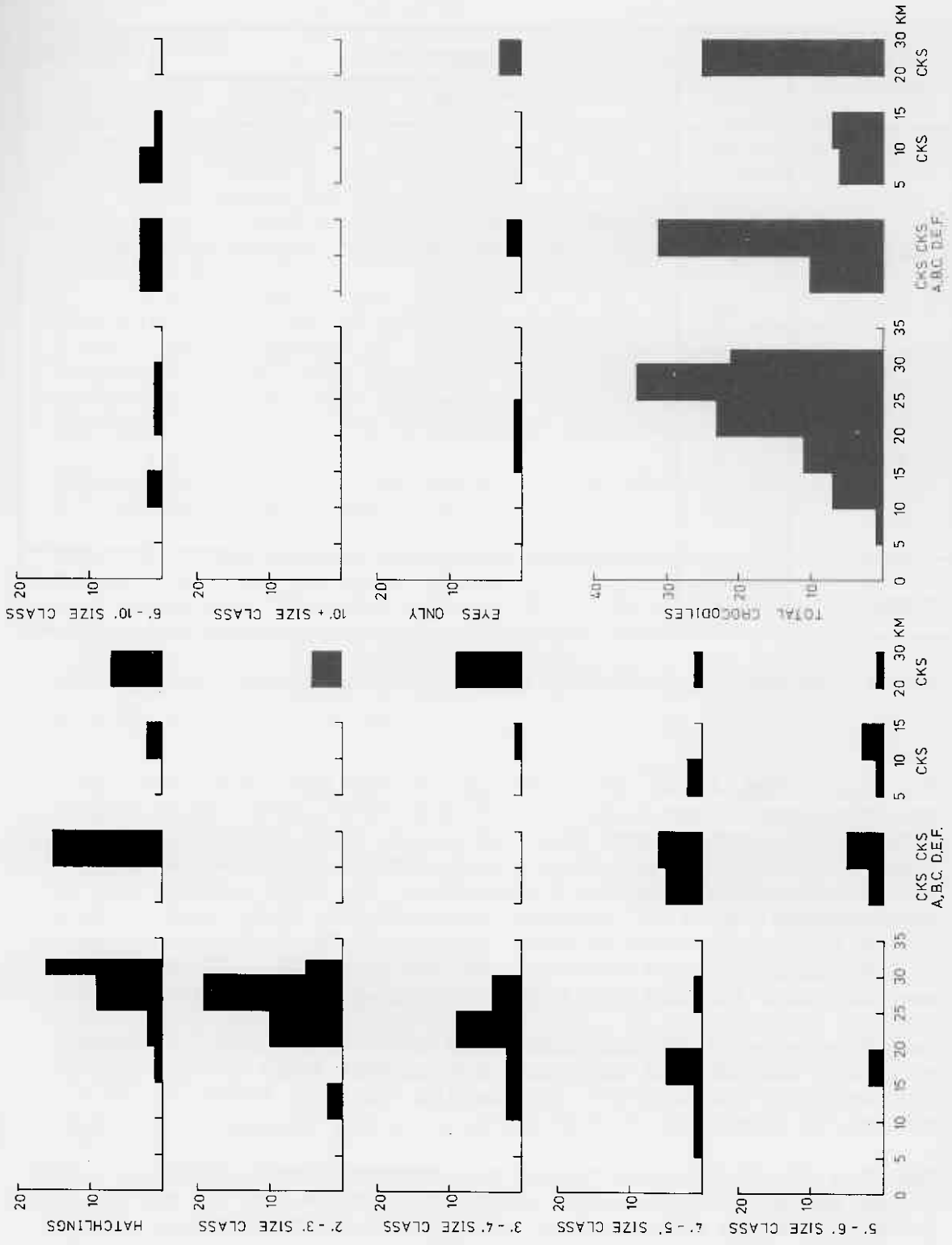

Figure 11. Crocodile distribution, Roe River system.

TABLE 5. CROCODILE NUMBERS AND SITUATION
ROE RIVER SYSTEM. 23-24 JULY 1977

SIZE (Metres)	No.	SITUATION						FEEDING
		IV	IVIW	OM	IM	SWOE	MS	
H	52			1		51		
.6-.9	40					40		1
.9-1.2	27			1	1	25		
1.2-1.5	22			2	1	18	1	
1.5-1.8	14					13	1	
1.8-2.1	8			1		7		
> 2.1	6					5	1	
EO	7	1				4	2	
TOTAL	176	1	0	5	2	163	5	1

Abbreviations as in Table 2.

The fact that forty 60 to 90 cm crocodiles (one year old animals) were seen indicates either that there were more hatchlings last season than this, or that mortality was lower. The remaining size class number distribution roughly parallels that of the other few reasonably good crocodile river systems in northern Australia. One slide, estimated to have been made by a 3.1 to 3.4 m crocodile was seen during the daytime. This animal was not seen during the night survey.

The figure of 2.25 non-hatchling crocodiles per kilometre of river and creeks compares favourably with 2.92 for the system with the highest population density known to us - the Blyth River in Arnhem Land.

The Roe River appears to have a comparatively good recruitment potential but whether this is due to a greater number of breeding crocodiles or to more favourable habitat is not known.

VI THE HUNTER RIVER

A. DESCRIPTION

The Hunter River (Fig. 9) flows into the north-east corner of Prince Frederick Harbour. Four kilometres from its mouth it is joined by a large tidal creek ("Porosus Creek") flowing from the north. North of the river mouth in Prince Frederick Harbour there are wide bays, lined with mangroves. The Hunter has three surveyable creeks running into it - here termed Creeks A, B and C.

The salinity profile of the Hunter (Fig. 12) suggests a very small inflow of fresh water from upstream. "Porosus Creek" has upstream salinities which are slightly higher than seawater. Both systems could become hypersaline by October or November.

Temperature profiles measured at the ship anchored at 2.5 km are also shown in Fig. 12.

Mangrove communities along the Hunter River and "Porosus Creek" are similar with respect to species composition and abundance. Extensive mudbanks are exposed below the mangroves during low tide.

The pioneer mangrove *Sonneratia alba* forms extensive groves in the downstream sections, and on many mudbanks a dense understorey of *Aegialitis annulata* occurs. Further upstream, the *Sonneratia* zone merges into a mixed riverside mangrove community of *Sonneratia alba*, *Comptostemon schultzii* and *Avicennia marina*. This plant association is particularly evident on accreting mudbanks. Behind this riverside pioneer fringe, a low closed-forest of *Rhizophora stylosa* is commonly observed. Due to steep cliffs that abut the streams, typical landward mangrove communities are often absent. However, in areas of slightly higher physiographic relief with suitable substrates, plant associations principally of *Camptostemon schultzii*, *Avicennia marina* and *Rhizophora stylosa* occur. Thickets of *Ceriops tagal* var. *australis* occur to a minor extent in the more landward areas.

B. CROCODILE NUMBERS AND SIZE CLASSES

The Hunter River and "Porosus Creek" were surveyed on the night of 25 July 1977. Table 6 shows the number of each size class and their situation and Fig. 13 shows their distribution in the river systems. Of the 47 crocodiles spotted, 15 were in "Porosus Creek" and 32 in the main river and its other side creeks.

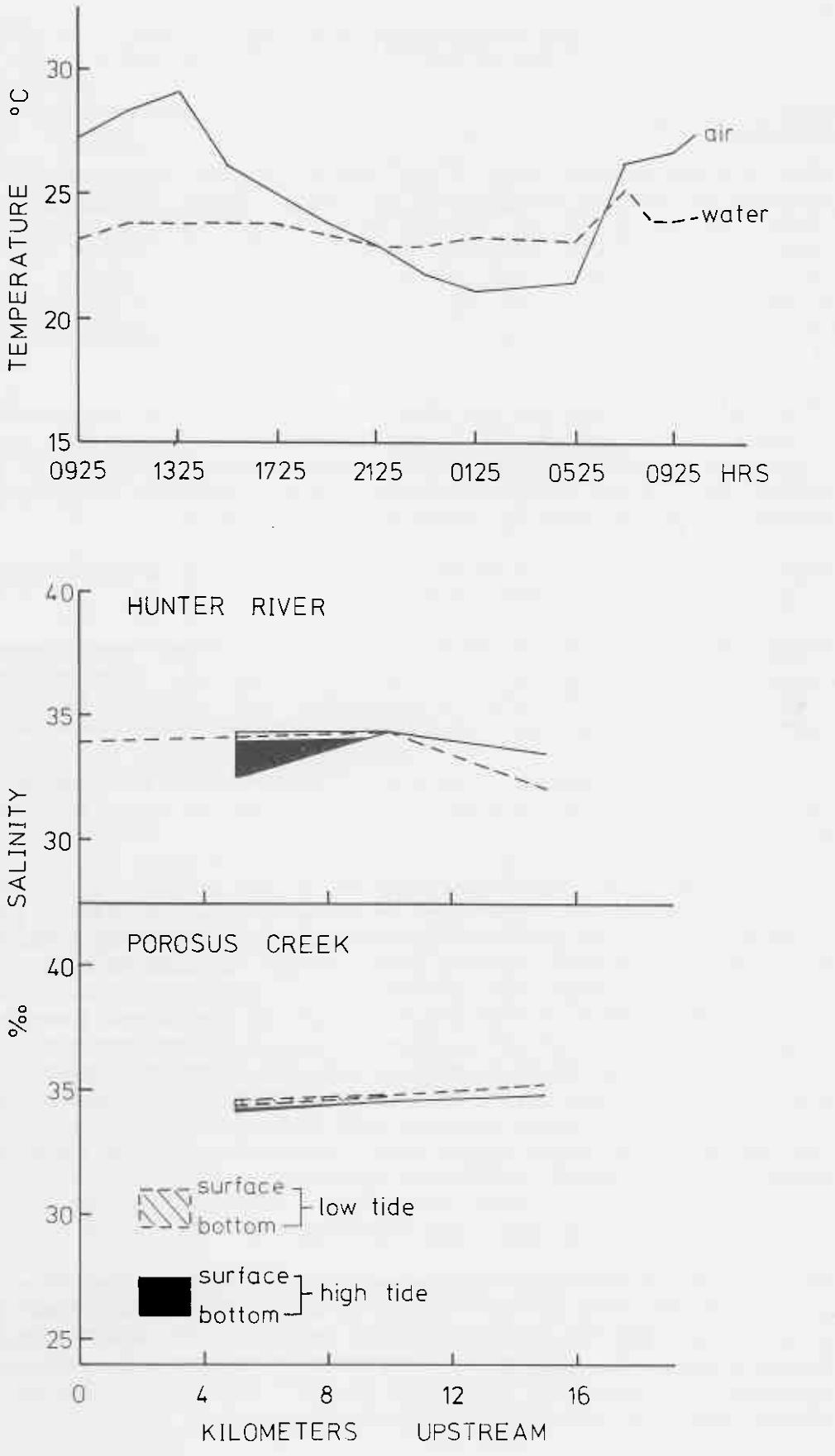

Figure 12. Temperature and salinity measurements in the Hunter River system.

TABLE 6. CROCODILE NUMBERS AND SITUATION
HUNTER RIVER SYSTEM. 25 JULY 1977

SIZE (Metres)	No.	SITUATION						FEEDING
		IV	IVIW	OM	IM	SWOE	MS	
H.	11					11		
.6-.9	7					7		
.9- 1.2	5					5		
1.2-1.5	10					10		
1.5-1.8	6				1	5		
1.8-2.1	4					4		
> 2.1	2					2		
EO	2					2		
TOTAL	47	0	0	0	1	46	0	0

Abbreviations as in Table 2.

Eleven hatchlings were seen in the system and the greatest number of these were in Creeks B and C in the upstream section of the River. This suggests the presence of at least one recent successful nest in the upstream section of the Hunter. It is also likely that there was another successful nest in "Porosus Creek".

In Arnhem Land it has been reported that nesting activity is restricted to fresh or brackish parts of rivers (Webb *et al.* 1977). Where hatchlings have been observed in iso- or hyper-saline waterways the nests have been shown to be in adjacent freshwater swamps. Insufficient time was available to search for old nests during this survey but it seems likely that nesting in the Hunter River system takes place in the upper reaches at a time when the heavy fresh water input of the wet season is occurring. It is unlikely that the hatchlings came from the Roe River since the hatchlings observed there were concentrated in the upstream sections of the river - if movement takes place one would expect to find scattered hatchlings in the downstream sections (Webb and Messel, in press).

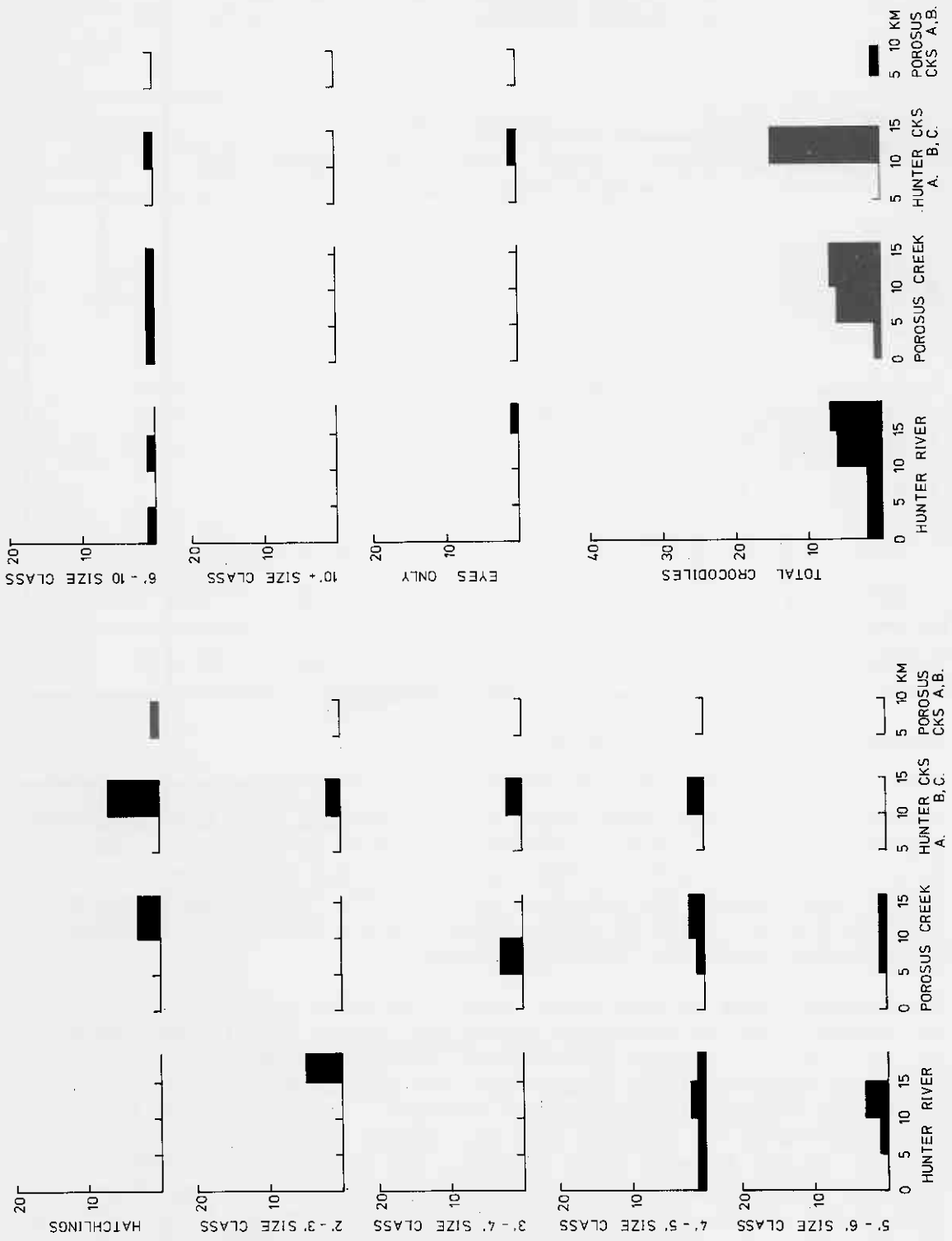

Figure 13. Crocodile distribution, Hunter River system.

Seven one year age class (60 to 90 cm) crocodiles were spotted, further reinforcing the suggestion that successful breeding takes place in the Hunter system. However, only six crocodiles longer than 1.8 m were seen on the spotlight surveys. No evidence for additional large animals was gathered during the daytime except for a 1.8 to 2.1 m crocodile which was sighted in the bay immediately outside the river mouth in Prince Frederick Harbour. These larger animals constitute the remnant from the period of high hunting pressure as well as possible immigration from the Roe. Studies on movements of *C. porosus* in Arnhem Land suggest significant movements of the larger crocodiles between river systems (Webb and Messel, in press).

As is the case in other river systems reported on here, the Hunter crocodile population has obviously suffered heavy depletion and it is not possible to say whether numbers have begun to increase, are stationary or are still falling. It seems reasonable to conclude that the upper sections of the Hunter River and its creeks provide some suitable habitat for nesting but the number of potentially breeding adults is low and the build up of the population, if it occurs at all, can be expected to be slow.

The Roe and Hunter River systems, which are adjacent to each other in Prince Frederick Harbour, together provide an area where, in the absence of poaching, Salt-water Crocodile numbers could be expected to return slowly to a population density and size structure similar to that prevailing before the period of extreme hunting pressure.

VII THE PRINCE REGENT RIVER

A. DESCRIPTION

The Prince Regent River flows into St George Basin (Fig. 14). The river is tidal for about 45 km upstream from its outlet into the Basin. However we were not able to proceed above a rock bar which occurs 40 km upstream (the 73 km mark on Fig. 14) although this would be possible at a higher tide.

For most of its course the estuarine portion of the Prince Regent runs through a rugged gorge and mud banks occur only intermittently in the main stream.

The riverside mangrove community along the river is typically a mixed low closed-forest of *Camptostemon schultzii*, *Rhizophora stylosa* and *Avicennia marina*. *Sonneratia alba* is frequent, being the more outward pioneer on accreting mudbanks. *Aegialitis annulata*

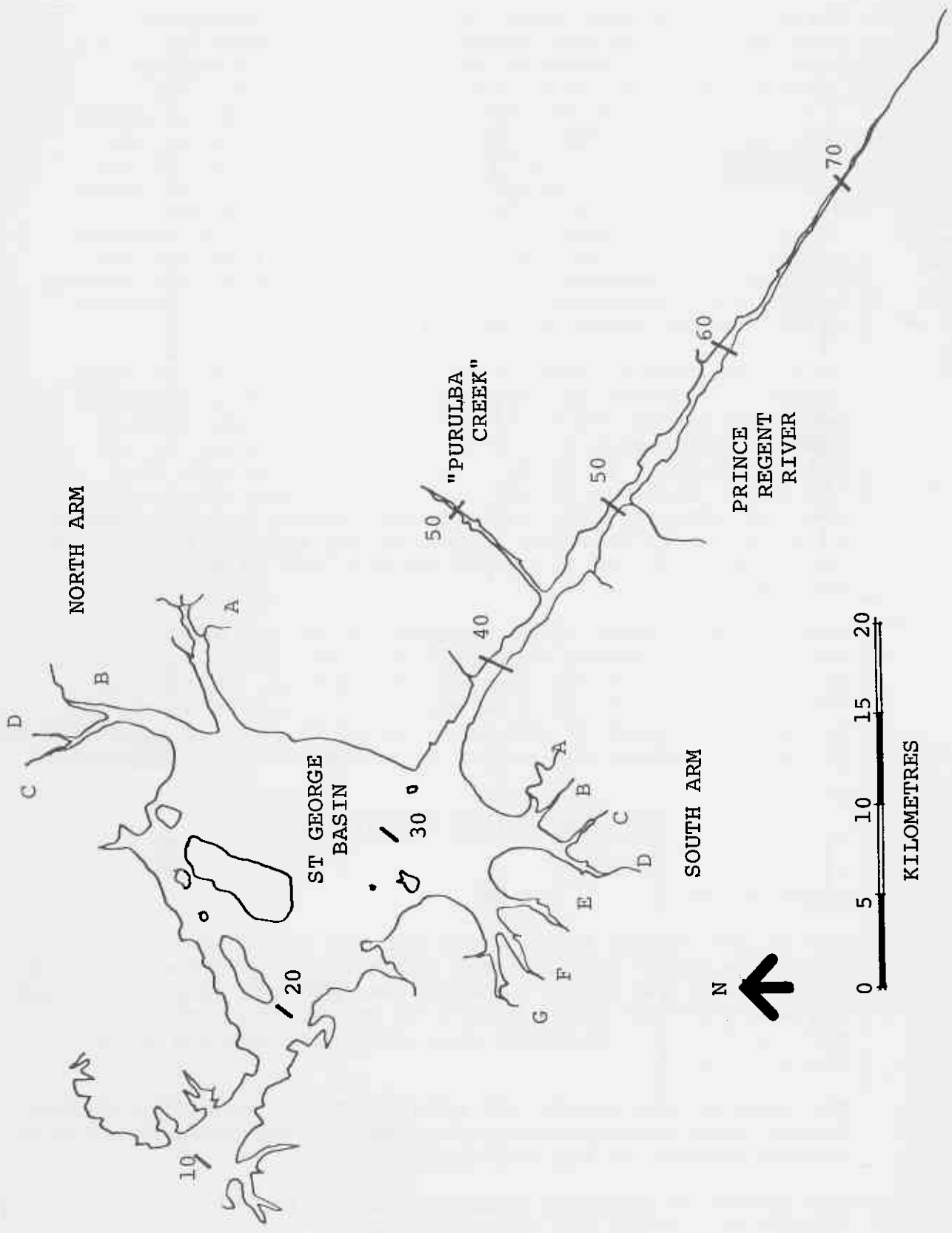

Figure 14. The Prince Regent River system.

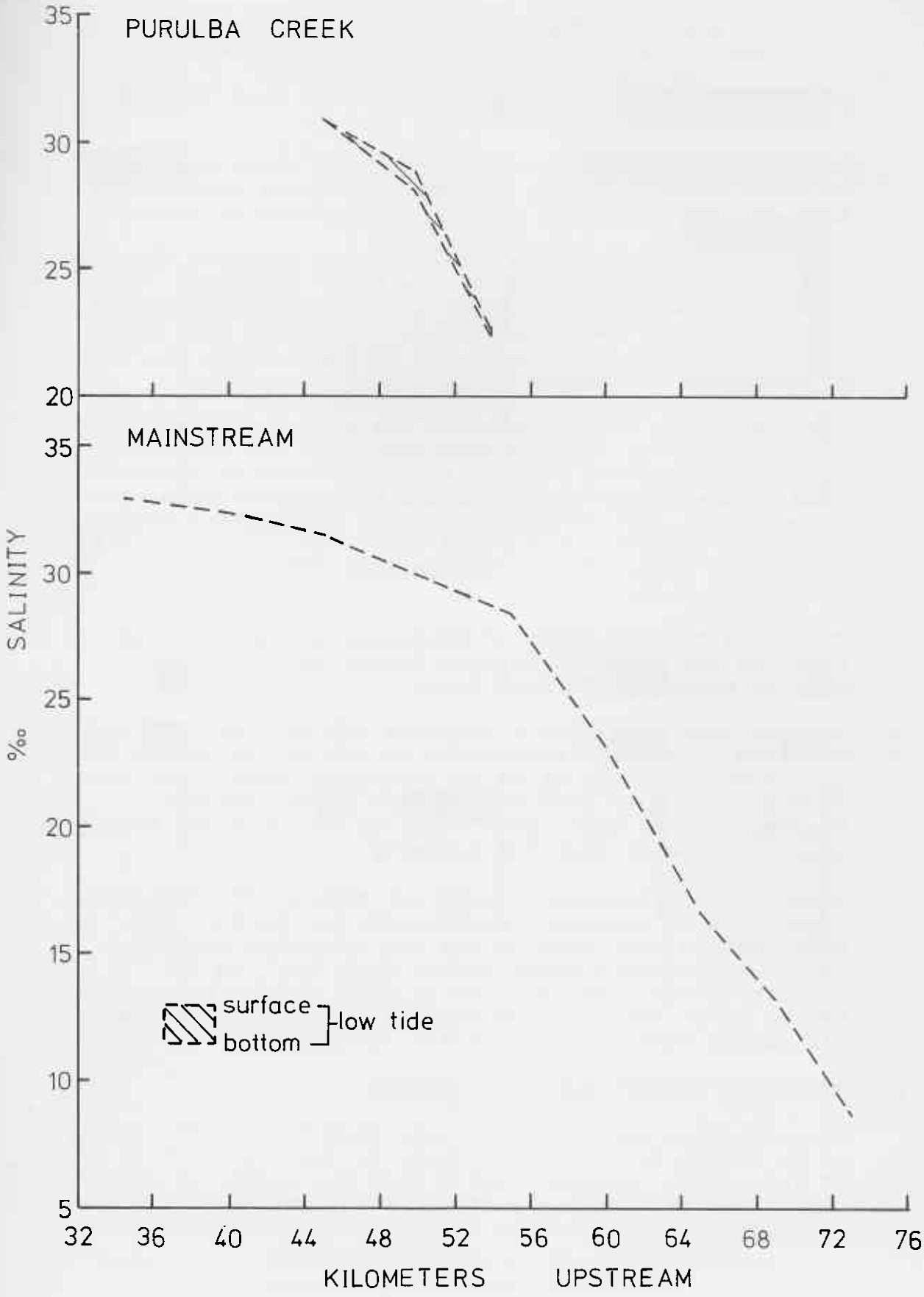

Figure 15. Salinity measurements in the Prince Regent River.

is often present. Sporadic *Ceriops* thickets with infrequent trees of *Excoecaria agallocha, Bruguiera exaristata* and *Xylocarpus moluccensis* occur on areas of slightly higher physiographic relief than the riverside mangrove communities.

A number of navigable creeks enter the river and some of these contained more extensive mangrove communities. Lack of time precluded a close examination of them.

In St George Basin there are two large mangrove lined arms, one lying each side of the River entrance. These arms are broken into a number of channels (here termed Creeks) each of which is further subdivided into side channels. These constitute two of the largest blocks of mangroves in Western Australia.

The vegetation comprises mixed low closed-forests of *Sonneratia alba, Camptostemon schultzii* and *Avicennia marina*. *Rhizophora stylosa* is to be found as a distinct band of low closed-forest behind the seaward pioneer fringe. The more landward mangrove communities commonly are mixed thickets of *Ceriops tagal* var. *australis* with occasional trees of *Avicennia marina* interspersed throughout them.

There are further areas of mangroves in small creeks entering the Basin at various places as well as in Munster Water and Rothsay Water.

Lake of time precluded a complete salinity profile being measured. Low tide salinities in the Prince Regent River and in the side arm at 44 km ("Purulba Creek") are given in Fig. 15. Both show fresh water input upstream. Readings in the Basin were close to 34 parts per thousand, that is close to seawater salinity.

Temperature measurements were not made at the Research Vessel due to equipment malfunction on the last day. Measurements were made during the crocodile surveys. In St George Basin water varied from 24.7^{o} to 25.7^{o}C and air varied from 20.5^{o} to 23.4^{o}C. In the Prince Regent River water varied from 23.7^{o} to 26.2^{o}C while air varied from 17.0^{o} to 26.1^{o}C.

B. CROCODILE NUMBERS AND SIZE CLASSES

The estuarine part of the Prince Regent River and parts of St George Basin were surveyed on the nights of 26 and 27 July 1977. Tables 7 and 8 show the number of each size class seen and their situation, and Figs. 16 and 17 show their distribution in the river, creeks and basin.

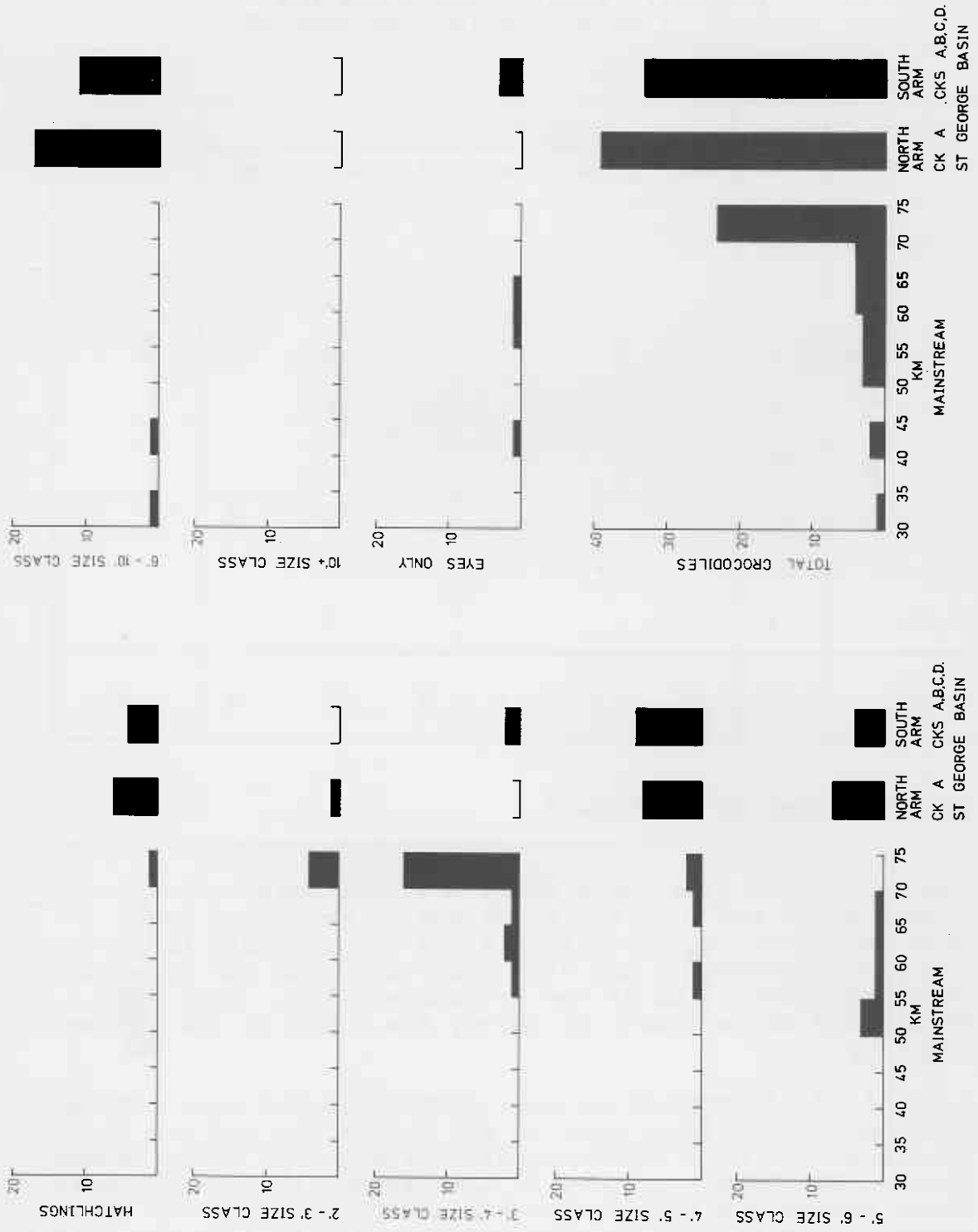

Figure 16. Crocodile distribution, Prince Regent River and St George Basin.

TABLE 7. CROCODILE NUMBERS AND SITUATION
ARMS OF ST GEORGE BASIN. 26 JULY 1977

SIZE (Metres)	No.	SITUATION						FEEDING
		IV	IVIW	OM	IM	SWOE	MS	
H	10			1		9		
.6-.9	1					1		
.9-1.2	2					2		
1.2-1.5	18		1		1	16		
1.5-1.8	10					10		
1.8-2.1	15		2			11	2	
> 2.1	13		6			7		
EO	3					3		
TOTAL	72	0	9	1	1	59	2	0

Abbreviations as in Table 2.

Due to lack of time, only Creek A in the north arm and Creeks A,B,C and D in the south arm of St George Basin were surveyed. Additionally it was not possible to survey the River between 73 and 78 km due to a rock bar impeding progress above 73 km at low or quarter tide. Many more days would be necessary to survey the whole of the system properly.

A total of 146 crocodiles were sighted in the area covered. Seventy-four of these were in the main river and its side creeks and 72 were in the mangrove-lined arms of St George Basin. The total included 25 hatchlings, 15 from the main river system and 10 from the Basin. Of those in the main river system 12 were in side creeks and only 3 in the main stream (in the 60 to 65 and 70 to 73 km sections). Similarly, only four 60 to 90 cm crocodiles were seen, all in the main river. In contrast we spotted twenty-five 90 to 120 cm and twelve 1.2 to 1.5 m animals. The small number of hatchlings and 60 to 90 cm crocodiles

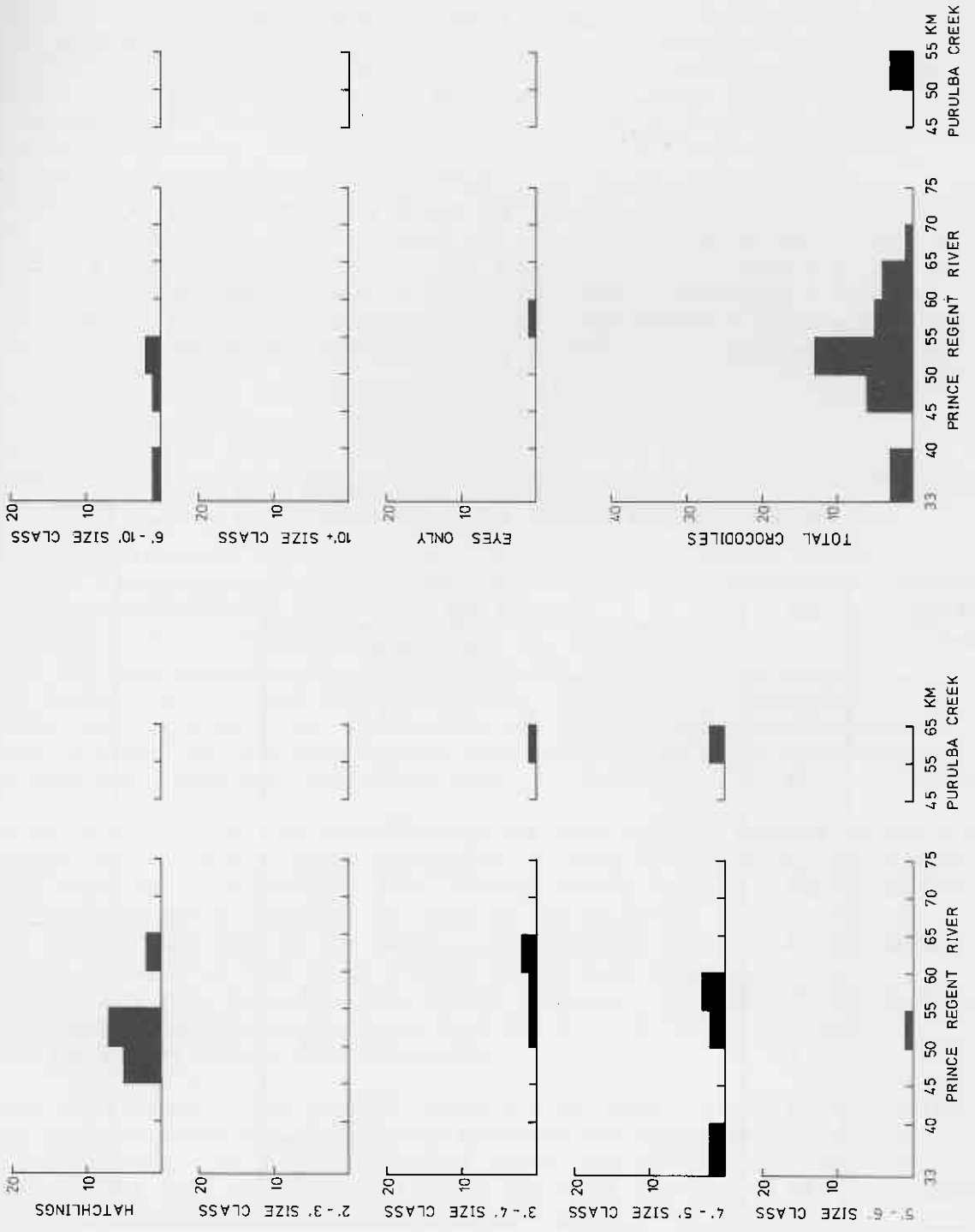

Figure 17. Crocodile distribution, Creeks flowing into the Prince Regent River.

observed may perhaps be attributed to our inability to survey above 73 km - it seems likely that this area contained more hatchling and one-year age class crocodiles. The banks between 70 and 73 km appeared suitable for nesting and those between 73 and 78 km appear, from air photographs, to be similar.

The 12 hatchlings sighted in 4 different creeks running into the Prince Regent appear to have resulted from at least three successful nests. In two cases - the creek at 52 km and Gariyeli Creek (48 km) - a 1.8 to 2.1 and a 2.1 to 2.5 m crocodile was observed a few metres away from a group of hatchlings. It is possible that in these parental care was still being provided (see Webb *et al.* 1977).

TABLE 8. CROCODILE NUMBERS AND SITUATION PRINCE REGENT RIVER AND ITS CREEKS, 27 JULY 1977

SIZE (Metres)	No.	SITUATION						FEEDING
		IV	IVIW	OM	IM	SWOE	MS	
H	15			2		13		
.6-.9	4					4		
.9-1.2	25	1		2		22		
1.2-1.5	12		2			10		
1.5-1.8	8					8		
1.8-2.1	5					1	4	
> 2.1	1						1	
EO	4		1			3		
TOTAL	74	1	3	4	0	61	5	0

Abbreviations as in Table 2.

Ten hatchlings were seen in the St George Basin arms, one in each of seven different side creeks and three in another side creek (in the north bay). It is not possible to say whether these hatchlings are the result of nests constructed in the Basin or whether they have drifted from upstream in the Prince Regent River - see Webb and Messel in press. The three hatchlings in close proximity in one small side creek suggests a nest in this place. If this is correct, the small number of remaining hatchlings and the fact that only one 60 to 90 cm crocodile was seen in the Basin, suggests high mortality of hatchlings in this region. This may possibly be attributed, in part, to the comparative clarity of the water in the Basin arms, providing increased chance of predation.

The distribution of crocodiles in the larger size classes in the main River and its creeks is similar to that of a badly depleted population, except for the almost complete absence of larger crocodiles near the mouth of the River (Table 8).

The distribution of the size classes in St George Basin (Table 7) is in striking contrast. Here the majority of crocodiles seen were greater than 1.2 m long, including 28 over 1.8 m. Considering that we only surveyed about half of the habitat in the two large arms of the Basin and allowing for 60% spotting efficiency (see Methods) there are probably in the order of 200 crocodiles greater than 1.2 m long in the Basin, most of which have reached, or are approaching, breeding age.

It is clear that the mainstream of the Prince Regent River, except for a small area upstream of the 70 km mark, provides poor crocodile habitat, i.e. steep rocky shores. Only 21 crocodiles were spotted in the 36 km between the mouth of the river and the 70 km mark. Additional to these, we saw three slides in the main river which had been made by crocodiles not seen on the night survey. These animals were estimated to have been 2.5 to 2.7, 2.7 to 3.0 and 3.4 to 3.7 m long, respectively.

Webb and Messel (in press) have shown that, in Arnhem Land, the larger size classes tend to move to the region near a river mouth. It is postulated that, in the Prince Regent, because of the lack of suitable habitat in the river proper, these animals move into St George Basin.

The Prince Regent River system crocodile population appears to have been heavily hunted in the past. It does, however, appear to have a reasonably good potential for recovery with a relatively large number of near adult crocodiles occurring in St George Basin. Our survey was too short term for us to be able to judge whether there is sufficient breeding habitat for this potential to be realised.

VIII DISCUSSION

During the short but concentrated survey reported here, we counted Salt-water Crocodiles in four major river systems in the north-west Kimberley - the Lawley, Mitchell, Roe-Hunter and Prince Regent.

The results show that in all these areas the crocodile populations remain greatly depleted following the hunting which took place in the fifties and sixties. Apart from our results this is confirmed by the fact that crocodile shooting became uneconomic by 1969.

During the whole survey we saw 463 *C. porosus* of which 109 were hatchlings. Only a small fraction of hatchlings appear to survive and they should not be included in any estimate of the viable population size. The breakdown of non-hatchling crocodiles is:

Lawley		44	-	11	hatchlings =	33
Mitchell		50	-	8	hatchlings =	42
Roe		176	-	52	hatchlings =	124
Hunter	:	47	-	11	hatchlings =	36
Prince Regent	:	146	-	25	hatchlings =	121

As discussed above we only surveyed about half of the two large mangrove lined arms in St George Basin. Assuming that the remaining half contained the same number of crocodiles the Prince Regent system would contain 218 - 35 hatchlings = 183 non-hatchling crocodiles. There are additional small creeks and bays in St George Basin, Rothsay Water and Munster Water which we did not examine.

If we assume that we saw only 60% of the crocodiles present (see Methods) the maximum number of non-hatchling crocodiles for each system becomes:

Lawley		55
Mitchell		70
Roe		207
Hunter		60
Prince Regent	:	305
Total	:	697

This constitutes an extremely low population considering the extent of the systems surveyed. Furthermore our survey supports the contention that there are very few large adults in the systems examined.

We cannot say that the crocodile populations of the rivers examined are recovering. As discussed earlier, the potential for recovery in the Lawley and Mitchell Rivers is low while that in the Roe-Hunter systems and the St George Basin-Prince Regent system appears a little better.

Simply because our surveys revealed a number of sub-adults which have entered the population does not imply an increase in the total population - they may not be replacing natural mortality. Recent counts in Arnhem Land have revealed that numbers are dropping rather than increasing in river systems with comparable numbers to those we counted (Messel 1977).

The Prince Regent River Nature Reserve has an important part to play in any recovery of *Crocodylus porosus* in Western Australia. The reserve already holds good populations of *C. johnstoni* (Storr and Smith 1975).

It is clear that there are far too few Salt-water Crocodiles in this region of the Kimberley to contemplate allowing culling for the hide trade. In our opinion there are also far too few to allow the limited taking of crocodiles to attempt "farming". In southern United States of America, where *Alligator mississippiensis* suffered a somewhat similar hunter induced population decline, numbers were allowed to increase beyond 500 000 before culling was allowed. Numbers are now at about 750 000.

Future monitoring of Salt-water Crocodile populations in the Kimberley will be required to find out whether in fact numbers are increasing or decreasing.

IX ACKNOWLEDGEMENTS

Our thanks are due to Drs G.J.W. Webb and B.R. Wilson for helpful suggestions in relation to this report. The field assistance of B.R. Wilson, P.J. Fuller and A.J. Watson was of great value. Mrs J. Start drew many of the figures and Mrs T. Woodward typed the report.

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