Saltwater crocodiles (*Crocodylus porosus*) in the northwest Kimberley

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WAMSI Kimberley Marine Research Program

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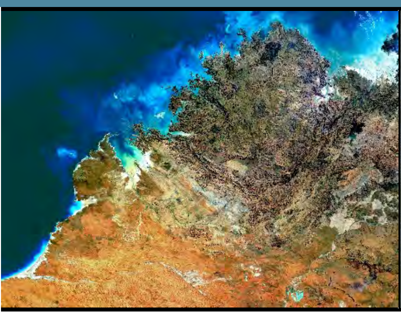
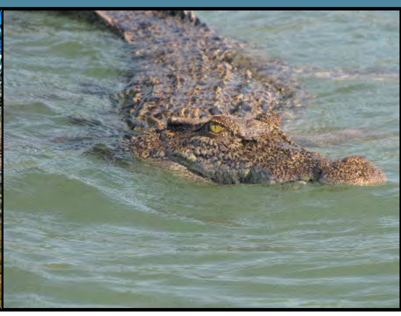
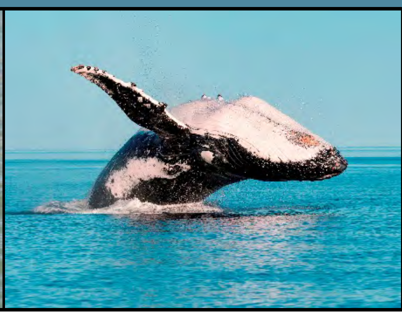
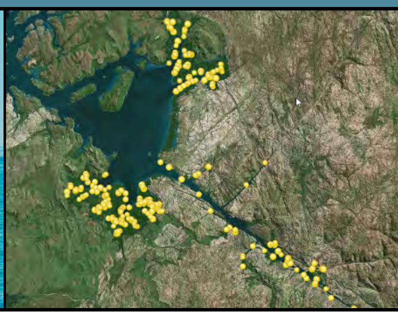

WAMSI Kimberley Marine Research Program

Initiated with the support of the State Government, the Kimberley Marine Research Program is co-invested by the WAMSI partners to provide regional understanding and baseline knowledge about the Kimberley marine environment. The program has been created in response to the extraordinary, unspoilt wilderness value of the Kimberley and increasing pressure for development in this region. The purpose is to provide science based information to support decision making in relation to the Kimberley marine park network, other conservation activities and future development proposals.

Front cover images (L-R)

Image 1: Satellite image of the Kimberley coastline (Image: Landgate)

Image 2: A large crocodile in the Roe river (Image: Tim Willing)

Image 3: Humpback Whale (Image: Pam Osborn)

Image 4: Spatial distribution of crocodiles in the Prince Regent River system in 2015 (Image: Andrew Halford).

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1 Executive Summary

Saltwater crocodile populations have been protected in Australia since 1969 when three previous decades of unregulated hunting had driven down numbers across the Kimberley and the Northern Territory (NT) to < 8000 individuals.

Since the advent of protection considerable research has been conducted on crocodile populations however the geographic focus has been in the NT where annual surveys of crocodiles since 1975 have demonstrated a spectacular recovery with population densities now at carrying capacity in many river systems.

Surveys were conducted annually between 1992 and 2012 in the Ord River, East Kimberley, as part of a monitoring program associated with egg harvesting in the region. Prior to our surveys in 2015 however, there had been no surveys in the West Kimberley (West of Cape Londonderry) since those of Professor Harry Messel and colleagues in 1986, some 30 years ago. At that time the total population of the West Kimberley was estimated at ~2,500 adults.

In late July and early August 2015 we surveyed the Prince Regent and Roe-Hunter River systems which had been identified by Messel as the two most favourable systems for crocodiles along the West Kimberley coast. With 206km of linear river length the Prince Regent is far longer than any river in the NT with only the Adelaide River coming close at 135km. The Roe-Hunter system at 103 km linear length is also longer than most rivers in the NT. However, the upper reaches of NT rivers contain billabongs and savannah floodplain habitats which are vital for nesting but are markedly reduced in the West Kimberley where the coast is defined by cliffs, boulder shores and high-sided ravines.

We counted a total of 626 non-hatchling crocodiles within the Prince Regent River system in 2015, along with 82 hatchlings. This compared to 242 non-hatchlings and 5 hatchlings counted in 1986, equating to a 259% increase in the abundance of non-hatchling crocodiles over 29 years. Within the Roe-Hunter river system we counted a total of 545 non-hatchling crocodiles and 131 hatchlings. This compared to 263 non-hatchlings and 10 hatchlings counted in 1986, equating to a 207% increase in the abundance of non-hatchling crocodiles over 29 years.

As well as more animals the size structure of the populations in 2015 had shifted from that seen in 1986 with a greater abundance of larger crocodiles (>1.8m), which is in accordance with what is known about recovery trends in crocodile populations in the NT.

Density in numbers and biomass of crocodiles in the West Kimberley rivers was compared to rivers in the NT with similar linear river lengths (as much as was possible) and relatively stable crocodile populations. Such comparisons highlight the extent to which further recovery is still possible and/or how different the West Kimberley river systems might be to the NT. We found a density of 3.04 non-hatchling crocodiles per km of river in the Prince Regent River system compared to 4.18 crocodiles per km in the Adelaide River. The disparity in biomass density was even greater, with 74.3kg per km of river compared with 274.02kg on the Adelaide River. This difference in biomass is due to the number of very large crocodiles (>3m), of which only 5 were seen on the Prince Regent River system compared to 63 counted in the Adelaide River in the same year. The increase in biomass with increasing length in crocodiles follows a power law with crocodiles over 3m gaining weight at ever increasing rates.

In the Roe-Hunter river system we found a density of 5.2 non-hatchling crocodiles per km of river compared to 6.6 crocodiles per km in the Daly River. The disparity in biomass density was even greater, with 134.9kg per km of river compared with 601kg per km on the Daly River. This difference in biomass is also due to the number of very large crocodiles (>3m) with only 24 seen on the Roe-Hunter river system compared to 84 counted in the Daley River in 2016.

While only 3 points are available to model trends (1978, 1986 and 2015) we note that abundances continue to increase in a strongly linear pattern across both systems, suggesting that crocodile populations are still actively

recovering. This concurs with the results of our comparisons with the NT rivers which clearly demonstrate major differences in total numbers, and in particular the number of very large crocodiles between the NT and West Kimberley.

Because of the clear differences in geomorphology of West Kimberley river systems it remains uncertain whether the dynamics of crocodile recovery will continue to closely mirror the NT systems. Less appropriate nesting habitat at the regional scale is a potential bottleneck of unknown magnitude but, if significant, could be expected to slow recovery dynamics relative to the NT. Nevertheless with over 200 hatchlings sited across both systems in 2015 there is clearly active recruitment into the population. Recruitment success is nevertheless closely tied to summer rainfall patterns and there can be large fluctuations from year to year. Kimberley rivers might eventually hold similar densities of crocodiles to the NT but it is equally possible that the major geomorphological differences may limit population size and structure to a lower level than is seen in the NT.

As well as spotlight surveys of crocodiles we undertook extensive tissue sampling of crocodiles across both systems (70 individuals) to contribute to a national study looking at the genetic connectivity between crocodile populations across Australia. Preliminary results demonstrate clearly that the populations in the Prince Regent and Roe-Hunter River systems are not related to NT populations. This indicates that local region dynamics are more important influences on crocodile populations in the West Kimberley and they should therefore be managed as a separate stock. We would expect connectivity with the East Kimberley populations but genetics samples have not yet been obtained from this area to confirm this.

From an ecological viewpoint our surveys confirm that crocodile populations in the West Kimberley have continued to recover from the unregulated hunting in the past. Based on this survey the health of crocodile populations in the greater Kimberley can be considered 'very good' with no natural predators, good water quality and an abundance of food. Comparisons with NT populations indicate that populations in WA remain in an upward recovery trajectory with densities and standing biomass continuing to increase.

1.1 Key Residual Knowledge Gaps

There remains a high degree of uncertainty around a complete regional understanding of recovery dynamics of crocodiles. While genetics has identified that West Kimberley populations are completely separated from NT populations it is not known how interconnected the populations are along the west coast. Apart from the Glenelg River which was surveyed by Messel and colleagues in 1978 and 1986, there have been no surveys done in rivers and creeks south of Prince Regent River which is also where the largest concentration of people are to be found. This will make it difficult for conservation managers to develop effective plans for dealing with the interactions generated by a growing crocodile population and its proximity to an increasing human population in the region, especially around the large population bases of Broome, Derby and Kununurra. Further research and monitoring should have a core focus on understanding what are the major influences and impediments to the expansion of crocodile populations southward from the major river systems of the West Kimberley.

Surveys of all river systems south of the Prince Regent River should be a priority to determine if crocodile populations are at similar densities and size structure to the river systems surveyed here. Biopsy samples should be collected from as many rivers as possible starting with the Cambridge Gulf river systems and moving west to help uncover the degree of connectivity that exists between systems along the entire West Coast. Aerial surveys should be done during the breeding season to help map the location and extent of nesting habitat, which has been identified as a major driver of population dynamics in saltwater crocodiles. Potential climate change effects on crocodile populations are unclear, although temperature is a major influence on sex ratios of hatchlings as they develop in the egg. Rainfall patterns also have a significant influence on overall nesting success each year.

1.2 Management Implications

Because the general health of crocodile populations is not in question, management should focus on human-crocodile interactions as a priority. This would still require addressing knowledge gaps around abundance and size structure as well as estimating the spatial extent of appropriate nesting habitat. The NT has had to deal with high levels of crocodile-human interactions for many years and their programs will be an appropriate information baseline from which to formulate plans for the Kimberley.

1.3 Products and Tools

This project and additional work with the Region and external collaborators has produced the following products and tools that have potential use by managers and scientists interested in understanding and managing crocodile populations;

- A biopsy pole system was developed for obtaining tissue samples from crocodiles. This technique was tested and used successfully for this project to collect 70 samples from the two surveyed river systems. A manuscript detailing this tool and its use has been accepted for publication in the journal Wildlife Society Bulletin. A Standard Operating Procedure has also been developed.
- A cooperative partnership has been developed with researchers from the NT who specialize in crocodile research and monitoring. This has resulted in sharing of data and participation in a national genetics' study of crocodiles.
- Making use of the Department of Biodiversity, conservation and Attraction's strong GIS capacity we have developed a database app for input and storage of data while in the field. The app utilizes the generic ESRI (ARCGIS) field collector app to enable real-time recording of crocodiles and their location during spotlight surveys. A significant advantage of this system is the ability to upload data to a centralized database which can be interrogated via a web interface in real time.
- Our surveys were designed and implemented according to best-practice methodology as developed by Messel and colleagues and further refined by crocodile researchers in the NT. To ensure the same methods are utilized for all future work we have developed Standard Operating Procedures for crocodile surveys that can be used in the long term monitoring program by Parks and Wildlife Service staff and joint managers.
- Capacity building and skills development has been implemented for park staff and aboriginal rangers in best practice techniques for long-term monitoring of saltwater crocodiles. Building this capability is crucial for ongoing monitoring and management of crocodiles.

2 Introduction

There are six species of *Crocodylus* found throughout South-east Asia, New Guinea and Australia, although only two species inhabit saltwater environments. Of these two, only *C. porosus* is found in Australia, with the other species, *C. siamensis*, highly endangered and restricted to small populations in Cambodia and Laos (Grigg & Kirshner 2015). While *C. porosus* (hereinafter saltwater crocodile) has a regional distribution its main population bases are restricted to Australia, West Papua and Indonesia. The species is considered extinct in Thailand, Singapore and Cambodia (Fig. 1 from (Webb et al. 2010)).

In Australia, saltwater crocodile populations have been protected since the late 1960's after three decades of unregulated hunting had driven their numbers to extreme lows. Only 3000-5000 individuals were estimated to remain across the entire Northern Territory (NT) when protections were put in place in 1971 (Webb et al. 2000). Standardized annual spotlight surveys of crocodiles since 1975 have since demonstrated a spectacular recovery of crocodile populations in the NT with population densities reaching carrying capacity in many river systems (Fukuda et al. 2011).

Since the advent of protection considerable research has been conducted on crocodile biology, population dynamics and recovery from hunting, however the geographic focus has remained with populations in the Northern Territory (NT) where crocodiles occupy a far greater spatial extent. There has been less complementary work in Western Australia, with one exception being an annual survey program on the Ord River system in the Cambridge Gulf region which was implemented as a monitoring component related to an egg harvesting program (WMI 2012). The last broad scale surveys conducted on saltwater crocodile populations in the greater West Kimberley region (west of Cape Londonderry) were done 30 years ago by Messel et al. (1987). At that time total population numbers were estimated at approximately 2,500 adults, representing a population slowly recovering from the excessive harvesting that was ended by the WA Government eighteen years earlier in 1969 (Semeniuk et al. 2011).

Prior to this project, the only conclusions that could be drawn from the paucity of data on WA populations were that saltwater crocodile numbers had increased from historical lows, most likely occupied their historical ranges and were no longer under any significant known pressures. The annual surveys of crocodiles in the Ord River system confirmed that there had been significant increases in the abundance of saltwater crocodiles in the Cambridge Gulf region since 2000, indicative of a recovering population (WMI 2012). Anecdotal reports suggested increases in the abundance of saltwater crocodiles at the southern end of the Kimberley and the presence of individual vagrant animals much further south from their recognised range e.g. in the Pilbara and Exmouth areas. This information raised concerns over increased potential for negative human interactions, and reinforced the need for updated information on West Kimberley crocodile populations.

With the advent of newly created Marine Parks across the Kimberley and a heavy focus on this region as a globally desirable tourist destination (e.g. www.tourism.wa.gov.au/About%20Us/News_and_media/Article/Tourism_at_forefront_of_Kimberley_2036/396), a better understanding of the spatial and temporal patterns of crocodile populations will enable conservation managers to develop the most appropriate management plans for continued conservation of crocodile populations while also providing for a safer experience for the growing human population in the region.

Our primary objective for the project was to obtain a count of the total number of crocodiles and their size structure within the Prince Regent and Roe-Hunter river systems. Counts from these systems will provide a baseline for interpreting the extent of the recovery of crocodile populations in this region from the last surveys in 1986 (c.f. Messel et al. (1987)). The Kimberley region differs from the NT in having far less appropriate habitat for crocodiles to build nests (see Fukuda & Cuff (2013) for assessment of nesting vegetation in NT). The Kimberley coastline and hinterland is chiefly composed of steep, rugged, ancient, deeply faulted sandstones with access up many rivers blocked to crocodiles by waterfalls and their associated gorges. Hence there are few areas of floodplain and very few freshwater swamps for nesting (Burbidge in (Webb et al. 1987)). River systems that pass landwards into savannah supratidal flats and floodplains provide the most productive nesting environments for crocodiles (Semeniuk et al. 2011). Apart from the Cambridge Gulf region there is limited suitable habitat available throughout the Kimberley Region with the Prince Regent and Roe River systems thought to contain the greatest extent of suitable nesting habitat along the West Kimberley coast.

We also sought to foster development of local capacity to enable monitoring of crocodile populations to be ultimately incorporated into management of country by Traditional Owners. Given the remote nature of the Kimberley and the large expanse of area which saltwater crocodiles inhabit, finding cost effective approaches for estimating crocodile abundances across all Kimberley rivers and implementing long-term monitoring programs will be very important. Traditional Owners as joint managers of the Kimberley Marine Parks with the Department of Biodiversity, Conservation and Attractions (DBCA)) have a vested interest in updating the knowledge on this species, and developing their own capacity for extending this project beyond the spatial and temporal limitations of this study.

To ensure any future work was comparable with this work we developed Standard Operational Procedures for surveying and monitoring crocodile populations which also serve as a framework for training of DBCA staff and Traditional Owner groups.

Professional networking between DBCA and crocodile researchers in the NT resulted in an invitation to join a NT study looking at the genetic relationship of crocodile populations across Australia. We were able to collect biopsy samples from our surveys for analysis and interpretation through this study, resulting in a much greater understanding of the connectivity between WA populations and the NT.

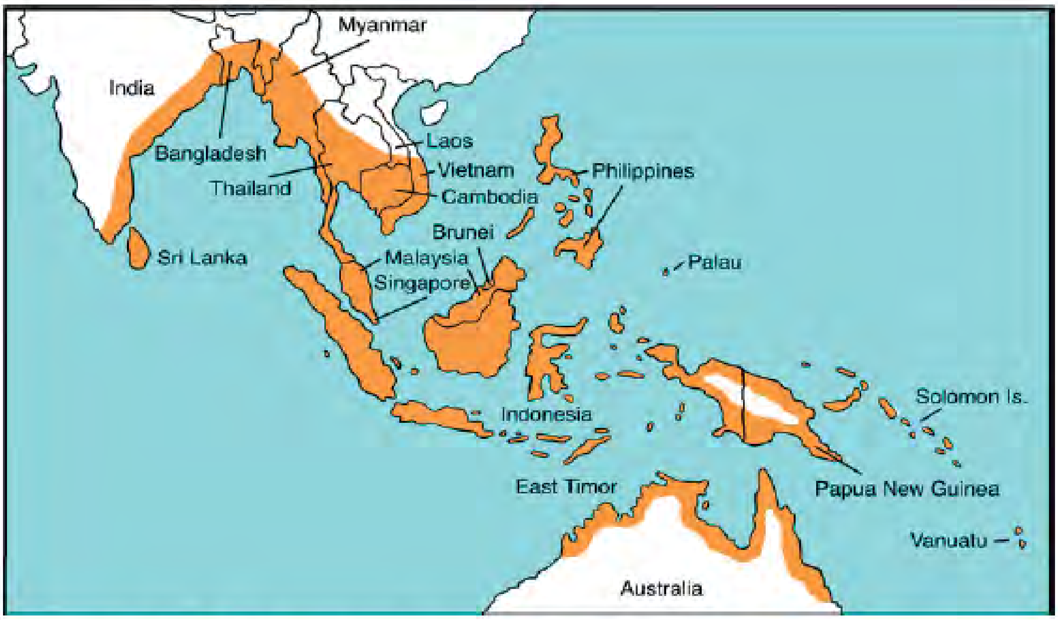

Fig. 1: Core distribution of C. porosus. Population centres are Australia, West Papua and Indonesia with highly reduced numbers elsewhere. Figure is from Webb et al. (2010).

3 Materials and Methods

3.1 Location

The Prince Regent and Roe-Hunter River Systems were chosen for surveys because they have previously been noted as the having the largest crocodile populations along the West Kimberley coast (Semeniuk et al. 2011). They are therefore appropriate systems to monitor, particularly when resources are insufficient for broadscale monitoring across the region. Fortuitously, these systems are also adjacent to each other (Fig. 2) which enabled resources to be concentrated in the one area. These rivers were also surveyed by Messel et al. (1987), providing a baseline from which to make historical comparisons. Our survey protocols followed Messel's as closely as practicable to ensure comparisons would be as valid and robust as possible.

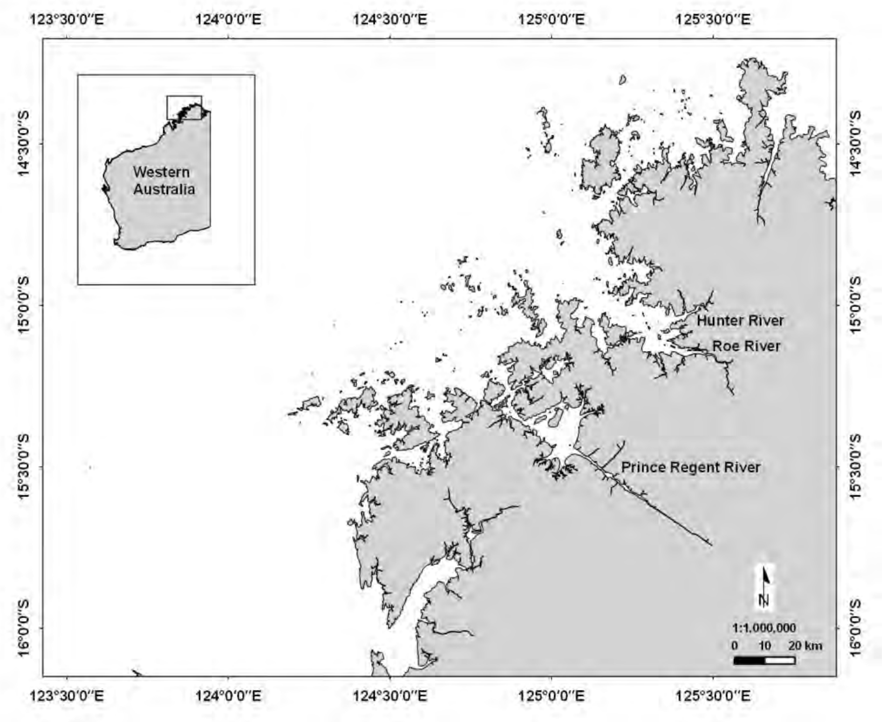

Figure 2: Location of river systems surveyed in 2015 in the West Kimberley.

3.2 Survey Methods

Spotlight surveys have been recognized for some time as the most effective method for obtaining population counts of saltwater crocodiles (Fukuda et al. 2013). This technique was developed by Messel et al. (1981) and has been used for monitoring of saltwater crocodiles in the Northern Territory for over 30 years. It provides a robust, scientifically validated, and repeatable method for collecting data on the abundance, distribution and size structure of populations (Fukuda et al. 2013). Because Messel et al. (1987) provided such detailed information on the location and timing of their surveys we were able to replicate theirs to a very high degree.

We refer readers to Fukuda et al. (2013) for a detailed description of spotlight surveys for crocodiles. Briefly, the technique takes advantage of the reflective nature of the tapetum lucidum of crocodiles eyes. Shining a strong spotlight on crocodiles eyes causes them to glow, making individuals easy to locate. The tendency for animals to freeze under the glare of the spotlight then enables a survey boat to approach close enough to effectively estimate length.

Crocodiles were sized in approximately 30cm increments, with all crocodiles under 0.6 m considered hatchlings and those crocodiles where only their eyes were seen classified as Eyeshine Only (EO). To enable estimates of total biomass to be calculated a formula was applied to estimate the size of crocodiles within the EO category. This formula was according to work done by crocodile researchers in the NT. Previous researchers have dealt with the problem of defining the size distribution of the EO category by distributing 50% of these counts equally among the 0.9-1.2m, 1.2-1.5m and 1.5-1.8m size classes with the other 50% distributed as one-third allocated to the 1.8-2.1m size class and two-thirds to size classes >2.1m. This weights the distribution heavily in favour of larger crocodiles, which are known to be the most wary. When the EO is an odd number, the bias is also given to the larger size classes (Messel & Vorlicek 1986).

3.3 Genetics Sampling

At the time this survey program was being developed we were given the opportunity to contribute to a national genetics research program being coordinated by crocodile researchers at the Department of Environment & Natural Resources, NT. This project is seeking to understand the population genetic structure of saltwater crocodiles in Australia, ultimately providing insights into how many discrete populations there are across Australia. The genetic markers of choice for this study were SNP's or Single Nucleotide Polymorphisms. This type of information will enable conservation agencies to develop management plans for this species at appropriate spatial scales. We took this opportunity to also field test a needle and pole system for collecting the tissue samples which successfully enabled us to collect 70 tissue samples from two major creek systems and from a range of crocodile sizes (Table 1).

Table 1: Number of tissue samples taken across the full size-range of crocodiles surveyed in the Prince Regent and adjacent Roe River systems.

Length (m)	# Samples
Hatchlings	6
0.6 - < 0.9	2
0.9 - < 1.2	2
1.2 - < 1.5	9
1.5 - < 1.8	9
1.8 - < 2.1	12
2.1 - < 2.4	13
2.4 - < 2.7	6
2.7 - < 3	3
3 - < 3.3	3
3.3 - < 3.6	2
3.6 - < 3.9	1
3.9 - < 4.2	1

We developed a biopsy sampling pole to enable relatively fast, safe and easily repeatable tissue sampling of crocodiles, successfully collecting 70 samples at a success rate of over 95%. The method has been formally written up and accepted for publication in the peer-reviewed journal Wildlife Society Bulletin. Our system was developed through modification of a store-bought pole and biopsy needle which was necessary to deal with the toughness of crocodile tissue layers which made standard biopsy needles ineffective (Fig. 3).

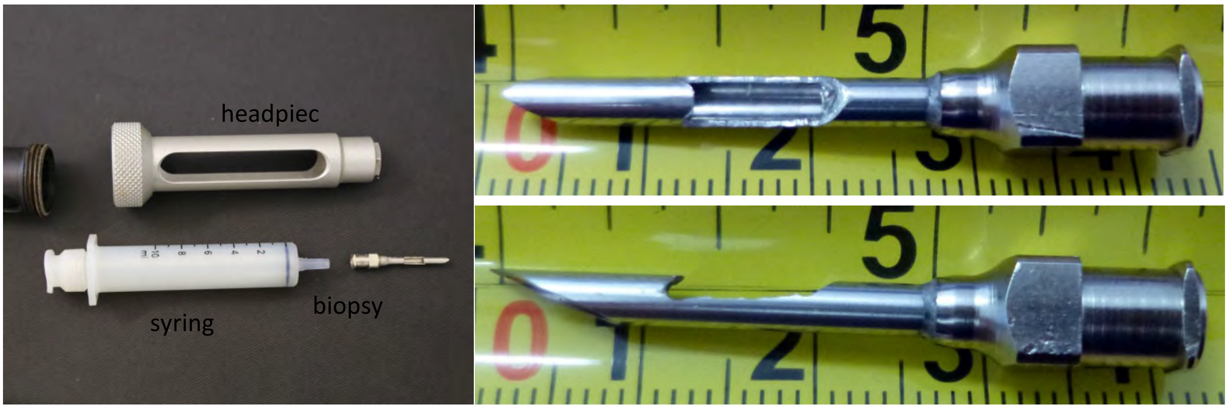

Fig. 3: (Left) The biopsy delivery system consists of a syringe with a biopsy needle attached, which is inserted in a protective aluminium headpiece for attachment to the pole. N.B. We removed the redundant plunger from the syringe body before inserting the syringe in the headpiece (Right) A standard 3mm x 25mm biopsy needle was modified to provide consistent (> 95%) success with sampling. The images show the shape of the notch that was cut into the standard biopsy needle.

3.4 Survey Details

Surveys were conducted along the Prince Regent River system between 23rd July 2015 and 28th July 2015 and along the Roe/Hunter River system between the 6th and 12th August 2015. Surveys were timed to fit with the coolest part of the year when water temperatures are warmer than night time air temperatures which favours crocodiles remaining in the water. To further enhance siteability of crocodiles, surveys were timed to run each night when the tides provided at least 1m of exposed bank, ensuring animals were not hidden amongst any vegetation lining the river. Surveys over successive nights started later to accommodate this. All surveys started and stopped at the same locations identified by Messel et al. (1987) during their surveys to ensure spatial and temporal consistency with previous surveys (Figs 4 & 5.). There are slight differences between the previous surveys which reflect the state of tides at any given moment. With significantly more crocodiles counted by us our travel times were also somewhat slower than the earlier surveys.

Data collection was streamlined through the use of an application associated with the ArcGIS spatial software package. The ArcGIS Collector app was installed on an Apple Ipad Air2 and a customized data entry form developed to allow electronic input of data from the field in real time. Once back at the mothership after each night’s survey, internet access allowed for immediate uploading of data to a central database stored at DBCA’s Kensington offices. A feature of this system was the ability to interrogate the data spatially through a web-portal to get a real-time perspective of the distribution of crocodiles as the surveys unfolded.

3.5 Comparison Surveys

Comparisons were made with NT rivers to provide a perspective on where in the continuum of recovery and population growth to place the West Kimberley populations. The river systems in the two regions are very different with the NT rivers considered the most optimal habitat for saltwater crocodiles because of the availability of extensive nesting habitat. Nevertheless without a pre-hunting baseline for comparison the NT rivers are the only comparative data we have. Crocodile populations are now considered stable and fully recovered in many of the NT rivers so they present a best-case scenario for the WA rivers to be compared to. The two rivers chosen from the NT were matched according to the linear length of the rivers. The Prince Regent River system is far larger than any system in the NT. Thus the Adelaide River was chosen as the best basis for comparison as it is the largest river in the NT. For the Roe-Hunter the Daley River was chosen for comparison as it has a similar length of approximately 100 km.

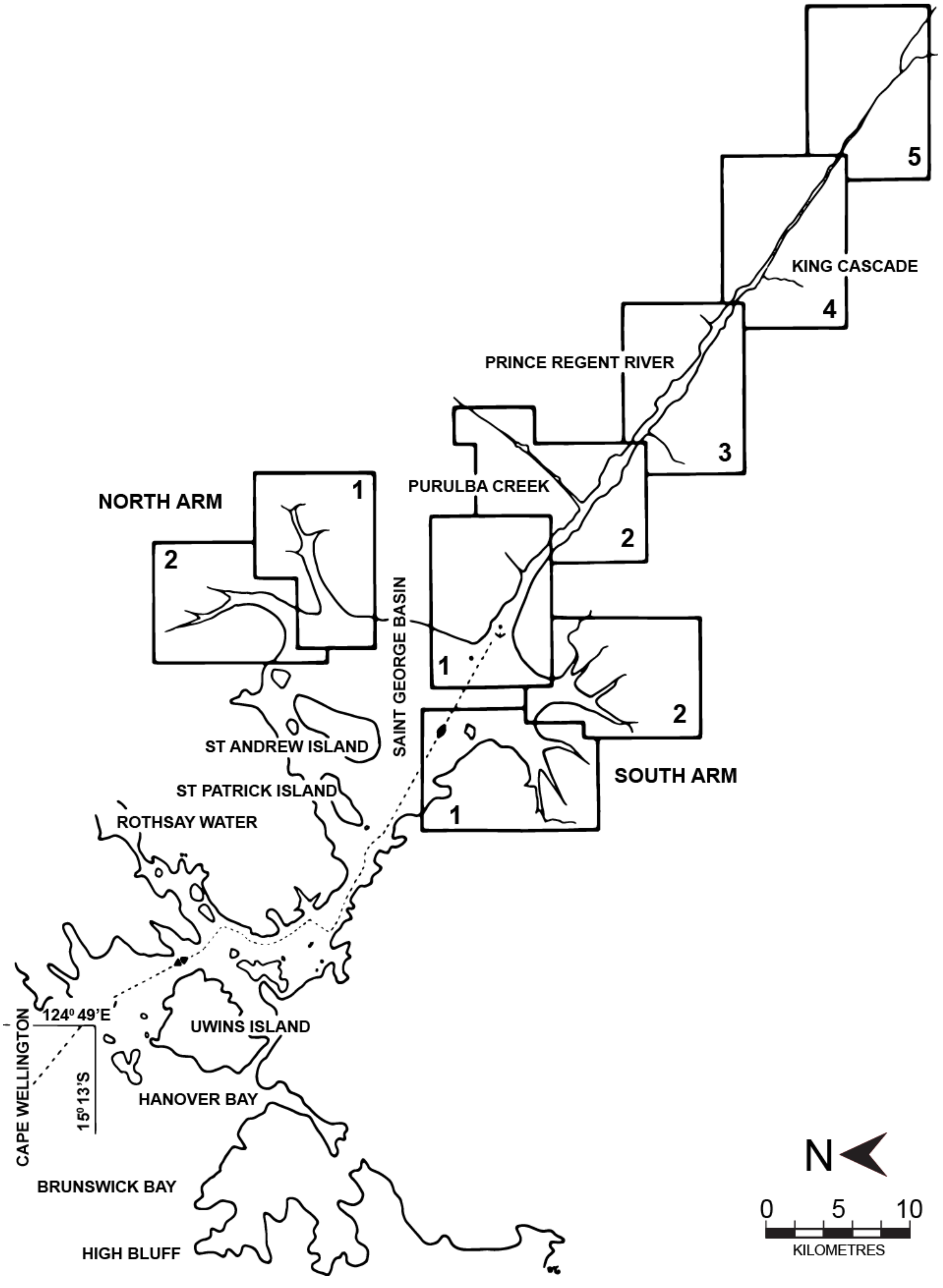

Fig.4: Map of Prince Regent River system with boxes indicating the sections surveyed by Messel et al. in 1978 and 1986 and repeated by this study. Map is copied from Messel et al. (1987).

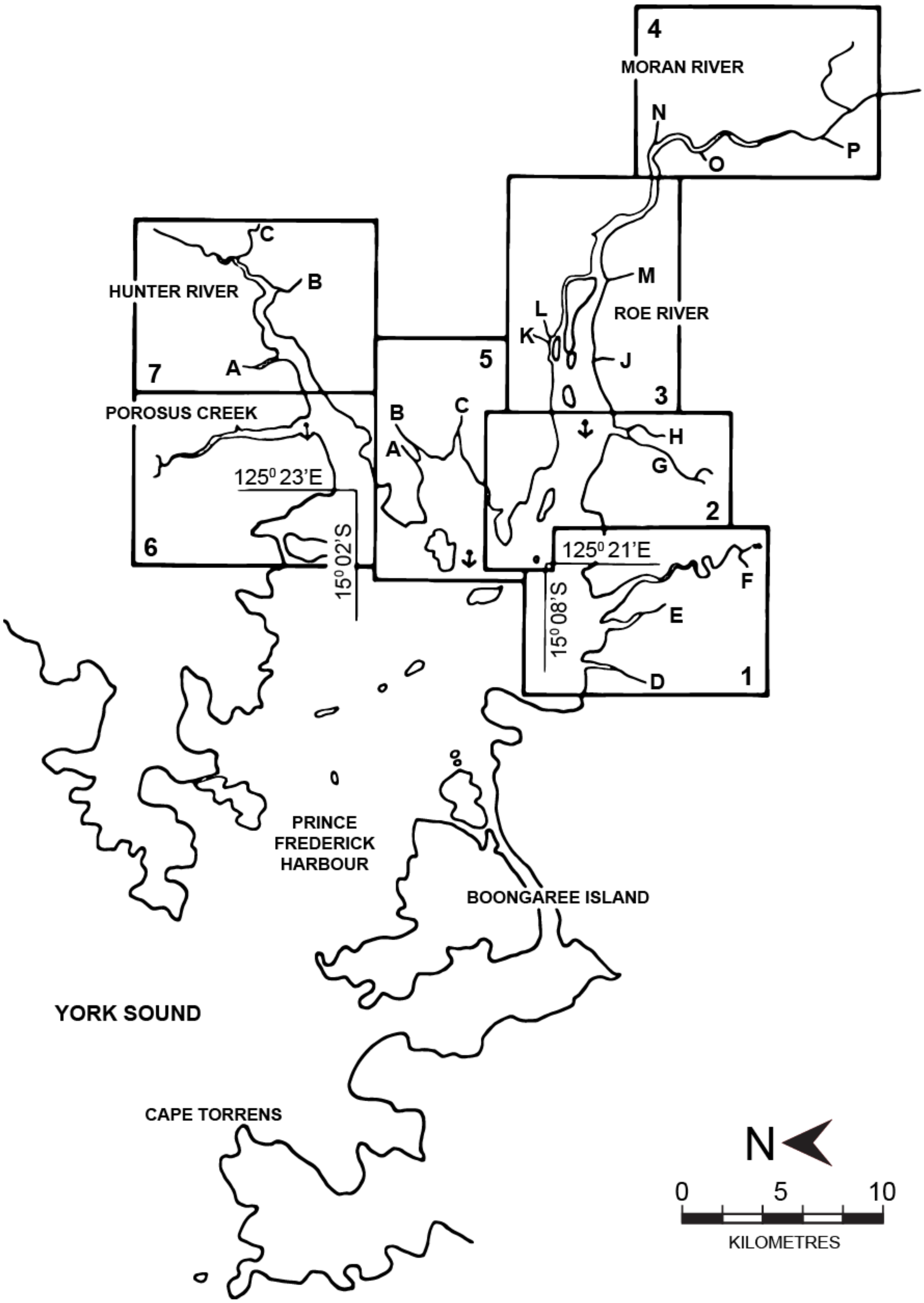

Fig.5: Map of Roe-Hunter River system with boxes indicating the sections surveyed by Messel et al. in 1978 and 1986 and repeated by this study. Map is copied from Messel et al. (1987).

4 Results

4.1 Prince Regent River System

4.1.1 Recruitment

Hatchlings (<0.6m- young of year) were sighted throughout the Prince Regent River system, mostly in the upper reaches of waterways (Figs. 7 & 8) close to likely nesting locations. While the north and south arms had hatchlings their numbers were small (n=15), with the majority of hatchlings (>80%) found in the upper reaches of the main river and its tributaries; a pattern consistent with what Messel et al. found in 1986. Creeks A in the North and South Arms were both identified as having nests in the 1978 surveys and the 2015 survey confirmed the presence of hatchlings in these same areas (Fig.8). There were 67 hatchlings found in the main river and its tributaries in the 2015 surveys indicating multiple nests were active in the previous season. Absolute hatchling numbers in this system compare favourably with rivers in the NT with the Adelaide River having 56 hatchlings in 2015. Available nesting habitat has never been formally quantified in this system and is a priority for future work. With only 3 data points it is difficult to generalize but it would appear that recruitment can vary greatly from year to year with 1978 a good year followed by 1986 as a poor year and 2015 as a good year. Wet season dynamics are extremely important to the success of nesting. For example, it is considered that many nests laid down early in a wet season could be flooded and destroyed but nests constructed towards the end of the wet season should remain viable (Messel et al 1986).

4.1.2 Non-hatchling crocodiles

Total numbers of non-hatchling crocodiles have increased from a low of 133 in 1978 to 626 in the latest survey in 2015, an overall increase of 370%. Between 1978 and 1986 when the second survey was conducted by Messel et al. 1986 the population had increased 82% to 242 non-hatchling animals. Between 1986 and 2015 the increase was 159%. Plotting of the total abundance (Fig. 6) suggests a linear population recovery remains underway, although multiple years of data are still required to support this statement with confidence.

Interestingly, when the different sections of the river system are plotted as individual points for each of the 3 years of data the growth rate is better described by a power curve, suggesting an escalation of the recovery rate over the past 10-15 years.

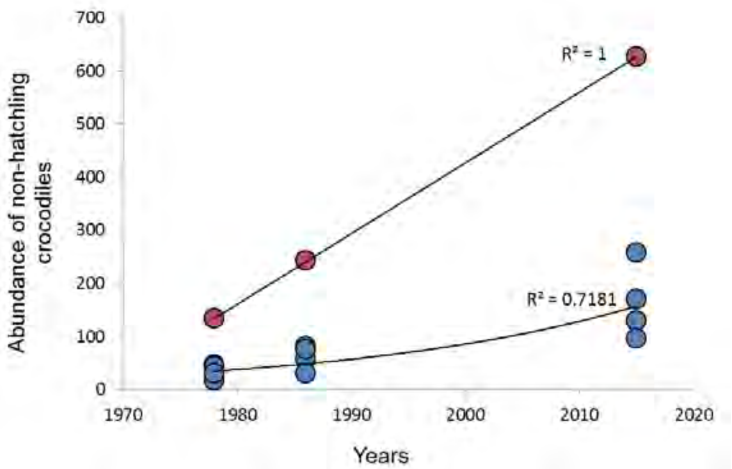

Fig. 6: Population growth rates at the entire river catchment level (brown points) and at individual section levels (blue points).

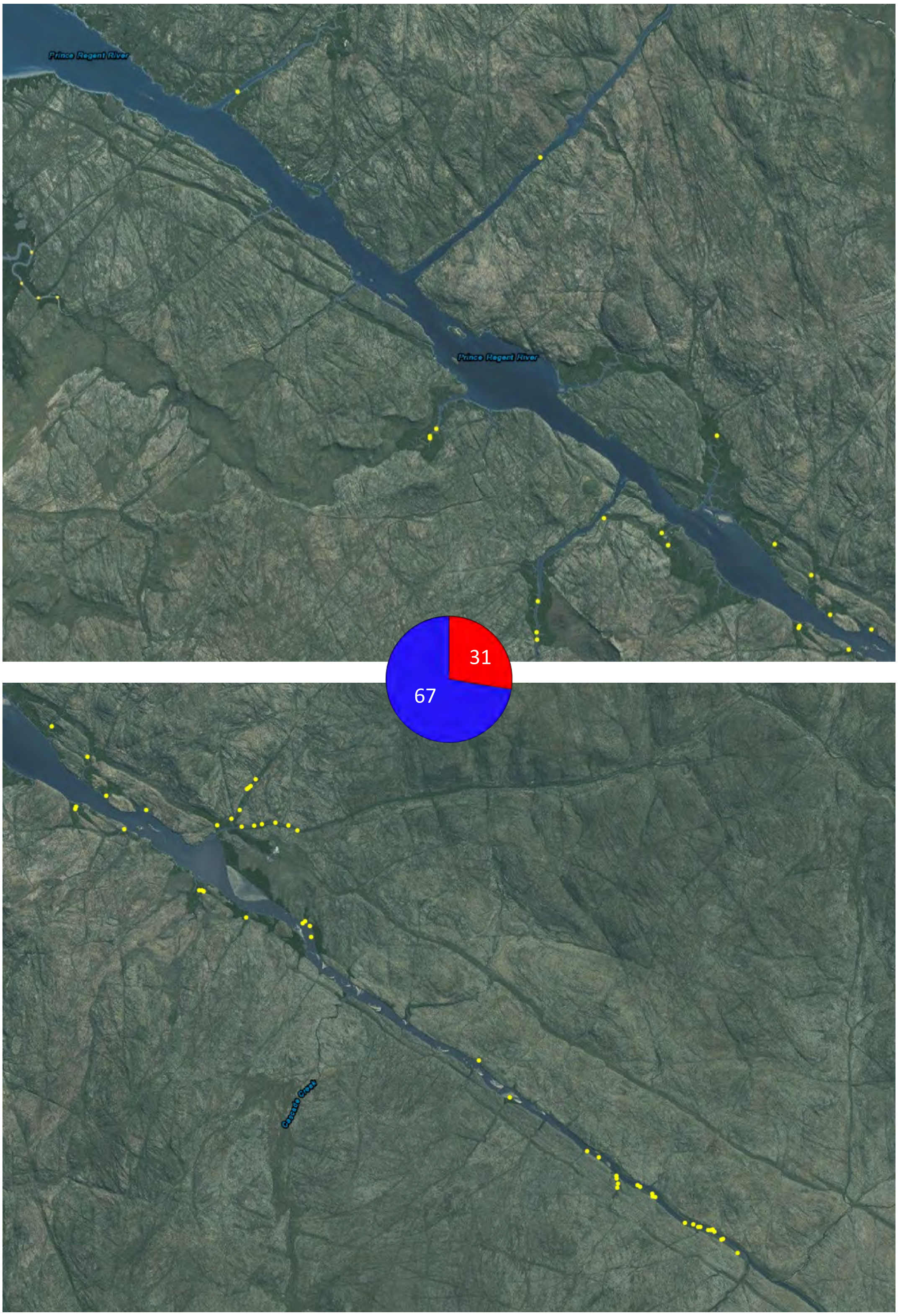

Fig. 7: Location of hatchlings in the downstream (upper) and upstream (lower) sections of the Prince Regent River. Pie chart represents the comparison in hatchling numbers from 1978 (red), 1986 (green) and 2015 (blue). There were no recruits sited in 1986.

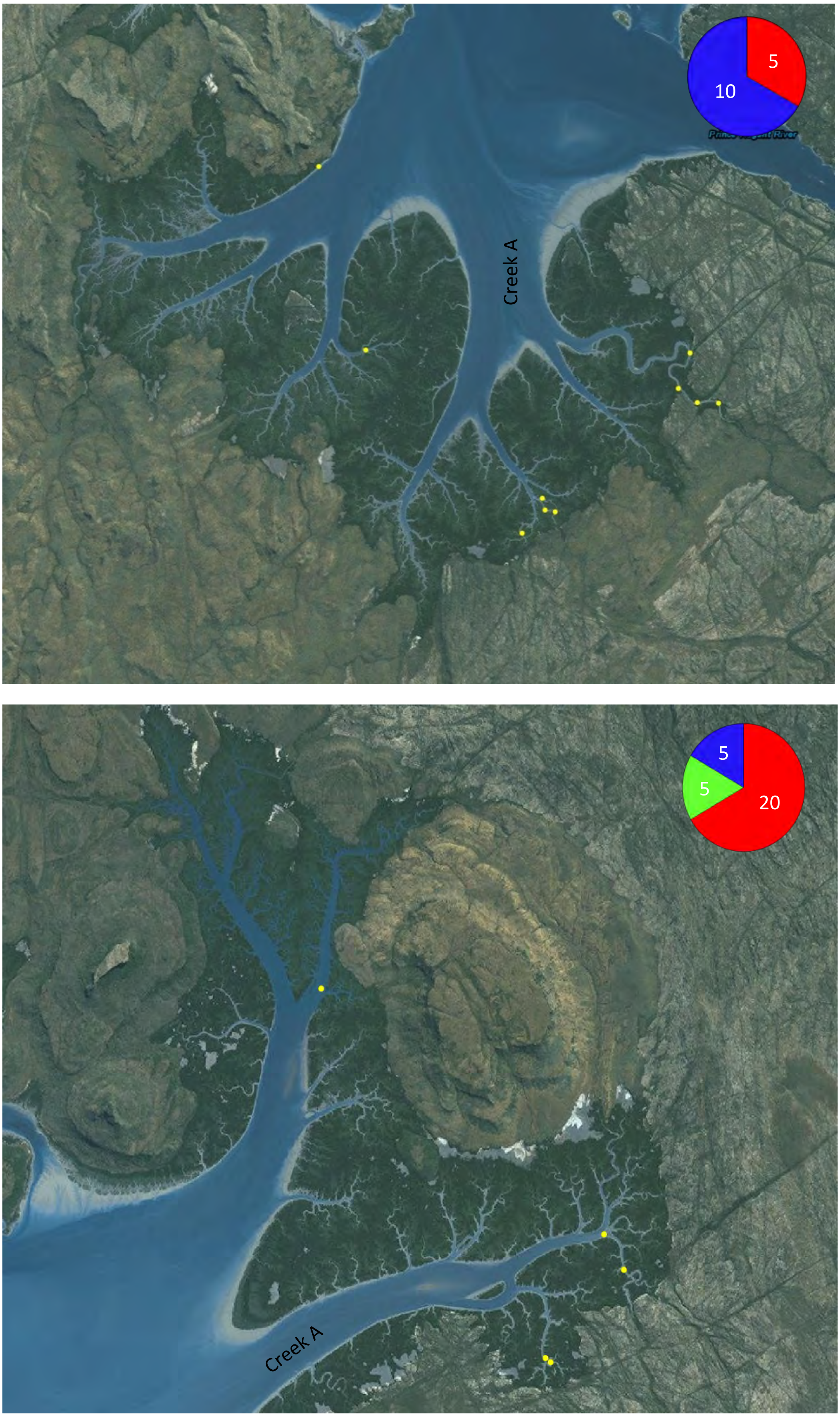

Fig. 8: Location of hatchlings in the South (upper) and North (lower) arms of the Prince Regent River System. .

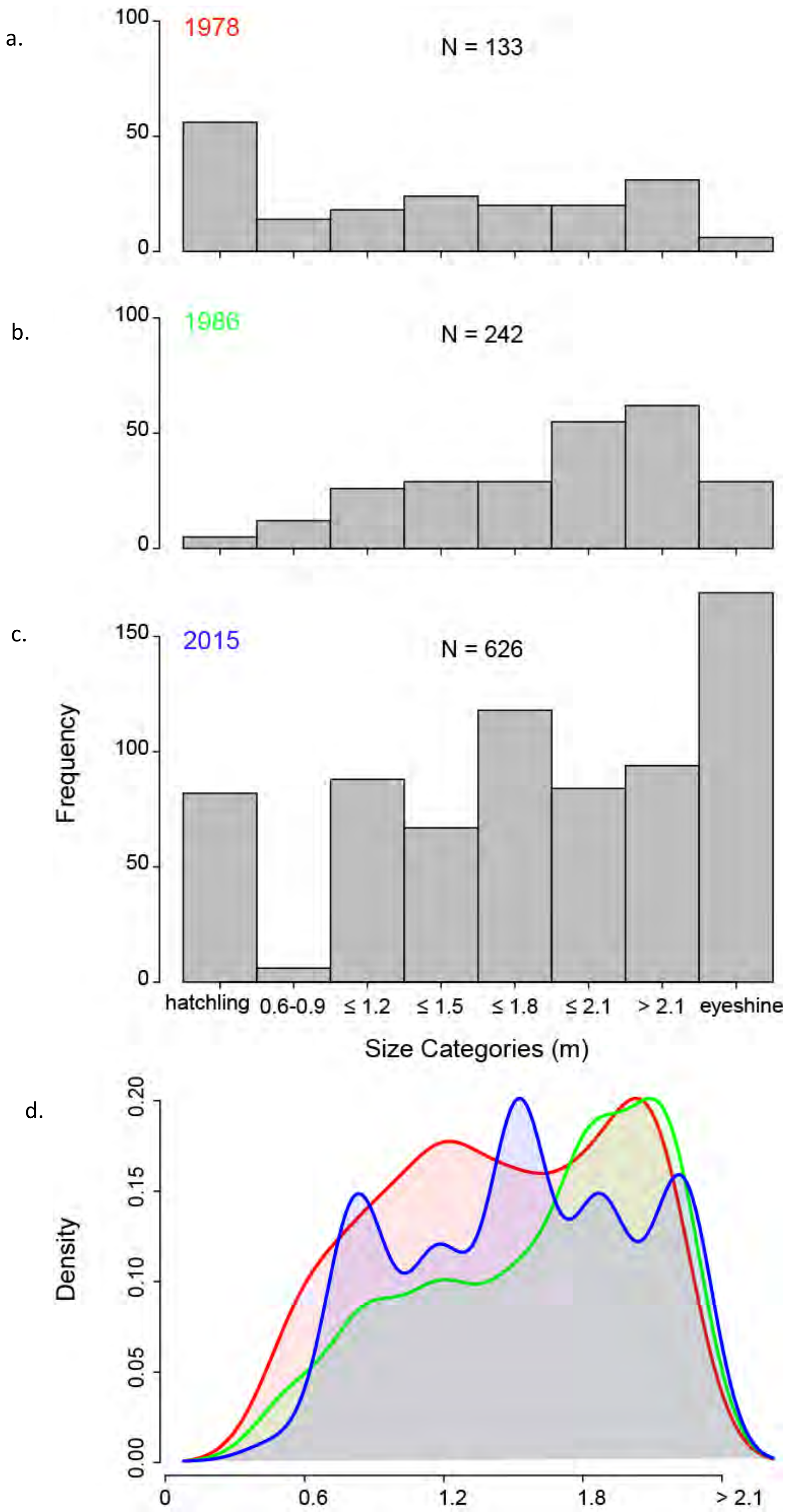

Fig. 9: Size structure of crocodile populations surveyed across the entire Prince Regent River system in 1978 (a), 1986 (b) and 2015 (c). Kernel density smoothing plots for each year (d) illustrate the most common size structure. The density plots do not include hatchlings or eyeshine categories. N does not include hatchlings but does include eyeshine.

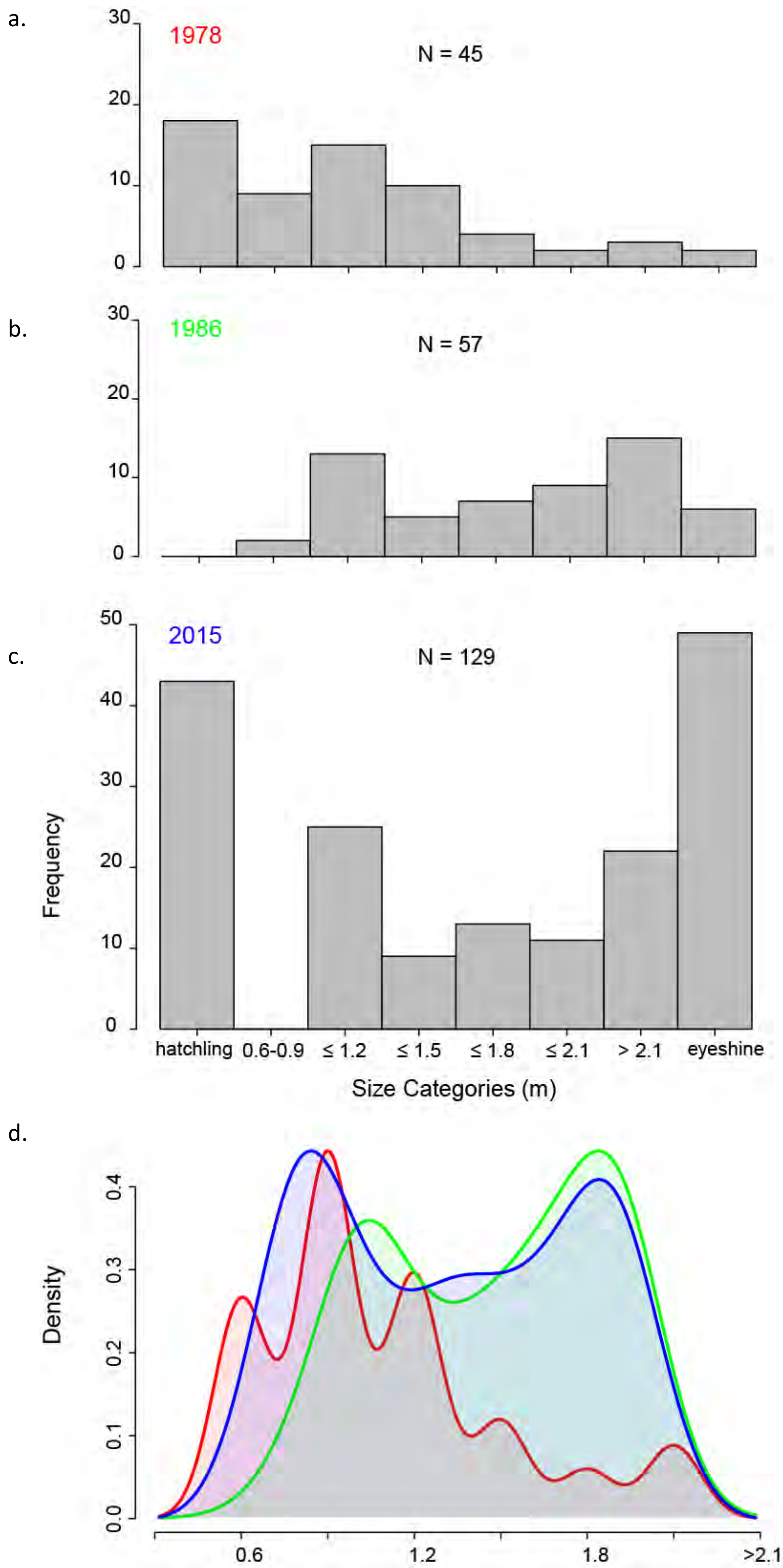

Fig. 10: Size structure of crocodile populations surveyed in the main channel of the Prince Regent River in 1978 (a), 1986 (b) and 2015 (c). Kernel density smoothing plots for each year (d) illustrate the most common size structure.

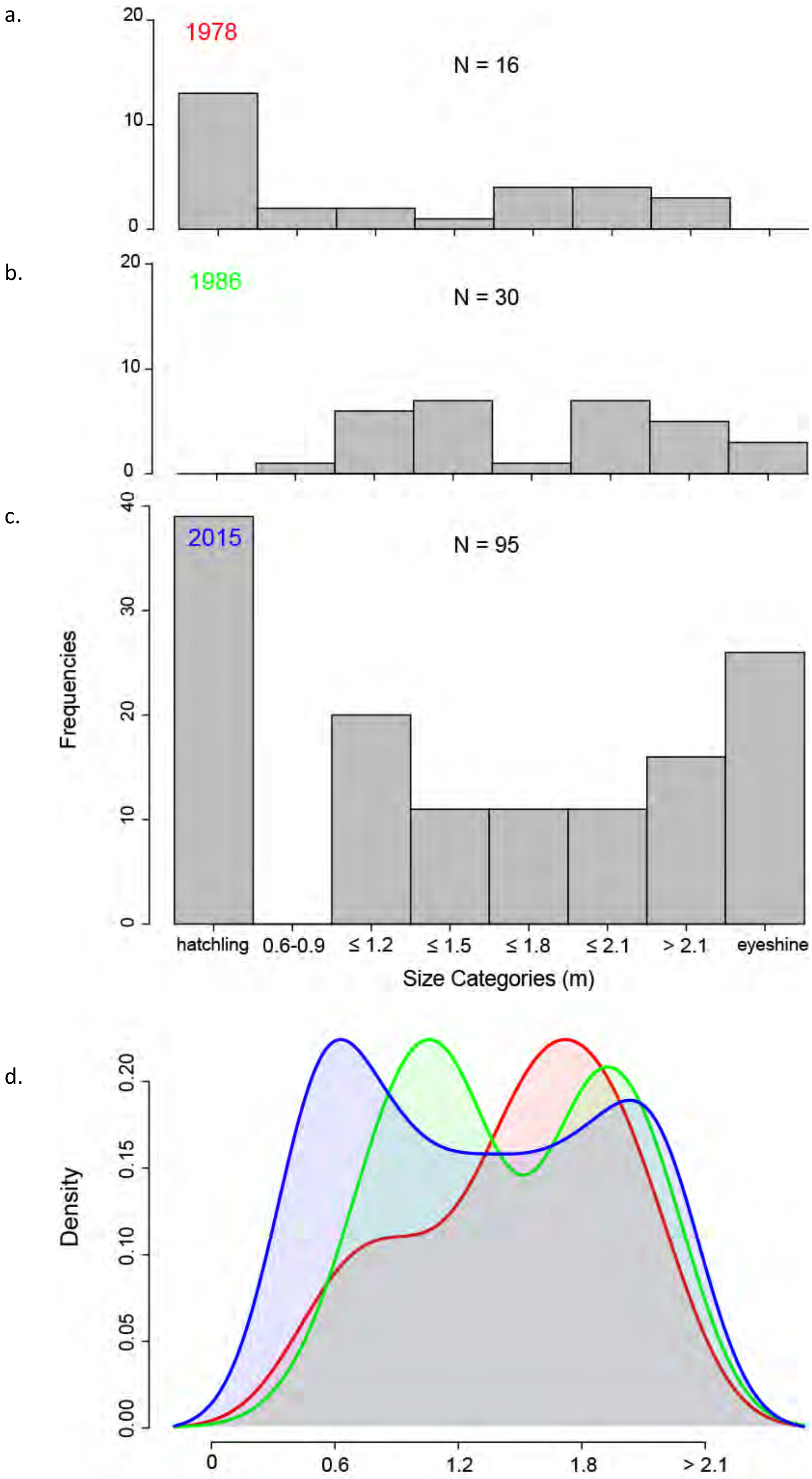

Fig. 11: Size structure of crocodile populations surveyed in the creeks running off the main channel of the Prince Regent River in 1978 (a), 1986 (b) and 2015 (c). Kernel density smoothing plots for each year (d) illustrate the most common size structure.

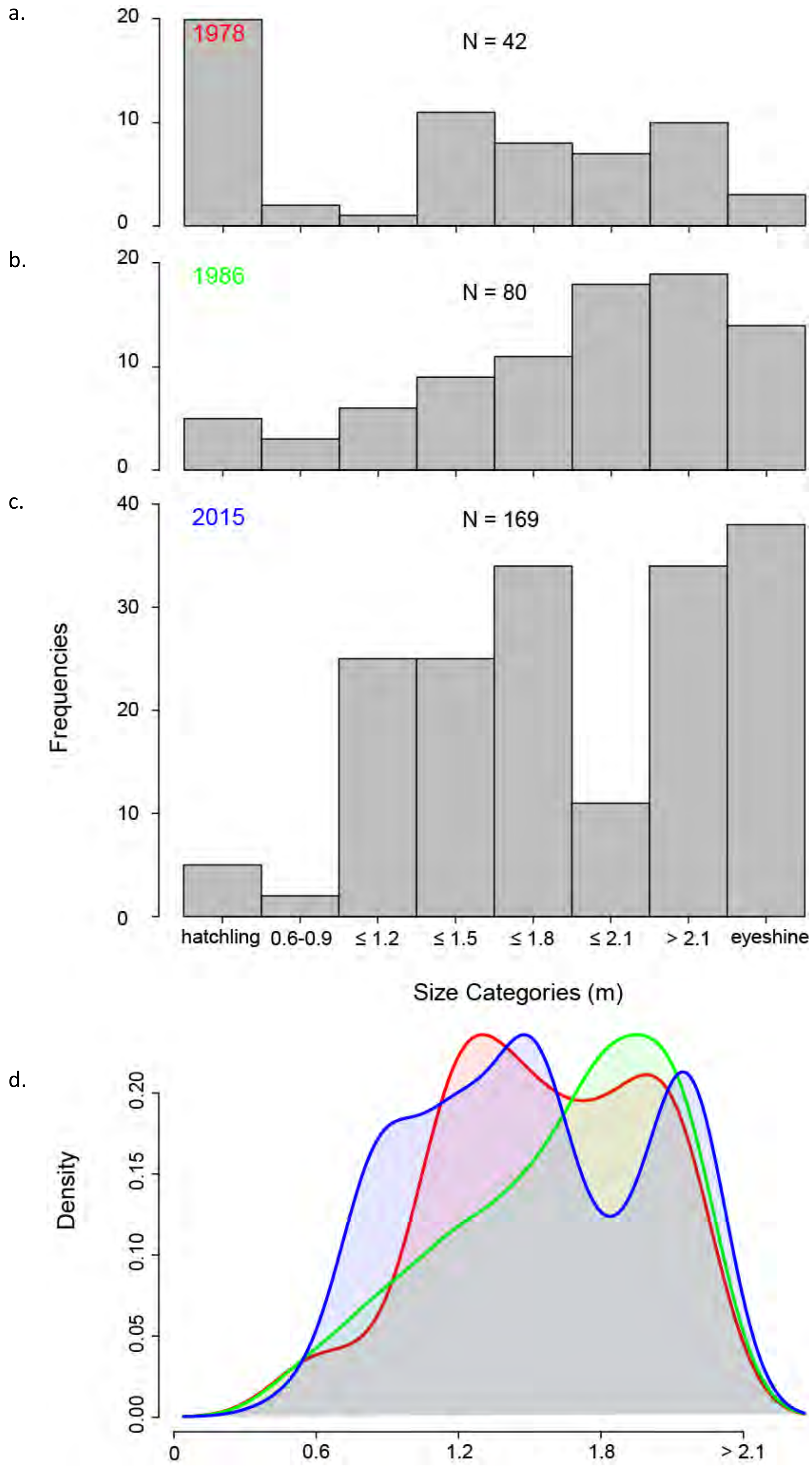

Fig. 12: Size structure of crocodile populations surveyed in the creeks of the North Arm of the Prince Regent River system in 1978 (a), 1986 (b) and 2015 (c). Kernel density smoothing plots for each year (d) illustrate the most common size structure.

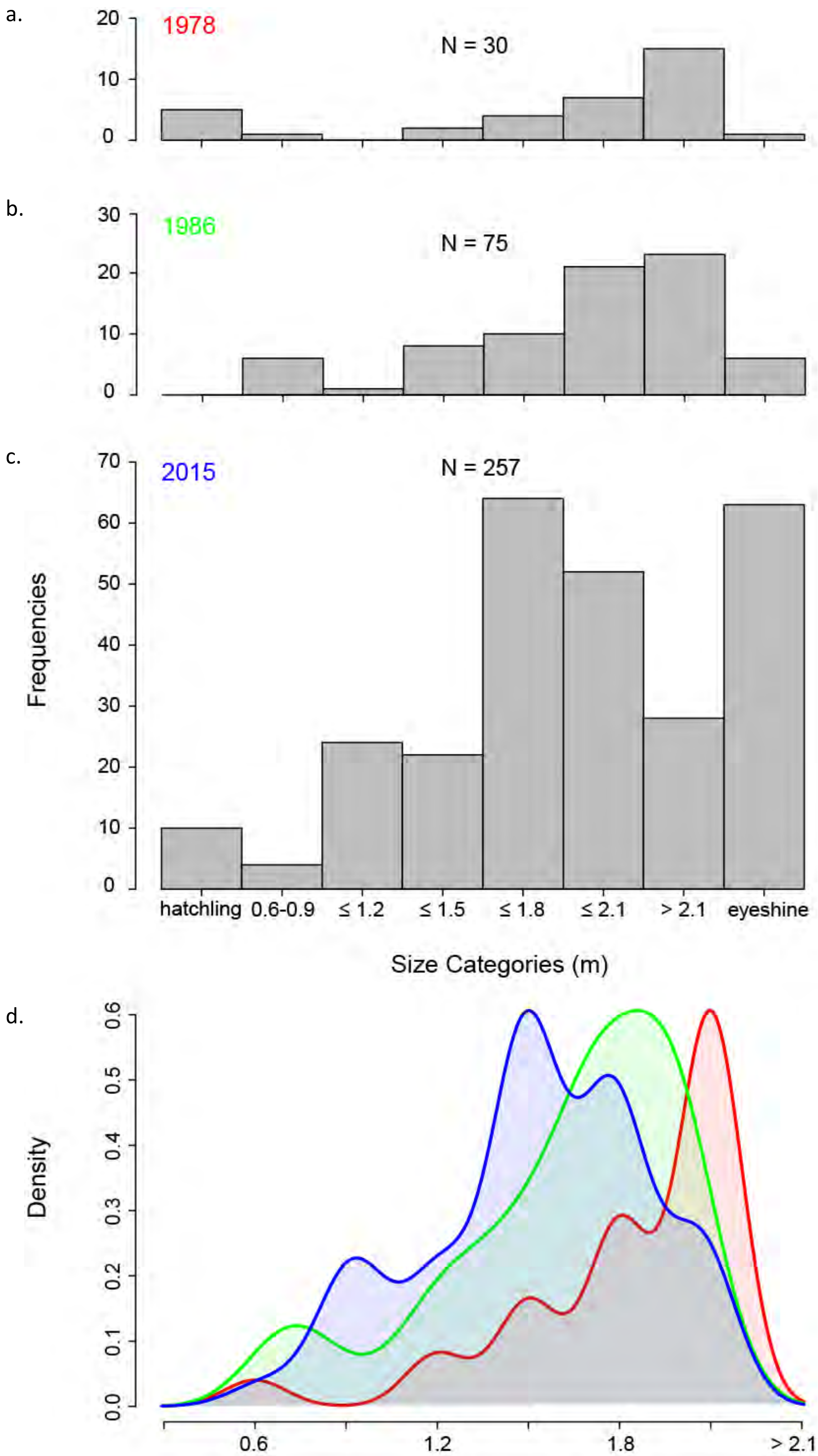

Fig. 13: Size structure of crocodile populations surveyed in the creeks of the South Arm of the Prince Regent River system in 1978 (a), 1986 (b) and 2015 (c). Kernel density smoothing plots for each year (d) illustrate the most common size structure.

Table 2: Abundance, size frequency, density and biomass of the crocodile population inhabiting the Prince Regent River System. Data collated from surveys in 1978, 1986 and 2015. Data from 1978 and 1986 taken from Messel et al. (1986). Data from 2015 collected by Halford et al. (2015).

Size (m)	all 1978	all 1986	all 2015	main 1978	main 1986	main 2015	main creeks 1978	main creeks 1986	main creeks 2015	north arm 1978	north arm 1986	north arm 2015	south arm 1978	south arm 1986	south arm 2015
hatchling	56	5	82	18	0	42	13	0	25	20	5	5	5	0	10
0.6-0.9	14	12	6	9	2	0	2	1	0	2	3	2	1	6	4
0.9-1.2	18	26	88	15	13	25	2	6	20	1	6	25	0	1	24
1.2-1.5	24	29	67	10	5	9	1	7	11	11	9	25	2	8	22
1.5-1.8	20	29	118	4	7	13	4	1	11	8	11	34	4	10	64
1.8-2.1	20	55	84	2	9	11	4	7	11	7	18	11	7	21	52
>2.1	31	62	94	3	15	22	3	5	16	10	19	34	15	23	28
Eyeshine (EO) **	6	29	169	2	6	49	0	3	26	3	14	38	1	6	63
total abun	189	247	708	63	57	171	29	30	120	62	85	174	35	75	267
total abun (no hatchlings)	133	242	626	45	57	129	16	30	95	42	80	169	30	75	257
river length (km)	206	206	206	43	43	43	25.2	25.2	25.2	63.5	63.5	63.5	74.3	74.3	74.3
density (incl hatchlings) nos/km	0.9	1.2	3.4	1.5	1.3	4.0	1.2	1.2	4.8	1.0	1.3	2.7	0.5	1.0	3.6
density (no hatchlings) nos/km	0.6	1.2	3.0	1.0	1.3	3.0	0.6	1.2	3.8	0.7	1.3	2.7	0.4	1.0	3.5
total biomass (incl. EO) (kg)			15299.1												
biomass density (no hatchlings) kg/km			74.3												
Ratio large/small (>1.8m)	0.7	1.2	0.7	0.2	0.9	0.8	0.8	0.9	0.7	0.8	1.5	0.6	3.3	1.7	0.8
Ratio eyeshine/non-hatchlings	4.7	13.6	37.0	4.7	11.8	61.3	0.0	11.1	37.7	7.7	21.2	29.0	3.4	8.7	32.5
% change in abundance		182.0	258.7		126.7	226.3		187.5	316.7		190.5	211.3		250.0	342.7

** Biomass calculations and Ratio large/small (>1.8m) both included the deconstructed EO counts. Biomass estimates were only done for 2015 counts where abundances were available for every size class. In this case our model followed that of Fukuda et al. with EO category split into <1.8m and >1.8m with a 4ft biomass multiplier (7.11) used for the EO counts in the <1.8m class and the 8ft biomass multiplier (57.73) used for the EO counts > 1.8m.

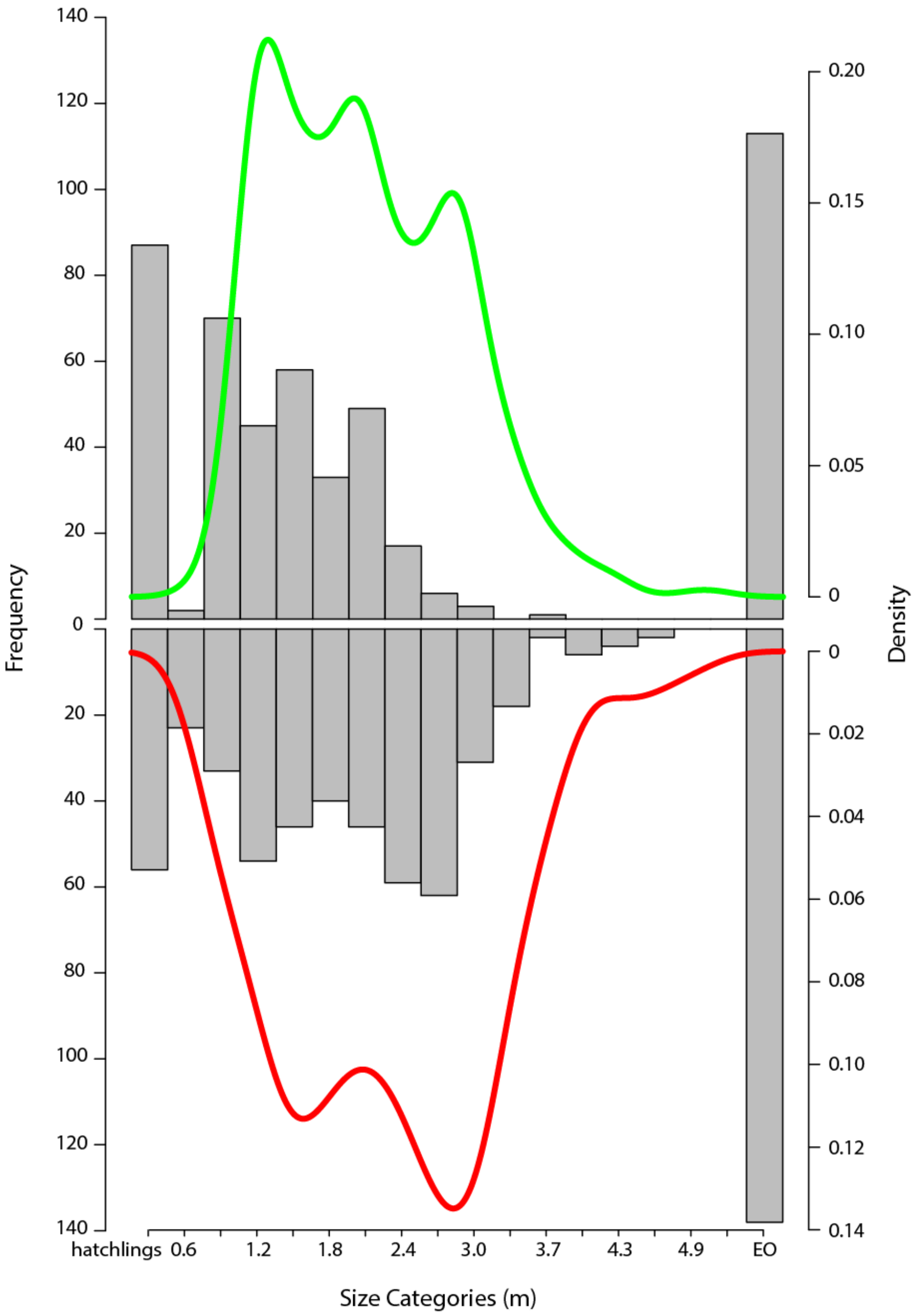

Fig. 14: Comparison of size structure of crocodile populations surveyed in the Adelaide River and Prince Regent River systems in 2015. While the Prince Regent is much longer at 206 km the Adelaide is the longest river in the territory at 135 km. Density plots are overlayed on the size-frequency histograms to highlight the most common size range in each system. Category 1 and 18 represent hatchlings and 'eyeshine only', respectively and were not included in the density plot calculations.

In 1978 the ratio of large to small crocodiles (>1.8m length/06-<1.8 m length) in the Prince Regent River System was calculated at 0.7 rising to 1.2 in 1986 but declining again to 0.6 in the 2015 survey. This pattern was consistent across all components of the river system and while this may seem counter intuitive for a maturing system the increase in numbers of larger crocodiles has been offset by a big increase in the number of 1.5-2.1m crocodiles in the system, especially in the North and South arms (see Fig 15). This ratio is 3 times smaller than the ratio of 1.7 for the Adelaide River in the Northern Territory .

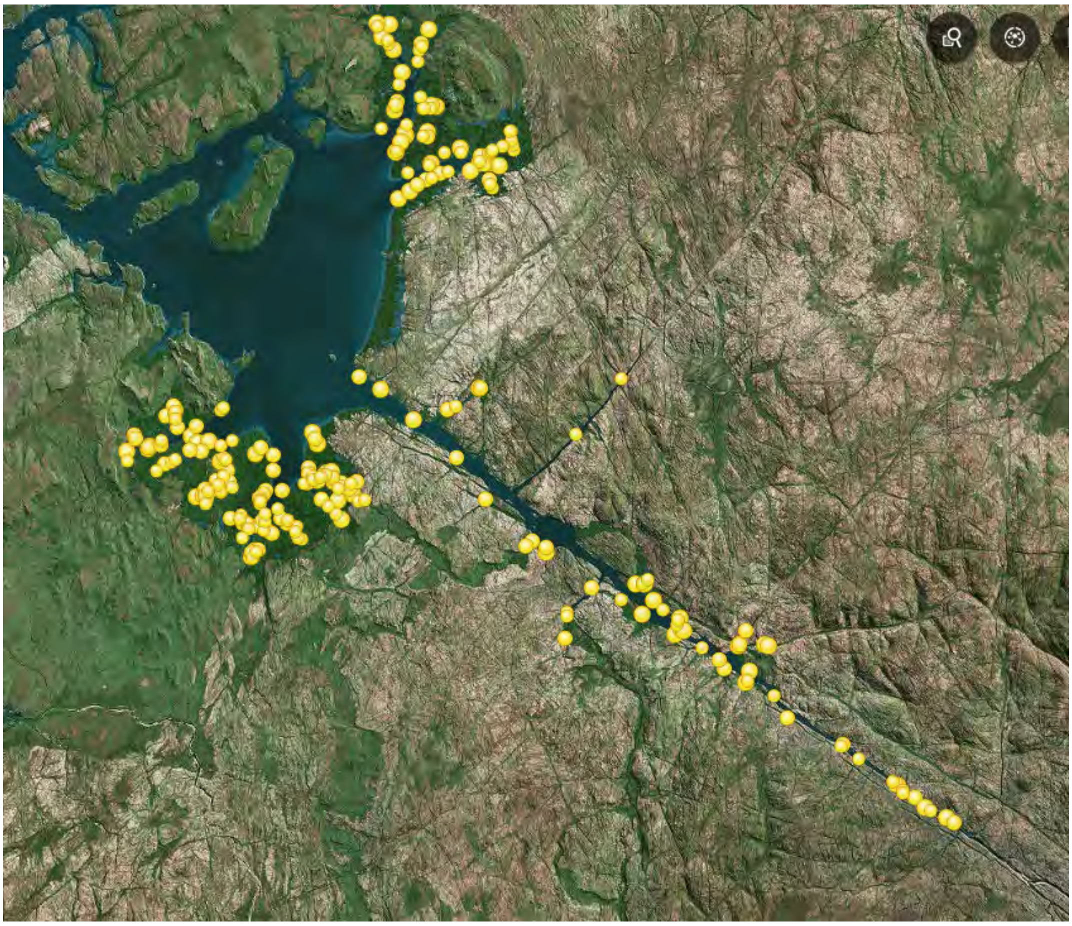

Fig. 15: Location of all crocodiles between 1.5-2.1 metres in length in the Prince Regent River System. Note that densities are much greater in the South and North Arms.

One of the big differences between the 2015 counts and the two earlier ones is in the proportion of counts that were identified as Eyeshine Only (EO). Eyeshines made up 27% of the total counts of non-hatchling animals in the Prince Regent System in 2015 compared to only 14% in 1986. This proportion rose to 61% for the main river channel and may well reflect a greater degree of caution being shown by crocodiles that are more exposed to human traffic in the main river. For comparison, the proportion of EO crocodiles in the Adelaide River in the NT was 24%. When the re-allocation of EO data was performed the ratio of large/small crocodiles changed little with a ratio of 0.7 for the entire system in 2015. The highest ratio across all components of the system was 0.8 in 2015 which remains significantly less than the ratio of 1.7 calculated for the Adelaide River.

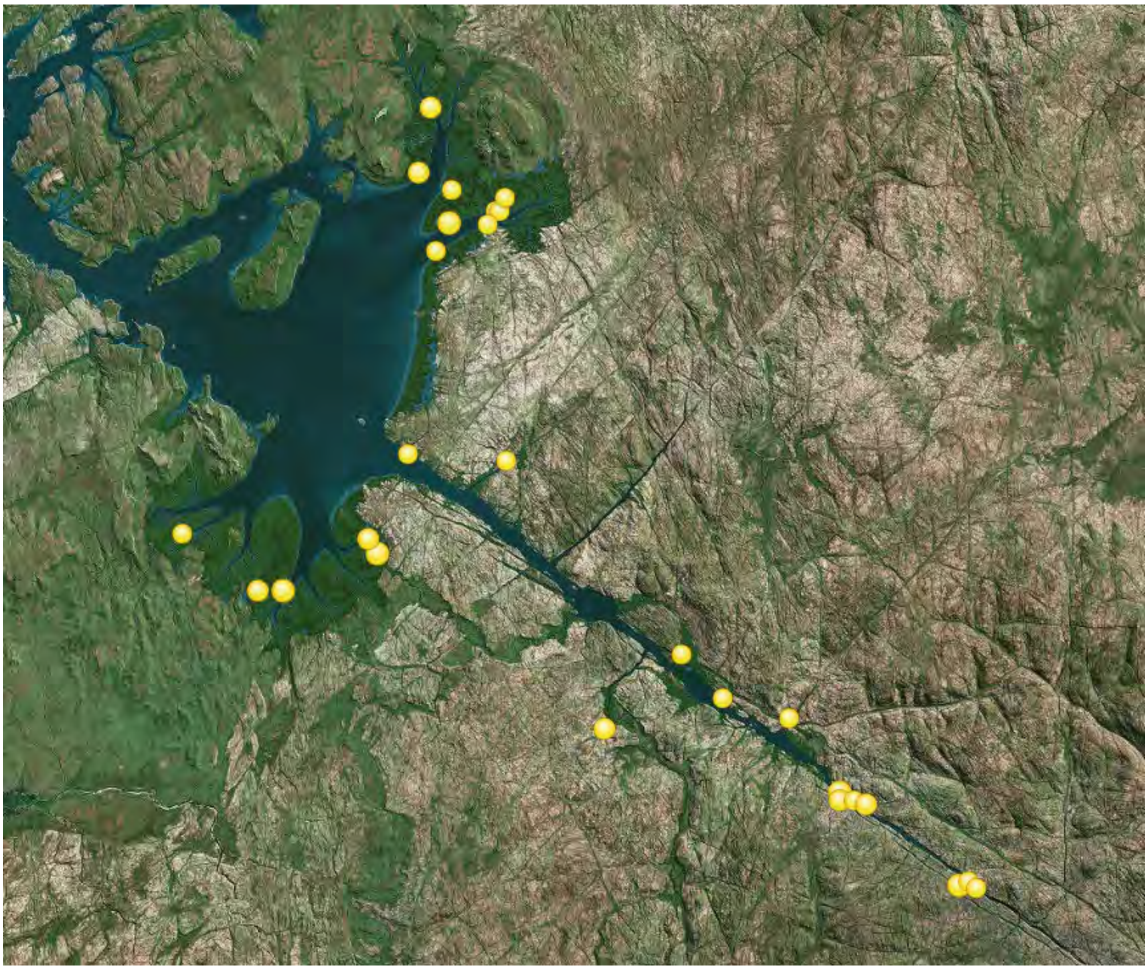

Fig. 16: Location of all crocodiles over 2.4m in length in the Prince Regent River System.

Mature saltwater crocodile populations are typified by relatively stable densities but increasing biomass as resident crocodiles continue to grow. The Northern Territory Department of Land Resource Management (DLRM) conducts annual spotlight surveys across 8 rivers as part of a long-term monitoring program. Their results showed that the population of nonhatchling *C. porosus* in most rivers continues to increase or remain stable. One of our comparison rivers - the Adelaide River – is considered stable and has a density of 4.2 animals/km with standing biomass of 274.02 $kgha^{-1}$ in 2015 (Saalfield & Fukuda 2013). In contrast the Prince Regent River system had a density of 3 animals/km with standing biomass of 74.3 $kgha^{-1}$ in 2015 (Table 1), indicating the crocodile population in this system is still some way from maturity. The differences in biomass are due to the differences in the number of large crocodiles in the 2 systems, with the Adelaide river containing 184 crocodiles over 2.4m in 2015 (Fig 14) whereas the Prince Regent system only had 27 crocodiles over this length (Fig. 14 & Fig. 16).

4.2 Roe-Hunter River System

4.2.1 Recruitment

Hatchlings (<0.6m- young of year) were sighted predominantly in the upper reaches of the Roe-Hunter river system with the majority in the Roe River (Figs. 18 & 19) close to likely nesting locations. While the Hunter River had hatchlings the numbers were small (n=23) indicating only one or two successful nests in the previous season. The majority of hatchlings (n=104) were found in the upper reaches of the Roe River and the numbers indicate multiple successful nests from the previous breeding season. The previous survey in 1986 found only 9 hatchlings across the entire system. Total hatchling numbers in this system in 2015 were 131 which was significantly higher than the 16 found in our comparison river the Daly in 2016. Unfortunately, there was no survey of the Daley in 2015 so this comparison has limited relevance given the difference in wet seasons between 2015 and 2016. Available nesting habitat has never been formally quantified in the Roe-Hunter system and has been identified as a priority for future work.

4.2.2 Non-hatchling crocodiles

Total numbers of non-hatchling crocodiles increased from a low of 160 in 1978 to 545 in the latest survey in 2015, an overall increase of 241%. Between 1978 and 1986 when the second survey was conducted by Messel et al. (1986) the population had increased 64% to 263 non-hatchling animals. Between 1986 and 2015 the increase was 107%. Plotting of total non-hatchling abundance (Fig. 17) suggests a linear population recovery remains underway, although multiple years of data are still required to support this statement with confidence. Plotting of individual components of the system also suggests a growth rate better described by a power curve albeit much less steep than that for the Prince Regent.

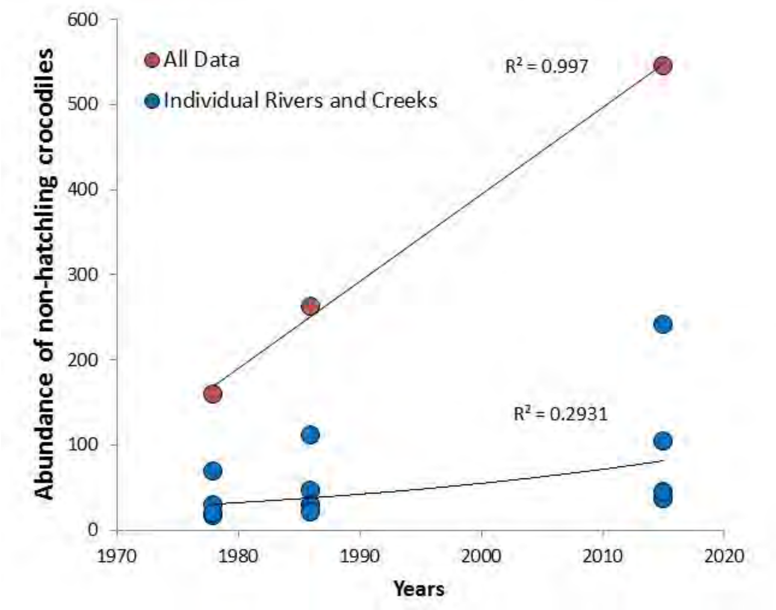

Fig. 17: Population growth rates at the entire river catchment level (brown points) and at individual section levels (blue points).

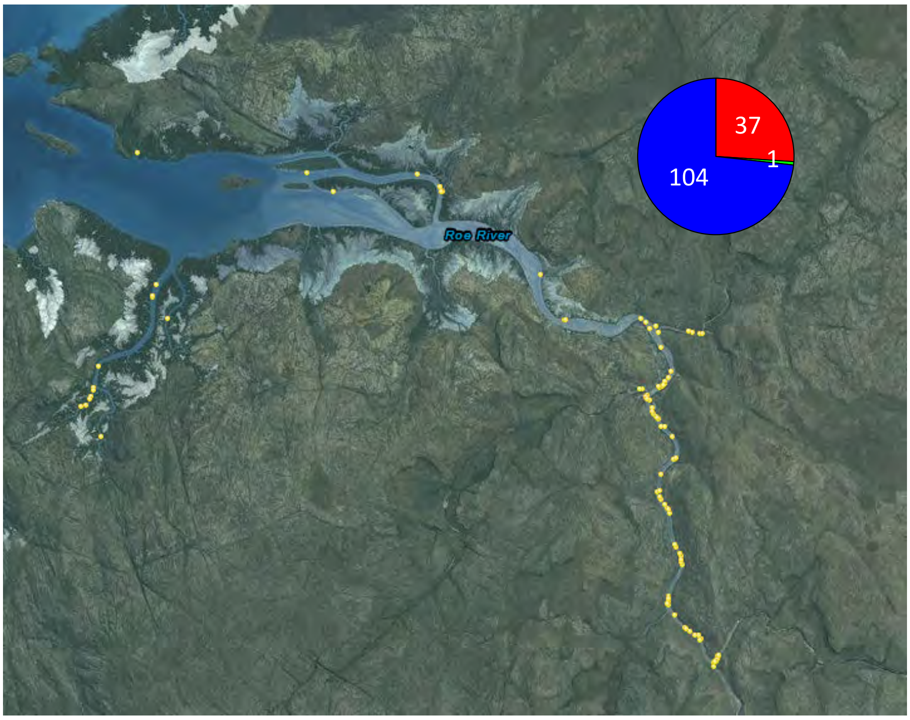

Fig. 18: Location of hatchlings sighted in the Roe River during 2015 surveys. Pie chart represents the comparison in hatchling numbers from 1978 (red), 1986 (green) and 2015 (blue).

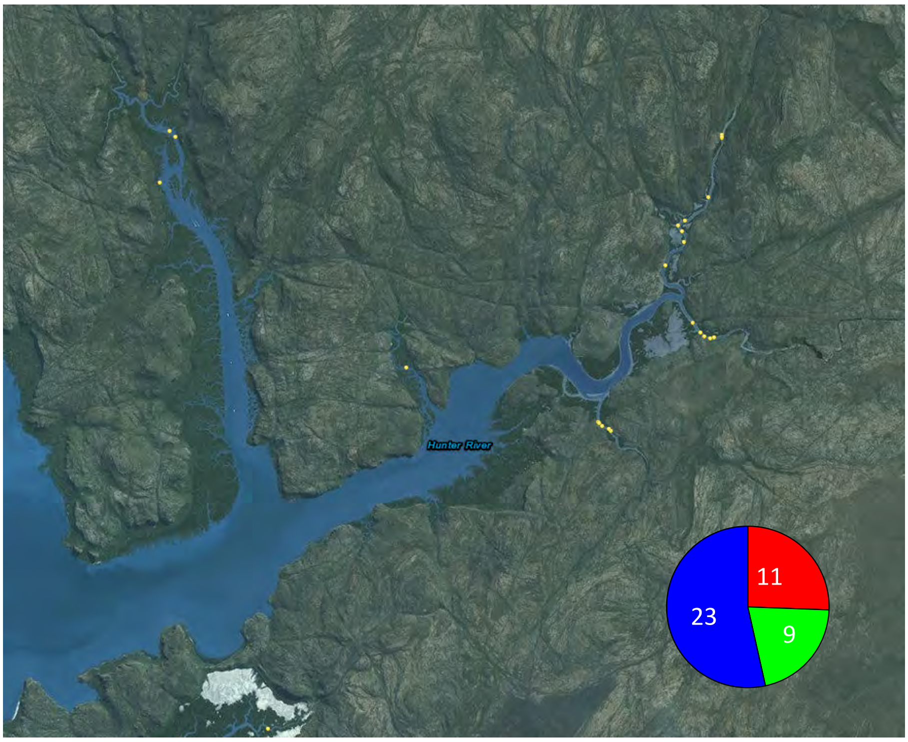

Fig. 19: Location of hatchlings sighted in the Hunter River during 2015 surveys. Pie chart represents the comparison in hatchling numbers from 1978 (red), 1986 (green) and 2015 (blue).

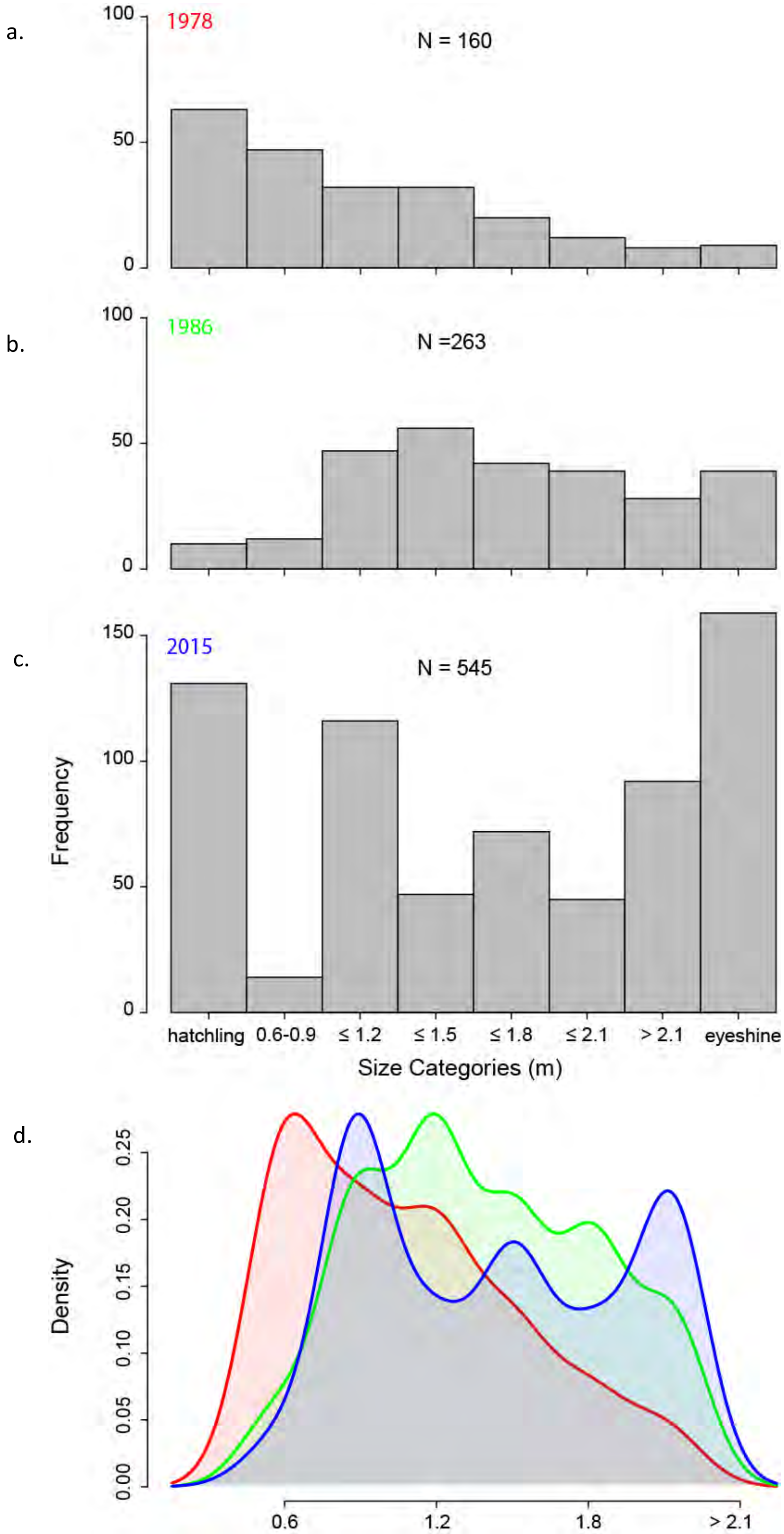

Fig. 20: Size structure of crocodile populations surveyed across the entire Roe/Hunter River system in 1978 (a), 1986 (b) and 2015 (c). Kernel density smoothing plots for each year (d) illustrate the most common size structure.

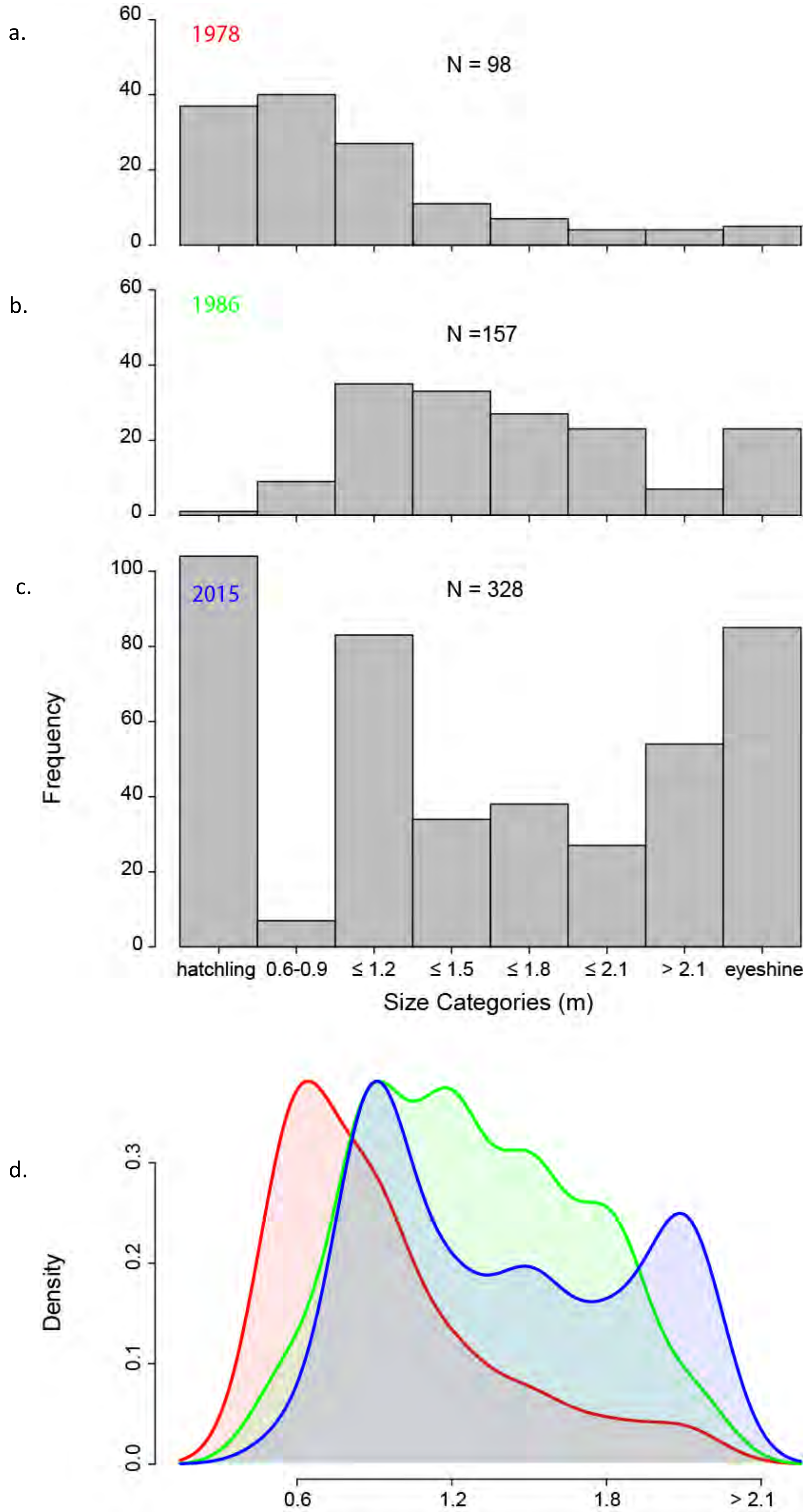

Fig. 21: Size structure of crocodile populations surveyed in the Roe river and its creeks in 1978 (a), 1986 (b) and 2015 (c). Kernel density smoothing plots for each year (d) illustrate the most common size structure.

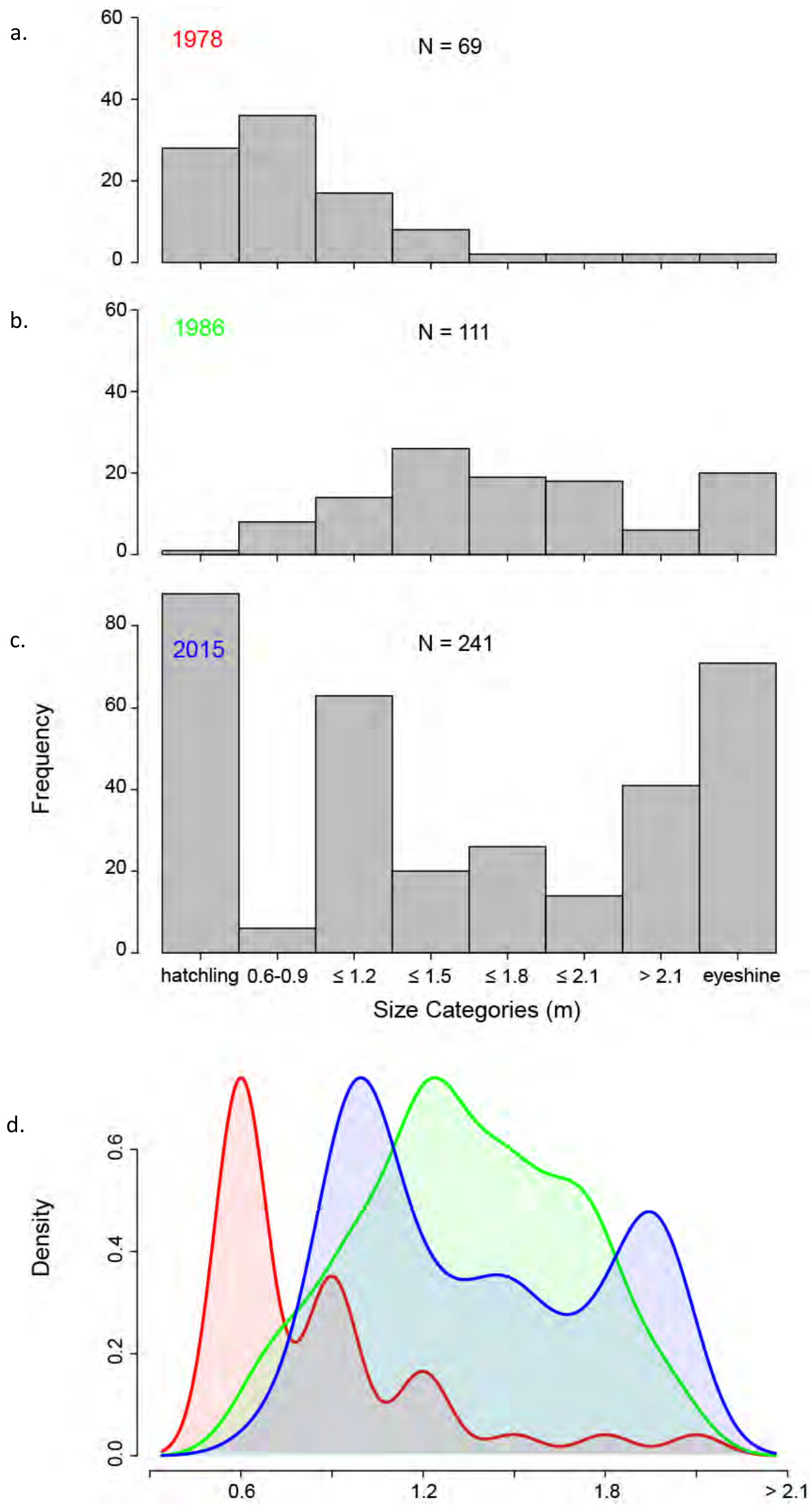

Fig. 22: Size structure of crocodile populations surveyed in the mainstream of the Roe River in 1978 (a), 1986 (b) and 2015 (c). Kernel density smoothing plots for each year (d) illustrate the most common size structure.

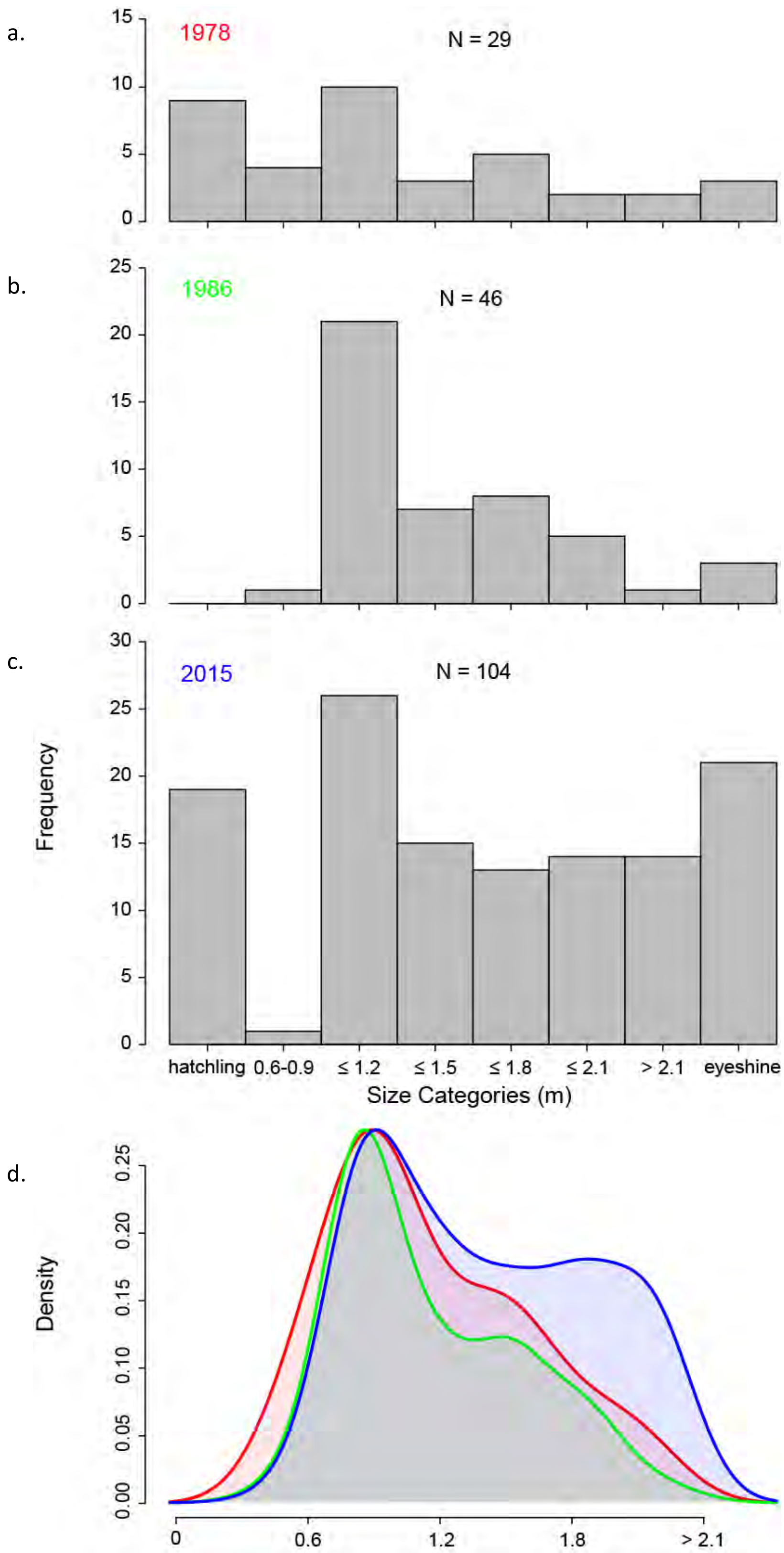

Fig. 23: Size structure of crocodile populations surveyed in the creeks running off the Roe River in 1978 (a), 1986 (b) and 2015 (c). Kernel density smoothing plots for each year (d) illustrate the most common size structure.

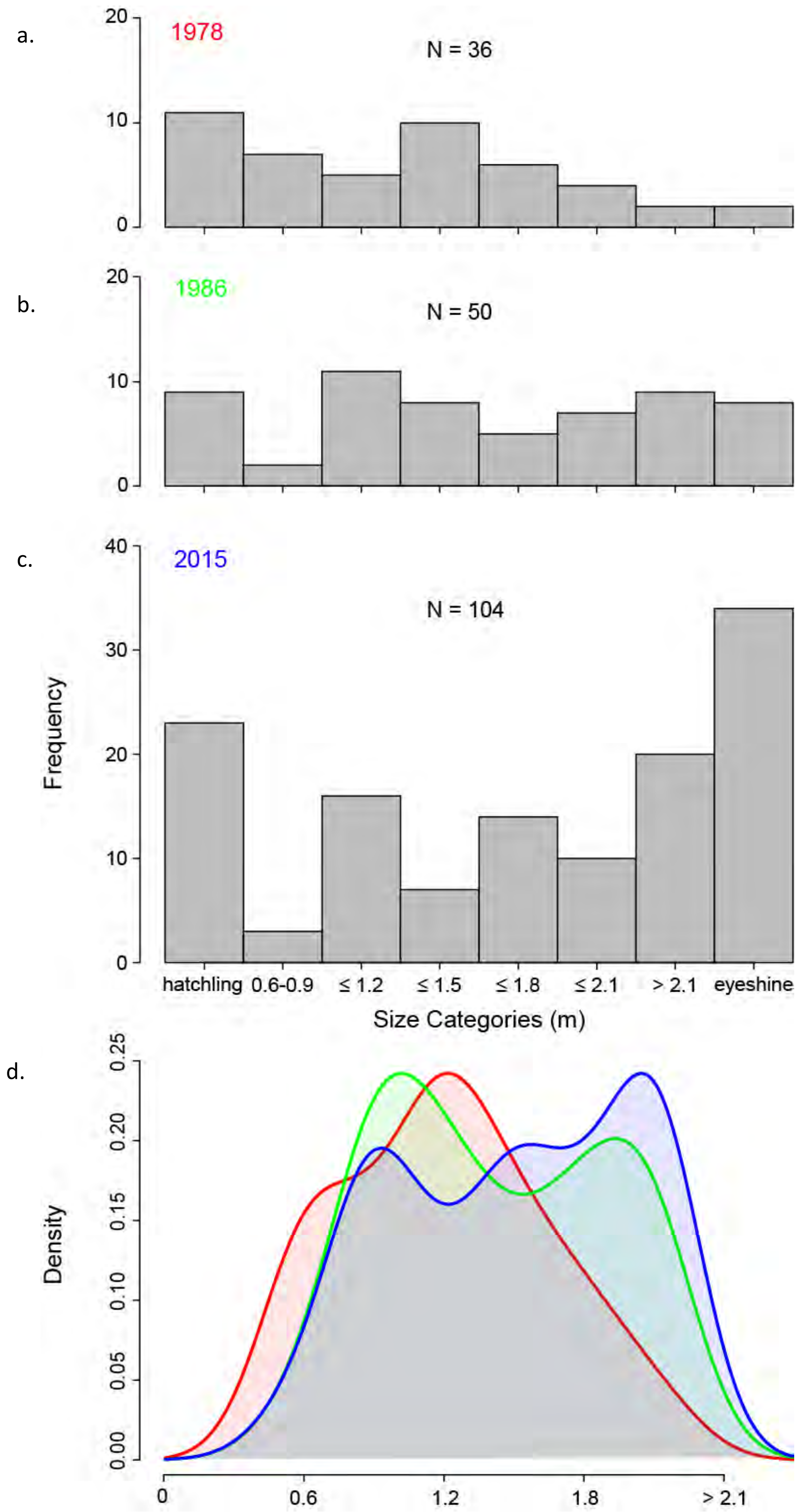

Fig. 24: Size structure of crocodile populations surveyed in the Hunter River and its creeks in 1978 (a), 1986 (b) and 2015 (c). Kernel density smoothing plots for each year (d) illustrate the most common size structure.

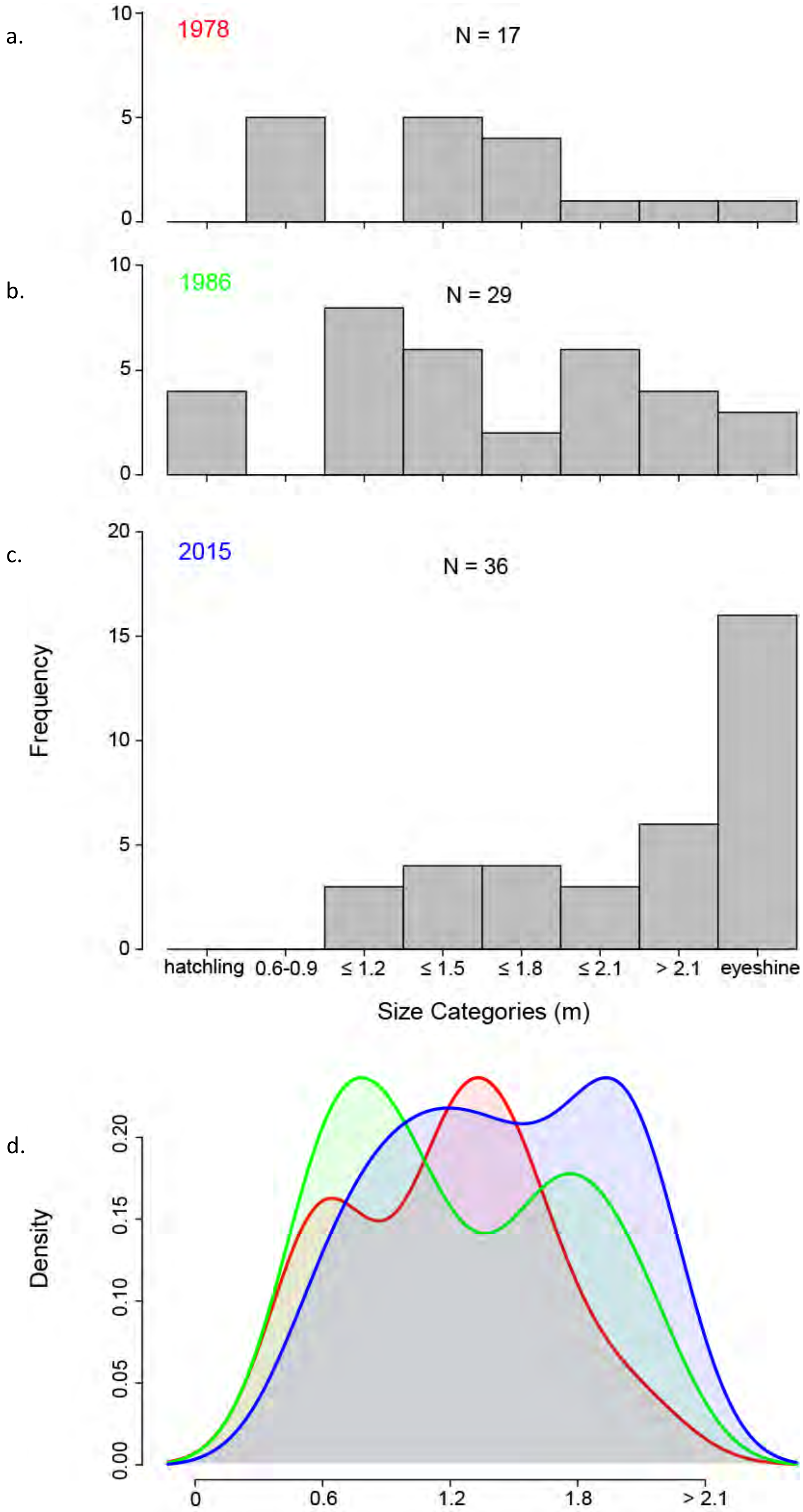

Fig. 25: Size structure of crocodile populations surveyed in the mainstream of the Hunter River in 1978 (a), 1986 (b) and 2015 (c). Kernel density smoothing plots for each year (d) illustrate the most common size structure.

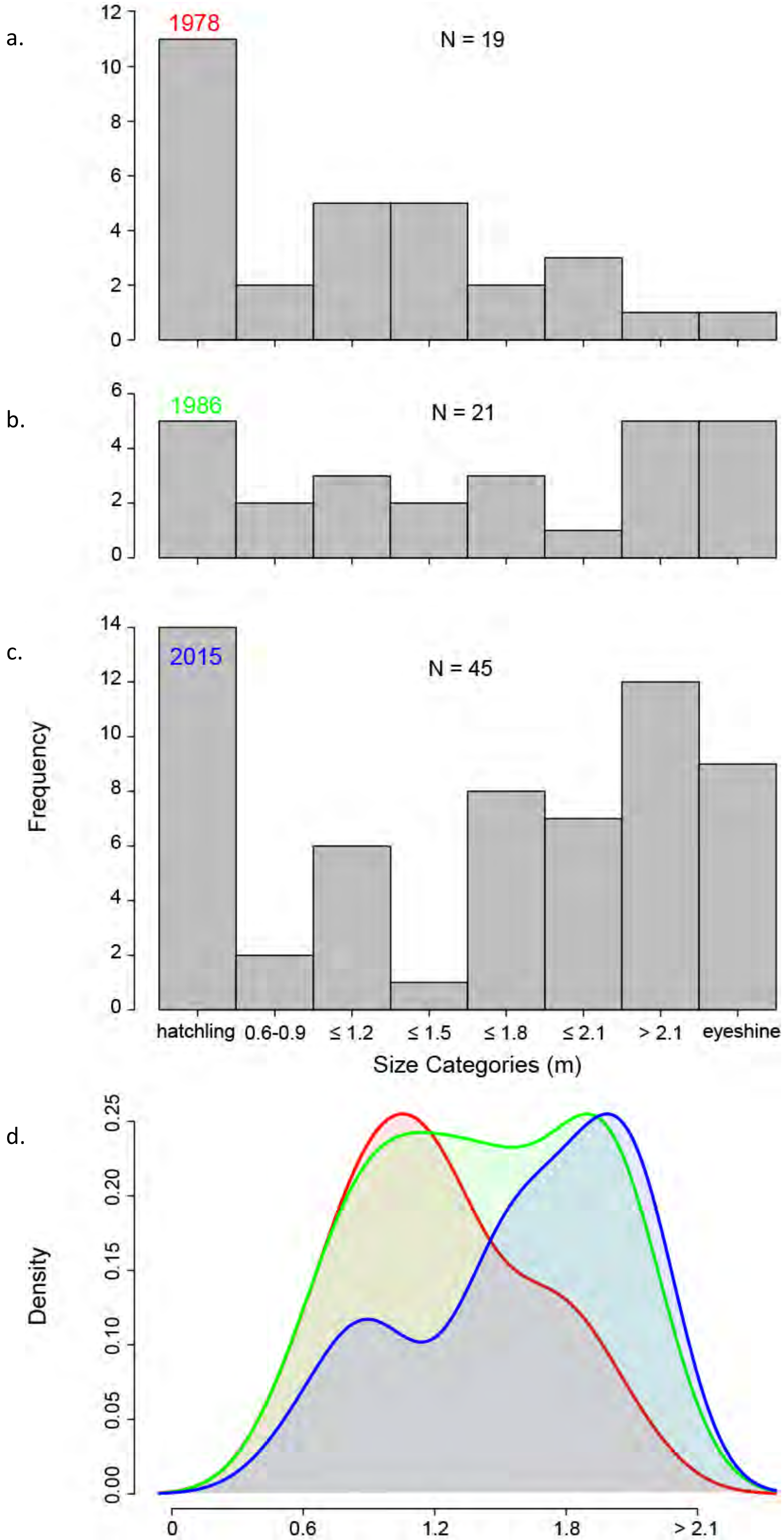

Fig. 26: Size structure of crocodile populations surveyed in the creeks running off the Hunter River in 1978 (a), 1986 (b) and 2015 (c). Kernel density smoothing plots for each year (d) illustrate the most common size structure

Table 3: Abundance, size structure, density and biomass of the crocodile population inhabiting the Roe-Hunter River System. Data collated from surveys in 1978, 1986 and 2015. Data from 1978 and 1986 taken from Messel et al. (1986). Data from 2015 collected by Halford et al. (2015).

Size (m)	all 1978	all 1986	all 2015	Roe main 1978	Roe main 1986	Roe main 2015	Roe creeks 1978	Roe creeks 1986	Roe creeks 2015	Hunter main 1978	Hunter main 1986	Hunter main 2015	Hunter creeks 1978	Hunter creeks 1986	Hunter creeks 2015
hatchling	63	10	131	28	1	88	9	0	19	0	4	0	11	5	14
0.6-0.9	47	12	14	36	8	6	4	1	1	5	0	0	2	2	2
0.9-1.2	32	47	116	17	14	63	10	21	26	0	8	3	5	3	6
1.2-1.5	32	56	47	8	26	20	3	7	15	5	6	4	5	2	1
1.5-1.8	20	42	72	2	19	26	5	8	13	4	2	4	2	3	8
1.8-2.1	12	39	45	2	18	14	2	5	14	1	6	3	3	1	7
>2.1	8	28	92	2	6	41	2	1	14	1	4	6	1	5	12
eyeshine	9	39	159	2	20	71	3	3	21	1	3	16	1	5	9
total abun	223	273	676	97	112	329	38	46	123	17	33	36	30	26	59
total abun (no hatchlings)	160	263	545	69	111	241	29	46	104	17	29	36	19	21	45
river length (km)	103.9	103.9	103.9	31.5	31.5	31.5	12.3	12.3	12.3	18.5	18.5	18.5	16.8	16.8	16.8
density (incl hatchlings) nos/km	2.15	2.63	6.51	3.08	3.56	10.44	3.09	3.74	10.00	0.92	1.78	1.95	1.79	1.55	3.51
density (no hatchlings) nos/km	1.54	2.53	5.25	2.19	3.52	7.65	2.36	3.74	8.46	0.92	1.57	1.95	1.13	1.25	2.68
total biomass (incl. EO) (kg)			14017.0												
biomass density (no hatchlings) kg/km			134.9												
Ratio large/small (>1.8m)	0.2	0.5	0.7	0.1	0.4	0.6	0.2	0.2	0.6	0.2	0.7	0.9	0.3	0.7	1.1
Ratio eyeshine/non-hatchlings	6.0	17.4	41.2	3.0	22.0	41.8	11.5	7.0	25.3	6.3	11.5	80.0	5.6	31.3	25.0
% change in abundance		164.4	207.2		160.9	217.1		158.6	226.1		170.6	124.1		110.5	214.3

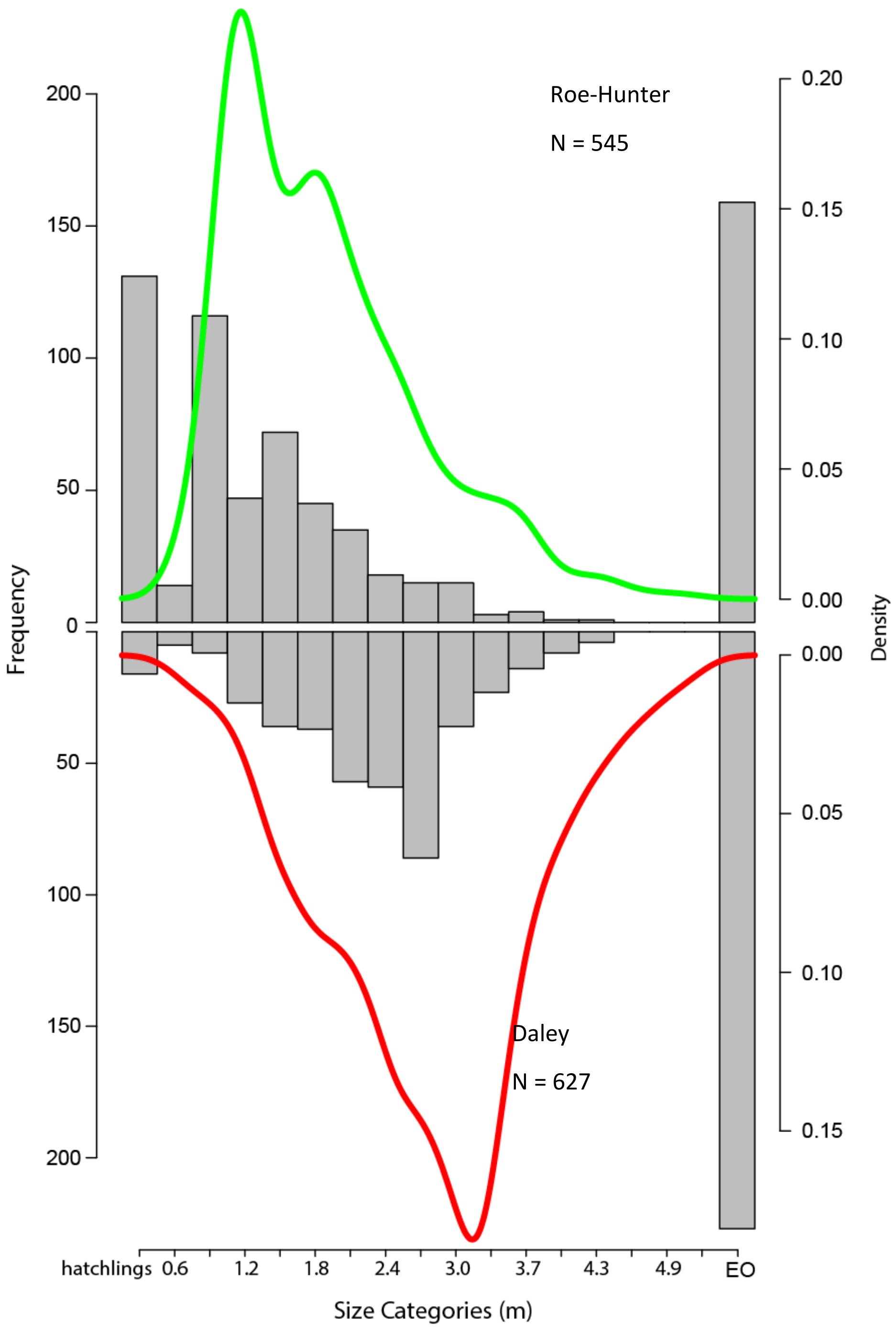

Fig. 27: Comparison of size structure for crocodile populations surveyed in the Roe-Hunter River system in 2015 and the Daley River systems in 2016 (no survey done in 2015). These two systems are of comparable length. Density plots are overlayed on the size-frequency histograms to highlight the most common size range in each system. Category 1 and EO represent hatchlings and EO respectively and were not included in the density plot calculations.

In 1978 the ratio of large to small crocodiles (>1.8m length/06-<1.8 m length) in the entire Roe-Hunter system was 0.2 rising to 0.4 in 1986 and 0.6 in the 2015 survey. This increasing pattern was consistent across all components of the river system. Again it can be seen that there are large numbers of juvenile crocodiles able to reside in 'holding' creeks/rivers outside of the main system (Fig. 20) although not to the extent seen in the

Prince Regent River system. When EO data was re-allocated the ratio of large/small crocodiles changed little with a ratio of 0.7 for the entire system in 2015. The highest ratio across all components of the system was 1.1 for the Hunter Creeks which remains significantly less than the ratio of 4.3 calculated for the Daley River. Eyeshines made up 23.5% of the total counts of non-hatchling animals in the Roe-Hunter river system in 2015 compared to only 14.2% in 1986. These proportions are remarkably consistent between the two river systems we surveyed. For comparison, the proportion of EO crocodiles in the Daly River in the NT was 36%.

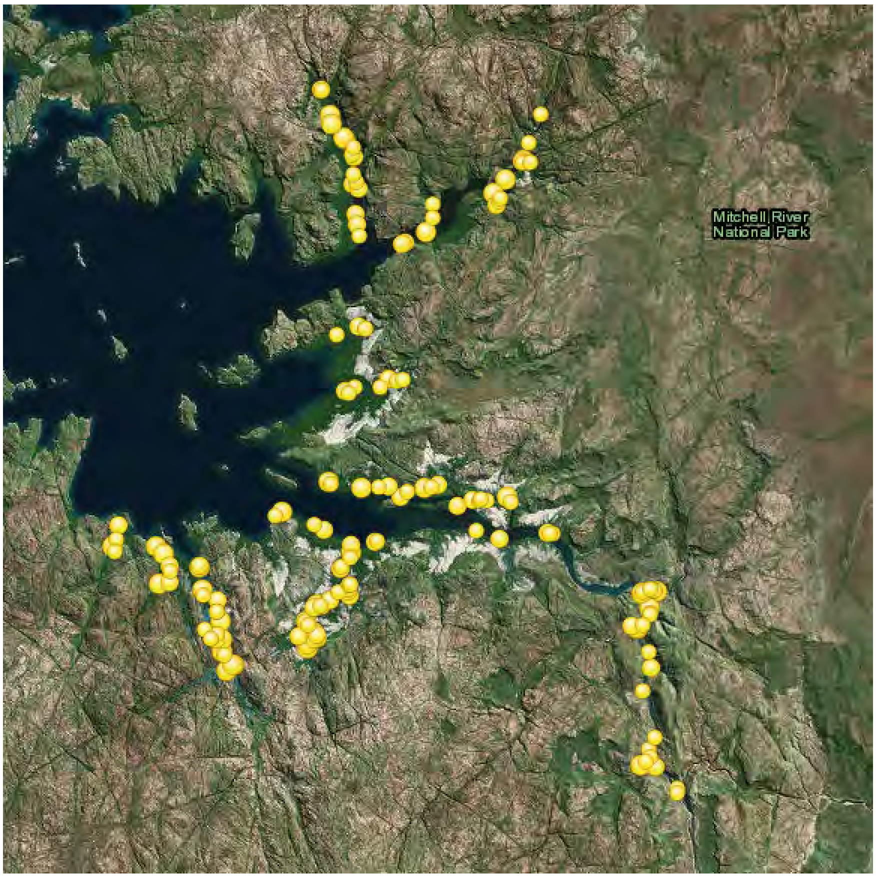

Fig. 28: Location of crocodiles 1.5 – 2.1m in length in the Roe-Hunter River system in 2015

Our comparison NT river for the Roe-Hunter River system was the Daly River which is ~95km long. In 2016 this river had a density of 6.7 animals/km with standing biomass of 600.9 $kgha^{-1}$. This far exceeds current population levels within the Roe-Hunter River system which was found to have 5.25 animals/km with a standing biomass of 134.9 $kgha^{-1}$ (Table 2), indicating the crocodile population in this system is still some way from maturity. The differences in biomass are again due to differences in the number of large crocodiles in the 2 systems. The Daly River had 230 crocodiles over 2.4m in 2016 (Fig 27) whereas the Prince Regent River system only had 27 crocodiles over this length (Fig. 27 & Fig. 28).

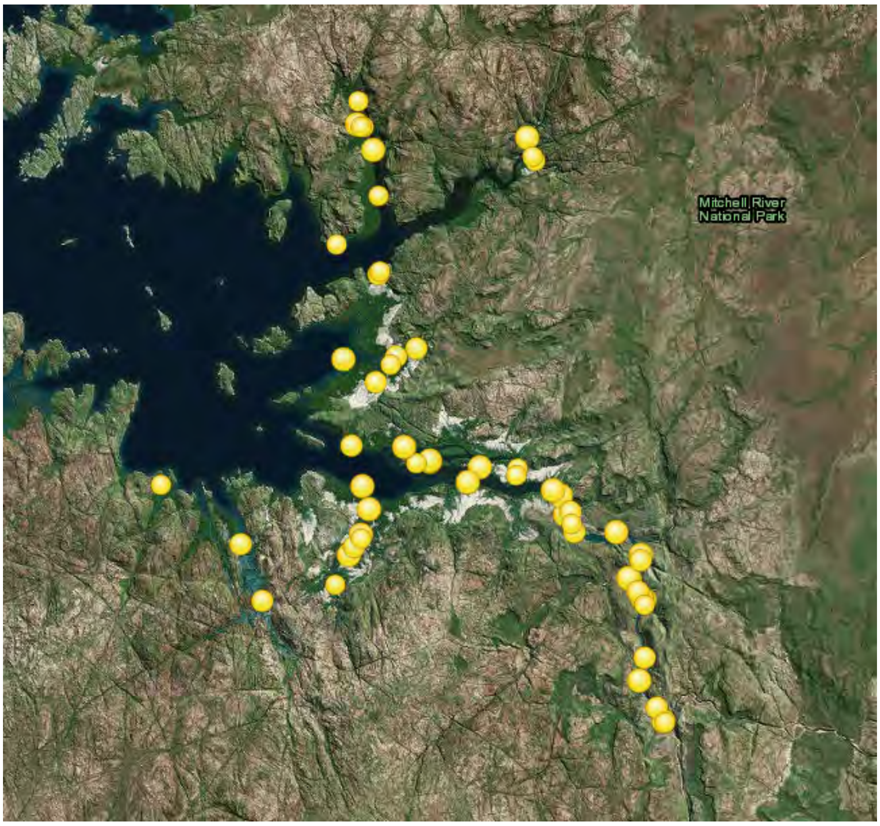

Fig. 29: Location of crocodiles >2.4m in length in the Roe-Hunter River system in 2015

4.3 Genetics Study

Preliminary results of the national genetics study of connectivity between crocodile populations has shown very clearly that the crocodile populations in Prince Regent and Roe-Hunter River systems are genetically distinct from the populations residing in the Northern Territory (Fig. 30). There are no samples analysed from the Ord River – Kununurra system yet which should provide more insights into regional connectivity patterns in WA. These results do confirm that these populations should be considered a separate population from the NT and be managed as such.

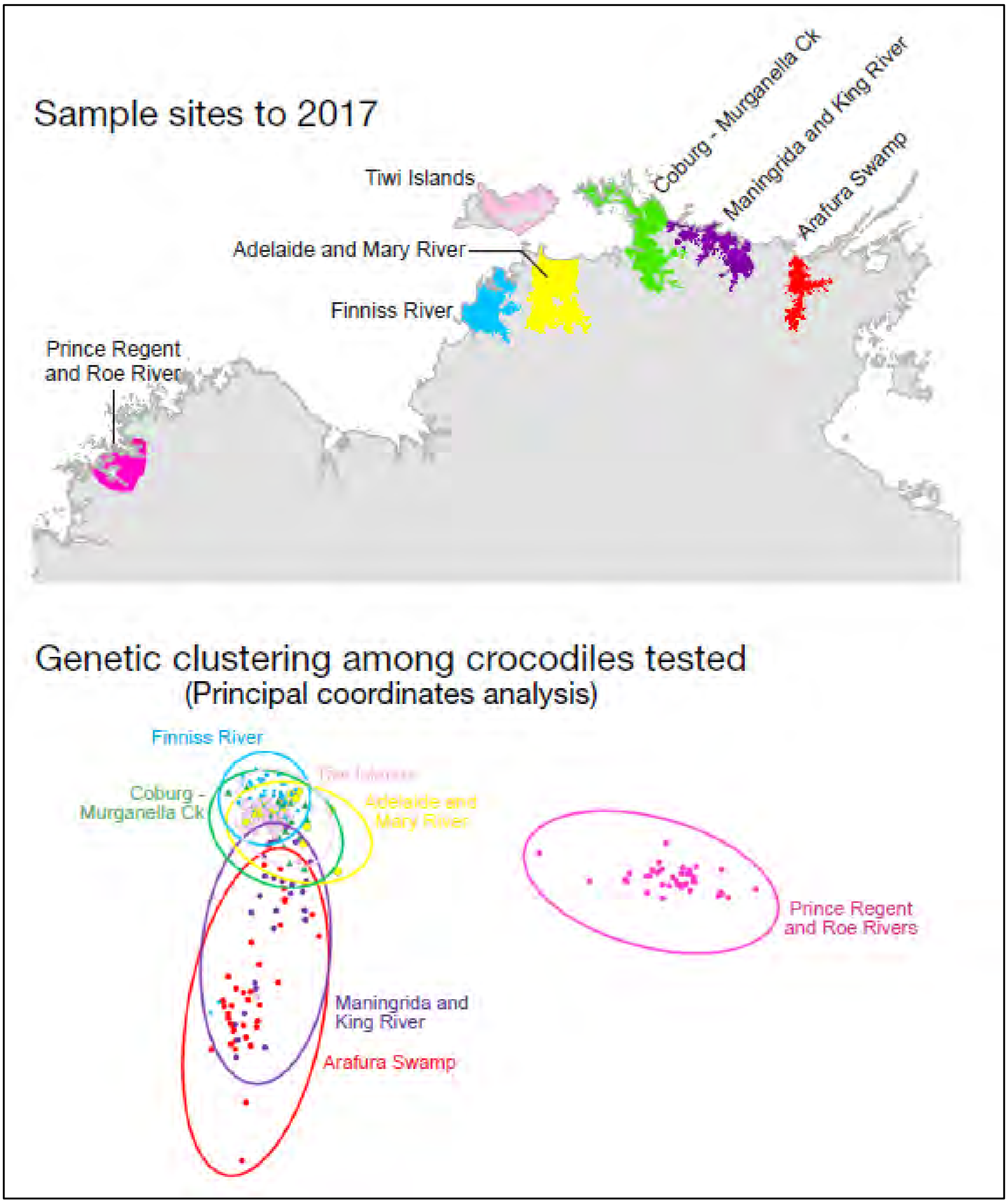

Fig. 30: Results of genetic testing of crocodile populations from Prince Regent and Roe/Hunter River systems and their regional neighbor populations in the Northern Territory.

5 Discussion

Our surveys of the Prince Regent and Roe-Hunter River systems in 2015 have provided the starting point for an updated assessment of the size-structure and abundance of saltwater crocodile populations in the greater West Kimberley. With the last surveys in this region having been completed over 30 years ago the data contained herein is critical for guiding development of effective management protocols for crocodile populations in the region. The health of crocodile populations in the greater Kimberley can be considered 'very good' with no natural predators, good water quality and an abundance of food. Our data provides empirical evidence for the continual growth and recovery of populations following a ban on hunting in 1970 with recovery levels starting to approach those of rivers in the NT where the recovery from hunting is largely complete. Further surveys of crocodile populations throughout the other major river systems in the West Kimberley will provide the data necessary for better understanding of crocodile/human interactions around coastal human population centres in the region.

The data clearly shows not only an increase in the abundance of crocodiles but also a shift in size structure of the crocodile populations between 1986 and 2015, with larger crocodiles (>2.1m) starting to become more common in the Kimberley river systems. Despite this trend very large crocodiles (>3m) remain relatively rare in both the systems we surveyed and significantly less than what is seen in the NT rivers. While densities of crocodiles are approaching similar levels to NT rivers there remain very large differences in standing biomass which is the primary indicator of a mature and stable crocodile population. Crocodiles grow slowly but put on biomass exponentially starting around the 3m size. Hence large standing biomass densities signify a population that has been allowed to grow undisturbed for a significant period of time.

The lack of larger crocodiles in the West Kimberley can be taken as evidence that these systems are still recovering from the hunting era, and relative to NT population parameters have room to expand both in abundance and biomass. However it remains to be seen how and whether the different river system structure prevalent in the West Kimberley will influence the ongoing recovery of the population. Food does not seem to be limiting with very high abundance of mullet and other fish species noted during the surveys in 2015. Hatchlings were also seen on numerous occasions feeding on mullet along the shoreline. Many of the main river systems in the west Kimberley have extensive areas of mangrove-lined tidal creeks near the mouth of the main 'breeding' river which provides holding areas for medium–size crocodiles that have been displaced from the main river where they were born (e.g. Prince Regent River, and to a lesser extent, the Glenelg River and Ord, Roe and Lawley River systems). The ability of this type of system to sustain a crocodile population at the same densities as the NT rivers has been questioned previously (see Semeniuk et al. (2011)) and only further monitoring of populations will provide an answer.

Density-dependent effects may already be operating in the Prince Regent system as we found very few crocodiles in the 0.6-0.9m range which is the first non-hatchling size cohort. This could indicate a poor recruitment year some 2 years previously or else there may be high mortality operating on the 0.6-0.9m size group. Given the principal 'spotter' for this survey has been involved in spotlight surveys of crocodiles for over 20 years we believe this result reflects natural mortality with the greater abundance of the 0.9-1.2m size class indicating high survival of crocodiles if they can get to >0.9m without being killed.

5.1 A Model of Crocodile Population Dynamics

Our assessment of the population structure of crocodiles in the Prince Regent and Roe/Hunter River systems has been guided by the seminal work of Professor Harry Messel and his colleagues who used their extensive surveys in the 1970's and 80's to develop a model of how and why crocodile populations are structured in the West Kimberley and NT. Their model is described in detail in a series of Monographs (refer to references in Messel & Vorlicek (1986)) however it is briefly summarized here to provide the reader with a deeper understanding of how crocodile populations are structured.

- The tidal waterways of northern Australia are categorized into Type 1, 2 or 3 according to their salinity signatures. Type 1 systems are the main breeding rivers usually having annual freshwater input, and often freshwater billabongs or swamps in which to nest. The other types have either seasonal freshwater influx or none at all and are usually poor or non-breeding systems.
- Non-breeding Type 2 and 3 systems obtain their crocodile populations through migration of sub-adult crocodiles from the Type 1 breeding systems from which they are forced out by older, bigger crocodiles. Mortality in this size-range can be as high as 60-70%.
- 'Dry' Wet seasons play a significant role in the dynamics of crocodile populations with drying, freshwater holes forcing resident crocs back into the rivers from where they originated, causing more movement of smaller crocodiles into Type 2 and 3 systems. This dynamic is probably less influential in the Prince Regent River system although the extent of semi-permanent freshwater billabongs and swamps in this area has not been investigated.
- Dynamics of crocodile populations result in a slow change from a population dominated by juvenile crocodiles to one dominated by large ones. Although definitive data do not exist, reports from early explorers and pilots during the 1930's and 40's suggest there were far greater densities of crocodiles back then, than there are now, including numbers of very large crocodiles. This suggests that recovery to pristine population structures is a slow and very long-term process.

5.2 Development of Operational Protocols and Training

In addition to updating our knowledge of crocodile populations in the West Kimberley our two other major objectives were (1) to document our procedures so that a standardized methodology would be available whenever further surveys were to be undertaken and (2) to increase the skills of DBCA staff and Traditional Owners to enhance regional capacity for future crocodile work.

We have developed a Standard Operational Procedure for spotlight surveys of estuarine crocodiles (Appendix 1) and a Standard Operational Procedure for biopsy sampling of crocodiles (Appendix 2). For the biopsy sampling we developed and effectively tested the use of a biopsy pole system to enable rapid and safe sampling of tissue samples from crocodiles. This technique is a relatively novel method for crocodile researchers and there is a scientific methods paper currently in peer-review with the journal Wildlife Ecology Bulletin. The use of an electronic data collection process is still being fine-tuned, however another Standard Operational Procedure will be developed to enable this technology to be utilized for future surveys.

Fig. 31: Principal Investigator on the crocodile project, Dr Andrew Halford and Dambimangari ranger Adrian Lane head out for a day time reconnoiter of a river section to be surveyed that night.

Fig. 32: Dambimangari traditional owner Gary Umbagai holds a hatchling crocodile caught so that a tissue sample could be taken as part of a genetics study on *C.porosus* population structure across Australia.

Traditional Owners participated on all aspects of the survey trips gaining first-hand experience of the techniques employed to survey and sample crocodiles (Figs 31 & 32). Long-term monitoring of crocodile populations in the West Kimberley will require the participation of Traditional Owners if a more comprehensive understanding of the spatial and temporal dynamics of estuarine crocodiles is to be achieved.

5.3 Conclusions

Extrapolating from the results of our surveys of the Prince Regent and Roe-Hunter River systems we have confirmed that there has been and continues to be a robust recovery of West Kimberley crocodile populations from their nadir in the early 1970's. These two systems have been recognized as having the most compatible habitat for crocodiles in the West Kimberley and hence serve as an appropriate bellwether for understanding patterns of recovery across the greater Kimberley. However, the devil is in the detail and other than generalizing about the buoyant recovery it is not possible to say what the population structure of crocodile populations is in the river systems not surveyed. Because of the clear differences in geomorphology of West Kimberley river systems it remains uncertain whether the dynamics of their recovery will continue to closely mirror the NT systems. Uncertainty around recovery dynamics of crocodiles in unsurveyed rivers will make it difficult for conservation managers to develop the most effective plans for managing a growing crocodile population interacting with a growing human population in the region, especially around the large population bases of Broome and Kununurra. Hence there is a need for further surveys of river systems along the West Kimberley coast to determine the size and structure of crocodile populations in more marginal systems. There appears to be no foreseeable threat to the continued recovery of crocodile populations in the Kimberley although climate change remains an unknown but potentially significant agent of change. Research and monitoring should have a core focus on (1) understanding what are the major influences on the expansion of crocodile populations south from Cape Levique, and (2) documenting the temporal and spatial changes in abundance and size structure of crocodile populations throughout the multiple river systems that exist south of Cape Levique.

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8 Communication

8.1 Proceedings/Technical Reports

Barrow, D (2016) Crocodile spotlighting surveys in tidal estuaries. Standard Operating Procedure. DBCA. 11pp.

Barrow,D and Halford AR, (2016) Biopsy pole collection of tissue samples from free-ranging crocodiles. Standard Operating Procedure. DBCA. 10pp.

8.2 Submitted manuscripts

Barrow, D and Halford AR (2017) A Modified Biopsy Needle and Pole Design for Rapid, Safe, and Easily Repeatable Tissue Extraction from Free-Ranging Crocodiles. Wildlife Ecology Bulletin (In Press)

Halford, AR and Barrow, D (2017) Snapping Back: Saltwater crocodiles back from the brink. Landscope

8.3 Presentations

- WAMSI conference (2015). Oral presentation entitled, “Status of saltwater crocodiles in the Kimberley”
- Tourism Operators Workshop (2016) Oral presentation entitled, “Marine Science in the Kimberley”
- Science on the Broome Coast (2016). Oral presentation entitled, “Status of saltwater crocodiles in the Kimberley”

8.4 Other communications achievements

- ABC Interview (2015) – ABC Broome journalist Erin Parke produced a story of our survey work ‘on site’ which was broadcast on regional, national and international news bulletins.
- ABC story on Landline (2015) - ABC Broome journalist Erin Parke produced a story on crocodile issues in the Kimberley which featured our work and was a major component on a Landline program.

8.5 Key methods for uptake

8.6 (i.e., advisory committee, working group, website compendium of best practice)

- Survey results are being used by the department to formulate plans for management and ongoing work.
- Training of Traditional Owner’s and implementation of surveys of river systems ‘on country’ has been targeted as a priority objective.
- Regular talks at community and professional gatherings.
- Lunch and Learn – Presentation and Discussion
- Lunch and Learn – Presentation of ESRI field application for collection of crocodile data

9 Future Opportunities

- Continued use of genetics to understand regional and local patterns of connectivity.
- Collaboration with NT crocodile researchers to incorporate results into national patterns.
- Incorporation of Ord/King River surveys into state database and national genetics study

10 Appendices

10.1 Management Questions

Key Question	Informed Response
What is the distribution and abundance of crocodile populations across the Kimberley?	Saltwater crocodiles (*Crocodylus porosus*) are found throughout all river systems in the Kimberley. Abundance is greatest in areas with the most extensive nesting habitats and has approximately trebled since hunting was banned in 1969, with a gradual shift in the size structure towards more crocodiles above 1.8m (6ft) in length. In comparison to comparable rivers in the Northern Territory, the West Kimberley rivers contain lower densities of crocodiles and much less standing biomass, reflecting the much lower abundance of very large crocodiles (> 3.0m/10ft). These characteristics suggest crocodile populations are still recovering from the effects of hunting but at a slower rate than the NT populations have. More survey work across the Kimberley is needed though to confirm the extent of recovery across their full range.
What, when and where are their critical habitats?	Critical habitats for nesting are found in areas subject to regular freshwater inundation during the breeding season, usually at the upstream end of rivers. Nests are made predominantly from grasses hence savannah floodplains, which are common in the NT but uncommon in the Kimberley, are the primary nesting habitat. The location and extent of nesting habitat in the Kimberley is not known and identifying these should be a priority for future work. Critical habitat for non-hatchling crocodiles is estuarine river systems which are relatively abundant along the Kimberley coast. However, unlike the rivers in the NT many of the Kimberley rivers have been formed through erosion of the surrounding bedrock which results in high sided ravines and rocky coasts which are less favourable habitat for crocodiles.
What are the major pressures on crocodiles in this region and how can they be measured using key indicators over the long-term (e.g. marine debris)?	There are few pressures on crocodiles in the region, with humans their only source of non-natural mortality. Gill-netting has been indicated as a source through accidental drowning. Water quality is good and our surveys in 2015 indicated there is an abundance of food. Climate change is a potential emerging threat with temperature a major factor in moderating sex ratios of crocodile offspring.

4. What cost-effective methods can be developed to enable effective condition monitoring of priority species?	In the face of limited pressures, monitoring of crocodile populations is best achieved through periodic spotlight surveys of river systems of interest. An SOP has been developed for the methodology behind these surveys and is available from the DBCA. Weblink to all SOP's is https://www.DBCA.wa.gov.au/plants-and-animals/monitoring/96-standards/99-standard-operating-procedures
NEW QUESTIONS POSED BY MANAGERS	
What do we need to know for management to assist in crocodile 'incursions'?	Data is needed on the abundance and size structure of crocodiles in river systems closer to the main population centres where human/crocodile interactions are more likely to occur. This information will provide managers with knowledge of the number of crocodiles that are being supported in these systems and whether their densities indicate a growing population or a more itinerant one. Surveys will also indicate the number of larger and potentially more dangerous crocodiles (> 6ft/1.8m) in these river systems. Density and biomass estimates from these surveys can also be compared to other more mature river systems to provide insights into the likely carrying capacity of rivers in the region.
Why are these habitats chosen by crocodiles (ie what makes good crocodile nesting habitat)?	Nests are most commonly made from grasses/sedges within floodplain areas which are usually located at the upstream end of rivers. Grasses are obviously easy material with which to build their preferred mound nests but it is not entirely clear why they prefer areas inundated with freshwater given they can survive outside this type of area. Nevertheless it is the preferred nesting habitat of nearly all crocodylians.
What do we know about home range?	Crocodiles exhibit a variety of ranging behaviours, with many animals existing within relatively small home ranges while others will undertake regular travel over 100s of kilometres. Movement patterns are a response to the complex social patterns of these animals. Density pressures are a primary driver forcing predominantly male crocodiles to leave their natal systems to avoid being attacked and killed by the larger dominant males.

What is the next river system that we should be looking at?	Given the lack of pressures on crocodile populations research and monitoring resources should be focussed on documenting the state of crocodile populations in river systems adjacent to areas with large human populations. As well as providing information on the number and size of crocodile populations, spotlight surveys will provide a clearer understanding of the carrying capacity of the smaller river systems.
Is there a correlation between presence of barramundi and crocodiles in the same river systems and potential for impact from gill net fishery - bycatch and/or competition)?	There is a lack of data available upon which to analyse this question. It is however an area in which data should be acquired. Adult crocodiles have not been shown to have diet preferences and will readily eat any items perceived as food.