Review of a Trial Harvest of Estuarine Crocodile Eggs in the Pormpuraaw Deed of Grant in Trust Lands

and

Recommendations as to an Experimental Commercial Harvest

Report to Department of Environment and Science

Dr Laurence E Taplin,

Adjunct Principal Research Fellow, College of Science & Engineering, JCUNQ

Cairns, 2017

Table of Contents

Executive Summary 6

Introduction 9

Approach...9

The Value of the BG/PLSR study 10

The DOGIT catchments...11

Extent of the DOGIT lands 11
Definition of the DOGIT lands used for this review..11

The DOGIT lands and their crocodile habitat in context..............................12

Estuarine crocodile habitat in the DOGIT catchments...13
Estuarine crocodile nesting habitat in the DOGIT catchments 16
Isolation...16
Conclusion...17

The number and distribution of nests across the DOGIT catchments..........................20

How well does the nesting habitat map align with known nests in the DOGIT catchments? 21
    From nests to nest sites 21
    The distribution of nest sites with respect to broad vegetation types..........................21

The viability and fate of nests in the DOGIT catchments 25

Nest viability 25
Nest fates of all nests..25
Nest fates of viable nests...25
Fates of viable nests plus nests lacking eggs...25
Conclusions 25

The extent and frequency of flooding in the Pormpuraaw DOGIT catchments..........26

Rainfall and flood patterns in the DOGIT catchments..27
    Rainfall patterns and extreme events 27
    Extreme events and nest fates..28
    Whole of catchment rainfall 28
    Correlation between whole of catchment rainfall and nest flooding 29
How do the rainfall data and nest flooding data align with other measures of flooding?....30
    Satellite mapping of flood waters..30
    Relationship between MODIS-mapped flood waters and nest flooding 30
Conclusions 35

Search effort in relation to total nesting habitat and the potential number of nests ...36

Search effort 36
Potential nest numbers across the Pormpuraaw DOGIT lands and Kendall River system..38
    Nest numbers excluding the Kendall River system...38
    Extending the estimate to the Kendall River system 39

Crocodile monitoring 43

Survey transect distances 43
Survey counts 43

What to do with the 2008 and 2009 survey data? 45
Standardising transect lengths and counts....................45
Is there any evidence that tide height has affected counts?....................46
Change in crocodile counts over time....................48
Is the size class structure indicative of a ‘mature’ population?....................49
    Waterways to the south of the Kendall River system 49
    The Kendall River system....................51
    Conclusions....................54
Recruitment into the DOGIT waterways 54

Harvest timing in relation to nest losses....................55

How many breeding females may be present in the DOGIT waterways? 55

Comparison of NT egg harvest with the potential Queensland harvest....................56

Potential harvest from the DOGIT lands....................57

What are the essential elements of a harvest proposal for the DOGIT lands 57

What should be the conservation and economic aims of a harvest? 58
What level of harvest might be sustained?....................58
Selective release of juveniles as an option....................60

Research and monitoring to underpin the experimental harvest....................61

What needs to be monitored?....................61
Control systems – are they warranted? 62
Searches for nests and monitoring of nest fates should continue beyond the end of harvest 63
What research and monitoring regime should apply to answer these questions?....................63

The detectability of change....................66

References 69

Annexe 1: Mapping of crocodile habitat and prospective nesting habitat in Queensland....................72

Annexe 2: Defining nest sites from the distribution of nests....................75

Annexe 3: Satellite mapping of flood waters 78

Annexe 4: Identifying and mapping individual nests 79

Annexe 5: Tidal patterns in the Gulf and western CYP....................80

Annexe 6: Total rainfall in the DOGIT catchments....................83

Annexe 7: Search effort in relation to total nesting habitat and the number of nests 85

Annexe 8: Tidal conditions for population counts in the DOGIT catchments....................86

Annexe 9: Standardised survey transect distances, transect counts and comparisons 88

Annexe 10: Are the DOGIT catchments approaching carrying capacity?....................90

List of Figures

Figure 1. The Pormpuraaw DOGIT lands (red hatching) in relation to the several catchments discussed in this report. 12
Figure 2. The extent of estuarine crocodile habitat in Queensland. 14
Figure 3: (a) The first mapping of nesting habitat in the DOGIT catchments (Magnusson et al, 1979, 1980) and (b) the author's revised mapping (refer Annexe 1). 18
Figure 4: Distribution of nests across the DOGIT catchments 2007-2017. 20
Figure 5: The fit of nests sites to nesting riverine (cream) and palustrine (blue) vegetation on (a) the Edward R/Balurga Ck system and (b) Mungkan Creek and the Chapman River.22
Figure 6: Distribution of nest sites in relation to the proportion of major vegetation types in the regional ecosystems underlying them. 24
Figure 7. Extensive flooding on the coastal plains of south-western Cape York Peninsula. 26
Figure 8. Monthly rainfall at Southwell Station in the DOGIT catchments between 1996 and 2017 (the full extent of data available). 27
Figure 9. Integrated total rainfall volumes for the whole of the DOGIT catchments region for nesting seasons between 2012-13 and 2015-16. 29
Figure 10. MODIS 14x3-day composite flood water imagery (black) for the whole 2013-14 nesting season superimposed on the DOGIT catchments (light green). 31
Figure 11. MODIS flood water mapping for nesting seasons (a) 2014-15, (b) 2015-16 and (c) 2016-17. 32
Figure 12. Nest sites (stars) mapped against MODIS flood waters for the 2013-14 nesting season (grey) and the land below 20m above datum level (effectively sea-level) in the sub-catchments of the DOGIT catchment lands. 33
Figure 13. Mapping of nest sites and MODIS flood waters onto ESRI WorldImagery of the southern portion of the DOGIT catchments – (a) nest sites, (b) nest sites and MODIS floodwaters 2013-14, (c) nest sites and MODIS floodwaters during a year with lower rainfall. 35
Figure 14. Areas covered during surveys for nests by boat (blue) and quad bike (violet) in relation to the extent of DOGIT lands 37
Figure 15. Coverage of potential nesting habitat by boat surveys in 2012-13 in the southerly DOGIT catchments from Malaman Creek to the Edward River/Balurga Creek system. 38
Figure 16. Locations of hatchling and 2-3ft size class crocodiles (red dots) in the Nassau and Mitchell River systems in 1986 and 1987 respectively. 42
Figure 17. Adjusted counts of non-hatchling crocodiles in the several DOGIT aggregation systems categorised by sighting conditions, based on review of the likely state of the tide for each survey. 48
Figure 18: Trend in non-hatchling counts on (a) linear and (b) log scales in the four most frequently counted DOGIT waterways. 49
Figure 19. Numbers and proportions of non-hatchlings crocodiles by size class in DOGIT river systems, excluding the Kendall/Holroyd system. 52
Figure 20. Numbers and proportions of non-hatchlings crocodiles by size class in the Kendall/Holroyd River system. 53
Figure 21: Proposed nest census transects for the DOGIT catchments (a) the four southerly river systems and (b) the Kendall River system. 65
Figure 22: Power analysis of annual surveys on the four most proximate river systems to Pormpuraaw over a ten-year period. 68
Figure 23. Recorded nest locations on Mungkan Creek in (a) the 2012-13 nesting season and (b) all nesting seasons. 76

Figure 24: Nearest neighbour distances between nests mapped in the DOGIT catchments 2012-2015 77
Figure 25. Maximum monthly (spring) tide height at (a) Karumba and (b) Weipa by year (1979-2008). 80
Figure 26. Thirty years of tidal data for (a) Karumba and (b) Weipa. 81
Figure 27. Daily tidal maxima at Christmas Creek in the Pormpuraaw DOGIT lands 82
Figure 28. Catchment areas in the Pormpuraaw DOGIT lands relevant to the egg harvest proposal. 83
Figure 29. Box and whisker plot of mean monthly rainfall in DOGIT sub-catchments, ordered by latitude (S -> N) and averaged across years from 1996-2017 84
Figure 30. Comparison of Karumba tide height data (red line) with exposed bank conditions on the Chapman River at Pormpuraaw during DES survey on the night of 20 August 2017. 87
Figure 31: Crocodiles shot in one night on the Kendall River ca 1951-52 by Bob Plant and his team. 90

List of Tables

Table 1. Total area of estuarine crocodile habitat below the 20m contour level in the Pormpuraaw DOGIT catchments compared with estuarine crocodile bioregions across Queensland. 15

Table 2. Total area of prospective nesting habitat below the 20m contour level in the Pormpuraaw DOGIT catchments compared with estuarine crocodile bioregions across Queensland. 19

Table 3. Alignment between MODIS flood water mapping 2013-14 and nest flooding records from the DOGIT catchments data. 34

Table 4. Estimated proportion of potential nesting habitat in DOGIT catchments covered during boat transects. 36

Table 5. Estimated number of nests in the potential riverine nesting habitat of the DOGIT catchments, assuming the density index (nests/km2 of nesting habitat) is consistent for searched and unsearched areas of habitat. 40

Table 6. Assessment of the spotlight survey conditions during BG/DLSR surveys, judged according to DES survey standards. 44

Table 7. Survey transect distances calculated from Cybertracker log data provided by the PLSR. 44

Table 8. Actual and standardised transect distances used for adjusting non-hatchling counts from BG/PLSR population surveys. 45

Table 9. Re-estimated and adjusted counts and relative density of non-hatchling crocodiles by size class and river system. 46

Table 10. Population surveys by year on the Pormpuraaw DOGIT waterways. 46

Table 11. Crocodile capture records for the BG/PLSR study 50

Table 12. Discovery dates of nests by season as recorded in PLSR databases. 55

Table 13. Numbers of distinct transect records of nests surveys and visits included in PLSR databases by nesting season. 85

Table 14. Size distribution of crocodiles shot by Bob Plant and Bill Weare on one night in the early 1950s on the Kendall River system, compared with the size distribution recorded during BG/PLSR surveys. 91

Executive Summary

1. This report reviews the scientific study undertaken by Big Gecko and the Pormpuraaw Land and Sea Rangers Group into estuarine crocodile nesting, population counts and a trial harvest in the Pormpuraaw Deed of Grant in Trust (DOGIT) lands between 2008 and 2015.
2. The review finds the study has made a very useful contribution to knowledge of crocodile nesting in Queensland and more generally to our understanding of the crocodile population in this remote part of Queensland.
3. The review has confirmed the findings of the study, that flooding and predation cause extensive losses of crocodile nests in the DOGIT catchments and that recruitment of hatchlings into the local river systems is very low relative to the numbers of eggs being laid.
    - 3.1. Independent evidence from satellite mapping of flood waters provides confirmation of the vulnerability of nests in this low-lying area to major rainfall events.
    - 3.2. And evidence from long-term tidal patterns on western Cape York Peninsula helps confirm the study's assessment that high spring tides exacerbate flooding.
4. The review also confirmed the finding of the study that there was no detectable change in the number of non-hatchling crocodiles present in the DOGIT waterways over the course of the study.
    - 4.1. That finding is unsurprising, given the short length of the study, the inherent variability in counts of crocodiles even if the population is static, and the long life spans of crocodiles which can be expected to buffer change in non-hatchling numbers even if recruitment is lowered.
    - 4.2. More important would be evidence a marked decline in crocodile nesting or hatchling recruitment as the harvest proceeded. No such evidence emerged but environmental factors such as rainfall in the year preceding the nesting season can have marked effects on recruitment, sufficient to swamp the impact of harvest.
5. The review did identify a number of issues with the data collected during the study and some details of the analysis and findings. Many of these were overcome with the very open assistance of the Pormpuraaw Land and Sea Ranger group who provided all their raw data.
    - 5.1. The review's conclusions are, therefore, based on Big Gecko's published reports of 2008 and 2009, its draft report of 2017 and on the reviewer's own analysis of a large subset of the data.
6. The review finds, based on extensive work on crocodile habitat and crocodile nesting habitat in Queensland over recent years[1], that:
    - 6.1. The DOGIT catchments contain only 4% of the primary coastal riverine habitat in Cape York Peninsula and the Gulf Plains and just over 5% of that region's prospective crocodile nesting habitat. Thus any harvest proposed for the DOGIT catchments would leave the vast bulk of Queensland's habitat undisturbed.
    - 6.2. The review also confirms, based on the study's reports of the locations of 63 nests over four years and past work on nests and nesting habitat in Queensland and the Northern Territory, that:

---

[1] Refer Annexe 1.

        - 6.2.1. There is no good quality nesting habitat in the study area. Patches of moderate quality habitat do exist and are used, but they constitute a small fraction of the nesting habitat in the DOGIT lands.
        - 6.2.2. The vast majority of nests and nest sites (which can be used repeatedly from year-to-year) lie in highly flood-prone areas.
        - 6.2.3. Nonetheless, the multi-year patterns of rainfall and flood waters suggest that, from time to time, nests laid early will survive high waters and contribute to recruitment. This should be factored into the design of any proposed harvest.

7. The review lacked information sufficient to address questions about the full geographic extent and timing of nest searches, particularly helicopter searches. There was sufficient detail to estimate the proportion of nesting habitat actually searched by boat, which appears to have been a primary means of discovering nests in later years, and to estimate – albeit crudely – the number of nests that might have remained undiscovered.
    - 7.1. The total number of nests estimated for the DOGIT catchments including the Kendall River system is about 48 in favourable nesting years and perhaps half that number in poor years. Both ‘good’ and ‘poor’ years were encountered over the course of the study.
    - 7.2. There may be some growth in those numbers if the non-hatchling population increases beyond its current levels. However, the evidence available points to slow population growth at best in these Gulf waterways, so substantial short- to medium-term increases in the breeding population appear unlikely.
8. The review agrees with the conclusion of Big Gecko that a trial commercial harvest of crocodile eggs is potentially viable.
9. The number of nests available for harvest appears likely to remain comparable to the numbers discovered in the Big Gecko trial over the November-February period – i.e. some 10-20 depending on whether it is a good or poor nesting season.
10. The review, however, proposes that a harvest should not be designed to harvest a particular quota of nests or eggs. It should instead allow collection of any nests/eggs discovered during a defined harvest period (Nov-Feb) in the early wet season, using boat-based searches and any nests discoverable by quad bike/foot searches. Helicopter survey is ruled out as impractically expensive given the low density of nests.
11. The review concludes a trial commercial harvest as set out below poses no demonstrable risk to the estuarine crocodile in population in Queensland or to the regional population on the west coast of Cape York Peninsula and the Gulf Plains.
12. It recommends that, if such a harvest is to be approved, it:
    - 12.1. Should run for a period of 10 years in the first instance – approximately the time required for a female hatchling to grow to maturity.
    - 12.2. Should permit the harvesting of all nests discoverable by boat and quad bike/walking in the DOGIT catchments between 1 November and 28 February for a period of five years. It anticipates that logistics and economics will limit searches to much the same areas worked during the four years of trial harvest.
    - 12.3. Should give consideration after five years to revising the date for the end of harvesting to 14 February, subject to review of scientific data to be collected

under a proposed monitoring program. The rationale for that decision point and timing is set out in some detail in the review.

12.4. Should provide for a small number of juvenile crocodiles to be reared at Edward River Crocodile Farm for release to the wild at Year 5 or Year 10, should that be deemed appropriate after review of the population survey data.

12.5. Should not require ‘control systems’ to be established on the DOGIT lands. Population changes in unharvested systems outside the DOGIT lands that are included in the current Department of Environment and Science (DES) survey program provide a better basis for comparison. However, if nest harvest on the remote Kendall River system is logistically or economically impractical, its population should be counted annually and can also serve as something of a local ‘control system’.

13. A simple monitoring scheme is proposed, consisting of:

13.1. Thorough recording of nesting activity throughout the nesting season on all six waterways on which nests have been discovered (Malaman Creek, Chapman River, Mungkan Creek, Edward River, Balurga Creek and the Kendall River system). This should include some census tallies or counts of nests[2] along defined boat transects at specific intervals to ensure that indices of early- and late-season nesting effort are estimated.

13.2. Annual population surveys (with close DES oversight) during mid-winter tides that will produce data comparable with other Queensland Government surveys.

13.3. Annual capture and marking of hatchlings and yearlings on all six waterways.

13.4. Some additional data recording and tracking of the hatching success and subsequent fates of eggs after they are harvested. This will require agreement with Edward River Crocodile Farm regarding details and feasibility.

14. The monitoring activity mirrors closely what the Land and Sea Ranger teams have been trained for by Big Gecko and they have the capacity to do the work, with some scientific oversight to ensure data integrity and conformity to DES survey standards.

15. Changes of concern in spotlight counts or recruitment should be detectable with adequate statistical power over the time course of the proposed harvest.

---

[2] ‘Tallies’, in this context, are counts of nests based on the results of prior efforts to locate and harvest nests – they are a simple arithmetic exercise using data collected during harvesting. ‘Counts’ are the results of surveys conducted specifically to identify and catalogue nests along defined transects – some nests will be known at the onset of a survey from previous egg harvesting but some will be newly identified. The aim of the survey is to count methodically <u>all</u> nests identifiable along the transect.

Introduction

1. I have been asked by the DES to undertake a review of the scientific study conducted by Big Gecko (BG) and the Pormpuraaw Land and Sea Rangers (PLSR) between 2007 and 2015 and to advise on the proposal that they should be permitted to harvest estuarine crocodile eggs from the wild.

2. The scope of the work as defined by DES includes:

   2.1. Reviewing the methods, results and conclusions included in the Big Gecko reports.

   2.2. Using the reports and analysis to develop a harvest proposal.

   2.3. Setting out evidence on whether this harvest program would be detrimental to the wild population.

   2.4. Proposing the general design of a monitoring program that would be required to assess whether the harvesting program is having a detrimental effect on the population around Edward River.

   2.5. Advising on which river/s should be monitored as control systems, the intensity and timing of the monitoring that would be required in order to provide meaningful statistical power, and the most appropriate methods to be used to detect demographic change.

Approach

3. I obtained copies from DES of the two final BG reports covering their 2007-08 and 2008-09 nesting season work and BG's draft Summary Report of 26 June 2017 covering the 2011-12 through 2014-15 nesting seasons.

4. I visited Pormpuraaw for discussions with the PLSR group, who were closely involved with the study, particularly between 2011 and 2015, and who kept detailed records of their work. PLSR provided me with much useful background information and all of their raw data.

   4.1. I had discussions with the new lessees of the Edward River Crocodile Farm (ERCF), Clinton and Donna Paradise.

   4.2. DES officers also visited for a population count of Chapman River and Mungkan Creek, important sites in the Big Gecko/PLSR study. I accompanied the survey of the Chapman River and visited some of its nest sites.

5. I have sought to place the BG/PLSR study in its broader Queensland-wide context using my own recent work that has defined and mapped in detail the extent of estuarine crocodile habitat in Queensland and the extent of nesting habitat from the Northern Territory border down to the southernmost known breeding grounds on the Fitzroy River at Rockhampton.

   5.1. That work has not yet been published but no comparable work has been attempted for Queensland previously and it provides the most detailed overview of the extent and quality of crocodile habitat in Queensland, building on the regionalisation described by Taplin (1987). It follows quite closely techniques used for mapping crocodile habitat and nesting habitat in the Northern Territory and draws in some detail on that work, particularly for mapping nesting habitat.

6. I reconstructed and analysed in detail the PLSR-provided data to validate the analysis and conclusions drawn in the BG draft report of 2017.

6.1. PLSR reported that the data in their databases for the last four years of the study was the same data used by BG. This I was able to confirm in a range of ways, as my raw counts of nests, crocodile numbers and size classes aligned closely with the 2017 report.

6.1.1. The data recorded was very detailed and reconstruction was successful overall. It was not possible, however, to confirm the fate of numbers of nests that were recorded in the 2017 report. I have presumed this is because BG holds records additional to those PLSR provided.

6.1.2. Despite this, a sufficient sample of nests with known fates was available to validate the principal conclusions of the BG reports.

7. I examined, where records permitted, the effort expended and the proportion of nesting habitat covered by BG/PLSR teams during their searches. This allowed estimates of the numbers of nests that might exist in the DOGIT catchments beyond the limits of searches.

8. I sought independent information on the potential extent of flooding in the DOGIT lands over time and its relationship to the mapped nesting habitat, nest sites, rainfall and tide patterns. This helped with judgements about the likelihood that some or all nest sites are likely to be flooded in most or all nesting seasons, the timing of flood events and the rationale for harvesting nests expected to be flooded.

9. I reviewed the population data gathered by BG/PLSR and considered its usefulness for judging whether the trial nest harvesting had any impact on the population. That necessarily included consideration of the state of tides during searches, which can impact greatly on counts (Messel et al, 1981a; Bayliss, 1987; DEHP, 2016a,b).

9.1. That analysis required detailed reconstruction and validation of PLSR data and reconstruction of survey transects for the last four years of research. Transects for 2007-08 and 2008-09 were included in Britton (2009, 2010).

9.2. All data was reanalysed according to current DEHP survey standard methods, which follow those used for my own 1980s surveys.

The Value of the BG/PLSR study

10. Notwithstanding some challenges in working with the data, we should not underestimate the value of the research done by BG and the PLSR. The DOGIT lands have never been a particular focus for published estuarine crocodile research in Australia, despite the 1969 establishment of the Edward River Crocodile Farm.

10.1. Its waterways are small and remote. The costs of research here are high relative to the return of data (see Taplin 1987, 1989 for overviews).

10.2. Neither Messel’s team in 1979 (Messel et al, 1981b) nor my own in the late 1980s did any population surveys or nest discovery here – it was simply not a high enough priority. DES records indicate the Chapman River was surveyed by Queensland National Parks and Wildlife Service teams in 1997, 1998 and 2001 and Mungkan Creek in 1997 and 2001. There things rested until the BG/PLSR study.

11. There has been very little scientific research into crocodile nesting in Queensland, again because government research under DES and the Queensland National Parks and Wildlife Service (QNPWS) has given priority to population surveys.

11.1. My own research into crocodile nesting during the 1980s was a second order priority but did include aerial survey by fixed wing aircraft and helicopter to identify potential nesting habitat, incidental searches for nests on many systems during population surveys, investigation of nests on the populated east coast between Daintree and Ayr, and quite detailed searches of swampland nest sites in and around Weipa and Port Musgrave.

11.2. Nonetheless, five years of work identified only 75 nests across the whole of Queensland north of Ayr. The BG/PLSR study has identified over 60 in the DOGIT catchments alone and recorded much detail about their viability and fate. This is salient work that allows us to consider the viability of nest harvesting there.

The DOGIT catchments

Extent of the DOGIT lands

12. The DOGIT lands encompass the downstream parts of the catchments of all the waterways between Malaman Creek to the south of Pormpuraaw and Hersey Creek to the north. They also take in small parts of the Coleman River in the south and the Kendall/Holroyd River system in the north (Figure 1).

Definition of the DOGIT lands used for this review

13. The BG/PLSR study extended outside DOGIT lands during 2007-08 and 2008-09 as the teams explored nesting in the region (Britton 2008, 2009). It encompassed the Mitchell/Coleman River system and Topsy Creek to the south and much of the downstream Kendall/Holroyd River system in the north. The 2012-15 nesting and population studies excluded the Mitchell/Coleman system but included the Kendall/Holroyd system.

13.1. For this review, I have included the Kendall/Holroyd system in the definition of DOGIT lands/catchments for ease of referencing.

14. The southern boundary of the DOGIT lands aligns closely with the northern boundary of the Gulf Plains crocodile bioregion as defined by Taplin (1987). The bulk of the DOGIT lands lie in the southern part of the North-west Cape York bioregion in that definition but, viewed in the light of the BG/PLSR study, would be better considered part of a new sub-region lying south of the Weipa Plateau physiographic region.

15. The DOGIT catchments/subcatchments vary greatly in size but, because of the extremely low relief in these Gulf rivers, merge into one another[3]. There are referred to as catchments from hereon for ease of reference, but most are in fact sub-catchments. The catchment boundaries are, in many cases, quite ambiguous.

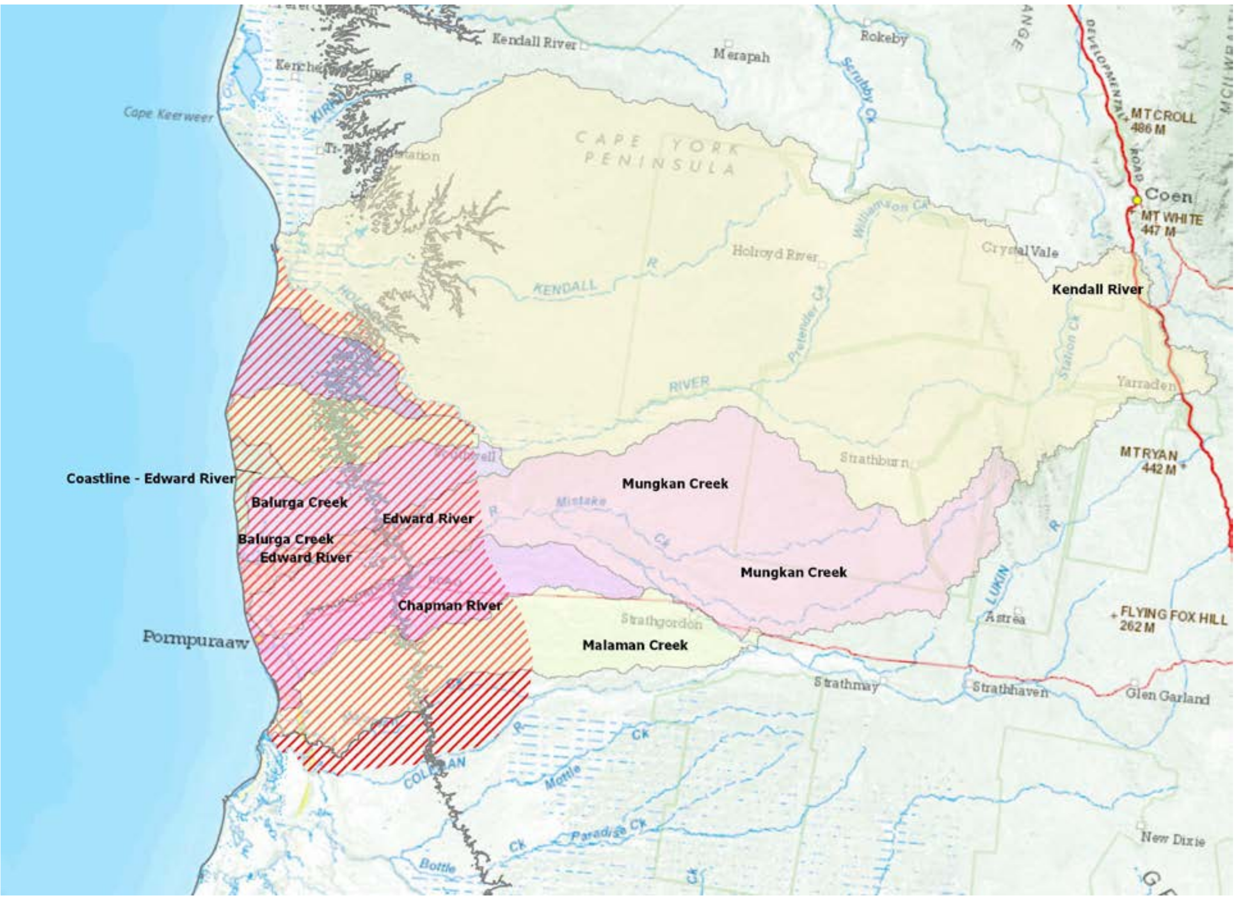
16. The Kendall River and Mungkan Creek catchments extend considerable distances inland. This matters little in terms of crocodile habitat, as the inland habitat is not especially favourable, but is relevant to their flood regimes. The large catchments can deliver considerable amounts of floodwater to nesting areas close to the coast and, in the case of the Kendall River, likely contribute to the presence of substantial freshwater swamps upstream (Britton 2008, 2009, 2017).

---

[3] Catchments and subcatchments were extracted in 2014 from geospatial datasets published by the Australian Department of Environment (DOE, 2004).

Figure 1. The Pormpuraaw DOGIT lands (red hatching) in relation to the several catchments discussed in this report.

Catchments and sub-catchments are from the spatial dataset *Nested Catchments Data for the Australian Continent* (DOE, 2004). The 20m contour line, which defines the margin of the principal habitat of estuarine crocodiles in this region and the effective inland boundary of the research reviewed, is shown in black.



The DOGIT lands and their crocodile habitat in context

17. It is important to consider the proposal for harvesting in the DOGIT catchments at an appropriate scale. For that, we need to consider such questions as:

    17.1. How important are the DOGIT catchments to the conservation of crocodiles in Queensland? What proportion of crocodile habitat in Queensland lies within the catchments and what is its quality relative to other regions of Queensland?

    17.2. Are the DOGIT catchments peculiarly isolated from other estuarine crocodile habitat in Queensland, such that management interventions there might have undue influence on the local or regional population?

    17.3. Does effective crocodile conservation in Queensland hinge on the exploitation of crocodiles there?

18. The first question is particularly important, as we cannot deal with the DOGIT lands in isolation from the rest of Queensland without the risk of getting the impact of any proposed egg-harvesting out of proportion.

18.1. There is, however, good reason to consider the Queensland situation in isolation from Australia as a whole. Queensland has specific legislative responsibilities in relation to crocodile conservation and considerable differences from other parts of Australia that are relevant to decisions on crocodile management.

19. Work completed by the author to contribute to Queensland's current crocodile survey program allows us, for the first time, to estimate the total extent of estuarine crocodile habitat and nesting habitat across the whole of its known breeding range in the State. Details of how that task was approached are set out in Annexe 1 and the resulting map is at Figure 2.

19.1. For the current review, I have considered only habitat below the 20m contour, as this is where crocodiles are found predominantly. They do extend to higher altitudes and long distances inland (as high as 400m ASL in parts of the mountain ranges of north-east Queensland and at least 100km upstream in some waterways) but the numbers encountered are small relative to those at lower near-coastal elevations. And the vast bulk of their potential nesting habitat lies in this elevation zone (see below).

19.2. Limiting consideration to the zone below 20m thus underestimates the habitat available to the species and makes for conservative conclusions.

<u>Estuarine crocodile habitat in the DOGIT catchments</u>

20. The DOGIT lands account for just 2.3% of the riverine habitat in Queensland below the 20m contour and 2.1% of palustrine and lacustrine habitats (Table 1).

20.1. If we exclude the extensive area south of Cooktown that has the bulk of the human population, the most intensive land-use and climatically marginal habitat to the south, the proportions rise marginally to 3.3% and 4.2% respectively.

20.2. And if we limit the comparison to north-western Cape York Peninsula (Queensland's prime crocodile habitat) and the Gulf Plains there are further small shifts to 3.9% and 5.7%.

21. It is instructive also to compare the estimates of crocodile habitat in Queensland with those developed for the NT as part of their submission to transfer the Australian population to CITES Appendix 2 (Webb et al, 1984).

21.1. Webb estimated the total extent of riverine and smaller waterways across the NT at some 17,200km, excluding what they termed "freshwater reaches". In comparison, the extent of such habitats in Cape York (north and west of Cooktown) and the Gulf [4] is estimated as 20,300km of which (coincidentally) 17,200km lies on the NW Cape and Gulf Plains (Table 1).

21.2. As to swampland/palustrine habitat, the NT estimate is 3,773km^2, compared to 1,058km^2 for Cape York and the Gulf and 802km^2 for the NW Cape and Gulf Plains.

21.3. Lacustrine habitat has not been compared as the approaches to estimating its extent differed and it is of very limited extent in Queensland.

---

[4] Queensland estimates are limited to the near-coastal area below the 20m contour,

Figure 2. The extent of estuarine crocodile habitat in Queensland.

This mapping includes riverine, lacustrine and palustrine habitats and extends inland to the 200m contour. Riverine habitat below 20m ASL (red), 20-100m ASL (green), 100-200m ASL (grey). Palustrine (violet) and lacustrine (blue) habitats are not differentiated by elevation. South of Rockhampton, crocodiles appear to occur as singleton animals rather than established populations and may best be considered vagrants or non-breeding residents.

Table 1. Total area of estuarine crocodile habitat below the 20m contour level in the Pormpuraaw DOGIT catchments compared with estuarine crocodile bioregions across Queensland. [5]

BioRegion #	**Bioregion & Sub-Region**	**Riverine habitat below 20m datum (km)**	**Palustrine habitat below 20m datum (km2)**	**Lacustrine habitat below 20m datum (km2)**	**Total palustrine & lacustrine habitat below 20m datum (km2)**
1a	Gulf Plains - Massacre Inlet	1,866	48	0	48
1b	Gulf Plains - Albert-Leichhardt drainage	2,835	13	0	13
1c	Gulf Plains - Norman-Flinders drainage	4,087	44	21	61
1d	Gulf Plains - Mitchell-Gilbert drainage	3,900	281	7	288
2	North-west Cape York	4,541	416	0	416
3	North-east Cape York	1,611	136	23	159
4	Princess Charlotte Bay	953	50	0	50
5a	Coastal Plains - Cape Melville - Cooktown	471	70	8	78
5b	Coastal Plains - Cooktown - Ayr	3,392	383	2	385
5c	Coastal Plains - Ayr - Rockhampton	4,469	578	2	580
6a	Burdekin - Fitzroy Region - Burdekin River drainage	204	7	0	7
6b	Burdekin - Fitzroy Region - Fitzroy River drainage	873	135	5	140
1 - 6b	**Total – whole of Queensland**	**29,202**	**2,161**	**68**	**2,229**
1 - 5a	**Total – excluding the coastal plains south of Cooktown**	**20,264**	**1,058**	**59**	**1,117**
1 - 2	**Total – NW Cape York Peninsula & Gulf Plains**	**17,229**	**802**	**28**	**830**
	Pormpuraaw DOGIT catchments	670	47	0	47
1 - 6b	Pormpuraaw DOGIT catchments proportions – whole of Queensland	2.3%			2.1%
1 - 5a	Pormpuraaw DOGIT catchments proportions - excluding coastal plains south of Cooktown	3.3%			4.2%
1 - 2	Pormpuraaw DOGIT catchments proportions - NW Cape York Peninsula & Gulf Plains	3.9%			5.7%

---

[5] The bioregions and sub-regions are essentially those defined by Taplin 1987, but have been refined as part of current reviews of Queensland crocodiles by (a) redefining the upper 'limit' of crocodile habitat as the 200m contour, rather than whole catchments and (b) breaking down the regions and sub-regions into areas lying 0-20m, 20-100m and 100-200m above the elevation datum (effectively sea level).

Estuarine crocodile nesting habitat in the DOGIT catchments

22. The distribution of prospective nesting habitat in the DOGIT lands, as mapped by Magnusson et al (1979, 1980) and my more recent and refined mapping is shown in Figure 3. A few points are noteworthy.

    22.1. Firstly, despite ranging widely and at times far inland, when locating favourable nesting habitat, Magnusson's mapping of the DOGIT catchments did not extend beyond the 20m contour. Emeritus Professor Gordon Grigg has confirmed that this inland limit was set by their spotter's judgement of when the likelihood of encountering nesting habitat fell away.

        22.1.1. The BG/PLSR teams limited their nest searches to almost precisely these elevations between 2008 and 2015 (Figure 14). I understand that to have resulted from their assessment that there was a low likelihood of finding nests further inland. PLSR staff advised that estuarine crocodiles can be encountered in waterholes well inland, particularly after floods, but that nests have been found there only rarely despite quite frequent visits during feral animal and weed control patrols.

    22.2. Secondly, Magnusson rated the principal swamplands on the upstream Kendall River as Poor in quality and evidently did not consider many of the other palustrine areas worth rating. This is quite consistent with the low numbers of non-riverine nests found there by the BG/PLSR teams (see below).

    22.3. Thirdly, the new mapping shows considerable areas of prospective nesting vegetation on Christmas Creek and Hersey Creek – particularly grasslands. These areas are dominated by regional ecosystem (RE) 3.3.61 (Neldner et al, 2012) – mid-dense to dense grassland including grasses favoured for nesting such as *Oryza australiensis, Ischaemum australe var. villosum, Imperata cylindrica* and *Fymbristylis spp* (Magnusson et al, 1979, 1980; Fukuda & Cuff, 2013).

        22.3.1. Britton (2008, 2009) noted the presence of these grasslands on upstream areas of Christmas Creek. Their surveys in 2007-08 and 2008-09 located neither nests nor hatchlings. These same REs support nesting in other DOGIT catchments. Britton thought the absence of nesting here might reflect a more severe, but localised flood regime.

        22.3.2. Thus, the estimate of prospective nesting habitat in the DOGIT lands based on the RE mapping may be optimistic.

23. The mapping data underpinning Figure 3(b) are available for the whole of Queensland and allow us to estimate the significance of the DOGIT catchments in relation to the whole (Annexe 1). There is no lacustrine nesting habitat below the 20m contour in the DOGIT catchments, so we can focus on just riverine and palustrine habitat.

24. The resultant picture is essentially the same as for crocodile habitat in the broad. The DOGIT lands account for 3.4% of Queensland's nesting habitat and some 5.5% of the total nesting habitat on the western side of Cape York Peninsula and the southern Gulf Plains (Table 2).

25. And comparison with the NT emphasises the very different environment in Queensland. Fukuda and Cuff (2013) estimated the total extent of nesting habitat in the NT at 41,100km^2. This contrasts greatly with the 7,029km^2 estimated for the whole of Queensland and 3,727km^2 in western Cape York and the Gulf Plains (Table 2). The contrast is stark.

Isolation

26. As to isolation, estuarine crocodiles occur in all the waterways that have been surveyed to the north and south of the DOGIT lands, including the adjacent large Archer River and Mitchell

River systems (Taplin 1988, 1989; Read 1998, 2001; Read et al, 2004). The DOGIT waterways are not isolated from other systems and, given the propensity of estuarine crocodiles to occupy and move considerable distances along coastlines, can be expected to gain and lose through migration to and from adjoining systems.

27. There is nothing to suggest that it makes sense to consider the DOGIT lands as a conservation and management issue in isolation from other parts of the north-west Cape and Gulf Plains. There is good sense in considering them separately from the eastern waterways of Cape York Peninsula which are of completely different character (Taplin, 1987) and from waterways of the populated east coast south of Cooktown, where the management issues associated with the high human population dominate.

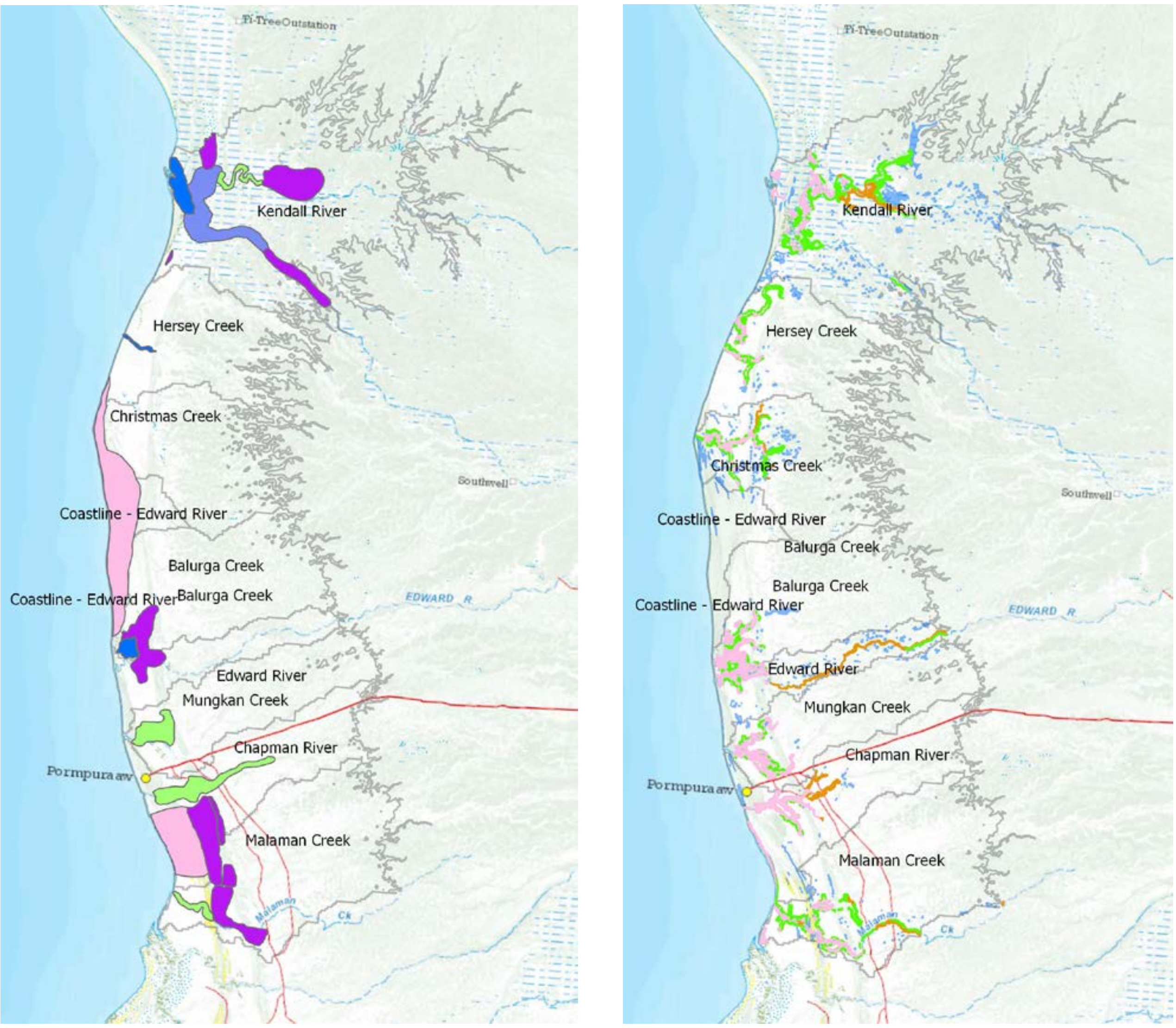
Conclusion

28. Even at the smaller scale of north-west Cape York and the Gulf Plains, the DOGIT lands are small and the likely consequences for the crocodile population of any short-term misjudgement about a sustainable harvest are small.

Figure 3: (a) The first mapping of nesting habitat in the DOGIT catchments (Magnusson et al, 1979, 1980) and (b) the author's revised mapping (refer Annexe 1).

Legend Fig. 3a: Marginal 1 (green), Marginal 2 (blue), Possibly Marginal 2 (blue-grey), Poor (violet), Indeterminate/Unknown (light pink). Catchments/sub-catchments are bounded upstream by the 20m contour. The definitions of Marginal 1, Marginal 2 and Poor habitat can be found in Magnusson et al, 1979, 1980).

Legend Fig. 3b: Grassland (green), samphire/Sporobolus grassland (pink); fringing forest/woodland (brown), palustrine habitats (blue). There is only one small (0.01 ha) area of sedgeland at the south end of the Edward River Crocodile Farm.


(a)

(b)

Table 2. Total area of prospective nesting habitat below the 20m contour level in the Pormpuraaw DOGIT catchments compared with estuarine crocodile bioregions across Queensland.

BioRegion #	**Bioregion & Sub-Region**	**Total Area below 20m datum (km2)**	**'Riverine' nesting habitat below 20m datum (km2)**	**'Palustrine' nesting habitat below 20m datum (km2)**	**'Lacustrine' nesting habitat below 20m datum (km2)**	**Total nesting habitat below 20m datum (km2)**	**Proportion of area comprising nesting habitat (%)**
1a	Gulf Plains - Massacre Inlet	4,819	223	48	3	279	5.8%
1b	Gulf Plains - Albert-Leichhardt drainage	4,360	426	13	0	439	10.1%
1c	Gulf Plains - Norman-Flinders drainage	10,978	624	44	62	730	6.6%
1d	Gulf Plains - Mitchell-Gilbert drainage	13,234	655	281	71	1,007	7.6%
2	North-west Cape York	10,182	856	416	0	1,272	12.5%
3	North-east Cape York	2,382	213	136	115	464	19.4%
4	Princess Charlotte Bay	2,005	228	50	0	278	13.9%
5a	Coastal Plains - Cape Melville - Cooktown	827	90	70	26	186	22.5%
5b	Coastal Plains - Cooktown - Ayr	5,140	503	383	13	899	17.5%
5c	Coastal Plains - Ayr - Rockhampton	6,113	613	578	13	1,204	19.7%
6a	Burdekin - Fitzroy Region - Burdekin River drainage	473	2	7	0	9	3.3%
6b	Burdekin - Fitzroy Region - Fitzroy River drainage	2,017	100	135	27	262	13.0%
	Total – whole of Queensland	**62,530**	**4,533**	**2,161**	**330**	**7,029**	**11.2%**
	Total – excluding the coastal plains south of Cooktown	**48,787**	**3,315**	**1,058**	**277**	**4,655**	**9.5%**
	Total – NW Cape York Peninsula & Gulf Plains	**43,573**	**2,784**	**802**	**136**	**3,727**	**8.6%**
	Pormpuraaw DOGIT catchments[6]	3,045	154	47	0	201[7]	6.6%
	Pormpuraaw DOGIT catchments proportions		3.4%	2.2%		2.9%	-
	Pormpuraaw DOGIT catchments proportions - excluding coastal plains south of Cooktown		4.6%	4.4%		4.3%	-
	Pormpuraaw DOGIT catchments proportions - NW Cape York Peninsula & Gulf Plains		5.5%	5.9%		5.4%	-

---

[6] Excludes Mitchell/Coleman River catchments

[7] All palustrine habitat selected for inclusion has been defined as potentially suitable for nesting, so the total areas of habitat and nesting habitat are identical. The nesting areas in relation to riverine and lacustrine habitat are taken to be in vegetation associations judged suitable for nesting and lying within 250m of the lake edge or riverine bank.

The number and distribution of nests across the DOGIT catchments

29. The nests recorded in the three Big Gecko reports and the PLSR databases are concentrated in the Edward R/Balurga Ck, Mungkan Ck and Chapman R systems, where most search effort was concentrated in the later years of the study. Few nests were found on Malaman Ck and surprisingly few on the Kendall/Holroyd system. Figure 4 includes, for completeness, 18 nests recorded after the study was completed, 3 in the 2015-16 nesting season and 15 in the 2016-17 season. These post-study nests are not considered further because these later discoveries were somewhat *ad-hoc*. Note the absence of nests in the Christmas Ck and Hersey Ck catchments, south of the Kendall/Holroyd system.

Figure 4: Distribution of nests across the DOGIT catchments 2007-2017**.**

30. I have focused for this review on nesting data for 2012-2015, as this is the only material that was independently reviewable. The 2007-08 and 2009-10 data is reported in considerable detail in the relevant final reports, but no raw data was available.
    30.1. I was able to identify 63 nests discovered across four nesting seasons. One of those was later excluded because its GPS location was recorded as the Chapman River boat ramp but track data clearly identified it must have been located earlier that day at one of three possible locations on Malaman Creek.
    30.2. The 63 nest records correspond closely with the 64 nests recorded by Britton (2017) and align closely in terms of the river system and year in which nests were discovered. The 63 nests in the PLSR databases included only 43 definitely recorded as containing eggs. Four (4) were definitely recorded as having no eggs, and 15 had no definitive records as to whether eggs were present at any time after discovery.

How well does the nesting habitat map align with known nests in the DOGIT catchments?

31. A key question for this review is the extent to which the new mapping of prospective nesting vegetation aligns with the nests identified by the BG/PLSR teams.

From nests to nest sites

32. To test the mapping of nesting activity onto prospective nesting habitat, we need to map nest sites rather than nests. Estuarine crocodiles show some nest site fidelity and it is not uncommon to find multiple nests in close proximity to one another. Some, perhaps many, of these may represent the same female nesting in successive or intermittent years at or close to a particular location. On occasion, a ‘false’ or ‘trial’ nest (without eggs) and an active nest with eggs may be found at one site in the same nesting season (Webb et al. 1977, 1983; Taplin, pers obs). The process used to define nest sites is set out in Annexe 2.

33. The mapping of nest sites onto the prospective nesting vegetation is reassuring. Figure 5 illustrates the fit for Edward River/Balurga Creek, Mungkan Creek and Chapman River.

34. Eighty-nine (89) nest sites[8] were identified in the DOGIT catchments. Sixty-one (61) of those were ‘captured’ by riverine REs and another 2 by palustrine REs that were mapped as prospective nesting vegetation – a total of 71%. That percentage increased to 85% if nests within 100m of the boundary of the RE polygons were counted.

    34.1. Given the coarse scale of the RE mapping - 1:100,000 is typical for Cape York pre-clearing vegetation (Neldner et al, 2012) - the fit is good, particularly as the vegetation was originally mapped without any reference to its utility for crocodiles.[9]

    34.2. The occurrence of nests in coastal swamps south of Mungkan Ck in Figure 5(b) shows that such habitat is used, but seemingly not often.

35. The good fit between nest sites and mapped nesting vegetation allows us to use the overall extent of nesting habitat in the DOGIT catchments to estimate the proportion of total nesting habitat covered during the BG/PLSR study and the potential for additional nests to have remained undiscovered.

The distribution of nest sites with respect to broad vegetation types

36. Figure 6 shows the proportions of broad vegetation types at each nesting site. Because regional ecosystems can include a mix of up to five vegetation associations, more than one broad vegetation type can be present at any nest site (this shows up in the radial axis of the graph from 0-100%).

    36.1. All vegetation associations were assigned to a broad vegetation type relevant to crocodile nesting. “Mangrove” refers here to vegetation on the inland fringe of REs mapped as mangrove – where crocodiles will nest in patches of grasses, saltwater couch, *Achrostichum,* etc. “Samphire” encompasses areas of mixed samphire and saltwater couch. “Grassland” and “Vine Thicket” are self-explanatory. “Melaleuca” encompasses areas of closed- and mid-tussock grassland and sedgelands associated with *Melaleuca* spp.

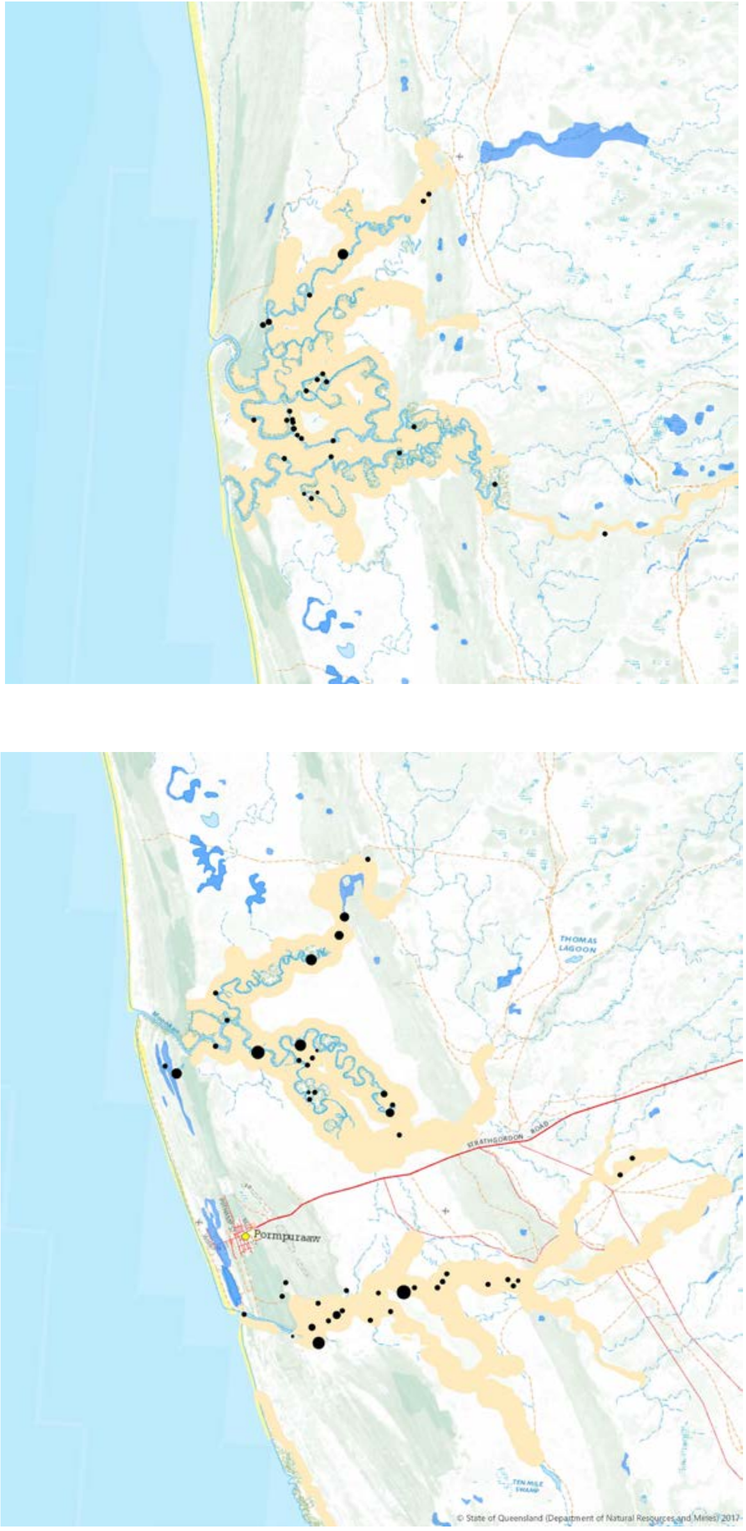
---

[8] This includes sites identified in 2007/08 and 2008/09 seasons. One wrongly-mapped site at the mouth of Chapman River was excluded.

[9] Some nests occurred in regional ecosystems (REs) that are known to be used occasionally for nesting but were treated as non-nesting vegetation for the State-wide mapping exercise. This pragmatic approach was employed because the RE mapping varied in its level of detail across regions and broad vegetation types.

Figure 5: The fit of nests sites to nesting riverine (cream) and palustrine (blue) vegetation on (a) the Edward R/Balurga Ck system and (b) Mungkan Creek and the Chapman River.

Nest sites are shown black dots/circles, whose radius is 25m where only one nest was found at a site over multiple years or the minimum bounding radius for sites with multiple nests. One nest at the mouth of Chapman R derives from a recording error.


(a)

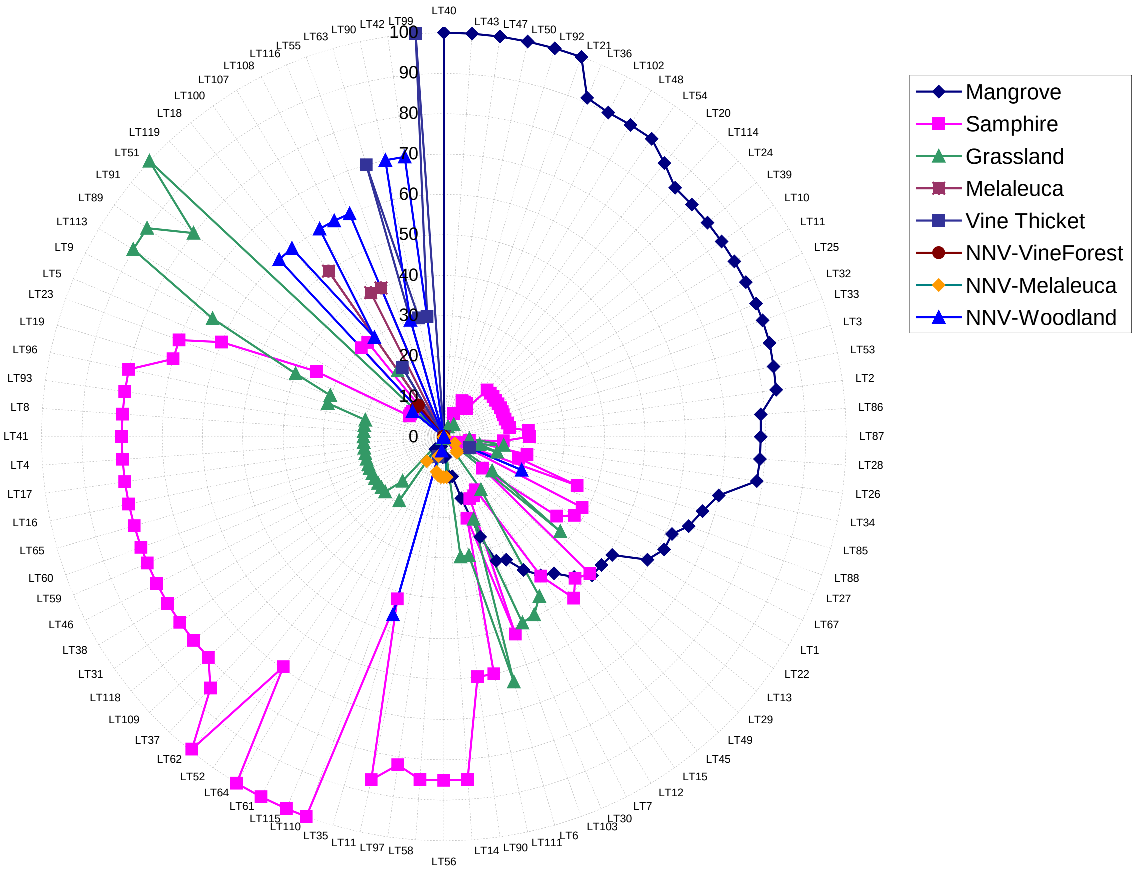
(b)

37. The vast majority of DOGIT catchment nests are constructed in areas of samphire/saltwater couch or on the fringes of mangroves where there is saltwater couch or patches of broad-leaved grasses. Large stands of predominantly broad-leaved grasses or Melaleuca swamplands, which provide more favourable nest sites (Magnusson et al, 1978, 1979, 1980), are used. However, they have a patchy distribution and limited extent in the DOGIT lands and only a handful of nests occur there. Indeed, only five sites (appearing at about 1000h in Figure 6) have more than 60% grassland in their underlying REs. The paucity of good quality nesting habitat, such as grassland and favourable Melaleuca associations with a good ground cover of grasses or sedges, is well-reflected here.

38. The pattern seen in the Pormpuraaw DOGIT catchments is entirely consistent with expectations that most nesting occurs, or can be expected to occur, in poor quality saltwater couch and marginal quality broad-leaved grass habitat, both of which are prone to extensive flooding. The pattern portrayed here is, as expected, entirely consistent with the descriptions of nesting habitat by Britton (2008, 2009, 2017) and earlier by Magnusson et al (1979).

39. My visit to some nest sites on the Chapman River in 2017 and examination of nest photographs recorded in the PLSR databases confirms that crocodiles are nesting here in some of the poorest quality habitat I have encountered in Queensland. A handful of the nests found have consisted of little more than mud and sticks, with a poor prognosis for any eggs laid. I have found low-grade nests like this in other rivers of the southern Gulf (Taplin, unpubl. obs). The low quality of the nesting habitat is doubtless a contributor to the low rates of recruitment found in the BG/PLSR study.

Figure 6: Distribution of nest sites in relation to the proportion of major vegetation types in the regional ecosystems underlying them. Nest sites (coded LTxxx for this review) are listed around the circle and the proportions of different vegetation types at each site along the radial axes. The vast majority of nest sites were located in samphire/saltwater couch and broad-leaf grass patches on the fringes of mangroves (01:00 – 17:00h on the circle) or in predominantly samphire/saltwater couch REs with a small proportion of broad-leaved grasses. All these areas are of low quality for crocodile nesting and are flood-prone. The only reasonable quality nesting habitat is located at ca 10:00-11:00h and ca 1700h, where there is a moderate to high preponderance of broad-leaf grasslands. The NNV prefix denotes areas defined, for Queensland-wide purposes, as 'not nesting vegetation'.[9]



The viability and fate of nests in the DOGIT catchments

Nest viability

40. Of the 62 nests we can pinpoint spatially, forty-three (43) were recorded as definitely having eggs on or after first discovery. Four (4) were recorded as definitely have no eggs. Fifteen (15) nests had no unambiguous records as to whether eggs were present at any time after discovery.

Nest fates of all nests

41. Of the 62 nests:

    41.1. Seven (7) had an unclear fate, principally because it was not always possible to identify whether predation, flooding or both was the cause of egg loss. And sometimes because the nest might have hatched before being predated, or been predated before it hatched. Definitive evidence was not available.

    41.2. Twenty-five (25) nests had no known fate recorded, many of them because the PLSR data recorded only a single visit (i.e. on first discovery) and the fate of the nest was not determined at that time. That is, the nest was not clearly flooded, predated or burnt when discovered.[10]

Nest fates of viable nests

42. Of the 43 nests that definitely had eggs, 41 contained viable clutches and 2 were recorded as having essentially full clutches of infertile eggs.

    42.1. Of the 41 viable nests, the fates of 27 were definitely recorded. Eighteen were flooded, 9 were recorded as definitely predated, and 3 suffered damage attributed to other causes (e.g. fire damage or egg loss not attributable to a specific cause). Several nests suffered more than one cause of egg loss – e.g. predation after flooding. The overall nest losses in this group were 22.

    42.2. Thus, of viable nests whose fates are known, 22 of 27 or 81% were lost – the vast majority to flood (18 of 22).

    42.3. I could draw no conclusions about 15 nests with viable clutches whose subsequent fate was either unclear or not recorded in the data available.

Fates of viable nests plus nests lacking eggs

43. If we add to the 27 known-fates nests, another 3 whose fate was definitely known but for which we have no evidence as to egg presence, we have 30 nests with known fates. Twenty were flooded, 9 were recorded as definitely predated, and 3 suffered some other fate.

44. Thus, of all nests whose fates are definitely known, 25 of 30 (83%) were lost to one cause or another. Twenty of 25 of those losses (80%) were attributed to flooding and 20% to other causes (either primary causes or following earlier flooding).

Conclusions

45. The principal conclusions of the BG/PLSR Reports on the fates of nests are supported very well by this analysis. Flooding and predation are major causes of mortality in the four river systems of the Pormpuraaw DOGIT lands.

---

[10] This is one particular area where additional data may have been available to BG that is not recorded in PLSR databases. This could arise from visits to nests late in the dry season to check on their fates. The PLSR data do contain many records of late dry season nest visits, so this type of information is not entirely missing. However, PLSR could not confirm whether or not additional data was collected but not recorded in their systems.

The extent and frequency of flooding in the Pormpuraaw DOGIT catchments

46. A very high proportion of the nests in the BG/PLSR study were partially or, more commonly, completely flooded. This is not surprising. Magnusson et al. (1979) recorded extensive flooding in parts of Gulf Plains north of Normanton and illustrated how damaging such floods could be when they inundated large areas of flat-lying nesting habitat (Figure 7). It was this factor, more than any other, that led them to rate most of the nesting habitat on the Gulf plains they surveyed as Poor or Marginal, based on their experience of similar habitat in the Northern Territory.
47. Britton (2008, 2009, 2017) noted that flooding was most likely during periods when high water levels following high rainfall coincided with spring tides. Magnusson (1982) recorded the impact of tidal flooding on riverbank nests in the downstream reaches of the Liverpool River system.
48. Long-term tidal data show that the annual tidal maxima in these parts of the Gulf and western CYP coincide consistently with the peak of the nesting season between January and March (Annexe 5). There is an 18-year cycle superimposed on these maxima, which can be seen in Figure 25 as a slight increasing trend in tide height from 1979-87, a decline from 1987-1997 and a subsequent increase. The peak-year to trough-year difference is about 0.5m, enough to have a material effect on flood risk depending on rainfall but not substantial enough to warrant consideration as part of the current harvesting proposal.

Figure 7. Extensive flooding on the coastal plains of south-western Cape York Peninsula.

Photograph recorded by Magnusson et al (1979) during their survey of nesting habitat and reproduced with permission.

Rainfall and flood patterns in the DOGIT catchments

Rainfall patterns and extreme events

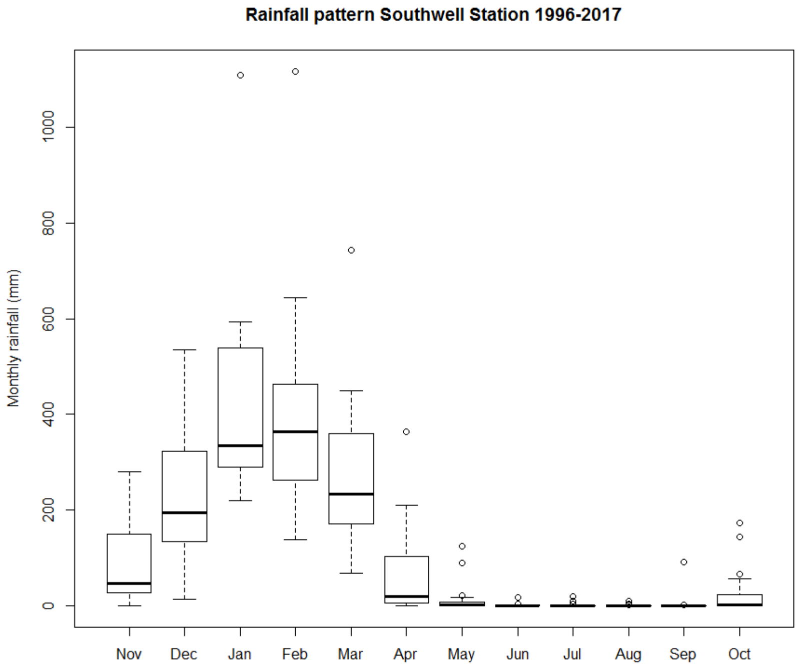
49. One of the findings of the BG study is that high flooding mortality is a sufficiently frequent occurrence in the DOGIT catchments that harvesting of nests laid early in the wet season should have little or no impact on the population. It is useful to examine that proposition in the context of available data on the rainfall and flood regimes in that region.

50. Only one currently active weather station, Southwell Station, lies within the DOGIT catchments region. The station lies close to the boundaries of the Kendall/Holroyd sub-catchment to the north and the Christmas and Hersey Creek sub-catchments to the west.

51. Mean rainfall at Southwell Station (typically 300-400mm) is not high relative to many areas in the Australian range of estuarine crocodiles. However, it is heavily concentrated in the wet season between November and April. The highest monthly rainfalls occur in January, February and, to a lesser extent in December and March (Figure 8). Extremes of monthly rainfall, especially likely to give rise to extensive flooding, occur particularly in January, February and March.

Figure 8. Monthly rainfall at Southwell Station in the DOGIT catchments between 1996 and 2017 (the full extent of data available).

The plot shows median rainfall (black bar), lower and upper quartiles (box), the minimum and maximum rainfall values lying within 1.5 interquartile ranges of the lower and upper quartiles (whiskers), and outlying values showing extreme rainfall events. The most extreme events fall in January, February and, to a lesser extent, March and pose the highest risks of flooding for crocodile nests.



52. There have been only three extreme rainfall months in the 21 years of records for Southwell Station – in January 1998 (1109mm), March 2012 (743mm) and February 2014 (1117mm). Serendipitously, two of those fell during the period of the BG/PLSR study and allow us to examine the relationship between rainfall and nest flooding.

Extreme events and nest fates

53. The 1998 event consisted of 408mm of rainfall over 7 days in early January and an intense fall of 562mm over 4 days in late January. The February 2014 event was concentrated into a fall of 811mm over 6 days in early February, followed by a one-day fall of 160mm just 5 days later. The 2012 event was somewhat different, arising from two weeks of moderate to heavy rainfall (20-70mm per day typically) and two heavier falls of 95 and 201mm.

54. The monthly rainfall totals in Figure 8 can conceal the potential impact of concentrated periods of heavy, but not extreme, rainfall which may overlap the Jan-Feb or Feb-Mar boundaries. The nesting season of 2007-08 was one such period, when extensive flooding was recorded by Britton (2008).

55. Total rainfall of 1115mm was measured in January and February 2008 but there was no extreme daily rainfall over the period (the maximum recorded was 72mm), so the flooding presumably resulted from the accumulated impact of that steady rain and perhaps some tidal effect. Notably, the January and February totals (539 and 577mm respectively) fall within the whiskers shown in Figure 8 – so are not out of the ordinary.

56. We can conclude that rainfall lying within the ‘normal’ monthly range for the DOGIT catchments during January and February is capable of flooding many nests.

Whole of catchment rainfall

57. To get a broader appreciation of the potential impact of rainfall-induced flooding on crocodile nesting habitat in the DOGIT catchments, gridded (raster) data on daily rainfall across Australia was examined. This allows estimation of the total volume of water falling onto the study area and potentially able to contribute to flooding. It also allows, to the extent the limited weather station network on Cape York permits it, some examination of whether there is variation in rainfall patterns across the various DOGIT catchments, which might warrant consideration of different harvesting strategies.

58. No latitudinal or other trends/patterns were found between catchments, likely reflecting the paucity of rainfall stations in CYP (Annexe 6). The rainfall data alone, therefore, give no grounds to differentiate for harvesting purposes between southerly and northerly sub-catchments. Nor do they give grounds to expect that the northerly Kendall/Holroyd River system will be substantially more favourable for nesting or differ in its susceptibility to flooding.

59. Total rainfall was therefore summed across the whole of the DOGIT catchments (Figure 9), broken down by day, month and year.

    59.1. Looking first at the 2013-14 nesting season (third row from the top) we see modest falls between November and January and then a short, sharp period of extremely high rainfall in early February. This was undoubtedly the event that led to many nests flooding that year (Britton, 2017).

    59.2. The 2012-13 nesting season, in contrast, shows a two-week period of more modest falls, which was also sufficient to cause nest mortality (Britton 2017).

60. More generally, Figure 9 highlights the great variability of both the amount and timing of rainfall year-on-year. In 2014-15, for example, there was no substantial rainfall until March, by which time the highest spring tides may have fallen by 0.5m or more relative to January-February highs (Figure 25), sufficient to make a material difference to flood losses.

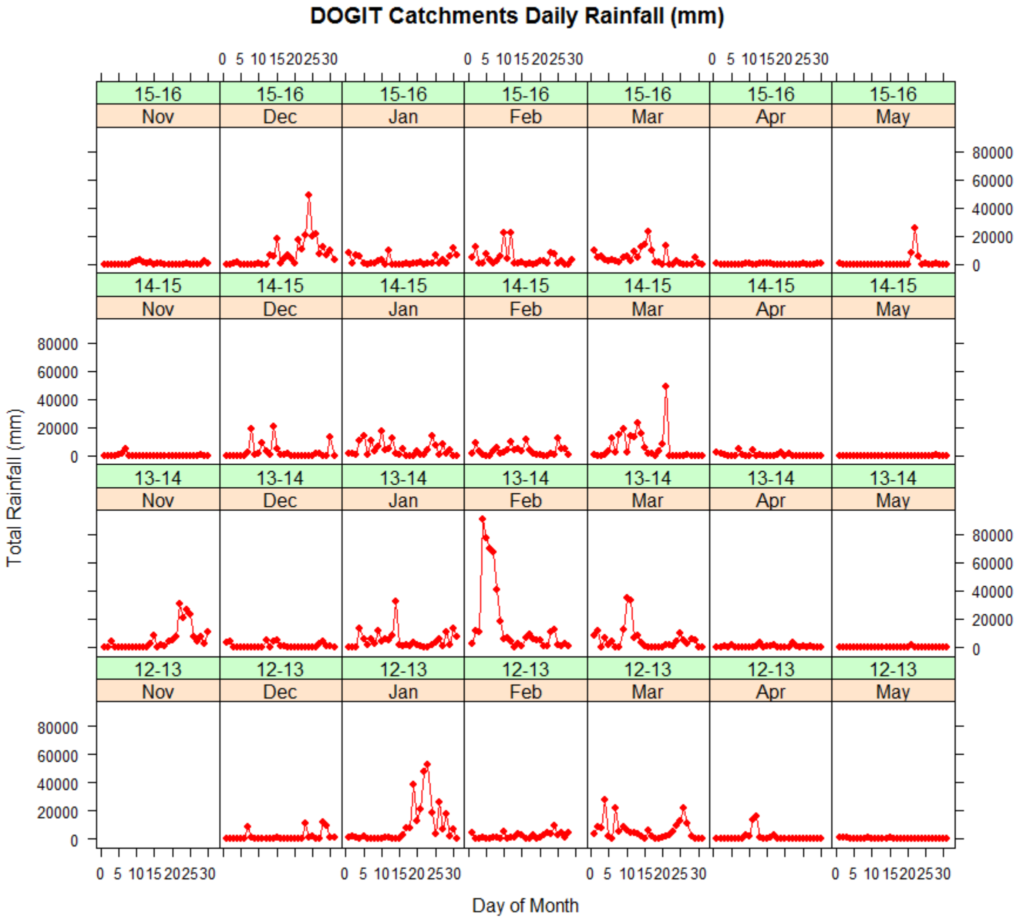
    60.1. And in 2015-16, the first substantial rains came in December, and would likely have led to the first big nesting pulse, but there was little rain subsequently and the likelihood of flood losses appears low.

Correlation between whole of catchment rainfall and nest flooding

61. We can correlate the rainfall patterns in Figure 9 with recorded nest fates during 2012-13, 2013-14 and 2014-15.
62. Available data for 2012-13 reveal 17 nests with known fates across four catchments, of which 11 included flooding as a cause of egg death. Three nests were not visited/discovered until May, but 8 of the 17 (47%) were affected by flooding that doubtless followed the prolonged moderate-high rainfall event of late January 2013, given the low rainfall across the entire catchment region in February.
63. In 2013-14, 20 nests were discovered. The fate of only seven could be determined from the data, six of which were flooded. All had eggs. Flooding accounted for five of the six recorded losses (83%) and can be attributed with confidence to the extreme rainfall event of early February 2014 (Figure 9). The sixth nest, which flooded between 15 Jan and 8 May, could well have been lost at the same time.
64. In 2014-15, 11 nests were recorded and the fate of 5 of them was recorded in the PLSR data. Only 2 were recorded as having flooded (40%), one of which appears to have had no eggs.

Figure 9. Integrated total rainfall volumes for the whole of the DOGIT catchments region for nesting seasons between 2012-13 and 2015-16.

Recalibrated data for November 2012 and earlier is not available on the BOM website.



65. Regardless of this uncertainty, the demonstrated losses of 40% of nests in 2014-15 to floods indicate that even the relatively modest rainfall experienced in March 2015 can be sufficient to trigger losses.

How do the rainfall data and nest flooding data align with other measures of flooding?

Satellite mapping of flood waters

66. Satellite data from the MODIS (Moderate Resolution Imaging Spectroradiometer) system can provide us an alternative assessment of flood risk in the DOGIT catchments. The procedure used to extract relevant MODIS data is set out in Annexe 3.

67. The extensive flooding of early 2013-14 is well illustrated in Figure 10. The very great extent of flooding on the DOGIT catchment plains where crocodile nesting is concentrated shows up clearly. Note also the way in which flood waters form wide bands spreading across catchment boundaries as they debouch onto the low-lying coastal plains.

68. MODIS data for the following three nesting seasons is in somewhat stark contrast, when we consider that the mapping shows the existence of <u>any</u> flood water in each tile over the <u>whole</u> of the nesting season (Figure 11). These perhaps more ‘typical’ years do show flood impact over the areas used for nesting by crocodiles, but the patterns might lead us to expect nest flooding to be lower in such years – contingent on the less easily assessed impact of coincident spring tides.

Relationship between MODIS-mapped flood waters and nest flooding

69. Of the 89 separate <u>nest sites</u> identified from the available data, 59 (66%) were intersected by MODIS flood waters during the 2013-14 nesting season (Figure 12).

70. If we examine actual <u>nests</u> that were discovered in 2013-14, 13 of the 20 nests recorded are intersected by MODIS flood map – amounting to 65% flood losses. After allowing for nests falling within one tile-length of MODIS flood water (Annexe 3), 18 of the full complement of 20 nests discovered in 2013-14 (i.e. 90%) lie inside this ‘extended’ MODIS flood zone. The two nests not shown as flooded both lay on slightly higher terrain adjacent to the coast that appears as an unflooded coastal zone in Figure 12.

71. If we focus on nests whose fates are actually known from the PLSR data, we find that 6 of 7 such nests (86%) were recorded as having been flooded (Table 3). The other nest site was covered by flood water in MODIS but the actual nest, which was laid down late, was not affected.

72. The close alignment between MODIS mapping and the known fates of nests gives some indication that flood mappings for other years may be a guide to nest fates. However, the number of nest sites intersected by MODIS flood waters in subsequent years was zero in 2014-15, 2 in 2015-16 and zero in 2016-17. So, while the MODIS data provide independent support for findings of high nest losses in years of very heavy flooding, they provide little support for high nest losses in arguably more ‘typical’ years – i.e. three of the four most recent nesting seasons.

Figure 10. MODIS 14x3-day composite flood water imagery (black) for the whole 2013-14 nesting season superimposed on the DOGIT catchments (light green).

The figures also show the extent of land in each catchment lying at less than 20m ASL (various colours). Figure 10(a) shows the overall extent of the flooding in the Gulf Plains. Figure 10(b) shows in more detail the impact on the DOGIT catchments.

(a)

(b)

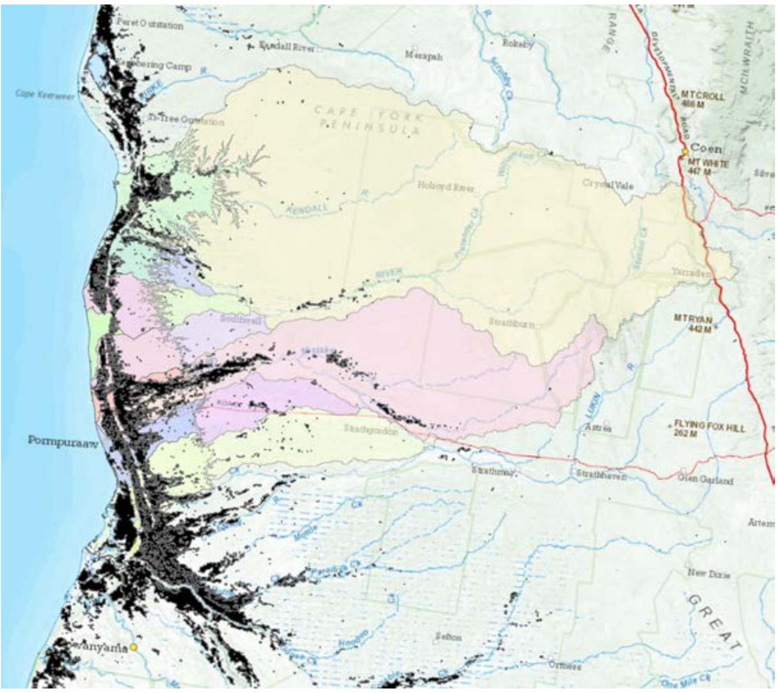
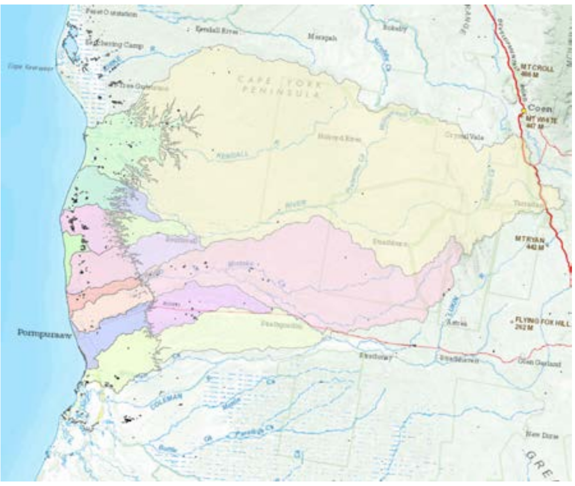


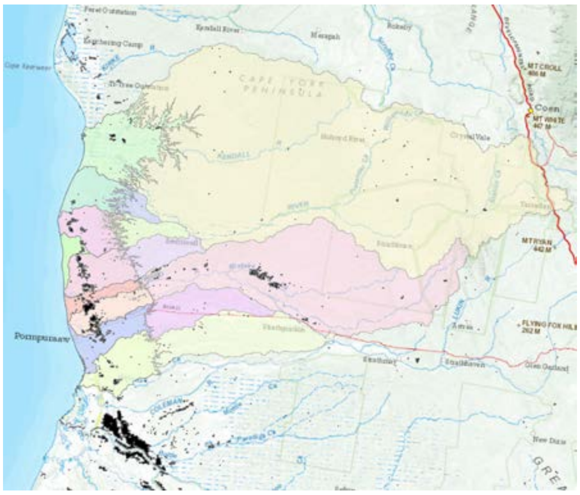
Figure 11. MODIS flood water mapping for nesting seasons (a) 2014-15, (b) 2015-16 and (c) 2016-17.

Note the very limited extent of flood waters mapped compared with 2013-14 (previous Figure) and the considerable similarities in apparent flooding susceptibility from year to year.

(a)



(b)



(c)

Figure 12. Nest sites (stars) mapped against MODIS flood waters for the 2013-14 nesting season (grey) and the land below 20m above datum level (effectively sea-level) in the sub-catchments of the DOGIT catchment lands.

The nest sites include all sites used at any time for nesting in the whole course of the BG study and some identified after 2014-15. Nest sites highlighted blue are those which were intersected by MODIS-mapped flood water at some time during 2013-14. That does not imply that there was a nest present at every site at the time of the flood – only that any nest present is likely to have been flood-affected.

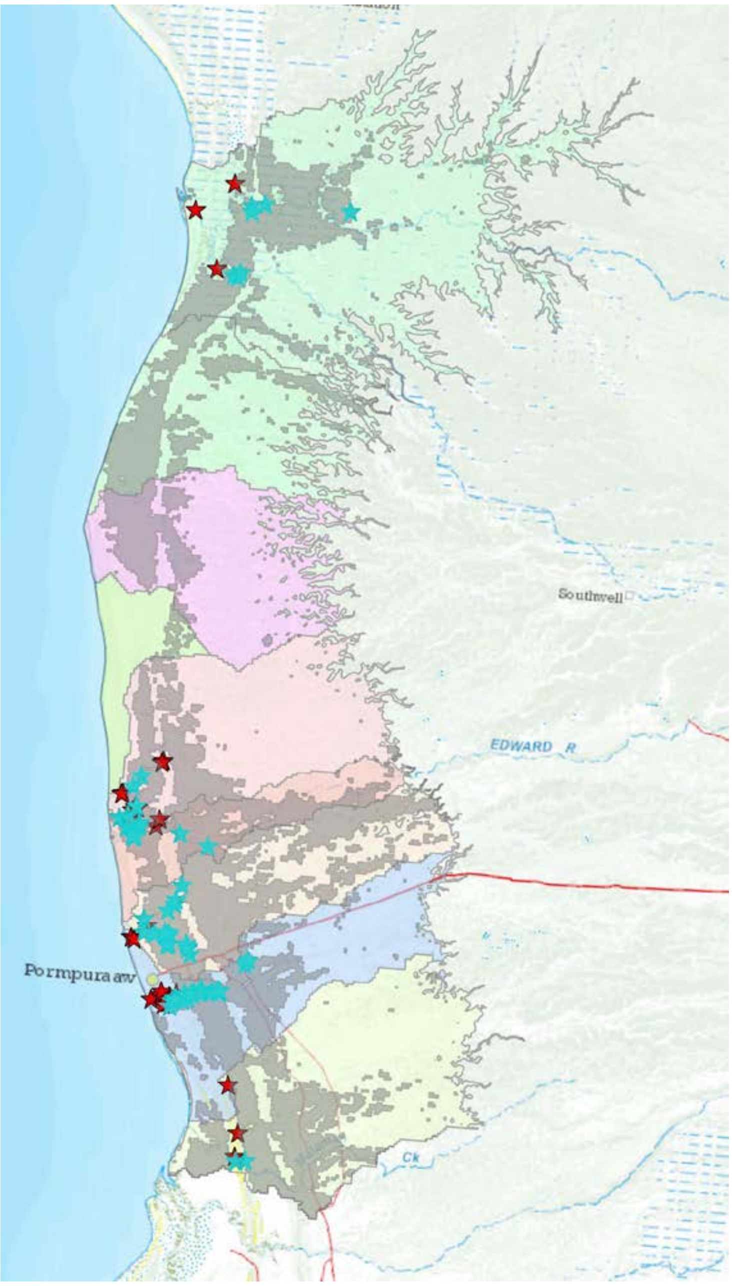


Table 3. Alignment between MODIS flood water mapping 2013-14 and nest flooding records from the DOGIT catchments data.

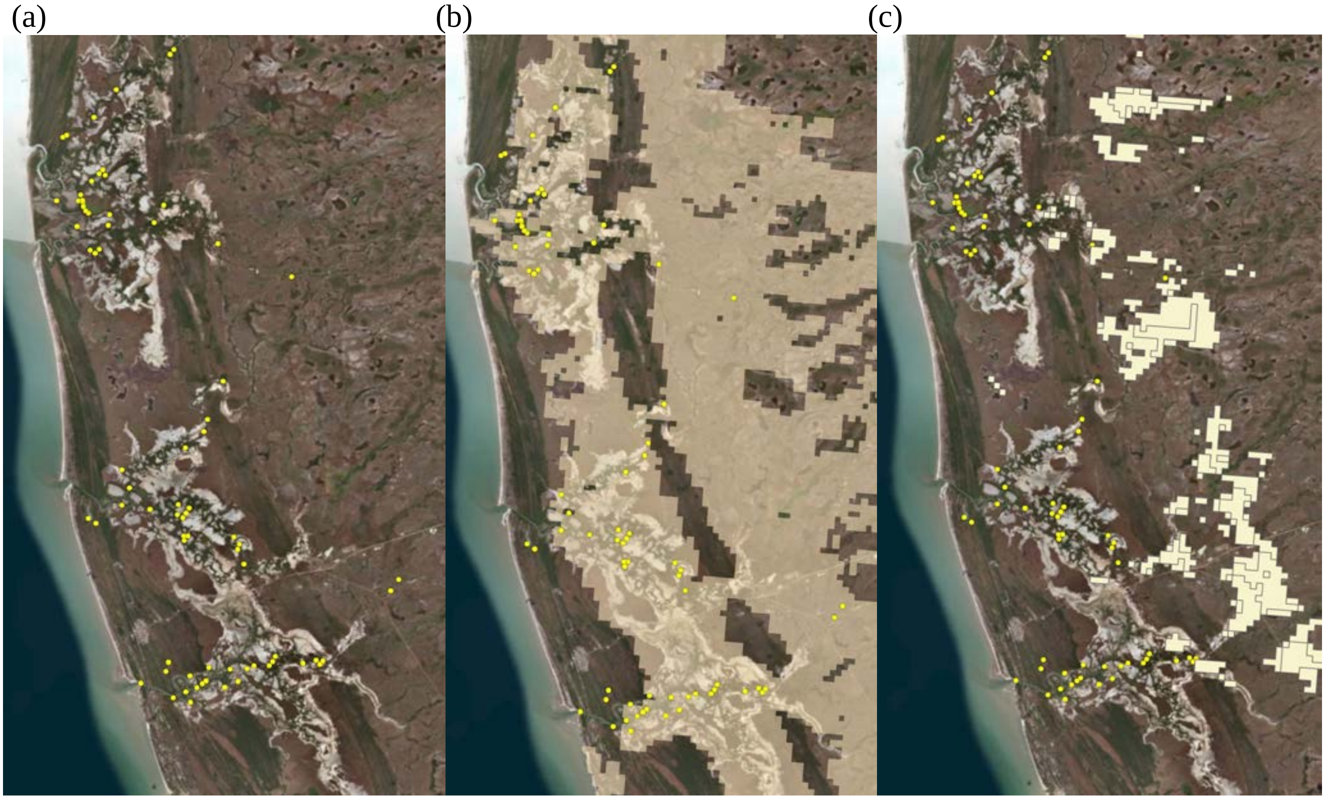
Five of seven nests with known fates were intersected by MODIS flood pixels. One of these escaped because it was laid down after the flooding. Two nests (marked by asterisks) that were recorded as flooded were not captured by the MODIS flood map. Both were very close to the river bank and their respective tiles (overlapping the river proper) were excluded as permanent water, while adjacent tiles were mapped as flooded.

Waterway	**Nest Number**	**Date at which nest was found flooded**	**Notes** **NF/F – not/flooded;** **NP/P – not predated**	**Nest site flooded in MODIS map?**
Malaman Creek System	LT27-3-13/14	8 May	2 visits 15 Jan & 8 May 14. Active NF, NP when found - 44 eggs present, 38 good. F when visited May.	No*
Chapman River System	LT16-1-13/14	9 Mar	Single visit 9 Mar. F. 56 eggs lost.	No*
Chapman River System	LT37-14-13/14	Not flooded	2 visits 29 May & 10 Jun 14. NF NP at last visit. 20 eggs.	Yes – but late season nest escaped floods.
Chapman River System	LT62-1-13/14	9 Mar	2 visits 8 Jan & 9 Mar 14. Active NF NP - 37 eggs when found. Flooded & predated in Mar.	Yes
Mungkan Creek System	LT11-11-13/14	27 Feb	2 visits 27 Feb & 6 Mar 14. F, NP on 1st visit - 45 eggs present, none harvested. P on 2nd visit - attributed to goanna.	Yes
Mungkan Creek System	LT32-9-13/14	20 Feb	2 visits 20 Feb & 6 Mar 14. Active F when found - no record of any eggs present. F, NP when revisited - 47 eggs present Totally Flooded.	Yes
Mungkan Creek System	LT56-1-13/14	27 Feb	2 visits 27 Feb & 6 Mar 14. F, NP when found - 47 eggs present, presume all dead.	Yes

73. Overlay of ESRI© World Image imagery over the catchments between Chapman River and Balurga Creek gives further insight into flooding patterns (Figure 13).

    73.1. Figure 13(a) shows how nest sites are predominantly located in the narrow band of low-lying saltpan and saltwater couch plains that lie between higher former beach ridges. Figure 13(b) shows how the major flooding of 2013-14 effectively built up against the easternmost line of old beach ridges as streamflow debouched onto the plains and how it has channelled through narrow cuts in those ridges before spreading out to cover almost the entirety of the low-lying plains between the ridges. Figure 13(c) shows a smaller body of flood water that extends only minimally into these same low-lying plains, most of it lying to the east of the inland ridge line.

Figure 13. Mapping of nest sites and MODIS flood waters onto ESRI WorldImagery[11] of the southern portion of the DOGIT catchments – (a) nest sites, (b) nest sites and MODIS floodwaters 2013-14, (c) nest sites and MODIS floodwaters during a year with lower rainfall.



74. These images reinforce the proposition that spring tides, when combined with high runoff during ‘normal’ years can cause nest flooding. The water flowing into the inland reaches of the major streams will encounter incoming tidal flows and the 2013-14 map shows how those waters will spread out over the salt pans and saltwater couch plains. As the vast majority of nests are built on or close to river banks and cannot be elevated significantly above the floodplain for want of topographical relief, they will be early casualties of such tide-influenced flooding.

Conclusions

75. The data available for the review support strongly the findings in Britton (2008, 2009, 2017) that flooding is a major cause of egg death in nests on the DOGIT catchments and that large flood events, such as occurred in 2007-08 and 2013-14 can cause extensive mortality among nests laid early in the season.

76. MODIS data for 2013-14 are quite consistent with the BG/PLSR records of nests being flooded. The data does not correlate, however, with BG/PLSR records for later years when rainfall was lower and/or less concentrated in time. This finding lends support to Britton’s assessment that flooding linked to spring tides is also a significant factor.

---

[11] Map image is the intellectual property of Esri and is used herein under license. Copyright © 2017 Esri and its licensors, including NPSR, HERE, Garmin, USGS, METI/NASA, NGA/Earthstar Geographics, CNES/Airbus DS. All rights reserved.

Search effort in relation to total nesting habitat and the potential number of nests

Search effort

77. The data available for the review were not well-suited for detailed analysis of search effort without a great deal more effort than was judged worthwhile (Annexe 7). However, it is important to get some appreciation of the extent of search effort in relation to the available nesting habitat, not least to judge what proportion of the nests actually present might have been discovered.

78. Suitable data for estimating effort was available only for 2012-13 to 2014-15 when boat and quad bike searches were confined to a very small part of the DOGIT catchments. Boat coverage of Edward River/Balurga Creek in 2014-15 was more limited than in earlier years (Figure 14).

79. Data for 2013-14, when 19 of 20 nests (95%) were first located during boat or quad bike surveys, show it is possible to identify the majority of nests in the regularly surveyed parts of these waterways without relying on helicopters. That is important, because the expense of helicopter survey likely precludes ongoing use given the low numbers of nests.

80. We can estimate the proportion of available nesting habitat effectively covered by the boat transects by applying a 250m buffer around pooled annual transect lines (Figure 15), after assuming that any nest lying within that 250m buffer is potentially discoverable.[12] The proportion of riverine nesting habitat covered by boat surveys varied from 33-80% between systems (Table 4).

81. The proportion was high for Mungkan Creek – in part because its nesting habitat is limited to downstream, navigable reaches of the system which were quite extensively covered. It was lower for the other systems, which include some nesting habitat in woodland fringes along upstream reaches that are not navigable by boat (Figure 3 & Figure 5).

Table 4. Estimated proportion of potential nesting habitat in DOGIT catchments covered during boat transects.

	Estimated riverine nesting habitat (km2)	**Area covered by boat transects (km2)**	**Proportion covered by boat transects (%)**
Malaman Creek System	22.1	7.4	33
Chapman River System	16.3	6.1	37
Mungkan Creek System	15.0	12.0	80
Edward River/Balurga Creek System	30.1	19.0	63

82. Despite intensive survey activity, BG/PLSR turned up only some 63 or 64 nests in four years. The overlap between nests and buffered boat survey coverage indicates 56 of 62 nests were potentially discoverable by boat and another 5 were discoverable at known nest sites using quad bike/walking. This supports the assessment that helicopter survey, while advantageous, is not a critical requirement for locating a high proportion of nests.

---

[12] The same buffer distance as was earlier applied to waterways to define the extent of potential riverine nesting habitat (refer Annexe 1)

Figure 14. Areas covered during surveys for nests by boat (blue) and quad bike (violet) in relation to the extent of DOGIT lands

The maps depict 2012-13 (a), 2013-14 (b) and 2014-15 (c) nesting season efforts. Quad bike excursions were not so much surveys as specific visits to known nests or areas known to have been used for nesting in earlier years. Boat surveys were conducted as active searches for signs of crocodile nests both around known nest sites from previous years and areas not previously known to have been used. They included searches on foot to pinpoint nests when possible nesting activity was located.

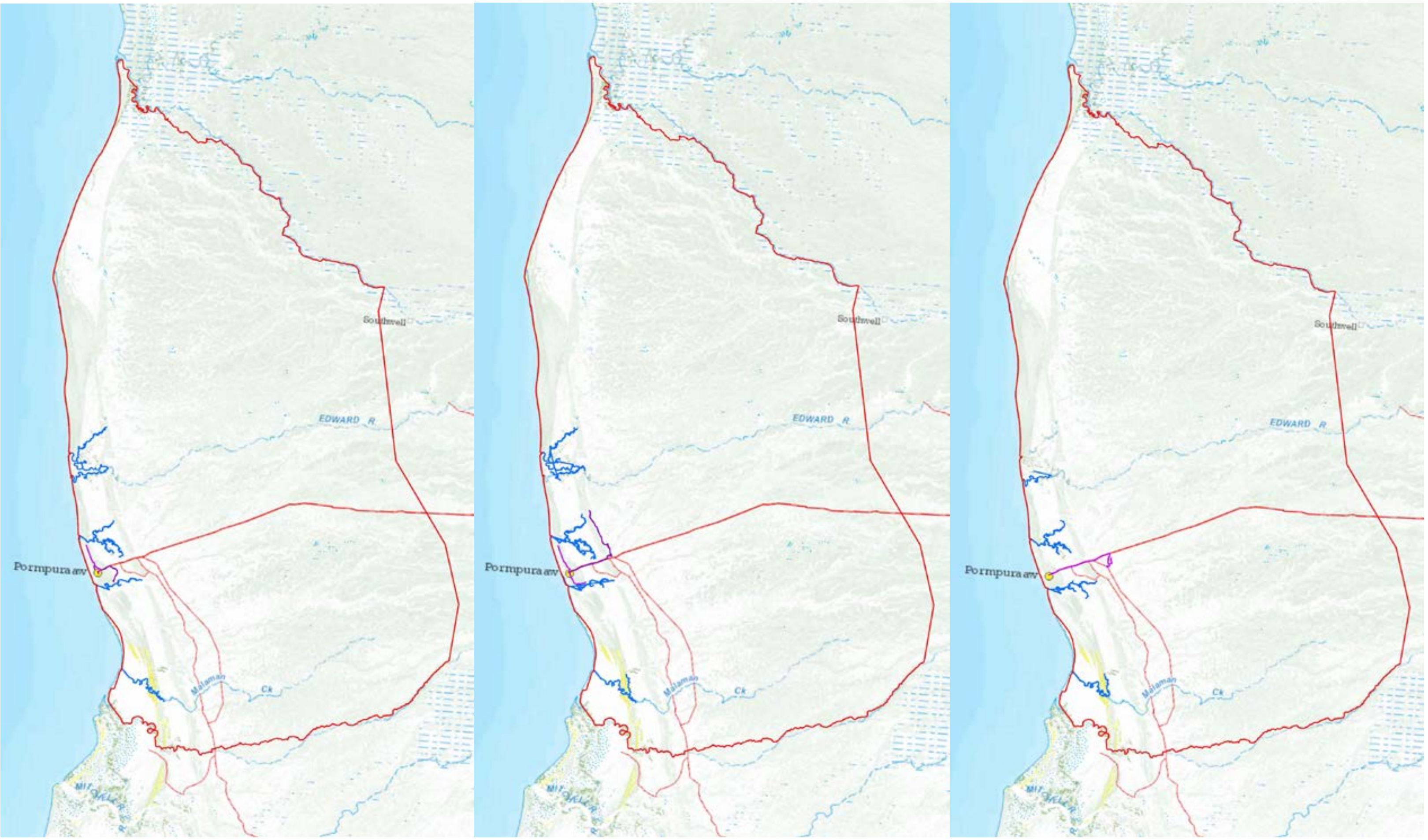
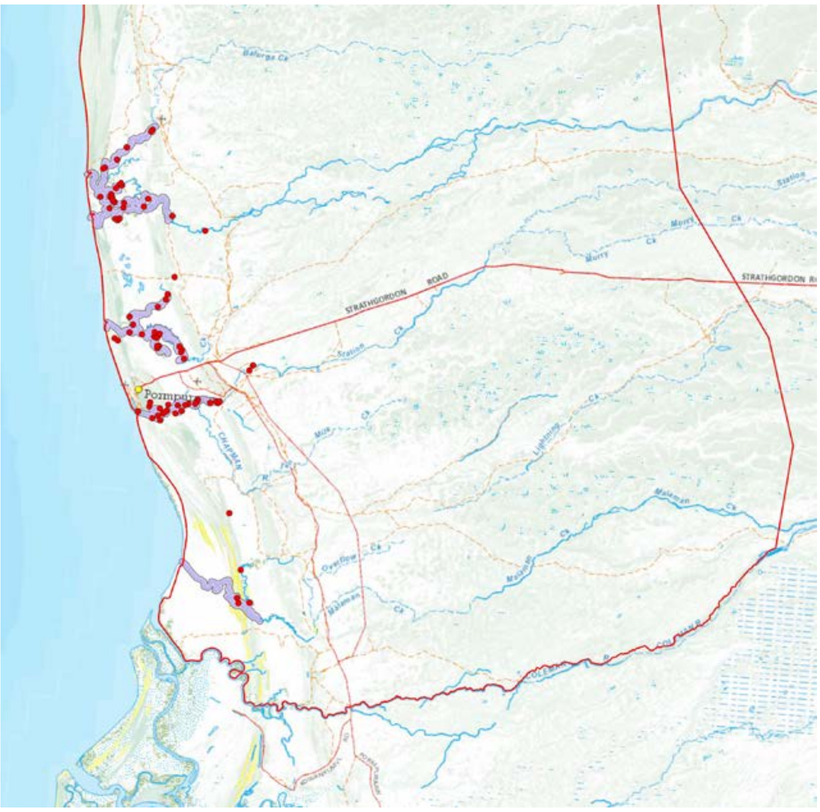

(a) (b) (c)

Figure 15. Coverage of potential nesting habitat by boat surveys in 2012-13 in the southerly DOGIT catchments from Malaman Creek to the Edward River/Balurga Creek system.

Samphire and grassland are mapped in two shades of green while fringing woodland habitat upstream is mapped blue-grey. The 250m buffer around the aggregated boat transects is shown in light purple and overlaid with all nest sites identified over the course of the study. Note that three nest sites were located in upstream areas mapped broadly as forest/woodland in the Queensland Regional Ecosystems dataset. However, the vast bulk of the nest sites located are in downstream, navigable reaches.



Potential nest numbers across the Pormpuraaw DOGIT lands and Kendall River system

Nest numbers excluding the Kendall River system

83. We can use the number of nests located by boat on each system to calculate a ‘density index’ for the mapped nesting habitat and then estimate, optimistically, how many nests might be found across the whole of the mapped nesting habitat if we assume density is consistent between the searched and unsearched parts (Table 5).

    83.1. The maximum number of nests we might expect to be present in the entire riverine nesting habitat in a ‘good’ year like 2012-13 amounts to 37 and in poor years is about half that number.

84. It is instructive to compare the nest density index in the DOGIT catchments with comparable indices developed for NT habitat by Fukuda and Cuff (2013), based on very extensive commercial harvests. NT nest densities varied greatly between habitat/vegetation types and ranged from 0.04 per km^2 in samphire habitat to 0.26 per km^2 in tall closed tussock grassland and 0.34 per km^2 in Melaleuca swamplands. Those densities are of the same order of magnitude as were found in the DOGIT catchments.

85. Nonetheless, the DOGIT estimates have to be treated with caution, for several reasons:

85.1. Firstly, they suggest the proportion of nests undiscovered during the later years of surveys could be as high as 46% - e.g. in 2012/13 only 20 out of an estimated 37 riverine habitat nests were discovered. That appears optimistic, unless the combination of boat and helicopter survey did not overcome the difficulty of finding nests concealed in less open riverine vegetation. Britton (2009) did note that nests constructed from mud under dense canopy were difficult, if not impossible, to detect from the air.

85.2. Secondly, the estimates of prospective nesting habitat may be over-optimistic, despite their good (and somewhat conservative) fit to nest discoveries.

85.3. Thirdly, and perhaps most likely, the assumption in Table 5 of uniform nest density across searched and unsearched habitat may be too optimistic.

85.3.1. The BG/PLSR teams did invest considerable energy in 2007-08 and 2008-09 surveying quite widely to identify and characterise the best areas on which to concentrate later search effort (Britton, 2008, 2009). Helicopter transects for the first two years were unavailable for review, so it was not possible to determine whether the upstream waterways were surveyed and rejected for further study or were excluded at the outset based on prior knowledge.

85.3.2. We do know, however, that only one nest was located on any of the five southerly river systems in wooded river margins upstream of the boat transects. And there is evidence that crocodiles in the Gulf rivers nest quite commonly in areas close to the limits of navigability of waterways on low tides – evidenced by the occurrence of hatchlings and yearlings in small upstream waterways on rivers to south (Figure 16).

86. Notwithstanding these uncertainties, it is extremely unlikely that the BG/PLSR searches located 100% of the nests in the areas searched, and the results hold out two important prospects:

86.1. A harvest of boat-discoverable nests would likely leave a number of nests undisturbed and able to contribute to recruitment.

86.2. Alternatively, if a harvest was extended to a greater proportion of the prospective nesting habitat considerably more eggs would be harvestable.

Extending the estimate to the Kendall River system

87. What if we extend the estimate to include the Kendall/Holroyd system, which has a very healthy crocodile population?

88. Here Britton (2008, 2009) recorded 5 and 6 new nests[13] respectively for the 2007-08 and 2008-09 nesting seasons. Seven (4 and 3 respectively) of those 11 nests were riverine and potentially discoverable in boat surveys. The Kendall/Holroyd system has some 35km^2 of potential riverine nesting vegetation, giving densities for 2007-08 and 2008-09 of 0.11 and 0.09 nests/km^2. This is at the lower end of estimates for the more southerly DOGIT waterways (Table 5) assuming the whole of the Kendall's riverine habitat was searched (in this case by helicopter).

---

[13] Two were considered false nests.

Table 5. Estimated number of nests in the potential riverine nesting habitat of the DOGIT catchments, assuming the density index (nests/km2 of nesting habitat) is consistent for searched and unsearched areas of habitat.

Nesting Season	**Total nests located**	**Nests located within boat transect coverage**	**Density index**	**Prospective number of nests at uniform density**
Malaman Creek System				
2011-12	1	1	0.14	3
2012-13	1	1	0.14	3
2013-14	1	0	0.00	0
2014-15	0	0	0.00	0
Chapman River System				
2011-12	2	2	0.33	5
2012-13	6	5	0.82	13
2013-14	5	5	0.82	13
2014-15	4	3	0.49	8
Mungkan Creek System				
2011-12	2	2	0.17	3
2012-13	7	6	0.50	8
2013-14	9	7	0.58	9
2014-15	3	3	0.25	4
Edward River/Balurga Creek System				
2011-12	3	3	0.16	5
2012-13	9	8	0.42	13
2013-14	5	5	0.26	8
2014-15	4	4	0.21	6

89. The Kendall/Holroyd system also has quite extensive swamplands in its upstream reaches. This potentially productive habitat was one factor that drew the study team to work this area (PLSR, pers comm).

    89.1. Absent any information on the transects flown during helicopter survey in these palustrine areas we can, at a minimum, assume the team flew the whole of the small area (4.3 km^2 based on RE mapping) in which one active nest was found in 2007-08 and three active nests in 2008-09. The low swampland nest numbers are perhaps surprising, but not inconsistent with the assessment of this area as Poor nesting habitat by Magnusson et al (1979, 1980).

    89.2. The numbers give density indices of 0.23 and 0.70 nests/km^2 for 2007-08 and 2008-09, no higher than some riverine habitats to the south (Table 5). Those density indices would obviously be reduced if it proved more swampland had been surveyed.

90. The entire area of potential palustrine nesting vegetation in the Kendall/Holroyd catchment amounts to some 21.4km^2. A more realistic estimate of the area relevant to this assessment, is their extent upstream of about longitude 141.72°E. This excludes palustrine areas close to the coast which are different in nature and appear to be used only infrequently for nesting. This upstream area amounts to some 15.5km^2 and is a generous estimate as it includes numerous

shallow ephemeral swamplands in depressions, similar to those that are common inland of the principal crocodile habitat in the more southerly waterways.

90.1. Using that 15.5km^2 estimate, the Kendall system's palustrine areas would contribute only a maximum of about 11 nests in a 'good' year. And they would not necessarily be harvestable. Britton (2009, 2017) noted the area is logistically difficult to access during the nesting season and considered it impractical to include in a future harvest.

91. Our estimate of nests across the whole of the riverine and palustrine nesting habitat in the five southern waterways and the Kendall River system thus amounts to about 48 in a good year and about half that in a poor year.

91.1. This excludes a modest amount of nesting that likely occurs from time to time in catchments like Hersey Creek, Christmas Creek where limited nesting habitat and no nests were found (Britton 2008, 2009). And a modest number of nests that occur in areas not mapped as prospective nesting vegetation.

Figure 16. Locations of hatchling and 2-3ft size class crocodiles (red dots) in the Nassau and Mitchell River systems in 1986 and 1987 respectively.

Locations are compared to the DOGIT catchments below the 20m elevation contour. Only 6 of the 79 crocodiles depicted were hatchlings. Some post-hatching dispersal from nesting locations is likely to have occurred among the 2-3ft size class. Note the occurrence of small crocodiles in upstream waterways, often at or close to their navigable limits. The upstream reaches of these waterways were surveyed using a very shallow draft 3m punt, so the surveys extend into waters that would be unnavigable for larger vessels except on high tides. Prospective riverine (grey) and palustrine (blue) nesting habitat is shown for the DOGIT catchments.

Crocodile monitoring

92. The BG/PLSR teams conducted counts of crocodiles in the study area across a number of years. Their objectives appear to have included:

    92.1. Assessing the extent of recruitment and survivorship of hatchlings in the various systems, as an adjunct to the nesting success study.

    92.2. Assessing the numbers and size distribution of crocodiles in the various waterways.

    92.3. Monitoring the population for change over the time that trial harvesting of eggs occurred.

93. The BG/PLSR teams conducted their surveys on tides that were typically higher than those used routinely for State-wide surveys in the 1980s and during the current DES survey program. Higher tides reduce ‘sightability’ of crocodiles (Messel, 1981a, Bayliss 1987), as recognised in the Big Gecko report of 2009 (p.126). The report indicates BG/PLSR used higher tides to extend the navigable distance in these short, often shallow river systems and to reduce the number of eyes-only sightings, some of which can be caused by shallow water preventing close approaches. BG noted the impact of higher tides had on sightability and aimed for consistency between surveys.

    93.1. This is relevant to the interpretation of the BG/PLSR survey results and to the design of surveys proposed as part of future monitoring.

94. Annexe 8 provides some details of methods used to assess the likely tidal conditions during BG/PLSR surveys. My overall assessment of the ‘suitability’ of tides is set out in Table 6, based on DES survey standards. As noted by Britton (2009, 2017), surveys in later years were apparently planned to occur on essentially full tides and the tide analysis supports that.

95. Notwithstanding that *post-hoc* assessment of tides is challenging, the majority of surveys were conducted in circumstances that make comparison with historical and current Queensland Government surveys difficult.

Survey transect distances

96. Transect distances were standardised for this review and comparisons made using common transects, as set out in Annexe 9. Final transect distances used to calculate relative densities of non-hatchlings are in Table 7.

Survey counts

97. Counts conducted between calendar years 2010 and 2014 were reconstructed in detail using PLSR-supplied data. The raw PLSR data aligned well overall with the data reported in Britton (2017). Some discrepancies in the draft report were identified and corrected.

98. The counts as used for the analysis here were also corrected to remove sightings that, based on GPS logs, sighting times, sighting locations and other information were judged to be return-trip sightings (Annexe 9). This adjustment reduced non-hatchling counts across all of the 2010-2014 surveys from 572 to 465, a reduction of some 19%.

Table 6. Assessment of the spotlight survey conditions during BG/DLSR surveys, judged according to DES survey standards.

Surveys during marginal sighting conditions can be problematical because sighting probability can fall steeply between high and low tide conditions – tending to plateau at high sightability when there is plenty of exposed bank and at low levels when there is none (Messel et al, 1981a). In between those plateaus, it can be difficult to be confident sighting probabilities will remain reasonably constant as the tide rises or falls by modest amounts.

Tide Assessment	**Good**	**Marginal**					**Poor**						**Grand Total**
River	2008	2008	2009	2010	2011	2014	2008	2009	2010	2011	2013	2014	
Balurga Creek		1	1			1	1		1		1	1	**7**
Chapman River		1		1	2	1	1	1	1	1	2	1	**12**
Christmas Creek	1	1	1									1	**4**
Holroyd River		1					1	1	1			1	**5**
Kendall River		1	1				1		1			1	**5**
Malaman Creek	1		1				1			1	1	1	**6**
Mitchell River							1	1					**2**
Mungkan Creek				1		1	2	1	2	2	2	1	**12**
Coleman River - All	1						1	1					**3**
South Mitchell River	1		1				1						**3**
Edward River							2	1	1		1	1	**6**
Grand Total	**4**	**5**	**5**	**2**	**2**	**3**	**12**	**6**	**7**	**4**	**7**	**8**	**65**

Table 7. Survey transect distances calculated from Cybertracker log data provided by the PLSR.

Transect distances have been re-estimated to bring them to a common basis with other DES survey data.

		Transect Distance (km)							
Year	Night Of	Malaman Creek	Chapman River	Mungkan Creek	Edward River	Balurga Creek	Christmas Creek	Holroyd River	Kendall River
2010	20-Oct-10					43.6			
	21-Oct-10				16.4				
	22-Oct-10		22.9						
	24-Oct-10							21.8	31.0
2011	31-Aug-11		16.3						
	01-Sep-11			31.5					
	03-Sep-11	23.6							
2013	02-Oct-13		20.9						
	03-Oct-13			36.7					
	04-Oct-13				16.6				
	05-Oct-13					49.9			
	06-Oct-13	22.8							
2014	15-Sep-14		21.7						
	17-Sep-14			35.6					
	18-Sep-14				15.7	43.3			
	19-Sep-14	22.6							
	23-Sep-14							13.6	38.4
	24-Sep-14						15.8		

What to do with the 2008 and 2009 survey data?

99. Incorporating the 2008 and 2009 population survey data in the review was difficult in the absence of detailed information on whether the counts in Britton (2008, 2009) included any return trip sightings. The potential adjustment to non-hatchling counts could be sufficient to outweigh any likely increase or decrease in the actual density of crocodiles over the 6-year period of the study, based on estimates of rates of increase for Queensland rivers (Read et al, 2004; Taplin/DEHP, unpubl obs).

99.1. It was judged preferable, nonetheless, to examine changes in the counts of crocodiles over the entire period 2008-2014. To do that, the 2008 and 2009 counts for each waterway were adjusted by the mean percentage of overestimation calculated for 2010-14 for each waterway. The adjustments were -25% for Christmas Creek, -23% for the Chapman River, -17% for Mungkan Creek, -10% for Edward River system, -4% for the Kendall River system, and 0% for Malaman Creek. While this is a crude adjustment, it was considered the most appropriate approach in the circumstances.

Standardising transect lengths and counts

100. The count data were then adjusted to a standardised transect length (Table 8), using methods set out in Annexe 9. The final corrected and adjusted counts are summarised in Table 9.

Table 8. Actual and standardised transect distances used for adjusting non-hatchling counts from BG/PLSR population surveys.

Transect distance (km) by river system and year	**2008**	**2009**	**2010**	**2011**	**2013**	**2014**	**Standardised Transect Distance (km)**
Chapman River	26.3	25.8	22.9	16.3	20.9	21.7	**23.5**
Christmas Creek	16.3	14.9				15.8	**15.7**
Edward River System	57.1	54.9	60.0		66.5	59.0	**59.5**
Kendall River System	55.2	58.3	52.8			52.0	**54.6**
Malaman Creek	17.5	21.9		23.6	22.8	22.6	**22.7**
Mungkan Creek	35.6	35.7	19.9	31.5	36.7	35.6	**35.0**

Table 9. Re-estimated and adjusted counts and relative density of non-hatchling crocodiles by size class and river system.

River	Year	H	2-6’	6-11’	>11’	EO	NH	Relative Density (NH/km)
Malaman Creek	2008	0	3	4	6	4	17	0.75
	2009	0	0	9	1	5	15	0.66
	2011	2	1	5	1	12	19	0.84
	2013	0	11	10	3	3	27	1.19
	2014	1	15	11	2	7	35	1.54
Chapman River	2008	0	3	8	7	1	19	0.81
	2009	0	2	10	3	4	19	0.81
	2010	0	3	5	1	1	10	0.43
	2011	0	1	6	3	12	22	0.94
	2013	7	6	15	3	3	27	1.15
	2014	0	8	5	1	11	25	1.06
Mungkan Creek	2008	0	1	4	3	6	14	0.40
	2009	0	2	3	6	2	13	0.37
	2010	21	5	2	2	9	18	0.51
	2011	0	11	7	1	10	29	0.83
	2013	0	8	0	3	0	27	0.76
	2014	0	8	6	1	4	19	0.53
Edward River System	2008	1	16	15	7	7	44	0.74
	2009	7	16	17	3	9	44	0.74
	2010	4	12	7	2	7	28	0.87
	2013	0	6	17	1	8	32	1.23
	2014	0	4	14	0	11	29	1.08
Christmas Creek	2008	0	1	4	2	0	7	0.45
	2009	0	0	3	2	7	12	0.77
	2014	8	0	5	0	4	9	0.57
Kendall River System	2008	2	21	25	10	19	74	1.36
	2009	8	15	23	14	17	69	1.26
	2010	8	19	17	1	20	56	1.03
	2014	13	33	26	6	33	98	1.80

101. Finally, allowance had to be made for the unbalanced matrix of surveys by river system by year, as there are only two waterways in which counts were conducted in every year of survey (Table 10). Any comparisons of river x year combinations would have to be done selectively.

Table 10. Population surveys by year on the Pormpuraaw DOGIT waterways.

River System	2008	2009	2010	2011	2012	2013	2014
Malaman Creek	Y	Y		Y		Y	Y
Chapman River	Y	Y	Y	Y		Y	Y
Mungkan Creek	Y	Y	Y	Y		Y	Y
Edward River System	Y	Y	Y			Y	Y
Kendall River System	Y	Y	Y				Y

Is there any evidence that tide height has affected counts?

102. To test whether tide heights might have had a material effect on counts, the tide classification of Survey counts

103. Counts conducted between calendar years 2010 and 2014 were reconstructed in detail using PLSR-supplied data. The raw PLSR data aligned well overall with the data reported in Britton (2017). Some discrepancies in the draft report were identified and corrected.

104. Table 6 was used but, in three instances, surveys were re-scored ‘poor/marginal’ where different parts of a single system were surveyed on different nights.

105. A plot of counts, categorised by tide condition and including 95% confidence limits,[14] shows that there is no obvious effect of poor or marginal tides on counts across years (Figure 17). Noting that even the ‘marginal’ tides identified here would be rejected for formal DES surveys, it is reasonable to conclude that any differences attributable to the changes from poor to marginal sighting conditions have been outweighed by other influences.

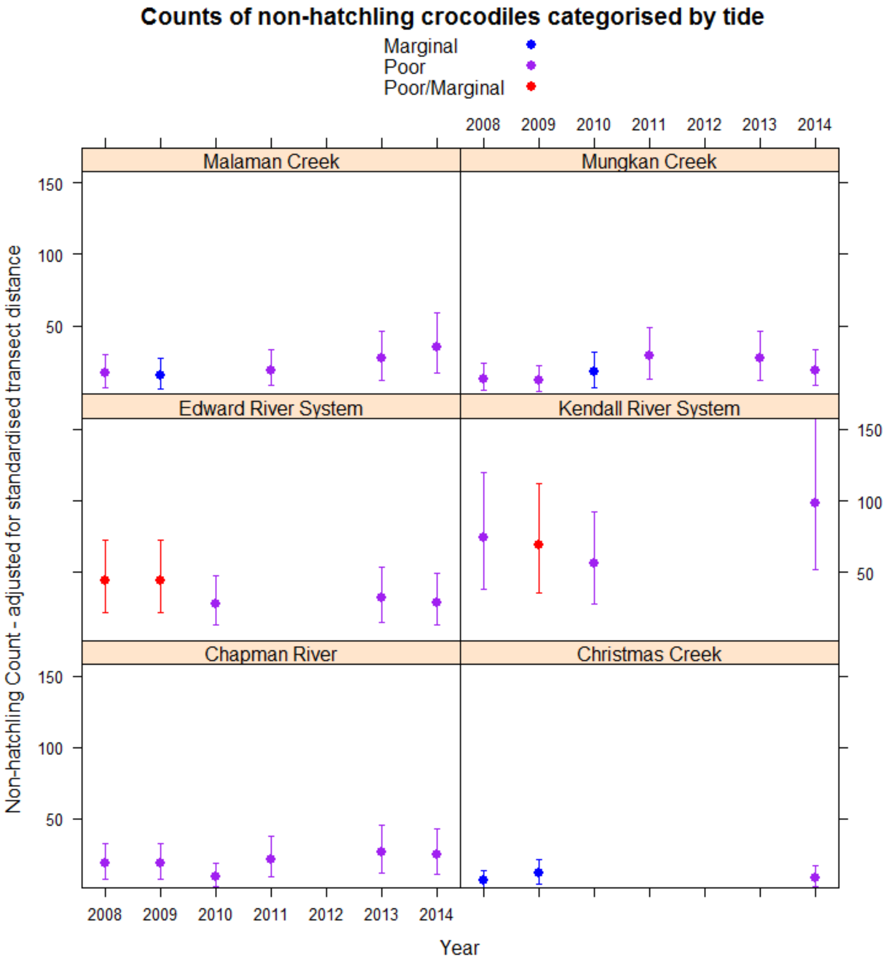
106. The BG/PLSR survey counts have, therefore, been treated here as collected under more or less consistent sightability conditions. This was identified by Britton (2008, 2009, 2017) as one of their primary objectives.

---

[14] 95% confidence limits around individual counts are calculated based on such counts following a negative binomial distribution with shape parameter theta = 15, to account for overdispersion in count data collected during comparable surveys in Queensland (Taplin, unpubl obs). Dwyer et al (2012) applied a negative binomial distribution with theta = 25 to DES count data from eastern coastal waterways of Queensland.

Figure 17. Adjusted counts of non-hatchling crocodiles in the several DOGIT aggregation systems categorised by sighting conditions, based on review of the likely state of the tide for each survey.

Error bars are estimated 95% confidence limits for the count.



Change in crocodile counts over time

107. The data have not been examined statistically in any detail, given uncertainties in the base data, particularly adjustments to 2008 and 2009 data. Figure 17 suggests there were no marked changes in counts of non-hatchlings over the seven-year study period.

108. Given the low numbers, the non-hatchling data for the four most frequently surveyed systems can usefully be pooled to look for any trend (Figure 18). Fitting a negative binomial glm to the data indicates the slope (r = 0.10) is not significant at the p=0.05 level (p = 0.17). If a Poisson distribution was to prove a better fit to these particular counts, the slope would reach significance (p = 0.03). There are insufficient data to conclude a Poisson distribution is more appropriate than the negative binomial, which has been found the best fit in other analyses (Taplin, unpubl. obs).

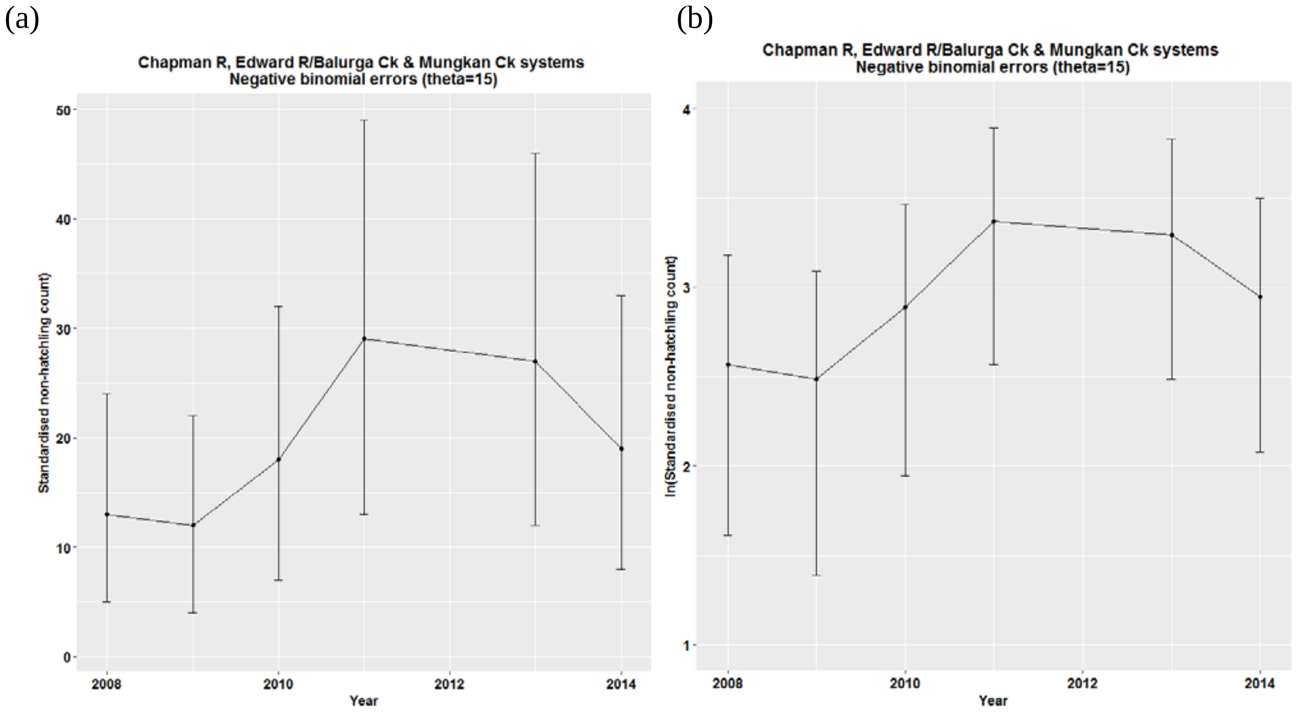
109. In any event, it is clear that the positive slope is driven particularly by low values for 2008 & 2009 counts, which were adjusted downwards by 10-23% to account for possible anomalies in the raw data (refer para. 102). If that adjustment is inappropriate, then the upward trend would largely disappear and the smaller upward trend would not be significant.

110. This re-examination of adjusted data supports Britton's (2017) conclusion that there were no detectable signs of change in non-hatching numbers over the short period of the study.

111. As the survey regime was not standardised to conditions for which sightability estimates are available (e.g. Messel et al, 1981a; Bayliss, 1987), it is difficult to be sure how many more crocodiles might have been sighted during a standard survey. We should expect counts to be higher, but by what proportion is unclear.

112. Nonetheless, the measured relative densities (non-hatchlings/km) are not markedly different from those encountered in other river systems of the southern and western Gulf (Taplin 1988a, 1990; Read 1998, 2001; Read et al 2004). DEHP surveys currently underway should shed additional light on this issue.

Figure 18: Trend in non-hatchling counts on (a) linear and (b) log scales in the four most frequently counted DOGIT waterways.



Is the size class structure indicative of a ‘mature’ population?

113. It is well-established that as populations of estuarine crocodiles in the NT have recovered from hunting, the proportion of large animals in the population has increased at the expense of juvenile and sub-adults (Webb et al, 1984, 1989; Fukuda et al, 2011). This pattern is, unsurprisingly, apparent in Queensland’s far-less frequently surveyed waterways but to a less marked extent, given Queensland populations have been characterised by lower relative densities and slower rates of increase than many NT rivers (Taplin 1988a, 1990; Read 1998, 2001; Read et al, 2004).

114. Britton (2017) reported that the size-class structure in the DOGIT catchments’ is indicative of a population approaching carrying capacity – i.e. one in which the proportions of adults and sub-adults are high relative to juveniles (excluding hatchlings whose numbers fluctuate markedly year-on-year). This conclusion was re-examined using the adjusted and standardised counts. Data for the four southern waterways have been pooled given the low counts and the Kendall/Holroyd is considered separately

Waterways to the south of the Kendall River system

115. It is common practice to estimate non-hatchling size class proportions using only crocodiles that have been sized. When we do that here, we find the proportion of juvenile, sub-adult and adult animals in the pooled DOGIT waterways has decreased from 72% and 74% in 2008 and 2009 respectively to 56% in 2014. Figure 19, however, shows that the absolute count of non-

hatchlings (NH) increased a little in 2014 and almost all of the increase was attributable to the juvenile (2-6ft) size class. What has fallen off markedly is the count of large animals (> 11ft).

115.1. This is not entirely surprising, given work done during later years of the study to capture and tag large animals. PLSR data show 25 crocodiles were captured in the four systems (Table 11). Nineteen (19) of them were between 2.1 and 4.0m in length and the majority were captured in October and November 2013 (some 2014 captures post-dated that year's population count, so are not relevant).

115.2. The numbers are quite sufficient to explain the close correspondence between the decline in large crocodiles sighted between 2008 and 2014, and the increase in EO counts. PLSR have confirmed that the larger animals were much harder to approach in spotlight surveys after the catching exercise (R Morris, pers comm).

115.3. If we make the reasonable presumption that the EO crocodiles can be allocated to the 6ft and upwards size classes, the proportion of medium and large crocodiles has remained at 70-80% during the study (Figure 19).

Table 11. Crocodile capture records for the BG/PLSR study

Waterway	**2011**	**2013**	**2014**	**Total**
Malaman Creek		3	2	**5**
Chapman River	1	5	4	**10**
Mungkan Creek	1	4		**5**
Edward River & Balurga Creek		5		**5**
Total	**2**	**17**	**6**	**25**

The Kendall River system

116. The Kendall River system provides some additional insights. Revised NH counts show modest fluctuations with perhaps a small increase by 2014 (Figure 20). They also show a similar, if smaller, decline in counts of large animals between 2008 and 2014 and an increase in EO counts that can't be attributed to any recorded capture operations. Britton (2017) commented on that increase.

117. Given the uncertainties in these counts because of the tidal circumstances under which they were made, it is unwise to read too much into the fluctuations. It is worthwhile, however, to compare the size structure of the population with an anecdotal but unusually detailed account on what may well have been the first harvest of crocodiles from this system circa 1951/52 (Annexe 10).

118. The comparison between the 1951/52 experience and the BG/PLSR counts supports Britton's suggestion that this, and perhaps other waterways in the DOGIT catchments, may be approaching some sort of 'carrying capacity', albeit at low density compared to NT systems

119. We do not know the 'carrying capacity' of any of the Cape York and Gulf rivers in Queensland. However, the biomass density in the Kendall River system is unquestionably high for Queensland at 107 kg/km.

    119.1. In comparison, the Wenlock River had a fairly stable biomass density of 52-70 kg/km during four surveys between 1988 and 2003, the Staaten River 31-52 kg/km during three surveys from 1997-99, and the North Kennedy/Normanby/Bizant Rivers at Rinyirru National Park 19-31 kg/km during three surveys from 1997-99.[15]

    119.2. The Wenlock River, as part of the Port Musgrave complex, is unquestionably the most productive system for crocodiles in Queensland and has a higher NH density than any other system encountered in Queensland. That system, for one, appears to have largely stabilised in terms of NH density since 1988 (Taplin/DEHP, unpubl obs).

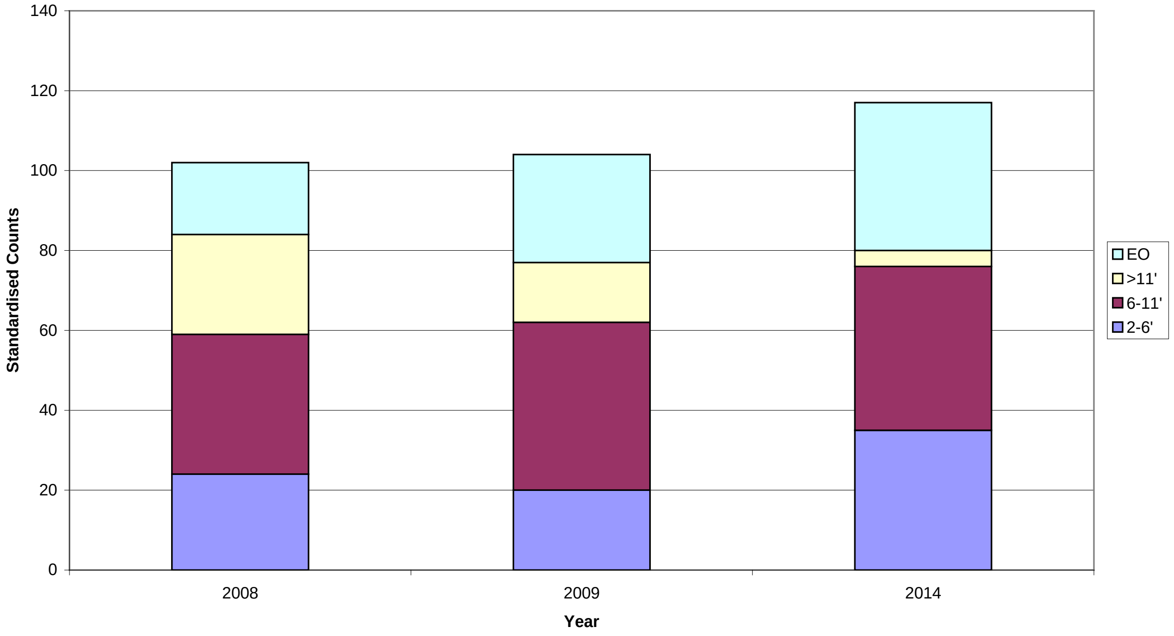
---

[15] These calculations derive from new work compiled for a forthcoming analysis of DES's current survey program. They use raw survey data from DES and older QNPWS databases which have now been corrected to remove return-trip sightings from transect passes and other anomalies. The revised estimates of biomass density differ greatly from those in Fukuda et al (2007, 2008), where an erroneous formula was used to calculate mass from length and the Queensland data included many anomalous records.

Figure 19. Numbers and proportions of non-hatchlings crocodiles by size class in DOGIT river systems, excluding the Kendall/Holroyd system.

Only years in which all rivers were surveyed have been included.

DOGIT waterways - excluding Kendall River System - NH Counts by Size Class



DOGIT waterways - excluding Kendall River System - NH Proportions by Size Class

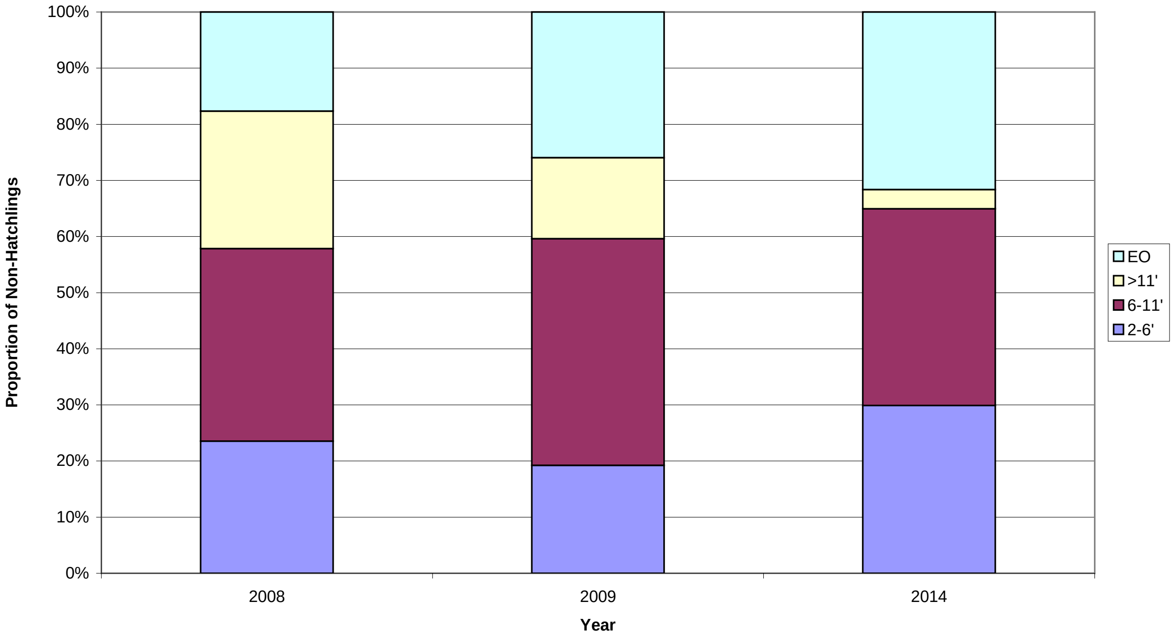
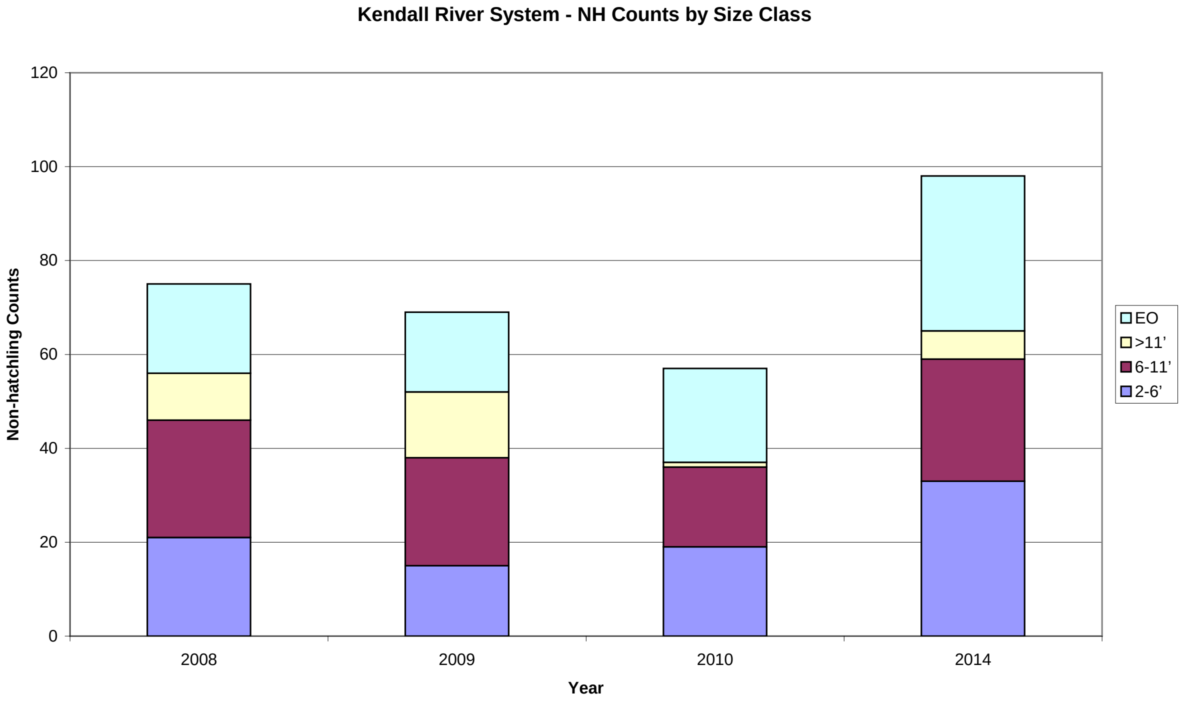
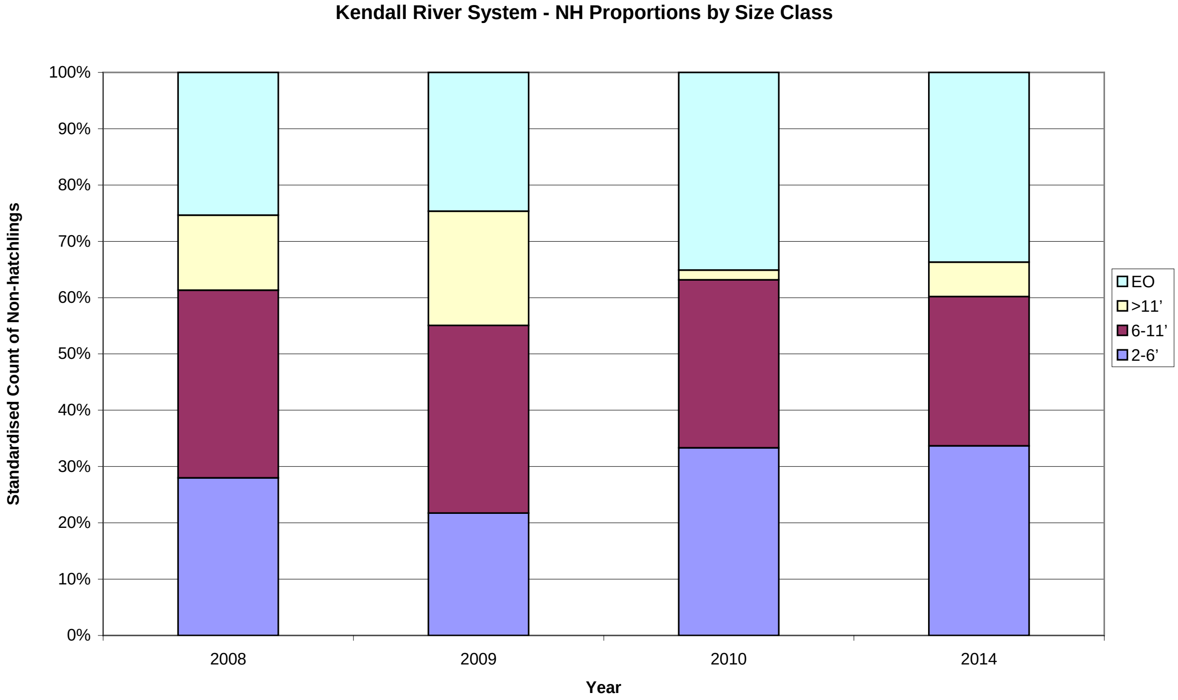


Figure 20. Numbers and proportions of non-hatchlings crocodiles by size class in the Kendall/Holroyd River system.





119.3. At 107 kg/km, the Kendall River system is comparable in biomass density with the Liverpool and Cadell Rivers in the NT but much lower than many other monitored systems there (Fukuda et al, 2011). Both the Liverpool and Cadell Rivers appear to have largely stabilised in NH numbers and biomass density, but both have adjoining rivers (the Tomkinson and Blyth Rivers respectively) that had biomass around 200 kg/km ca 2008 and, in the case of the Tomkinson River, increasing numbers also.

119.4. In respect of size-class distribution, the Kendall River system does have a low proportion of crocodiles under 6ft in length (ca 30%), falling within the fairly wide spectrum typical of NT rivers that are showing signs of stabilising at high NH density, high biomass density and large proportions of animals over 6ft (Fukuda et al, 2011).

Conclusions

120. The pioneering surveys by BG/PLSR are commendable, not least for identifying the Kendall River system as one of the best examples of a maturing crocodile population in Queensland. The DOGIT waterways, particularly the Kendall River system, have healthy crocodile populations with a high proportion of potential breeders. And the data give no indication that the trial harvest has had any short-term impact on population status.

<u>Recruitment into the DOGIT waterways</u>

121. While the several Big Gecko reports focus principally on hatchlings as indicators of recruitment into the systems, there is some utility in examining also the fluctuations in numbers of 2-3 ft animals. These form a distinct cohort in Queensland (and NT) rivers and we can regard them as animals that hatched during the previous year’s nesting season. We can also consider them highly likely to have arisen from nests within the DOGIT rivers, given indications that dispersal increases after animals reach the 3-4 ft size class in about their third year after hatching (Webb & Messel, 1978; Webb et al, 1984; Messel & Vorlicek, 1987).

122. Britton (2017) reported that only 2 hatchlings were found in 2010 and 19 in 2013 during surveys conducted specifically to look for hatchlings. He also reports on hatchlings found during population surveys in Sep-Oct of 2010, 2011, 2013 and 2014 when 31, 2, 8 and 22 were located respectively. After minor corrections, those numbers tally closely with revised numbers developed for this review of 33, 2, 6 and 22 respectively.

123. Treating the 2-3 foot animals of one year as from the same cohort as hatchlings in the preceding year, we can get a slightly different fix on the effectiveness of the surveys in detecting hatchlings and/or the mortality in this cohort from one year to the next. Not many comparisons are possible, because not all waterways were counted every year.

123.1. Malaman Creek: A zero-count for hatchlings in 2013 was followed by sighting of fifteen (15) 2-3 foot animals in 2014.

123.2. Chapman River: A zero-count for hatchlings in 2010 was reflected in the sighting of only one (1) 2-3 foot animal in 2011. And six (6) hatchlings sighted in 2013 corresponded quite closely to just eight (8) 2-3 foot animals sighted in 2014.

123.3. Mungkan Creek: Twenty-one (21) hatchlings sighted in 2010 were reflected in eleven (11) 2-3 foot animals in 2011 while a zero-count for hatchlings in 2013 contrasted with eight (8) 2-3 foot animals sighted in 2014.

123.4. Edward River System: A zero-count for hatchlings in 2013 was followed by sighting of just four (4) 2-3 foot animals in 2014.

124. These low counts over short periods and very variable comparisons across years suggest a need for caution in concluding there is high post-hatchling mortality during the first year of life. That may well be the case, but there are clearly other factors at work that can confound the counts.

125. The counts of hatchlings and yearlings reinforce the poor quality of the nesting habitat. BG/PLSR counted just 82 hatchlings during their study, or around 3 per waterway per year on average.

126. The BG/PLSR data confirm unequivocally that successful recruitment into the DOGIT waterways is very limited, as reported by Britton (2009, 2017), despite the number of nests and viable eggs that were discovered.

Harvest timing in relation to nest losses

127. It is useful to examine the effect of harvest timing on the take-off of eggs. Britton (2017) considers that a harvest constrained to the period before mid-February would target the nests most likely to be killed by flooding, while leaving subsequent nests that have a much higher chance of survival, to contribute to the crocodile population.

128. I have no data on the estimated laying dates of nests for the 2011-12 through 2014-15 nesting seasons, but there is quite comprehensive information on the dates on which nests were first discovered. It appears that, averaged over those four nesting seasons, the timing of a harvest cut-off during February would create a quite nice ‘hinge-point’ (Table 12).

128.1. If a harvest had been conducted and timed to cease on 28 February, then 48 of the 62 nests discovered could have been harvested and 14 would have been left to provide recruitment into the waterways. But if a harvest had been brought forward to 14 February, then only 37 nests would have been harvested and another 11 nests would have been left for waterway recruitment.

128.2. That small change in end-date for a harvest thus has an effect sufficient to be material both for the economics of the harvest (potentially reducing the egg take by ~25%) and for recruitment (potentially adding ~80% to the number of discovered nests left to develop).

128.3. It is quite likely that this result arises from the responsiveness of estuarine crocodiles to weather patterns, where it is not uncommon to have bursts of nesting following the first onset of heavy rain in November-December and after later occurrences of heavy rainfall.

129. The finding provides opportunity to vary a harvest off-take using simple administrative adjustments to the harvest period, while monitoring the effect on economics and recruitment. The scale of the swing in both economic and biological dimensions is sufficient that its impact should be measurable as long as sufficient time is allowed for natural variability in climate/weather and recruitment to ‘average out’ over a period of years.

Table 12. Discovery dates of nests by season as recorded in PLSR databases.

Nesting Season	**Total Nests Discovered**	**Discovered 1 Nov to 28 Feb**	**Discovered after 28 Feb**	**Discovered 1 Nov to 14 Feb**	**Discovered after 14 Feb**
2011-12	8	7	1	7	1
2012-13	23	21	2	18	5
2013-14	20	13	7	9	11
2014-15	11	7	4	3	8
Total	**62**	**48**	**14**	**37**	**25**

How many breeding females may be present in the DOGIT waterways?

130. The BG/PLSR teams captured crocodiles during their study. The data available for review show 24 crocodiles were captured or found dead, 5 of which were in the 2-6ft size class (so not of interest here) and 2 of which were 12-13ft males. In the 6ft and upwards size classes, that

include the breeding size females of interest, the sex ratio of captures was 12:7 in favour of females.

130.1. Sex ratio in crocodilians can favour a preponderance of females but a much larger sample of animals from the Liverpool River had a sex ratio of 0.5 (Webb et al, 1984). For the current purpose, it is safe to assume a sex ratio of 0.5 for the DOGIT waterways, but hold open the possibility that there may be a higher proportion of breeding females present.

131. If we pool the 2014 NH counts for all surveyed DOGIT waterways, we have 145 animals of known size comprising 68 in the 2-6ft size class, 67 from 6-11ft, and 10 over 11ft. An additional 70 EO crocodiles were sighted, which we would expect to be larger and wary animals, based on past experience and analysis (Webb et al, 1984; Taplin et al, 1989) and the analysis of size class proportions above.

131.1. Standard practice for DES surveys is to allocate eyes-only crocodiles to NH size classes in proportion to the numbers of sized animals in each class. Here, it is more conservative to allocate ⅓ of them to each of the three NH size classes. Addition of 23 animals to the 6-11ft size class brings overall numbers to 90.

131.2. Given our presumed sex ratio of 0.5, that gives an estimate of 45 breeding size females in the surveyed rivers. That number is high relative to the number of nests actually discovered in these systems in even good years (Table 5) but not in relation to the estimate of 48 total nests in a good year and 24 in a poor year (refer para 83).

131.3. Given the female : male ratio may be higher than 0.5 and the EO are more likely to be larger animals, the data suggest a significant number of nests may have remained undiscovered or there is 'reserve' of non-breeding or infrequently breeding females. Either prospect suggests there is potential for additional recruitment that will help buffer the system against a harvest.

Comparison of NT egg harvest with the potential Queensland harvest

132. The NT Wildlife Trade Management Plan for the Saltwater Crocodile for 2016-2020 sets a harvest ceiling of 120,000 eggs per annum, estimated to be some 50% of the annual nesting effort (Saalfeld and Fukuda, 2017). Their experience since the late-1980s with egg harvest has shown that large harvests of eggs have had little or no discernible effect on recovery and growth of the crocodile population (Fukuda et al, 2011).

133. The offtake of 120,000 eggs from some 40,000km^2 of nesting habitat amounts to 3 eggs per km^2 per annum on average. Applying that same, clearly sustainable, harvest rate to Queensland would give a harvest estimate for the NW Cape and Gulf Plains of some 11,200 eggs per annum based on its nesting habitat (Table 2).[16] Given nest density indices (nests/km^2) of habitat in the DOGIT catchments are comparable to those in the NT and nest losses and post-hatchling mortality are clearly high, as in the NT (Webb et al, 1984; Webb & Manolis, 1993), the 50% harvest rate is a useful reference level.

133.1. The estimate of 11,200 eggs can stand well for the whole of Queensland's remote areas, given that the eastern seaboard of Cape York Peninsula comprises only enormous areas of unproductive dunefields where there is no evidence of substantial nesting and the Rinyirru National Park, which is a conservation area (Taplin, 1987, 1988a; Taplin et al, 1989; Read et al, 2004).

---

[16] The eastern side of Cape York Peninsula has been excluded because it comprises principally extensive, low productivity dunefields with poor nesting habitat (Taplin et al, 1989; Hawkins et al, 1986; Taplin 1987) and Rinyirru National Park. South of the dunefields, which extend to Cooktown the habitat is shared with a large human population and, to the south, is climatically marginal.

133.2. And it is not sensible to consider nest harvest potential from remnant crocodile populations on the populated east coast at this point, given the conservation and management objectives and the pressures on the crocodile population are quite different.

Potential harvest from the DOGIT lands

134. Britton (2017) variously estimated the potential harvest of eggs from DOGIT land nests likely to be drowned or otherwise lost as 500-700 eggs per year on average, based on the 2011/12-2014/15 data or 900-1200 eggs per year using data from 2007/08 and 2008/09. As details of the latter are not available for review, the estimate here is based only on the later four years of work.

135. The data reviewed here confirmed 43 nests that definitely contained eggs were located between 2011/12 and 2014/15 in southern waterways between Malaman Creek and Balurga Creek and four that contained no eggs. We can better align this figure with Britton's 2017 count of 64 nests with eggs if we conclude that 15 nests with ambiguous egg-presence records in PLSR data did in fact contain eggs – for a total of 58 nests, or roughly 15 per year.

136. Assuming 50 eggs per nest, the gross production of eggs from these known nests would average 750 per year. Given 'good' years can generate some twice the number of nests as 'poor' years, that corresponds to a gross production of 1000 eggs in good years and 500 in poor years.

137. The gross production from known nests would have to be reduced by the proportion of eggs left to develop naturally after the peak of rainfall/flooding in February (some 20% under the model proposed below) – for an average net take of 400-800 eggs, assuming that nests can be harvested before eggs are lost. That is in the same ball-park as Britton's 2017 estimates of 400-900 and 500-700 harvestable eggs.

138. That presumptive harvest from known nests is reasonable in relation to the total estimate of 48 nests in good year and 24 in a poor year for the DOGIT catchments including the Kendall River system. If those estimates are in the right ball-park, total annual production of eggs should be in the order of 850 – 1700 (allowing for some 70% of nests proving viable, per Britton, 2017) and would imply a harvest rate of about 50%.

What are the essential elements of a harvest proposal for the DOGIT lands

139. The NT experience should give us the confidence to adopt a comparable approach in the DOGIT lands, involving experimental harvest and scientifically sound monitoring of the impact (if any) on recruitment and population status.

140. Measuring population responses in crocodiles requires long-term effort - well-illustrated by the results of monitoring since 1979 in the NT. After nearly 40 years monitoring and many years of harvesting, some of those populations are still in the process of maturing to stable density, biomass density and, very likely, size/age distribution (Fukuda et al, 2011).

141. The overall trends in Queensland river systems are likely to mirror those in the NT, with increased NH density, increasing proportions of larger crocodiles, and increasing biomass over time as the population recovers from pre-1974 hunting and matures. It looks likely, however, that many Queensland rivers will stabilise at considerably lower NH density and biomass than NT systems and that rates of population increase will be lower (Read et al, 2004; Taplin/DEHP, unpubl. obs).

141.1. For example, Queensland's prime habitat and most productive nesting system on the Wenlock River at Port Musgrave appears to have stabilised since 1988 at a mean transect count of 230 non-hatchlings (coefficient of variation = 19% over 6 surveys) and a mean density of 4.4 NH/km (data from surveys by Taplin, Read and DES).

141.2. Over a 28-year period, the proportion of crocodiles under 6ft has fallen from 45% to 37% across Port Musgrave as a whole. This is consistent with, but not as dramatic as changes seen in the NT (Fukuda et al, 2011).

141.3. Port Musgrave has long had by far the highest numbers and highest NH density of crocodiles in Queensland during surveys since 1979 (Messel et al, 1981b; Taplin, 1988a; Read et al, 2004). That situation looks unlikely to change as new survey data becomes available (DEHP/Taplin, unpubl obs).

142. With low rates of increase and small populations in the DOGIT waterways, we need to set a long time horizon for a trial harvest to give sufficient time for the response to harvest to become measurable and for any adjustments to harvest levels to flow through. The DOGIT waterways, like those of the NT, are subject to highly variable rainfall and flood events which have major impacts on nesting success (This review; Britton, 2008, 2009, 2017; Fukuda & Saalfeld, 2014). It will be essential to measure change over sufficiently long periods that the effects of good and bad years for nesting can be accounted for.

What should be the conservation and economic aims of a harvest?

143. Conservation aims should be:

143.1. To maintain a healthy breeding population of estuarine crocodiles in the DOGIT waterways that is commensurate with public safety for residents.

143.2. To stabilise, in the long-term, the numbers and size structure of the crocodile population at levels commensurate with the conservation and economic aims.

143.3. To reduce the extent of unlawful killing of crocodiles in DOGIT waterways by providing incentives to local residents to help police activities on their lands and reduce accidental and deliberate killing of crocodiles.

144. The desired economic aims of the harvest, as advised by the PLSR Group and the current lessees of the Edward River Crocodile Farm, are:

144.1. To harvest eggs in sufficient numbers to contribute materially to the production capacity of the crocodile farm and to sustain some employment at the farm for local indigenous people.

144.2. To contribute to a program of important work for the PLSR Group that will help it continue it broader conservation program.

144.3. To better inform the Queensland Government’s responses to requests from other indigenous groups to harvest crocodile eggs from their traditional lands.

144.4. To provide incentives for the aboriginal land owners and their commercial partners to encourage better protection of crocodile in Gulf waterways, where there has been frequent evidence of crocodiles being killed (Taplin, 1985, 1988, unpubl. obs; Read et al 1998; Britton, 2008, 2009, 2017).

145. Both PLSR and the farm lessees consider the opportunities for employment arising from an egg harvest will likely be modest in light of the numbers of nests likely to be harvestable, but important nonetheless given otherwise limited employment opportunities at Pormpuraaw.

What level of harvest might be sustained?

146. The answer to this question cannot be ascertained *a priori*. The aim should be to answer it through an experimental commercial harvest and attendant monitoring.

147. The NT has shown that a harvest of something less than 50% of the estimated egg production, spread broadly across NT catchments, has been entirely sustainable with no identifiable impact on the population. There is no *a priori* reason to think a harvest of comparable proportions in the DOGIT lands would have a more material effect on the population.

148. The NT approach was essentially to increase harvest numbers incrementally while monitoring the response in a large and productive population spread across many big river systems. The large

numbers of crocodiles available to be counted helped with the statistics of counting and the detection of harvest effects.

149. I do not consider an incremental approach like this can work for the DOGIT lands because the numbers of animals are small and the statistics of counting would require very long trial periods that would be attempting to detect what might be very small effects. It would be possible to spend many years of research and monitoring simply attempting to decide whether a shift from a 20% to a 30% harvest could be contemplated. That is not necessary.

150. As set out previously, there are few reasons for concern about a trial commercial harvest here:

150.1. The area has recovered well from a historically massive impact when estuarine crocodiles throughout Queensland were shot to commercial extinction. Its recovery shows the species' resilience when its habitat remains intact. And increases on the populated east coast between the mid-1980s and the early-2000s shows resilience in the face of extensive human impacts.

150.2. The DOGIT area contains a small fraction of Queensland's total habitat and is buffered north and south by the largest extent of largely undisturbed and moderate to good quality habitat in the State.

150.3. There is very little human settlement in the region to add impact, unlike areas like Weipa to the north and Normanton/Karumba to the south.

150.4. The small scale of the experiment means that, whatever the outcome, it will have only local impact.

150.5. There is no evidence to suggest a harvest could remotely threaten the population status of the species in Queensland.

151. The approach I propose would begin with a ten-year timespan, which is close to the time to maturity of female crocodiles in the NT (Saalfeld et al, 2015), so would take us approximately through one female generation:

151.1. It would permit harvesting of all nests discoverable by boat or quad bike/foot survey over the period Nov 1 to Feb 28 each year for a period of five years (refer Table 12).

151.1.1. With this level of harvest, we would expect to see a substantial impact on the already low levels of recruitment unless (a) late nests with low flooding risk are indeed making the major contribution to recruitment and/or (b) compensatory mechanisms are contributing to increased nesting after the end of harvest.

151.1.2. If neither of these things happens, then recruitment should show a decline from the current three animals per river system per year to zero - that is an effect that should be detectable over five years allowing for the random effects of rainfall and floods.

151.1.3. If local recruitment does indeed drop to zero, then we have effectively set up a test of immigration into the area from adjacent waterways north and south. This we would expect to emerge as an influx of 3-4ft and somewhat larger juvenile and sub-adult size classes, given these are the sizes at which (possibly density-dependent) dispersal increases (Webb & Messel, 1978; Messel et al, 1981a; Webb et al, 1984; Bayliss & Messel, 1990).

151.2. If population monitoring shows there has been no recruitment of animals to the hatchling or 2-3ft size classes in the first five years through local nesting, then the off-take would be reduced for a further period of five years by allowing a harvest of nests discoverable over the period Nov 1 to Feb 14 each year.

151.2.1. This would effectively the reduce the average annual harvest by ca 25% and increase the number of discovered nests left to contribute to recruitment by ca 80% (Table 12).

That is a sufficiently large intervention to have a reasonable chance of changing the level of recruitment over a five year period.

152. By the end of that 10-year period, any substantial biological impact and the economic viability of the harvests should be readily apparent.

153. Such a harvest program must then consider the potential impact of a hiatus in recruitment to the sub-adult and breeding population of up to 10 years, assuming no immigration occurs.

153.1. That has potential to have a longer-term detrimental effect locally, but could be compensated by release of a small number of juvenile animals reared from collected eggs.

153.2. Consideration could be given to that at the five-year point, which would effectively mimic a prolonged period of negligible recruitment followed by a significant birth pulse from a good year, such as is seen in natural populations (Smith & Webb, 1985). And further consideration can be given at the ten-year point.

Selective release of juveniles as an option

154. A selective release of crocodiles would also address another biological aspect of the targeting of flood-prone early nests. The tendency of estuarine crocodiles to commence nesting soon after the first heavy rains of the wet season and before the main flood-inducing peaks of January and February should not be assumed non-adaptive without good evidence.

155. The NT experience shows that flood losses among river bank nests can vary considerably by location and year (Webb et al 1984), though they are consistently high. This parallels what the BG/PLSR data suggests is likely to happen over the long term in the DOGIT catchments.

156. Fukuda and Saalfeld (2014) showed that recruitment into Northern Territory river systems was not a simple function of rainfall and losses to flooding. Instead, some rivers showed a trend towards higher hatchlings densities with higher rainfall in one or another month of the Oct-Dec period, early in the nesting season. In others, hatchling density declined with higher rainfall in the peak of the wet season. And 8 of 10 rivers examined had higher hatchling recruitment if there was high rainfall in the late wet season (April to May). They hypothesized that:

156.1. The positive relationship with early rainfall is likely linked to the onset of breeding, as suggested by Webb (1991).

156.2. The negative relationship with high rainfall during the wet season peak reflects heavy mortality from flooding, as has been reported frequently (e.g. Webb et al, 1977; Magnusson et al, 1978, 1979, 1980; Magnusson,1982; Webb et al, 1983, 1984).

156.3. The widespread positive relationship between hatchling density and late wet season rainfall might arise from extended nesting in favourably wet years, which might favour *inter alia* some repeat nesting by individuals and improved hatchling survivorship.

157. There may be entirely unrelated reasons why this behavioural response has continued despite seemingly strong reasons for it to be selected out. For example, early nesting could be strongly advantageous in habitats that are protected from flooding but perpetuated in more marginal habitats where the trait confers neutral or negative competitive advantages (Magnusson, 1982). However, I am not aware of any evidence to suggest that early nesting in flood-prone waterways of the Gulf has no net-positive selective advantage.

158. Absent such evidence, we should not be comfortable to harvest 100% of early nests. There is good reason to think that undiscovered early nests in a few areas safe from flooding will supply occasional recruits. However, it is not difficult to keep open the option of returning to the wild a small number of early- and late-harvested, farm-reared animals and this may prove important if the harvest led to a prolonged period of no recruitment.

Research and monitoring to underpin the experimental harvest

159. Monitoring to support this experimental harvest needs to be designed in such a way that most of it can be performed by the PLSR group, with independent oversight to ensure that (a) monitoring protocols are adhered to rigorously; (b) any training/retraining on survey protocols conforms to current DES standards; and (c) government can have confidence that the outcomes of the harvest will withstand independent scrutiny.

160. There is obvious potential for a conflict of interest where the proponents and beneficiaries of a harvest are involved in collecting data on its impact. However, there is also great benefit to wider Queensland Government priorities in involving the indigenous Land and Sea Ranger groups in scientific studies, as it helps equip then with transferable skills and knowledge and a better understanding of how quality science has to be conducted.

161. I see this as a consideration rather than an impediment to development of a good quality monitoring program.

<u>What needs to be monitored?</u>

162. There is a clear hierarchy of essential and desirable monitoring needs to answer the following questions:

Question	Timeframe for short-term answers	Timeframe for longer-term answers	Rationale
Q1. Has egg harvesting reduced annual recruitment in the hatchling and 2-3ft size classes or not?	2-3 years	5-10 years	• We should care less about the actual numbers of nests laid down and their precise fates than about whether they're contributing to recruitment. The measure is animals in the waterways, not nests or eggs. • Given that watercourses are the primary habitat available to new recruits, they are a sufficient focus for monitoring
Q2. Has egg harvesting reduced the number of animals entering the 3-4ft size class?	3-5 years	5-10 years	• This helps distinguish between local recruitment and immigration, assuming local recruitment drops to zero. • If reduced local recruitment is compensated by immigration, then localised high intensity harvesting may be viable, but extending the harvest to adjacent source areas may not.
Q3. Has egg harvesting impacted the numbers or biomass of crocodiles in the sub-adult and adult size classes?	NA	5-10 years	• Effects here will not be visible short-term because of expected growth rates to maturity and the statistics of counting in short, low density systems. • It will not be possible to answer whether egg harvesting has itself had an impact because of uncontrollable external impacts. • However, if relative density (NH/km) and/or biomass increase despite harvesting, we will get a measure of longer-term sustainability.

163. There is an abundance of less important questions that could be posed. But answering them would require detailed study by trained scientists and funding over a prolonged period. I consider this neither realistic nor practical for this project, given its limited State-wide significance.

164. Some questions will be answered as a matter of course if DES is able to sustain good oversight of the harvest operations. Questions marked * are those that can be easily answered on a nest-by-nest basis and should be routine aspects of sound husbandry for Edward River Crocodile Farm.

164.1. How many nests were discovered in each year, where were they located, and were the nests/nest sites flooded at some time during the nesting season?

164.2. How many eggs were taken?* What were the dimensions and mass of each egg in a representative sample?*

164.3. What was the estimated stage of development (in days post-laying) when eggs were discovered and/or harvested?*

164.4. How many eggs were rejected for collection on the basis of damage, death, development abnormality or infertility?*

164.5. How many eggs were returned for incubation?*

164.6. How many eggs hatched after incubation?* What were the suspected causes of failure to hatch?*

164.7. What was the length, weight and sex of each farm-incubated hatchling from harvested nests?*

164.8. What effort was required to discover nests and harvest eggs? Was the return on investment sufficient to make for a viable harvest?

165. A range of other post-harvest questions regarding the fates on animals reared on the farm have value for better understanding the post-hatching biology, but they are not essential for the evaluation of harvest strategy and can be left for negotiation as ‘nice-to-haves’ if their collection adds to, or doesn’t detract from, farm management.

165.1. One non-negotiable for the farm, however, is that it needs to be able to identify, at the five-year mark, cohorts of animals some 3-4 years of age suitable for release to the wild, should the review of harvesting suggest it’s necessary.

165.2. Any decision to release farm-raised animals would have to consider the risk of introducing diseases into the wild population and would need to ensure that only thriving animals were released.

166. A continuing focus of the farm-based information collection should be whether there are any differences in viability, growth rate, survivorship etc between animals from early (Nov-Jan) and late (Feb) nests. The feasibility of this would have to be negotiated with ERCF. Comparisons with nests laid down after February will not be possible as there is no proposal to collect them.

Control systems – are they warranted?

167. I have been asked to comment on what ‘control’ systems might be used to help evaluate the impact of nest harvesting. The Kendall River system was used as a ‘control’ of sorts for the BG/PLSR trial harvest but the results were inconclusive (see above).

168. The challenge of ‘control’ systems in these remote areas is in fact the lack of control that can be exercised. Net fishing occurs in many systems and there is no shortage of anecdotal evidence (and some systematic evidence from the 1980s) of accidental and probably some deliberate killing of crocodiles by fishermen over a long period (e.g. Taplin, 1985, 1988b; Read et al, 1998, 2004; Britton, 2008, 2009, 2017). Leaving a river system unharvested does not control for these other impacts.

169. Given the diversity of Queensland’s waterways and crocodile habitat, my recommended approach to assessing the consequences of the trial harvest is to compare population surveys from the DOGIT lands with those from other Queensland systems that are being surveyed as part

of the new DES survey program. That program samples rivers systematically across remote areas and provides a good basis for long-term comparisons with other Gulf systems including the Mitchell, Nassau, Staaten and Norman River systems (DEHP, 2016a).

170. That said, it is not practical to extend the types of detailed nesting and recruitment surveys on the DOGIT lands to these other river systems. The return on effort expended would be small and scarce research funds would be better invested elsewhere.

<u>Searches for nests and monitoring of nest fates should continue beyond the end of harvest</u>

171. It will be important to identify the numbers and fates of nest laid down before and after the end of harvest, to identify whether the high intensity early harvest has any discernible effect (positive or negative) on post-harvest nesting. That is in the proponents' interests, because it bears directly on the fraction of nests/eggs that might be taken in future seasons should the harvest continue.

172. There is a balance to be struck, however, been the intrusiveness and possible consequences of monitoring and the value of information obtained. Predation by pigs and goannas is identified as the main secondary source of egg loss in the DOGIT lands (Britton, 2008, 2009, 2017). There is some risk, in these very exposed nests, that the action of visiting the nest and exposing the nest cavity could increase predation (Magnusson, 1982).

172.1. The minimum data we need to collect are:

172.1.1. Location and approximate timing of nest construction.

172.1.2. Whether the nest contains eggs or not – i.e. has the potential to produce hatchlings.

172.2. Other questions such as the number and size of eggs, their stage of development when discovered etc, would be nice to have but can be traded off for the current purpose against maximising their potential to contribute hatchlings to the river system.

173. Location and timing require only regular surveys for nests by boat along defined transects. The presence or absence of eggs should be determined with minimal disturbance of the nest structure and thorough closure of any opening made.

173.1. The only circumstance in which I would recommend full opening of the nest chamber would be the discovery of nests within a 25-30m radius of earlier nests. In these cases, it will be valuable to identify the possibility of double-clutching by a single female or seeming tolerance of nesting by a different female after the first nest is harvested. Webb et al (1983) identified some characteristics of nests and egg clutches germane to this. Genetic testing of sampled eggs opens additional possibilities.

173.2. In all instances, there is benefit to gained from identifying the female in attendance at each nest, using any distinguishing features.

<u>What research and monitoring regime should apply to answer these questions?</u>

174. The monitoring regimes recommended to achieve these ends consist of:

174.1. *Population counts to DES standards* in July or August[17] of each year along consistent transects on each river system in the DOGIT lands, encompassing as a minimum all of the areas harvested.

174.2. *Efforts to catch, measure and mark* hatchlings and 2-3ft crocodiles in the system. The 2-3ft animals will become potential recaptures in later years and, subject to mortality and migration, will form a pool of adult animals for recapture in long-term studies.

---

[17] Tide table data from 1979-2021 indicates that these are the only months in which tides will consistently allow reliable survey. Dates for survey would be agreed in consultation with DES. I recommend a DES officer accompany all surveys as either spotter or observer to ensure data integrity and comparability with other DES surveys.

174.2.1. Small animals can be captured relatively easily without undue disturbance of the population as a whole. Capture work should be done soon after population survey.

174.2.2. Larger animals should be left undisturbed to reduce the impact on annual counts and minimise disturbance to breeding/nesting activity.

174.3. *Boat surveys for nests* at consistent intervals year-on-year.

174.3.1. Government should not try to prescribe when nest searches should occur, as the PLSR group and Edward River Crocodile Farm will need to maximise efficiency and effectiveness – i.e. returning the maximum number of viable eggs at minimum cost.

174.3.2. However, there is a need for some year-to-year consistency to ensure outcomes can be compared to underpin the science.

174.3.3. It would be desirable, for the scientific ends of the project, to ensure we compiled a tally of nests in early January, in mid-February (marking the hinge-point around which the harvest end-date would focus), in late-March (to identify nests constructed after the 'hinge point'), and in late May (marking the effective end of nesting), thus covering the whole nesting season. The early tallies can be compiled from results of egg-collection. The last two would require extra work.

174.3.3.1. The nest tallies should cover the transects identified in Figure 21, which are derived from actual transects employed by BG/PLSR teams and will ensure consistency in the data collection effort.

174.3.3.2. Details should be resolved with PLSR/ERCF staff, protocols established early, and not varied without prior consultation with DES.

174.3.4. Whether nests are surveyed and collected on the Kendall River system should be left for local decision-making. The system is 100km from Pormpuraaw by sea and further by road. It is questionable whether there is any possibility of cost-effective harvesting there given the small numbers of nests located, the difficulty accessing them (Britton, 2008, 2009, 2017), and the risk of egg mortality during transport on rough roads or seas.

174.3.4.1. If no nest harvesting is planning, then I do not think the cost of effort involved in trying to census nests there for monitoring purposes only can be justified. The money would be better spent elsewhere in Queensland.

174.3.4.2. However, population survey and capture/marking should be conducted annually, regardless of whether eggs are collected, to establish the amount of recruitment into this system and whether it is contributing migrants to more southerly systems. That would likely require a 4-5 day excursion (2 days survey and 3 days capture and mark).

174.4. *Collection of nest data from harvested nests* should be broadly consistent with the data collection conducted under the BG/PLSR study with some small amendments:

174.4.1. The data collected should be directed at answering all the questions at para 168.

174.4.2. All nests should be allocated a unique identifying code and it should be used as the key for all data collected in relation to that nest.

174.4.3. Efforts to collect spot temperatures from nests can be discontinued. If temperatures are to be monitored, then automatic data loggers should be used in a sound experimental design to answer specific questions.

174.5. *Collection of data from unharvested nests* should be less intrusive.

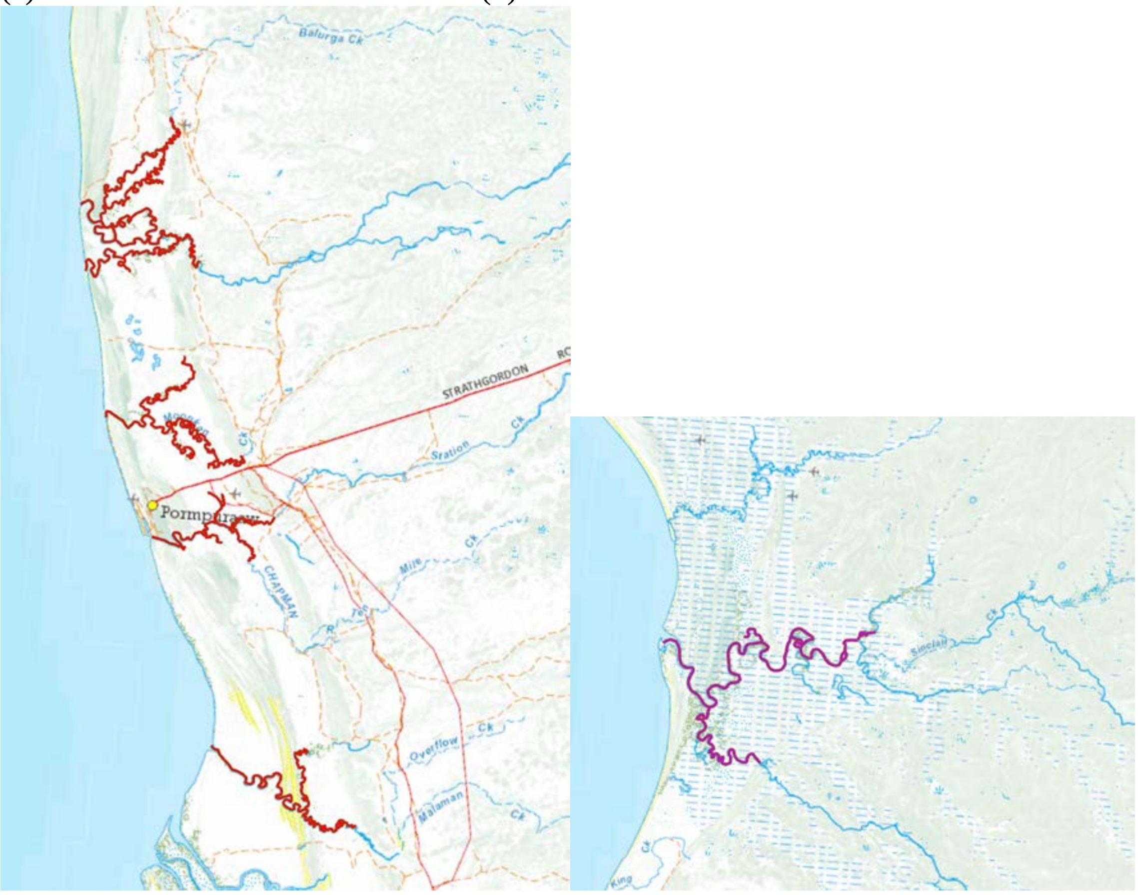
174.5.1. GPS location and photographs of the nest and its surrounding vegetation and location. Photographs should automatically record GPS location, date and time.

174.5.2. Whether or not the nest contains eggs – a simple Yes/No response.

174.5.3. A sample of three eggs per viable nest should be returned for measurement and estimation of their laying date. These should come from the top of the nest and be removed with minimal disturbance of nest structure. The eggs should also be labelled and preserved for later assessment by DES.

174.5.4. Nests should not otherwise be disturbed after discovery.

Figure 21: Proposed nest census transects for the DOGIT catchments (a) the four southerly river systems and (b) the Kendall River system.


(a) (b)

174.6. *Collection of survey metadata* is an important priority for assessing cost per unit effort and ensuring the integrity of the harvest regime.

174.6.1. All harvest activity in the field should be recorded diligently using the existing data collection systems devised by the PLSR group. Some modification of their databases and user interfaces is necessary to reduce the data integrity issues encountered in this review. Some enhanced training by DES will be required to be sure the requirements are understood.

174.6.2. The aim should be to maintain an unambiguous record of all harvesting and monitoring activity. There should be low tolerance in DES for failure to fully document all activity or inability to provide comprehensive records.

174.7. *Hatching and rearing of male and female animals* for potential return to the wild.

174.7.1. While nests collected can be incubated in whatever way optimises benefit for the farm, a proportion of the nests should be incubated to produce both sexes to assist with any later reintroductions.

174.8. *Monitoring on-farm outcomes* for progeny of different nests should be considered.

174.8.1. The minimum requirement should be that a complete record is kept for each nest of the eggs taken, the rates of hatching, infertility, deformity etc., and the size and weight of each hatchling.

174.8.2. It is not practical to levy other requirements on the farm, unless they wish to pursue additional research as part of their animal husbandry.

The detectability of change

175. To test how much change in the population might be detectable in pooled non-hatchling counts from the four waterways closest to Pormpuraaw (Chapman River, Mungkan Creek, Edward River and Balurga Creek), annual counts were simulated for a single survey per year of a constant set of transects.

176. The simulation assumed an initial count of 86 animals (the mean of the 2010-14 counts) and applied annual increases of 0, 5, 10 and 20% p.a. 5000 simulations were run for each level of increase over 10 years of survey. Counts were sampled from assuming a negative binomial distribution of counts with theta=15 as previously. For each randomised data set, the fit of a corresponding negative binomial generalised linear model of log (Counts) against Survey Year was tested. The significance level for detecting a trend in the population was set at $\alpha = 0.05$ and power curves constructed for different levels of growth or decline in the population.

177. The results show that a substantial change of at least 20% per annum over a period of close to 10 years would be needed to give the desired power, using only a single survey per year (Figure 22a). That is a consequence of the low absolute numbers of animals in these short systems and the effects of overdispersion on the count data. As the population increases the year-on-year variance in counts increases considerably Figure 22(b). The overdispersion effect is evident in the various graphs of non-hatchling density over time in maturing populations in the NT (Figure 3 in Fukuda et al, 2011).[18]

178. Given these systems averaged recruitment of only some 3 hatchlings per river per year during the BG/PLSR study, we need really focus only on complete collapse of hatchling recruitment as a result of harvesting all early nests. It would need only one late nest to achieve 25% survivorship each year to continue this rate of recruitment. The primary determinant of detectability will be the prevalence of ‘good’ and ‘bad’ years for recruitment during the course of the harvest.

178.1. That poses a logic problem because, to date, we have judged ‘good’ and ‘bad’ years on the basis of whether they resulted in recruitment. But there are sufficient indicators of what can contribute to a ‘good’ and ‘bad’ year from the BG/PLSR study and ongoing research in the NT (e.g. Fukuda & Saalfeld, 2014) that, during the course of such a harvest, it should be quite practical to judge that it is the harvest rather than some environmental influence that is likely having an adverse impact.

179. Using a single annual survey for the non-hatchling population limits our capacity to detect change in the population unless the effect of the harvest on recruitment is substantial and continues for at least 8-10 years. However, there is no need to be unduly concerned by that because:

---

[18] Non-hatchling density translates directly to counts when transect distance is kept more or less constant over time.

179.1. The DOGIT catchments are small and even dramatic change can be expected to have only local impact.

179.2. The generation time for the population will likely be something over ten years and any lack of a birth pulse over that period can be corrected by release of farm-reared juveniles. Hence the proposed initial duration of the experimental harvest.

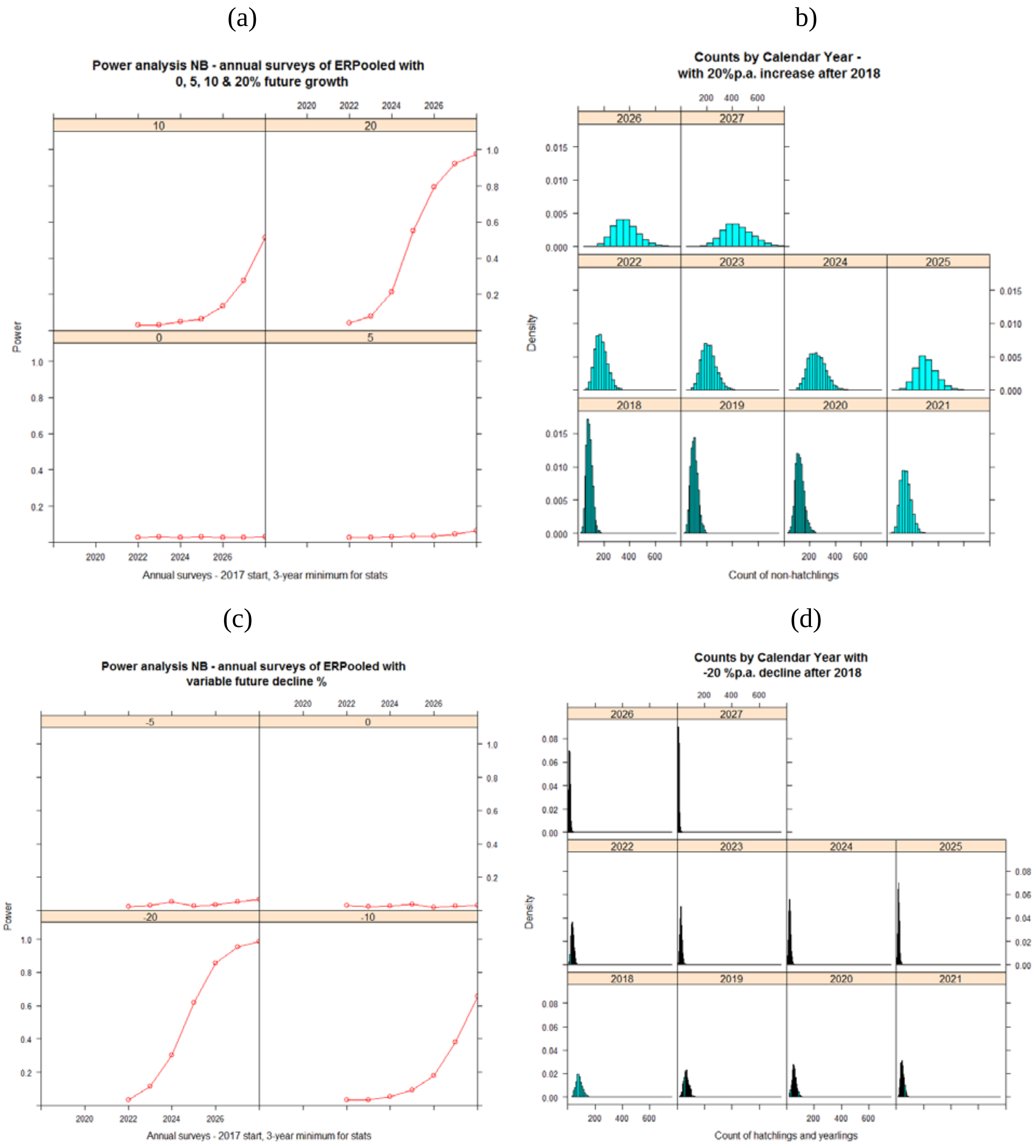
Figure 22: Power analysis of annual surveys on the four most proximate river systems to Pormpuraaw over a ten-year period.

(a) Power curves for growth rates of 0, 5, 10 & 20% p.a. in non-hatchling counts

(b) Negative binomial density distribution of counts by survey year for 20% increase p.a. in non-hatchling counts

(c) Power curves for decline rates of 0, -5, -10 & -20% p.a. in non-hatchling counts

(d) Negative binomial density distribution of counts by survey year for -20% increase p.a. in non-hatchling counts



References

Bayliss, P. 1987. Survey methods and monitoring within crocodile management programmes. In: Webb GJW, SC Manolis and PJ Whitehead (eds). Wildlife Management: Crocodiles and Alligators. Surrey Beatty & Sons. pp. 157-175.

Bayliss, P and H Messel. 1990. The population dynamics of estuarine crocodiles: An assessment of long-term census data. Proceedings 9th Working Meeting IUCN-SSC Crocodile Specialist Group, Lae, PNG. IUCN: Gland, Switzerland.

Britton, A. 2008. A survey of the estuarine crocodile (*Crocodylus porosus*) populations in Cape York Peninsula to support an experimental harvest of eggs. Final Report 2008: 2007/08 Nesting Season. Big Gecko P/L & Qld Department of Primary Industries and Fisheries.

Britton, A. 2009. A survey of the estuarine crocodile (*Crocodylus porosus*) populations in Cape York Peninsula to support an experimental harvest of eggs. Final Report 2009: 2008/09 Nesting Season. Big Gecko P/L & Qld Department of Primary Industries and Fisheries.

Britton, A. 2017. Results of an experimental harvest of estuarine crocodiles (*Crocodylus porosus*) eggs from wild nests around Pormpuraaw, Cape York Peninsula. Summary Report [draft version 26 June 2017]: 2011/2 – 2014/5 Nesting Seasons. Big Gecko P/L, Darwin, NT.

Brocklehurst P and A Gibbons. 2003. The Northern Territory and Commonwealth of Australia National Vegetation Information and Analysis: NT Vegetation Compendium Project Report. Department of Lands, Planning & Environment, Natural Systems Division, Darwin, NT.

Brocklehurst, P, D Lewis, D Napier and D Lynch. 2007. Northern Territory Guidelines and Field Methodology for Vegetation Survey and Mapping. Technical Report, Department of Natural Resources, Environment and the Arts, Palmerston, NT.

DEHP. 2016a. Crocodile Monitoring Plan.

DEHP. 2016b. Crocodile Monitoring Technical Manual.

DFO. 2017. Space-based Measurement, Mapping, and Modeling of Surface Water. Dartmouth Flood Observatory. http://floodobservatory.colorado.edu/.

DOE. 2004. Nested Catchments Data for the Australian Continent. Australian Government Department of Environment.

DoENR. 2012. NVIS Version 4.1- National Vegetation Information System, Northern Territory. Department of Environment and Natural Resources.

DSITI. 1988-2014. Statewide landcover and trees study Queensland. Department of Science, Information Technology and Innovation, Brisbane, Qld.

DSITI. 2015. Version 10.0 Regional Ecosystem Survey and Mapping, Queensland Herbarium, Brisbane.

Dwyer R, H Campbell, & C Franklin. 2012. Scientific review of the Department of Environment and Heritage Protection’s estuarine crocodile abundance and distribution data and methodology. Uniquest P/L Project 00984. Uni Qld, St Lucia.

Fukuda, Y, and N Cuff. 2013. Vegetation communities as nesting habitat for the saltwater crocodiles in the Northern Territory of Australia. Herpetological Conservation and Biology 8(3):641-51.

Fukuda, Y, and K Saalfeld. 2014. Abundance of Saltwater Crocodile Hatchlings is Related to Rainfall in the Preceding Wet Season in Northern Australia. Herpetologica 70(4):439-48.

Fukuda, Y, P Whitehead, and G Boggs. 2007. Broad-scale environmental influences on the abundance of saltwater crocodiles (*Crocodylus porosus*) in Australia. Wildlife Research 34(3):167-76.

Fukuda, Y, P Whitehead, and G Boggs. 2008. Corrigendum: Broad-scale environmental influences on the abundance of saltwater crocodiles (*Crocodylus porosus*) in Australia. Wildlife Research 35: 170.

Fukuda, Y, GJW Webb, C Manolis, R Delaney, M Letnic, G Lindner, and P Whitehead. 2011. Recovery of saltwater crocodiles following unregulated hunting in tidal rivers of the Northern Territory, Australia. The Journal of Wildlife Management 75(6):1253-66.

Gallant, JC, TI Dowling, AM Read, N Wilson, P Tickle, & C Inskeep. 2011. 1-second SRTM Derived Digital Elevation Models User Guide. Geoscience Australia, Canberra ACT.

Geoscience Australia, 2006. Geodata Topo250K Series 3.

Letnic, M and G Connors. 2006. Changes in the distribution and abundance of saltwater crocodiles (Crocodylus porosus) in the upstream, freshwater reaches of rivers in the Northern Territory, Australia. Wildlife Research 33(7):529-38.

Magnusson, WE. 1982. Mortality of eggs of the crocodile *Crocodylus porosus* in northern Australia. Journal of Herpetology 16(2):121-30.

Magnusson, WE, GC Grigg, and JA Taylor. 1978. An aerial survey of potential nesting areas of the saltwater crocodile, *Crocodylus porosus* Schneider, on the North Coast of Arnhem Land, Northern Australia. Wildlife Research 5(3):401-15.

Magnusson, WE, GC Grigg, and JA Taylor. 1979. An aerial survey of potential nesting areas of the saltwater crocodile, *Crocodylus porosus* Schneider, on the on the West Coast of Cape York Peninsula. Report to Australian National Parks and Wildlife Service, Canberra, ACT.

Magnusson, WE, GC Grigg, and JA Taylor. 1980. An Aerial Survey of Potential Nesting Areas of *Crocodylus porosus* on the West Coast of Cape York Peninsula. Wildlife Research 7(3):465-78.

Messel, H, GC Vorlicek, AG Wells and WJ Green. 1981a. Surveys of tidal river systems in the Northern Territory of Australia and their crocodile populations. Monograph 1. Pergamon Press.

Messel H, GC Vorlicek, AG Wells, WJ Green, HS Curtis, CRR Roff, CM Weaver and A Johnson. 1981b. Surveys of tidal river systems in the Northern Territory of Australia and their crocodile populations. Monograph 16. Pergamon Press

Messel, H and GC Vorlicek. 1987. A population model for *Crocodylus porosus* in the tidal waterways of northern Australia: Management implications. In: Webb GJW, SC Manolis and PJ Whitehead (eds). Wildlife Management: Crocodiles and Alligators. Surrey Beatty & Sons. pp. 189-98.

NASA. 2017. NRT Global Flood Mapping. https://floodmap.modaps.eosdis.nasa.gov/projSummary.php

Neldner, VJ, BA Wilson, EJ Thompson and HA Dillewaard. 2012. Methodology for Survey and Mapping of Regional Ecosystems and Vegetation Communities in Queensland. Version 3.2 Updated August 2012. Queensland Herbarium, Queensland Department of Science, Information Technology, Innovation and the Arts, Brisbane, Qld.

Peach, B. 2000. Crocodile Men: History and Adventures of Crocodile Hunters in Australia. Universal Enterprises P/L, Cairns, QLD, Australia.

Read MA. 1998. Distribution and Abundance of the Estuarine Crocodile (*Crocodylus porosus* Schneider) in Queensland 1998. QNPWS Internal Report.

Read MA. 2001. Report on the Distribution and Abundance of the Estuarine Crocodile (Crocodylus porosus) in Queensland 2001. QNPWS Internal Report.

Read, MA, JD Miller, IP Bell, and A Felton. 2004. The distribution and abundance of the estuarine crocodile, *Crocodylus porosus*, in Queensland. Wildlife Research 31(5):527-34.

Saalfeld, K, and Y Fukuda. 2017. Northern Territory Saltwater Crocodile (*Crocodylus porosus*) Wildlife Trade Management Plan. Department of Environment and Natural Resources, Palmerston, NT.

Saalfeld, K., Y Fukuda, T Duldig, and A Fisher. 2015. Management Program for the Saltwater Crocodile (*Crocodylus porosus*) in the Northern Territory of Australia, 2016-2020. Department of Environment and Natural Resources, Darwin, NT.

Smith, AMA and GJW Webb. 1985. Crocodylus johnstoni in the McKinlay Area, NT VIII. A Population Simulation Model. Wildlife Research 12(3):541-544.

Taplin LE. 1978. Unpubl Field notes on estuarine crocodiles sighted at The Beach, Burdekin River.

Taplin LE.1985. Crocodile surveys - Gulf rivers. QNPWS Internal Report.

Taplin LE 1987. The Management of crocodiles in Queensland, Australia. In: Webb GJW, Manolis SC & Whitehead PJ, Wildlife Management: Crocodiles and Alligators. Surrey Beatty & Sons. pp:129-40.

Taplin LE. 1988a. The population status and management of estuarine crocodiles in Queensland: present situation and future prospects. In: Proceedings of the 9th Working Meeting of the IUCN Crocodile Specialists Group. Lae, Papua New Guinea. pp. 253-307.

Taplin LE. 1988b. Estuarine Crocodiles - Lakefield National Park. QNPWS Internal Memorandum, Townsville.

Taplin LE, P Bayliss and G Krieger. 1989. Crocodile distribution and Abundance - Cape York Peninsula: Report on a helicopter survey of eastern, northern, and north-eastern Cape York, May 1988. QNPWS Internal Report.

Webb, GJW. 1991. The influence of season on Australian crocodiles. In: Haynes, CD, MG Ridpath, and MAJ Williams (eds.) Monsoonal Australia: Landscape, Ecology and Man in the Northern Lowlands. AA Balkema, Netherlands. pp:125-31.

Webb, GJ, H Messel, and W Magnusson. 1977. The nesting of *Crocodylus porosus* in Arnhem Land, northern Australia. Copeia 1977(2):238-49.

Webb, GJW and H Messel. 1978. Movement and dispersal patterns of *Crocodylus porosus* in some rivers of Arnhem Land, Northern Australia. Wildlife Research 5(2):263-83.

Webb, GJW, SC Manolis, R Buckworth and G Sack. 1983. An examination of *Crocodylus porosus* nests in two northern Australian freshwater swamps, with an analysis of embryo mortality. Wildlife Research 10(3):571-605.

Webb, GJW, SC Manolis, P Whitehead, and G Letts. 1984. A proposal for the transfer of the Australian population of *Crocodylus porosus* Schneider (1801), from Appendix I to Appendix II of CITES. Technical Report. Conservation Commission of the Northern Territory, Darwin, NT.

Webb, GJW, PG Bayliss and SC Manolis. 1989. Population research on crocodiles in the Northern Territory, 1984–86. In: Proceedings of the 8th Working Meeting of the Crocodile Specialist Group of the Species Survival Commission of the IUCN. Ecuador. p 22-59.

Webb, GJW, and SC Manolis. 1993. Conserving Australia’s crocodiles through commercial incentives. In: Lunney, D and D Ayers (eds) Herpetology in Australia: a diverse discipline. Royal Zoological Society of New South Wales, Mosman, NSW. pp: 250-6.

Webb, GJW, SC Manolis, B Ottley and A Heyward. 1994. Crocodile management and research in the Northern Territory: 1992–1994. In: Proceedings of the 12th Working Meeting of the Crocodile Specialist Group of the IUCN. pp: 167-80.

Wilson, BA, PS Brocklehurst, MJ Clark and KJM Dickinson. 1990. Vegetation Survey of the Northern Territory of Australia. Conservation Commission of the Northern Territory, Darwin, NT.

Annexe 1: Mapping of crocodile habitat and prospective nesting habitat in Queensland

Habitat mapping

1. Mapping of the whole of the habitat actually or potentially occupied by estuarine crocodiles in Queensland followed procedures similar to those used by Webb et (1983) for the Northern Territory but used the most up-to-date spatial data available on the extent and characteristics of Queensland waterways and wetlands (palustrine and lacustrine). The result is shown in overview in Figure 2.
2. This exercise captured, in addition to perennial waterways close to the coast, large intermittent streams further inland that have lagoons and nearby lacustrine features that provide crocodile habitat, and palustrine environments that are widespread in some areas.
3. The inland limit of estuarine crocodiles was defined for this purpose as coinciding with the 200m contour derived from the latest available 1-sec digital elevation model for Queensland (Gallant et al, 2011). This decision was grounded in records of all Queensland surveys, reliable anecdotal reports of inland occurrences of estuarine crocodiles, and the paper of Letnic & Connors (2006) which reports estuarine crocodiles at elevations of around 200m ASL in the NT.
    - 3.1. Estuarine crocodiles have been recorded at least 100m ASL in the Burdekin River (Taplin, 1978), have been reported reliably as occurring near the 200m contour on the Lynd River during the 1970s (T Frisbee, pers comm), and extend close to 400m ASL in some of the short coastal streams of the Wet Tropics (DES survey data). However, across the state the vast majority of animals have been located at elevations of less than 20m ASL, including during helicopter survey.
    - 3.2. Constraining the extent of estuarine crocodile habitat in Queensland to the 200m contour, rather than whole catchments, gives an updated and more nuanced picture of the regional distribution of estuarine crocodiles than the whole-catchment approach of Taplin (1987).
4. Categorisation of watercourses was based subsequently on a breakdown of waterways into those lying between sea level and 20m ASL, those in the region 20-100m ASL and those 100-200m ASL. This division was based on extensive field observations suggesting that their primary habitat lay at less than 20m ASL, that smaller numbers would be found above the 20m contour, and smaller numbers again at the highest elevations.
5. Watercourses (i.e. rivers and creeks) providing potential habitat for crocodiles were selected using the following criteria:
    - 5.1. Perennial and intermittent watercourses below 20m ASL.
        - 5.1.1. The intermittent watercourses were further restricted to those adjoined by regional ecosystems defined as mangroves – this removed extensive areas of tidally intermittent watercourses crossing saline mudflats and samphire plains, particularly in the Gulf Plains regions.
    - 5.2. Perennial watercourses only where they are above 20m ASL – this excludes large areas of frequently dry temporary streambeds in upland areas.
6. To the watercourses were added lacustrine and palustrine areas lying within 2km of both perennial and intermittent waterways. This distance excluded considerable numbers of isolated and mostly temporary lagoons sufficiently distant from permanent water as to be unlikely crocodile habitat but captured many floodplain billabongs, lakes and lagoons. Wet season floodwaters can lead to crocodiles taking up residence in temporary refuges some distance from river mainstreams.
7. Unlike the NT habitat estimate, beaches have not been included in the estimate of crocodile habitat across Queensland at this point. The numbers of crocodiles sighted along the coast during

helicopter surveys in the late 1980s was extremely small and is not thought likely to add significantly to the total population.

  7.1. However, perennial streams and intermittent coastal streams bordered by mangrove that debouch onto beaches have been mapped, together with coastal swamplands and lakes.

<u>Nesting habitat mapping</u>

8. Drawing on a comparative study of crocodile nesting habitat across Western Australia, NT, and Queensland (Fukuda et al, 2007, 2008), I noted that the characterisation of nesting habitat used to compare its extent in NT and Queensland catchments was greatly constrained by limitations in the spatial data then available for cross-border comparisons.

9. In particular, Queensland has large areas encompassing almost the whole of the eastern seaboard from the tip of Cape York to Rockhampton in the south, where the landforms, physiography, climate and vegetation have essentially no counterparts in the NT (Taplin, 1987, 1989). Prominent examples are the very extensive siliceous dune fields and swamplands of eastern Cape York north of Cape Flattery and the many short, steep waterways of the northern Wet Tropics, many of them fringed by rainforest and vine forests but also having extensive adjacent swamplands and grasslands.

10. Notwithstanding these marked differences, the overall pattern of estuarine crocodile nesting behaviour in Queensland is very comparable with that in the NT – in terms of the types of habitat in which they choose to nest, the typical locations and characteristics of nests, their preferences for particular structural types of vegetation and their propensity, in marginal or poor nesting locations, to nest in whatever vaguely suitable habitat is available to them (Taplin, unpubl obs).

  10.1. Considerable similarities, and some important differences, in nesting habitat and observed nest sites were noted between the western coast of Cape York Peninsula and the north coast of Arnhem Land by Magnusson et al (1978, 1979, 1980).

  10.2. The highest number and concentration of crocodile nests found, over five years of study in Queensland, was in a small area of freshwater swamp at Port Musgrave that is structurally and floristically very similar to the considerably larger Melacca Swamp adjacent to the Adelaide River in the NT, which likewise supports high concentrations of nests (Taplin, unpubl obs; Webb et al, 1983).

11. Drawing on these similarities and differences, I have used the Queensland Regional Ecosystems (RE) database (Neldner et al, 2012) as the basis for a new mapping of prospective crocodile nesting habitat across the whole of Queensland north of the Fitzroy River at Rockhampton. Important additional data was provided to the author by the Queensland Herbarium, in the form of NVIS-consistent descriptions of the structural layers in each regional ecosystem, which allowed distinctions to be drawn between habitats with, for example, dense or sparse ground cover – an important feature if crocodiles are to find adequate vegetation for nesting.

12. Reports on NT vegetation mapping by Wilson et al (1990), Brocklehurst & Gibbons (2003), Brocklehurst et al (2007) were used in combination with the NT NVIS 4.1 spatial data (DoENR 2012) were useful in comparing Queensland RE’s with NT NVIS mappings.

13. Fukuda & Cuff (2013) provided a valuable reference point for those NT vegetation associations used for nesting that have close counterparts in Queensland REs. That study examined the distribution across habitat types of several thousand nests harvested for research and commerce and used NVIS-linked descriptions of the vegetation associations that could be compared to structurally and/or floristically similar regional ecosystems in Queensland.

14. Additional information was drawn from Magnusson et al (1978, 1979, 1980). They located and mapped many areas on western Cape York based on their NT experience and ranked them as ‘Good’, ‘Marginal’, ‘Poor’ or ‘Indeterminate’ nesting habitat.

14.1. Good habitat was limited to areas with freshwater swamp vegetation, including ferns and sedges and areas of broad-leaved grass under Melaleuca, mangrove or monsoon forest canopy.

14.2. Marginal habitat was used to describe extensive areas of broad-leaved grasses or fringing forest. This category was split into 'Marginal 1' for the principal areas and 'Marginal 2' where small areas of such marginal vegetation occur interspersed with, or grading into, less suitable habitat.

14.3. Poor habitat was used to describe areas of mangrove forest, mudflats, open sedge plains of *Cyperus scariosus* and *Sporobolus virginicus*, exposed shore communities and very isolated waterbodies.

14.4. The Indeterminate category was used to describe areas with no counterparts known to the authors from their NT experience.

15. Spatial mapping for Queensland REs constituting prospective nesting vegetation was drawn from Version 10.0 of the Regional Ecosystem Survey and Mapping dataset (DSITI, 2015) using their pre-clearing estimates of coverage. The pre-clearing areas were subsequently reduced by subtracting areas affected by intensive development and land clearing. Pre-clearing vegetation that has been subjected to intensive development was identified and subtracted using selected layers from Geoscience Australia (2006). Additional land clearing was identified from the Queensland Statewide Landcover and Trees Study spatial layers covering the period 1988 to 2014 (DSITI, 1988 – 2014) and subtracted also.

16. This penultimate mapping of prospective nesting habitat was then intersected with the three layers of crocodile habitat defined earlier – perennial and intermittent waterways, lacustrine habitats and palustrine habitats.

16.1. Before intersection, the waterways and lacustrine polygons were buffered by 250m, consistent with the approach used by Fukuda et al (2007, 2008) in their definition of nesting habitat for NT and Queensland catchments. Palustrine areas were left unbuffered.

17. Decisions on which REs to include in maps of prospective nesting habitat were inevitably more subjective as the mapping extended into areas south of the Burdekin River where very few records of crocodile nests exist, no nesting research has been done, and the habitats differ considerably from those in remote areas.

17.1. As the floristics of vegetation associations diverged, greater emphasis was placed on the broad vegetation types and the structural characteristics of the vegetation strata.

17.2. Care was taken, however, to ensure that the same set of core 'rules' applied across all regions of Queensland. For example, a decision to buffer vegetation around waterways by 250m to define prospective nesting vegetation was applied State-wide and not varied region-by-region.

17.3. Similarly, decisions about whether to include or exclude REs comprising fringing vine forest were made on a State-wide basis. This process led, overall, to somewhat conservative estimates of prospective nesting habitat as the majority of vine forest REs, which are common in the Wet Tropics region, were excluded.

Annexe 2: Defining nest sites from the distribution of nests

1. Determining what might constitute a ‘nest site’ cannot be done with any certainty from the data available, since very limited information was available about the characteristics of particular females using the sites. Some imperfect information can come from the width of the eggs laid (Webb et al, 1983) but only very incomplete egg dimension records were available for review.

2. An additional complication comes from the variability inherent in GPS fixes of location. This variability is shown clearly where there are records of repeated visits in a single nesting season to a particular nest – but the track data and point data at the nest site plot at slightly different locations. These errors proved to be small (typically less than 5-10m) relative to the larger distances relevant to deciding whether different nests are associated with a single nesting site.

   2.1. This is illustrated in Figure 23, which shows (a) the distribution of nests on Mungkan Creek in the 2012/13 nesting season and (b) the overall distribution of nests across all years. The inset in Figure 23(a) shows a magnified scene of the distribution of GPS fixes from multiple visits to one nest during 2012/13 – the pixel length in the inset is 10m and the maximum distance between GPS fixes some 14m.

   2.2. Figure 23(a) also shows that it can be reasonably straightforward to identify 7 different nest sites on this creek system in 2012/13, separated as they are by several hundreds of meters. Figure 23(b), however, shows much greater ambiguity when multi-year nesting patterns (represented by differently coloured dots) are considered.

3. Defining nest sites becomes a little simpler if we take two steps:

   3.1. Reduce the GPS-related positional uncertainty for nests visited multiple times in a season by calculating the mean centre of the fixes, as defined by ARCGIS.

   3.2. Examine the distribution of the linear distances between each nest and its nearest geographic neighbour, irrespective of nest season. That graph shows that the distribution has two principal modes at less than 20m and at about 220m (Figure 24). It is reasonable to assume that the large peak of nests in very close proximity is a good approximation to a group of individual nest sites, each likely to be attributable to a single nesting animal. It is also reasonable to assume that the mode at about 220m and the sprinkling of more isolated nests represent separate nest sites.

4. Somewhat closer examination is required to decide on nests in the less distinct peak from about 80-180m distant from their nearest neighbours.

   4.1. After examining these in some detail, only one nest distant from its nearest neighbour by 99m was judged to be best assigned to a single nest site. Several of the other nearest-neighbour pairs included a nest attributable to the early years of the study (2007-2009) and a nest from the 2011-14 period, a long enough interval for us to be unsure of changes in the usage of nest sites.

   4.2. Others included near-neighbour pairs in rather concentrated areas of nesting, where assignment to one nest-site or another was uncertain and it was judged safest to be conservative and assign them to different nest sites.

5. This exercise is inevitably a matter of judgement, but has the advantage for our purposes of reducing a large number of observations of nests down to a smaller number of nest sites, some of which had nests in close proximity in two, three or all four of the nest seasons studied from 2011/12 to 2014/15 and, in some instances, in earlier or later years.

Figure 23. Recorded nest locations on Mungkan Creek in (a) the 2012-13 nesting season and (b) all nesting seasons.

The inset shows the variation in GPS fixes (across 2 pixels) for multiple visits to a single nest site.

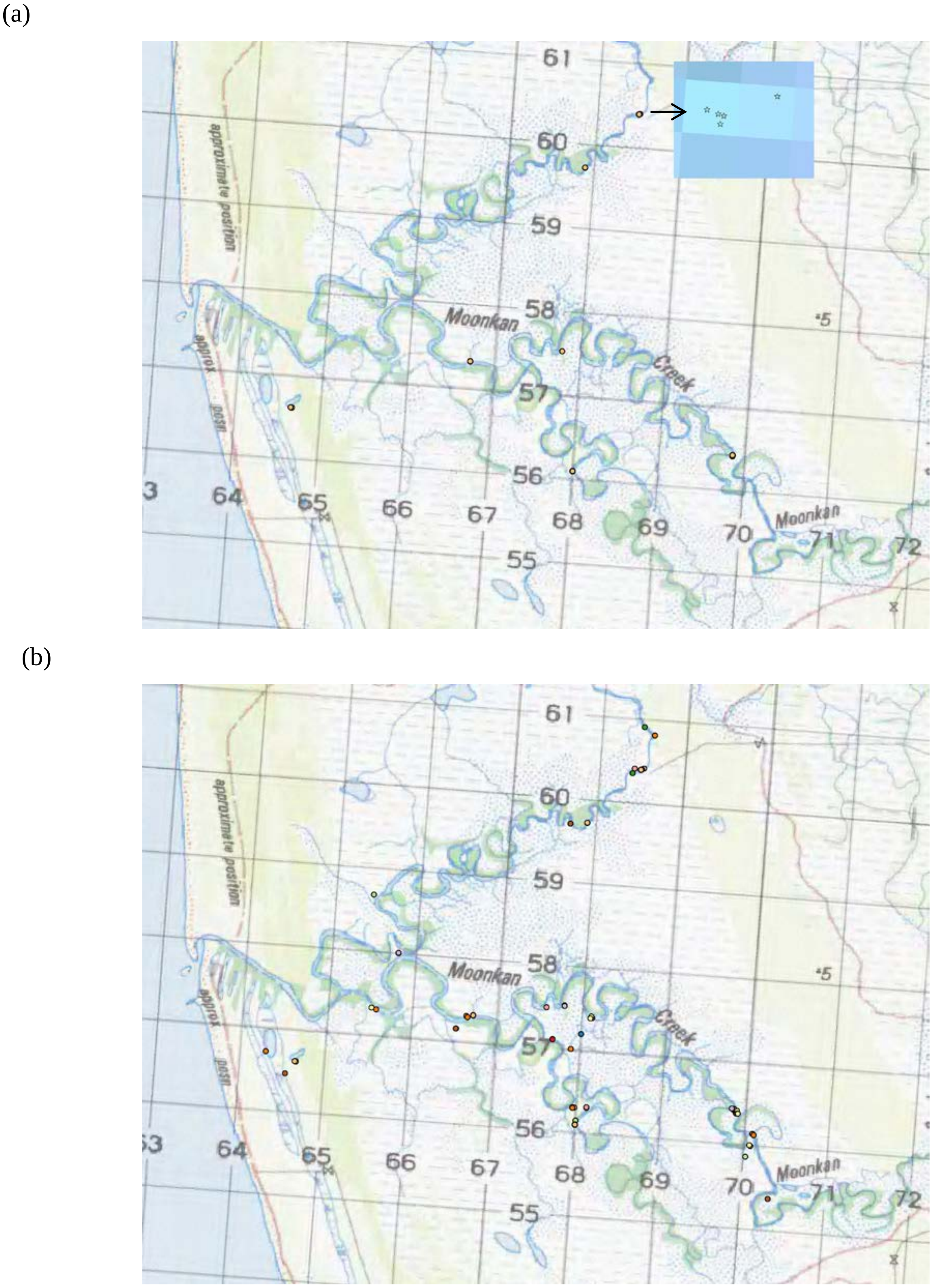
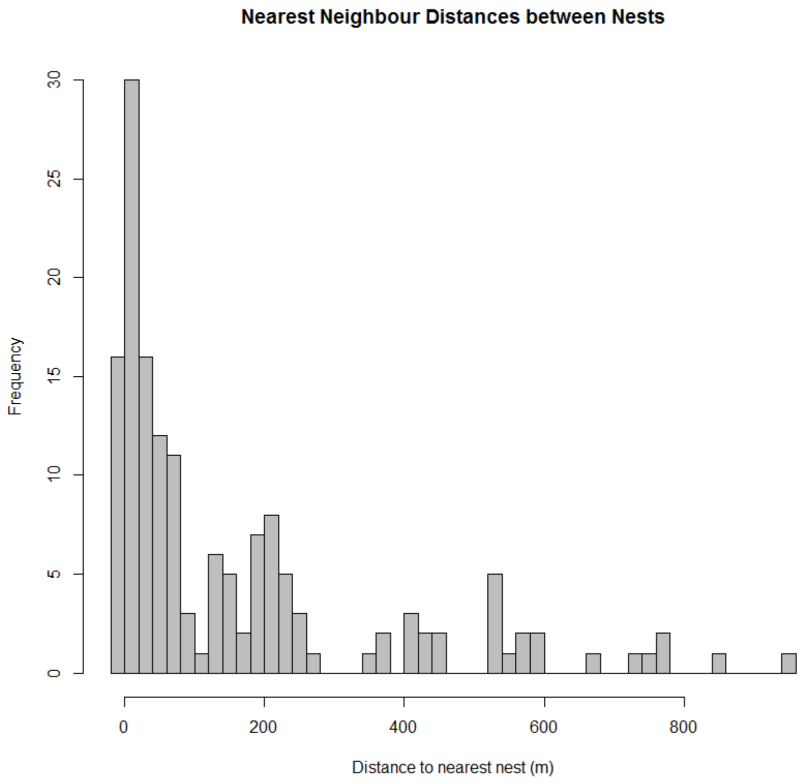


Figure 24: Nearest neighbour distances between nests mapped in the DOGIT catchments 2012-2015.



6. Having defined nest sites, we want now to identify how many of them lie within, or in close proximity to, mapped areas of nesting vegetation. We need first, however, to convert the point data for multiple nests comprising a 'nest site' to an appropriate shape best capturing the 'site'.
    6.1. There are too few observations of multiple nests at sites to usefully fit a bounding polygon to them. Instead, a bounding circle was fitted around the nests at each site, recognising that the circular 'arena' is a fairly uninformed fit to the likely distribution of nests we would find if we had a large sample. It is, however, a reasonable approximation, given the fairly broad mapping scale of the RE vegetation data.
    6.2. We also have to deal with nest sites defined only by one nest. For this purpose, all single nest sites were buffered spatially with a circle 25m in radius – which is the median radius of all nest sites with multiple nests. That estimate is not markedly different from the 30m estimated to be the closest distance between nests laid by different females in Melacca Swamp in the NT (Webb et al, 1983).

Annexe 3: Satellite mapping of flood waters

1. NASA’s Goddard Laboratory produces experimental global imagery at ~250m resolution that maps the occurrence of surface water, assessed to be flood water after subtracting known permanent water (NASA, 2017) .
2. The techniques used for mapping surface water are susceptible to errors, including those induced by cloud cover, flood water lying under some types of vegetation, and the differing angles at which satellite imagery is captured. Steep terrain can also cause problems because of shadows but should be of little concern in the DOGIT area’s flat plains. Nonetheless, the processed data available have been refined in light of many years of work by the Dartmouth Flood Observatory at the University of Colorado (DFO, 2017)
3. After examination of various imagery sets available, NASA 14-day composites of 3-day assessments were used for mapping. The NASA process assesses 3-day windows of data in the first instance to work around problems of rain-associated cloud masking the ground. The 3-day windows are then compiled into a succession of 14-day composites, which provide a ‘historical’ assessment of the occurrence of surface water over the preceding 14 days.
4. Surface water is marked as having been present in a tile if at least one of the 14 x 3-day assessments shows surface water in that tile and the tile is not classified as containing permanent water. The process will therefore, tend to underestimate flood water extent immediately adjacent to river banks because many of the approximately 250x250m pixels will be mapped as permanent water. And the satellite overpasses are unlikely to be record short-term tidal flooding reliably and consistently. The permanent water issue can be adjusted for in part by identifying nests that lie within one tile length of a MODIS flood-water tile.
5. The 14-day composite data is available only from mid-2013. That is sufficient for us to assess the studied nesting seasons of 2013-14 and 2014-15 and the more recent ‘unstudied’ nesting seasons, where some less systematic data are available. For this review, two-week ‘snapshots’ of flood extent were captured for successive 14-day periods covering 1 November to 30 June in each nesting season. Geoprocessed data for the whole nesting season were then overlaid on the Cape York Peninsula base map.

Annexe 4: Identifying and mapping individual nests

1. The raw data on crocodile nests available for the review made the compilation of a comprehensive nest database challenging:
    1.1. No unique identifier for each nest was included in the PLSR databases.
    1.2. Some nests were visited repeatedly during a nesting season, others only once.
    1.3. Some records showed more than one nest at much the same location during a nest season.
    1.4. Some records did not include location data.
    1.5. Numerous track logs from visits to nests showed evident searches for, or inspections of, nests but were not accompanied by records of the nest visited or its condition.
    1.6. And some records consisted solely of a handful of track points at an evident nest site.
2. It was necessary for this review to capture all of the nest-related data and all of the survey track information in a GIS system and then, nest-by-nest and day-by-day, relate individual tracks to individual nests.
    2.1. This exercise in cross-correlation of four different sets of electronic data and numerous paper records and electronic datasheets was successful. It led to a detailed database of surveys conducted, nests discovered and revisited (to gather eggs or check on their post-discovery condition), and the associated nest-related information.
    2.2. Many small inconsistencies between records in the raw data were resolved once the chronology of survey and visit events was compiled and each nest record was linked to the event chronology.
3. The most substantial issue was a significant number of nests for which no adequate records could be found as to their eventual fate.
    3.1. In some cases there was no evidence the nest had been visited more than once, despite there being good cause for a follow-up inspection – e.g. a newly discovered nest that did not yet contain eggs or a nest with eggs that had not yet been destroyed by flood or predators. In such cases, one would expect further visits to confirm whether eggs were later laid or damaged, but evidence of such visits was lacking in numerous instances.
    3.2. Nonetheless, analysis of the data for which good records were available confirmed the key findings of the BG/PLSR reports.

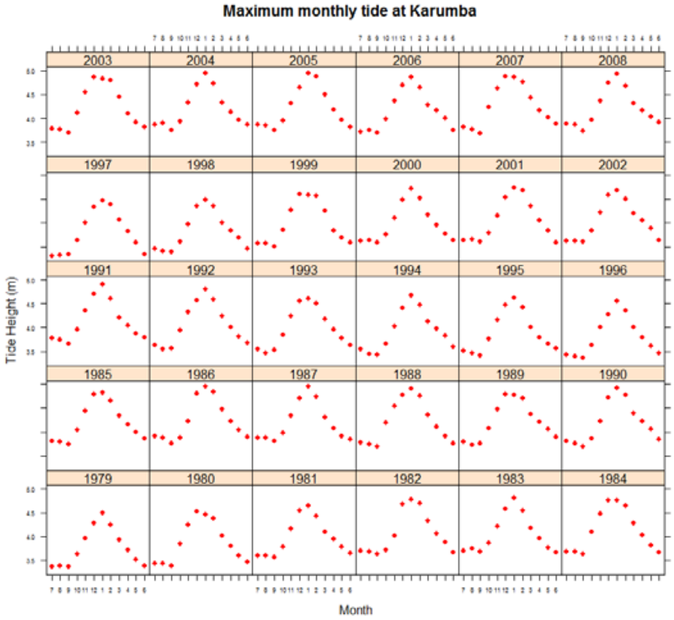
Annexe 5: Tidal patterns in the Gulf and western CYP

1. Long-term tide charts for Karumba and Weipa (the only long-term primary tide stations available for this section of the Gulf coast) show how the tidal component of flooding varies over long periods of time (Figure 25)[19].

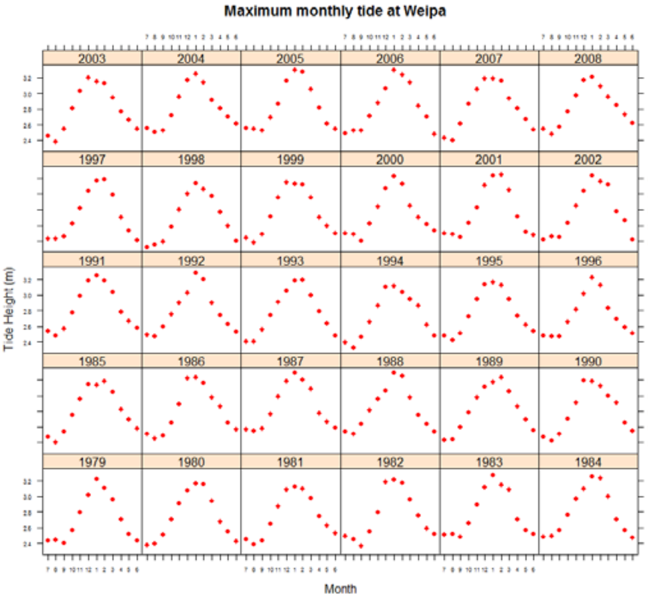
Figure 25. Maximum monthly (spring) tide height at (a) Karumba and (b) Weipa by year (1979-2008).

The x-axis is centred on December-January to show the consistent pattern of high tides in the early-mid part of the nesting season.

(a)



(b)



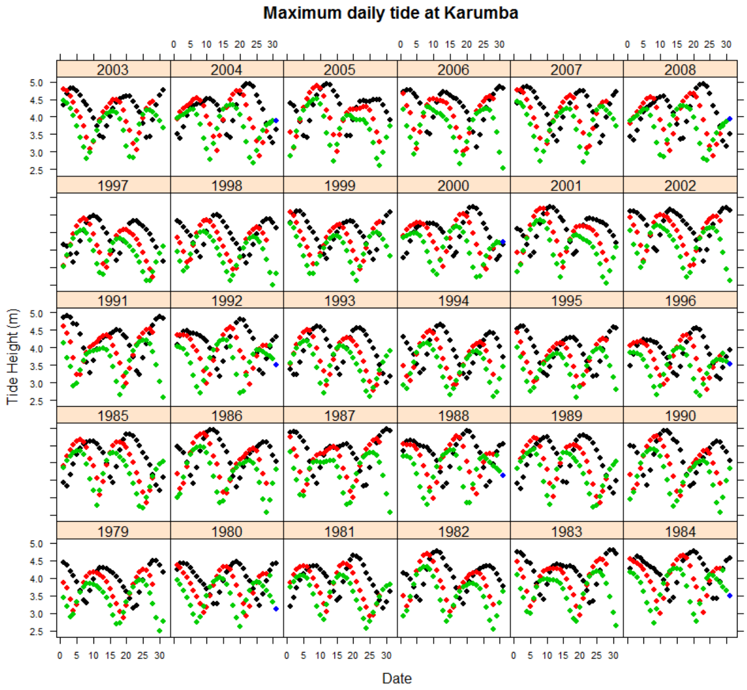
---

[19] Data for the minimum and maximum tide levels predicted for each month between 1979 and 2021 were provided to the author by the Australian Bureau of Meteorology (BOM) for use in reviewing tidal conditions during historical surveys and for planning future surveys.

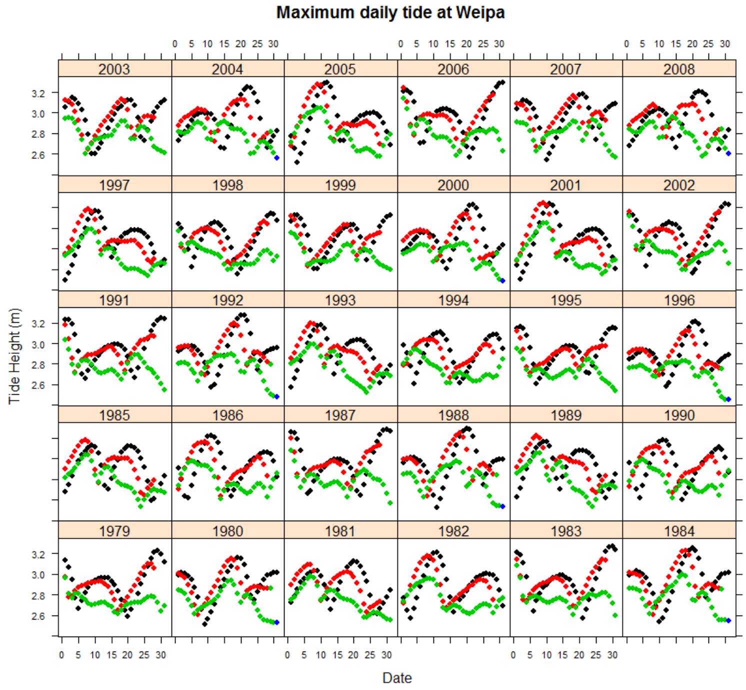
Figure 26. Thirty years of tidal data for (a) Karumba and (b) Weipa.

The plots show the pattern of tides for the months of January (black), February (red) and March (green). The absolute height of the tides varies over a multi-year cycle, but the pattern of spring tides across the three months is very consistent year-on-year – except for March tides at Weipa.

(a)



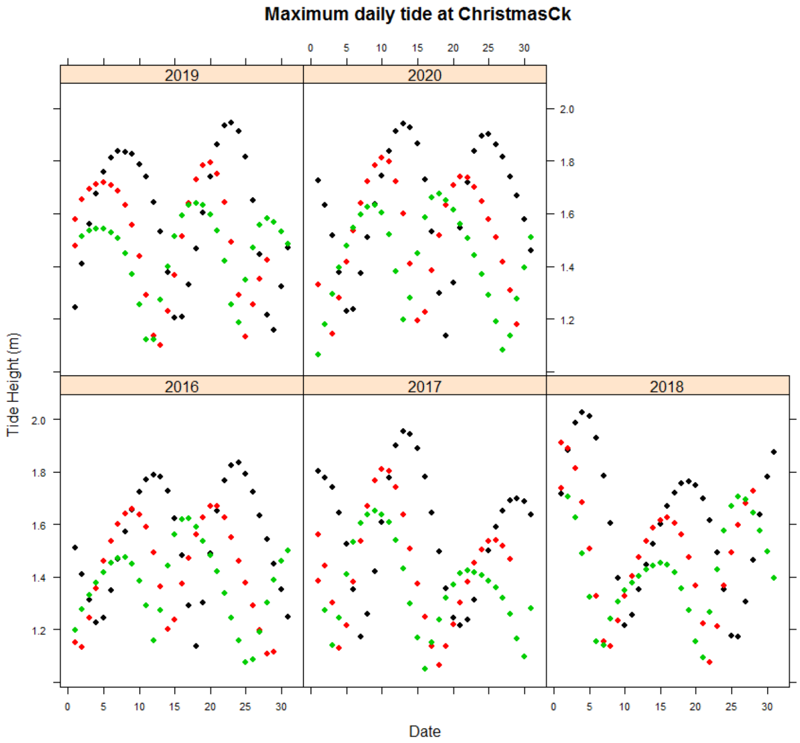
(b)



2. That the wet season tidal pattern in the DOGIT waterways mirrors the Karumba and Weipa patterns is shown by a much more recent set of predictions provided by BOM (Figure 27). The

predictions for 2016-2020 are based on only a short data series, but the same pattern occurs of recurrent high tides, at their highest in January and falling off over February and March.

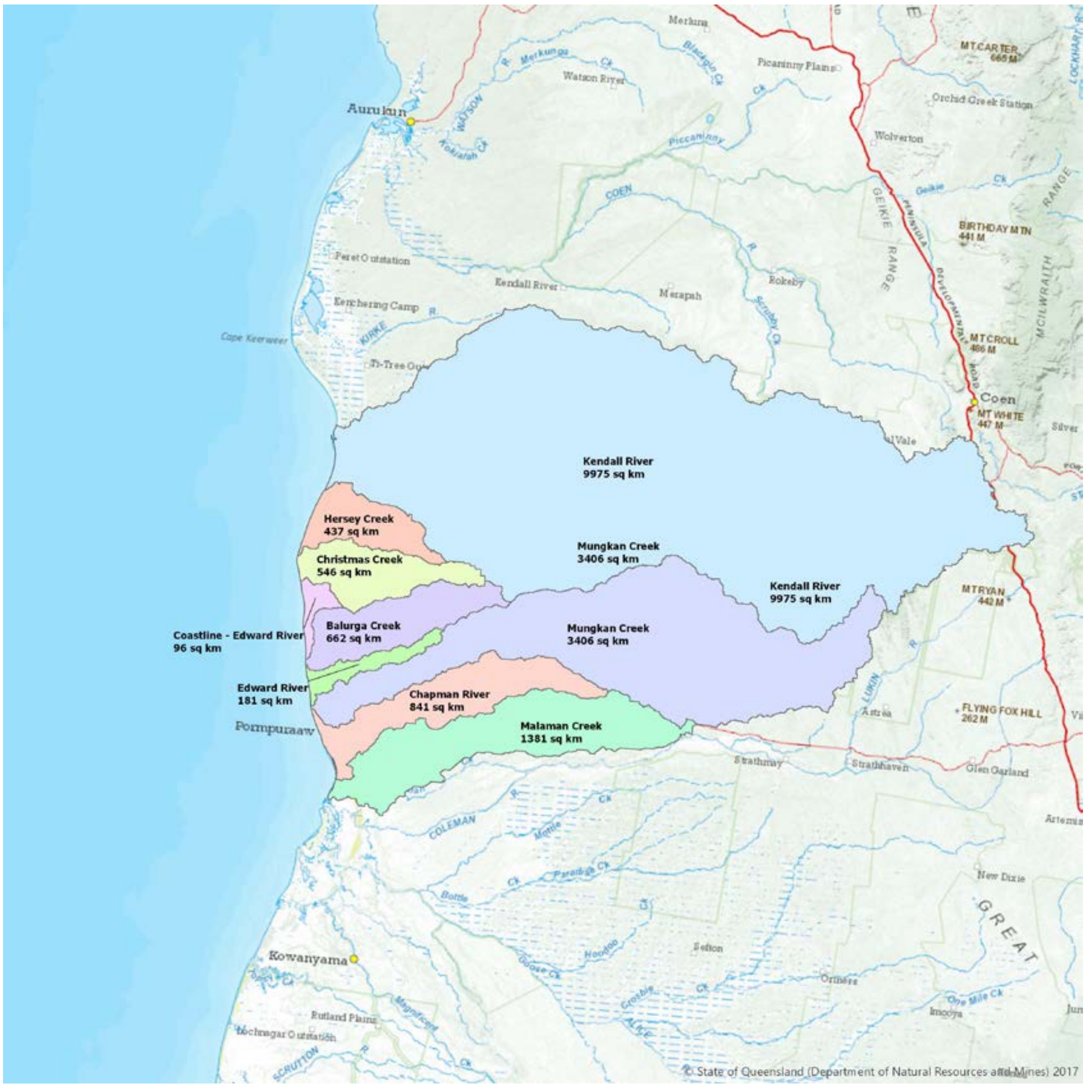
Figure 27. Daily tidal maxima at Christmas Creek in the Pormpuraaw DOGIT lands.



Annexe 6: Total rainfall in the DOGIT catchments

1. To estimate total catchment rainfall, raster data[20] covering the several catchments of interest was summed for each raster pixel on each day of the November-April periods of 2012-13, 2013-14, 2014-15, and 2015-16. These pixel data were then summed across each catchment to estimate the total daily rainfall across the whole of each of the DOGIT catchments.
2. The DOGIT area is dominated by the Kendall/Holroyd River and Mungkan Creek catchments. Catchment areas vary greatly - from 181 sq km for Edward River to nearly 10,000 sq km for the Kendall/Holroyd catchment (Figure 28).

Figure 28. Catchment areas in the Pormpuraaw DOGIT lands relevant to the egg harvest proposal.



3. Given the rainfall estimates for these catchments derive from complex smoothing of available rainfall data and there are few stations in and around the DOGIT catchments, it is unsurprising that no latitudinal trend shows up in mean rainfall (Figure 29). So the total rainfall estimate for each

---

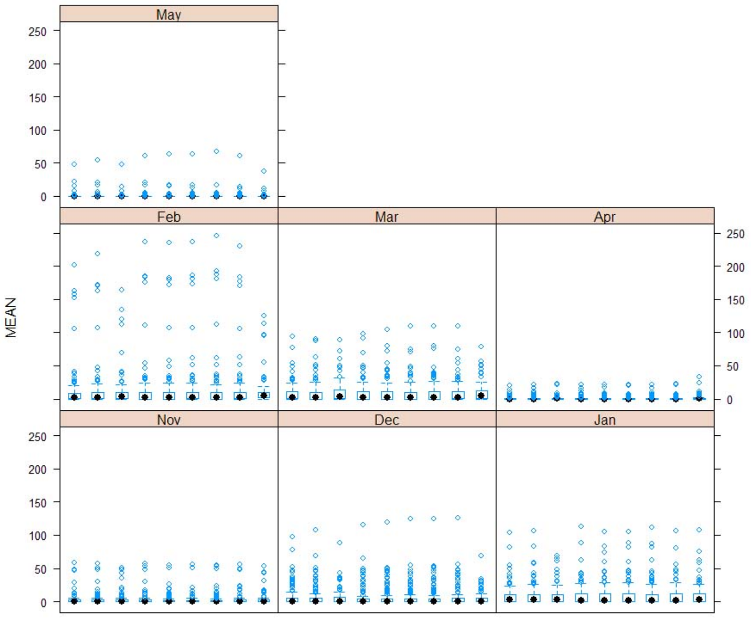
[20] Recalibrated data was used for this examination, consisting of daily data corrected at the end of each month to ensure the daily rainfall data sum to the corresponding monthly data (http://www.bom.gov.au/climate/austmaps/about-rain-maps.shtml). No recalibrated data is available on the BOM website for periods before Dec 2012, so the 2012-13 nesting season omits Nov 2012.

catchment is largely determined by mean rainfall across the DOGIT area as a whole and the catchment's area.

3.1. In steeper terrain, the extent of flooding could be expected to be quite catchment-specific and greatly influenced by catchment size. Here, however, the very flat coastal terrain makes for extensive areas of braided streams and largely undifferentiated floodplains that can overflow easily from one catchment to another.

Figure 29. Box and whisker plot of mean monthly rainfall in DOGIT sub-catchments, ordered by latitude (S -> N) and averaged across years from 1996-2017.

No latitudinal gradient is evident, as we might expect from the paucity of weather stations in and around the region. The horizontal axis of the graph shows (left to right) the catchments from south to north (Malaman Ck, Chapman R, Mungkan Ck, Edward R, Balurga Ck, Coastline, Christmas Ck, Hersey Ck & Kendall R).



4. It is sensible therefore to pool the estimates of rainfall across all the DOGIT catchments and examine whether it is likely that nest losses to floods across will be very frequent and, hence, whether harvesting early nests while leaving post-February nests to develop naturally, as proposed by Britton (2017), is reasonable in light of the data.
5. For this purpose, daily recalibrated rainfall data is available from BOM for only four nesting seasons – only two of which fall in the study period. This data is plotted for each season and month in Figure 9 in the main body of this report.

Annexe 7: Search effort in relation to total nesting habitat and the number of nests

1. The PLSR databases contain little or no data for the nesting seasons of 2009-10 and 2010-11, because the data recording system was still under development. Renewed survey activity commenced in 2011-12 (Britton, 2017), but PLSR have been unable to provide any records of activity in that year.
2. PLSR did advise that records of boat-based and quad bike-based nest surveys and post-discovery visits are quite comprehensive for subsequent years, but their records of helicopter transects are incomplete (Table 13). Some boat surveys were conducted at lower frequency in 2015-16 and 2016-17 seasons to monitor what was happening after the BG study ended, but only the presence of nests was recorded (PLSR, pers comm).

Table 13. Numbers of distinct transect records of nests surveys and visits included in PLSR databases by nesting season.

	Nesting Season							
Search Method	**09-10**	**10-11**	**11-12**	**12-13**	**13-14**	**14-15**	**15-16**	**16-17**
Helicopter				4	1	3		
Boat	2	1		22	25	15	12	10
Quad Bike/Foot				3	2	1		

3. Analysis of the most useful information from 2012-13 to 2014-15 shows that survey effort was confined to a very small part of the DOGIT lands and catchments and that boat coverage of Edward River and Balurga Creek in 2014-15 was more limited than in earlier years (refer Figure 14 in main text).
4. The absence of boat-based searches in Balurga Creek during 2014-15 appears to have arisen from helicopter surveys on 29 January and 29 March 2015, which covered this system but located no nests. The making of boat searches conditional on results of helicopter survey does not appear to have been the norm, however. In 2012-13, 11 of 23 nests (48%) are recorded in the data as having been first visited by helicopter and 52% by boat. In 2013-14, 17 of 20 (85%) were first recorded during boat transects, only 1 by helicopter, and another 2 during quad-bike/walking excursions. And in 2014-15, 4 of 11 nests (36%) were recorded first by helicopter, 6 by boat (55%), and 1 by quad-bike/walking survey.
5. It appears that, depending on circumstances in a particular nesting season, it is possible to identify the majority of nests in the regularly surveyed parts of these waterways by boat alone, as occurred in 2013-14.

Annexe 8: Tidal conditions for population counts in the DOGIT catchments

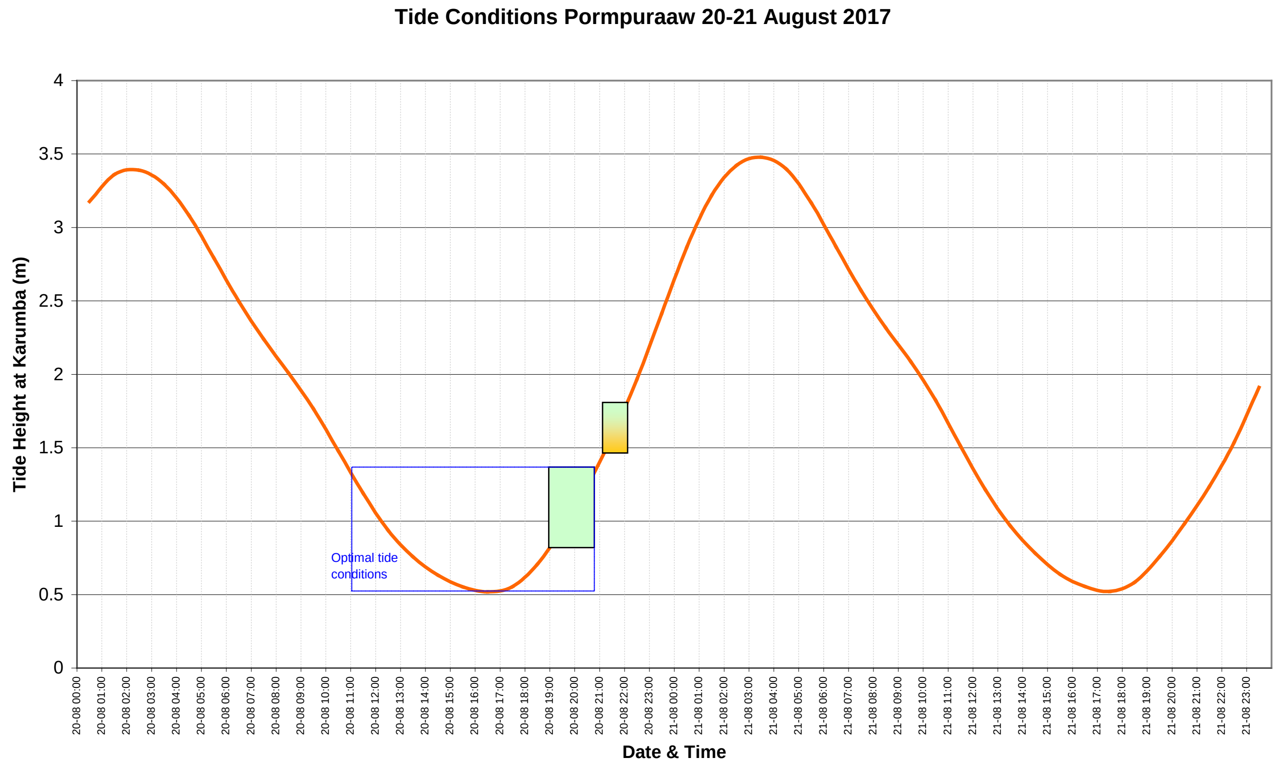
1. Many Queensland rivers have low tidal range relative to NT rivers (DEHP, 2017; pers obs), but the Gulf rivers generally, which I surveyed extensively in the 1980s, have adequate tidal range for a few months in the dry season to allow surveys conforming to DES standards.
2. A DES survey on 20 August 2017 of the Chapman River is useful to examine. There has been no tide station closer than Karumba or Weipa (with Aurukun as a secondary station) until Christmas Creek was added to the BOM predictive network circa 2016. Previous crocodile surveys have relied on predictions for Karumba adjusted for tidal lag. Tidal range at Karumba is greater than at Pormpuraaw, but the temporal predictions can be relied on (refer Annexe 5).
3. The Karumba tidal pattern during the survey is shown in Figure 30 (adjusted for the tidal lag of several hours experienced at Pormpuraaw. The tides were selected so as to have a low tide (at Karumba) of less than 0.7m during hours of darkness. This 'rule-of-thumb' was developed during extensive experience across Queensland in the 1980s and has been found to be a good predictor of optimal tides, giving sufficient exposed bank for sightability to plateau at a high level and sufficient low-tide time to cover long transects.
   - 3.1. Two surveys were conducted 'back-to-back', each starting at the mouth. The first commenced at 1900h and ceased at 2047h (the green box in Figure 30). Exposed bank (as defined by Messel et al., 1981a) was 100cm or more throughout.
   - 3.2. The second survey duplicated the first, commencing at 2105h and ending at 2208h (the green/yellow box in Figure 30). By then, sighting conditions at the mouth were marginal (~40cm exposed bank) but improved to 80cm upstream – largely as a consequence of tidal lag. The time available for survey under suitable conditions diminished considerably in the second survey (shown by the width of the box in Figure 30). After 2200h, the rising tide rapidly covered the exposed bank and conditions were unsuitable for survey.
   - 3.3. This survey showed that a predicted tide height of ca 1.8m at Karumba marks the approximate limits of suitable survey at Pormpuraaw, applying DES survey standards.[21]

---

[21] In all of these Gulf rivers, tide heights can vary from expectation depending on prevailing winds. However, tide charts are the only useful tool for systematic planning of population survey windows and, if metadata on exposed bank conditions are not recorded during surveys, historical tidal data are the only means of determining whether counts from different surveys can reasonably be compared.

Figure 30. Comparison of Karumba tide height data (red line) with exposed bank conditions on the Chapman River at Pormpuraaw during DES survey on the night of 20 August 2017.

Tide times have been corrected for the lag expected at Pormpuraaw. The lower green box shows the part of the tidal cycle exploited during the first survey, when exposed bank was over 100cm throughout. The upper yellow/green box shows the second survey timing, when exposed bank conditions were marginal at the mouth. The height datum of 1.8m at Karumba is taken as the limit of suitable survey tides on the Chapman River. The blue dotted line/box shows that up to10h of suitable tides can be exploitable, depending on the timing of the low relative to nightfall.



Annexe 9: Standardised survey transect distances, transect counts and comparisons

Standardised river maps and mid-stream distances

1. Transect distances used for this review differ slightly from those measured by Britton (2009, 2009, 2017) for two principal reasons.
   1.1. Firstly, transect km used for this review are based on 'standardised' river maps created by the author since 2010 for the purpose of geocoding and digitising historical and current Queensland survey data from 1979 to 2017.
      1.1.1. The original paper maps used by Messel for his 1979 surveys and the author for his 1980s surveys had river km measured 'mid-stream' using map measuring rollers on 1:100,000 topographic maps.
      1.1.2. To maintain consistency with the geospatial system now in use, these river maps were reproduced by manually re-digitising river lines from digital versions of the 1:100,000 map sheets and creating river distance markers at 1km intervals for large waterways and 0.5 – 0.1km intervals for small waterways.
   1.2. Secondly, there have been inevitable changes in some waterways since 1979, most particularly in the flat-lying Gulf Plains, including the DOGIT catchments, as tributaries and meander loops have been cut off and new channels created.
      1.2.1. Those changes are not reflected in the current set of river line maps so, for this review, distances along remodelled parts of systems were measured afresh in the GIS and used to calculate final transect distances (refer Table 7 in main text).

Year-on-year comparisons using unmatched transects

2. Extensive review of surveys in Queensland river systems from 1979 to the present by the author has identified instances where relative densities of crocodiles have been compared year-on-year across transects that differ in length and/or location. This is problematical because crocodile densities and size distributions are not homogeneous within systems.
3. Options to deal with this include:
   3.1. Discard all data collected from areas outside the common/shared transects. This has the disadvantage of excluding data collected at considerable time and expense.
   3.2. Compare only the longer common transects, where minor year-on-year variation is present but of less concern).
   3.3. Segregate the data using the shortest common transect to compare across all years and any (shorter) common transects to compare subsets of years – this maximises use of the data but complicates interpretation.
4. DES' current practice for historical data is to use Option 3.1 wherever possible, and Options 3.2 or 3.3 where the alternatives reduce the usable data excessively. This practice has been followed here – though in most instances the transects are quite closely matched in location and length and counts are easily adjusted.

Exclusion of return-trip sightings and tally discrepancies

5. For this review of comparative counts across systems, the DOGIT waterway counts have been corrected using the same guidelines applied to all other DES data for Queensland.
   5.1. A transect was taken to be the first spotlighting pass along a defined segment of waterway. The start and end points of transect segments were defined by either obvious markers (river mouth, farthest distance travelled upstream along a mainstream or tributary) or a junction with a tributary stream.

    5.2. Only crocodiles counted during a single transit of each transect were included in formal counts. Where the GPS records indicated crocodiles were counted during return trips along the same transect, the data were set aside as 'incidental' counts.

    5.3. Where there was more than one set of electronic records for the same survey, the two sets were compared and one selected as the primary record. The differences between the duplicate records were very small in terms of numbers and size classes recorded and not material to the conclusions.

    5.4. Size class data were taken from the primary record and the 'first-pass' data only.

6. The practice of recording animals during 'first-pass' and return trip sightings can be problematical. It is common during surveys, particularly when quickly retracing steps to catch the tide on another survey segment, to sight both animals previously counted and animals that were definitely missed on the first pass. These are sometimes distinctive and evidently 'new' animals – e.g. very large, wary animals that might be seen on a rapid transit but missed during the slower systematic survey pass.

    6.1. It is tempting to include these in the count, as some are clearly 'additional' animals. But to do so compromises the integrity of the count data. And to include other less distinctive animals, perhaps on the basis of their location, and presume them new rather than repeated sightings of a single animal runs the same risk.

    6.2. The problem is compounded because not all transects are subjected to 'first-pass' and return trip counts. Some segments are loops and only traversed one way. And some transects might be traversed twice in a short period under similar tidal circumstances while others might be traversed at the start of a survey and then at the end of the same survey, at quite different states of the tide.

7. Our practice in Queensland surveys is to note possible 'additional' animals during return trips but to exclude them from formal counts and comparisons. They can, of course, be valuable as incidental observations.

<u>Adjusting counts for minor year-on-year changes in transect length</u>

8. It is current practice in DES survey comparisons to deal with counts of crocodiles rather than relative densities (number per km of waterway) as it is easier to estimate counting errors and test the likelihood that observed changes are real. That practice has been adopted here.

9. Given the small sizes of the systems and their interlinked waterways, counts were combined for the Kendall and Holroyd Rivers, which constitute a single river with one entrance to the sea, and for Edward River and Balurga Creek, which form parts of a single interconnected river system, albeit with two entrances to the sea.

10. Tidal conditions result in small differences in transect length between years and counts have to be adjusted accordingly. Counts were adjusted to a standard transect distance for each system, in most instances by simple proportioning of counts because differences between transects were modest (see Table 8 in the main text).

11. A different approach was used to adjust for the short transect distance on Mungkan Creek in 2010 (20km against 32 - 37km in other years). The number of animals in the non-surveyed parts of this waterway was estimated from the average proportion of animals found in the corresponding part of the system in 2011, 2013 and 2014 (17%, 26% and 19% respectively). This follows the approach used by Fukuda et al (2013) for some NT surveys.

Annexe 10: Are the DOGIT catchments approaching carrying capacity?

1. Bob Plant, a former shooter who worked Queensland river systems, has given an account of a trip to the Kendall River in about 1952, when he and Bill Weare encountered a greater concentration of large crocodiles than any they had seen anywhere else in Queensland (Peach, 2000). Plant, who had wide experience in Cape York, described it as their best night's hunting ever. His description hints that this might have been the first time this very inaccessible system was harvested. In which case, it may give us a rare insight into what an undisturbed crocodile population in this region could look like.

2. In one night Plant and Weare shot 23 animals – a take that was sufficiently memorable to be worth a photo (Figure 31). From the description of the size distribution of crocodiles shot (all photographed apart from two 14-15 ft animals too large to haul out), and from some 'eyeball' estimation of size classes from the photograph, we can approximate the size distribution they encountered on that first night and compare it with the BG counts (Table 17).

Figure 31: Crocodiles shot in one night on the Kendall River ca 1951-52 by Bob Plant and his team.

Reproduced with permission from Peach (2000).

Bill Weare with 21of the 23 large crocodiles shot in one night in the Kendall River. *Photo: Bob Plant*

3. While we have only this one snapshot, several points are notable:
    3.1. Plant was very clear that they encountered no hatchlings and very few small crocodiles in the system – just one 4ft animal on the first night (visible in the photo). They did encounter numbers of very large crocodiles. It is, of course, possible that they shot this river after a succession of poor nesting years, and the absence of hatchlings and yearlings was aberrant.

3.2. They took 60 crocodiles in total over several days (four days explicitly mentioned and ‘several more’). Given the small size of this river system and the good ‘take’, we might surmise they would have covered much of the readily navigable waters. Plant himself said they worked the system well upstream until they ran into too many obstacles (Bryan Peach, pers comm).

3.3. Based on the BG/PLSR surveys, it would be possible to repeat Plant’s experience today in relation to the numbers of crocodiles from 6-11ft and over 11ft in the system. In 2008, the team counted 6 animals 12-13ft in length and 3 animals of 13-14, 14-15 and 15-16ft (Britton, 2008).

Table 14. Size distribution of crocodiles shot by Bob Plant and Bill Weare on one night in the early 1950s on the Kendall River system, compared with the size distribution recorded during BG/PLSR surveys.

Year	**H**	**NH2to6**	**NH6to11**	**NHGT11**	**NHEO**	**NHTotal**	**Notes**
1951-52	0	1	15	7	?	23	Numbers from one night’s take near mouth. 60 animals taken from system.
2008	2	21	25	10	19	74	
2009	8	15	23	14	17	69	
2010	8	19	17	1	20	56	
2014	13	33	26	6	33	98	

4. The Kendall River system population is quite remarkable in a Queensland context – there is no comparable record of which I am aware of a system with such a high proportion of large animals. Nonetheless, the presence of numbers of hatchlings and yearlings in the BG/PLSR counts is notable and suggests the population may still be ‘maturing’.