FLATBACK TURTLE, *Natator depressus*, 2017-2018 BREEDING SEASON, AT CURTIS, PEAK AND AVOID ISLANDS




Colin J. Limpus, Nancy N. FitzSimmons, Fiona Hoffmann, Erwin Hoffmann, Jaz Laws, Duncan J. Limpus, Maree McLaren, John M. Sergeev, Felicity Shapland and Trevor Turner.

DEPARTMENT OF ENVIRONMENT AND SCIENCE

Cover photographs:
Scenes from the census of nesting flatback turtles, *Natator depressus,* 2017 – 2018 at Curtis, Peak and Avoid Islands. Photographs taken by Nancy FitzSimmons, John Sergeev and Erwin Hoffmann.

This report should be cited as:

Colin J. LIMPUS, Nancy N. FITZSIMMONS, Fiona HOFFMANN, Erwin HOFFMANN, Jaz Laws, Duncan J. LIMPUS, Maree McLAREN, John M. SERGEEV, Felicity SHAPLAND and Trevor TURNER (2018). Flatback Turtle, *Natator depressus*, 2017-2018 Breeding Season, at Curtis, Peak and Avoid Islands. Brisbane: Department of Environment and Science, Queensland Government. Report produced for the Ecosystem Research and Monitoring Program Advisory Panel as part of Gladstone Ports Corporation's Ecosystem Research and Monitoring Program. 67 pp.

This report has been produced for the Ecosystem Research and Monitoring Program Advisory Panel as part of Gladstone Ports Corporation's Ecosystem Research and Monitoring Program. The study was undertaken under a Consultancy Agreement (CA12000291 [130032]) between Gladstone Ports Corporation and the Queensland Department of Environment and Science (formally Department of Environment and Heritage Protection) to monitor marine turtle nesting at Peak, Avoid and Curtis Islands.

This publication has been compiled by the Queensland Department of Environment and Science (DES).

FLATBACK TURTLE, *Natator depressus*, 2017-2018 BREEDING SEASON, AT CURTIS, PEAK AND AVOID ISLANDS.

Colin J. Limpus, Nancy N. FitzSimmons, Fiona Hoffmann, Erwin Hoffmann, Jaz Laws, Duncan J. Limpus, Maree McLaren, John M. Sergeev, Felicity Shapland and Trevor Turner

Contents

EXECUTIVE SUMMARY

This report summarises the results of monitoring the eastern Australian flatback turtle nesting population at Curtis, Peak and Avoid Islands during the 2017-2018 breeding season. A two-week mid-season census was conducted at all three islands and full season monitoring was done at Curtis Island. This is the second time that full season of data has been collected at Curtis Island. Table 1 provides a comparison of reproductive parameters recorded at these three central Queensland flatback turtle index beaches with high-lighting of those parameters that are considered to be indicators of poor population performance.

Number of nesting females and nests

- A total of 28 individual nesting flatback turtles and 35 clutches of eggs were recorded at Curtis Island during the two-week census period (24 November –7 December 2017). Over the entire breeding season 43 individual flatback turtles, 168 nesting crawls and 138 clutches were recorded.

- A total of 232 nesting crawls from 158 individual nesting flatback turtles and 157 clutches of eggs laid were recorded at Peak Island during the two-week census period (24 November –7 December 2017).

- At Avoid Island during the mid-season census period, 88 nesting crawls and 62 clutches were recorded. There was an incomplete census of nesting females during the mid-season census period with only 46 individual flatback turtles recorded. With intermittent monitoring throughout the entire breeding season, 69 individual flatback turtles were recorded.

Recruitment

- Recruitment of new nesting females into the breeding population during the mid-season census period has been declining at Peak Island and the value of 10.8% of the recorded turtles is regarded as low for flatback turtles.
- Curtis Island had a moderate level of recruitment, at 21.4%, during the census, and new recruits constituted 20.9% of turtles for the entire season.
- During the mid-season census at Avoid Island 23.9% of nesting turtles were new recruits, and this value reduced to 18.8% for the entire season.

Remigration intervals and rookery fidelity

- The most common remigration interval for nesting females at Curtis Island was two years, followed by three or four years. At Peak Island most turtles re-migrated after two years, with several females also returning on three-year intervals. Some turtles that were observed returning after three years (up to 8 years) may have nested elsewhere during the intervening years. At Avoid Island, most turtle re-migrated after two years.
- Nesting females continue to display high fidelity to each island. Only two nesting females were originally tagged while nesting at a different rookery. One female was tagged at Mon Repos in 2014 and nested at Curtis Island this season – a 166 km shift in nesting location. This is the largest recorded shift in nesting beach

for a Flatback turtle. The other female shifted 67 km from nesting at Facing Island in 2014 to nesting at Peak Island in 2017.

Demographic parameters

- Nesting flatback turtles at all three islands show normal demographic features for the eastern Australian flatback turtle stock in terms of female size, clutch size and egg size.
- At Curtis, Peak and Avoid Islands new recruits to the nesting population were smaller than females with a past breeding history.
- The length of the nesting season was recorded at Curtis Island with nesting commencing on 8 October 2017 and the last nest laid on 13 January 2018.
- The first emergence of hatchlings occurred on 5 December on Curtis Island and on 6 December at Peak Island.
- The incubation period from laying to hatchling emergence to the beach surface was 47.5 days at Curtis Island, 47.8 days at Peak Island and 46.7 days at Avoid Island.

Population trends

- At Curtis Island the size of the nesting population during the two-week mid-season census period has approximately halved during the past decade, even though the recruitment of new adults into the nesting population has been increasing during the same period.
- At Peak Island the mid-season census counts of mean numbers of nesting crawls and the mean number of clutches laid suggest that the nesting population appears to be maintaining stability or declining at a very slow rate across the last ten breeding seasons.
- The census study at Avoid Island has not been in progress for sufficient time to reliably assess a nesting population trend at this island.

Hatchling production

- Curtis Island: Nesting success was at a level of 82.1%. Hatching success of eggs in undisturbed nests was 74.7% from mid-season clutches laid and 77.1% across all nests throughout the season. Emergence success from undisturbed clutches was 64.2% from mid-season clutches and 71.3% across the entire nesting season.
- Peak Island: Nesting success was 67.7%, which has increased from past years. Data were obtained from 61 marked mid-season nests that had a low average hatching success of 55.9% and hatchling emergence success of 39.1%. Very low hatching success of eggs (60.5%) and hatchling emergence success (46.9%) was recorded from the 134 nests excavated from across approximately the first half of the nesting season. These poor incubation results from natural nests tentatively are attributed to elevated temperatures at the island and root invasion of the nests.
- Avoid Island: Data were obtained for 49 marked mid-season nests that had a low average hatching success of 62.0% and hatchling emergence success of 56.9%. Across the entire season these values were slightly higher: hatching success = 69.2%; hatchling emergence success = 64.7%.

Temperature profiles and weather events

- While the breeding season commenced with low sand temperatures as a result of heavy rainfall, measured sand temperatures at nest depth remained above the pivotal temperature, the theoretical temperature for a 50:50 hatchling sex ratio, for flatback turtles for the majority of the season.
- Based on sand temperature measurements and incubation period to hatchling emergence values, it is predicted that strongly female biased hatchling sex ratios will have been produced at all three census islands.
- Beach erosion from Tropical Cyclones *Dylan* in 2014 and *Marcia* in 2015 at Avoid Island continues to limit access by turtles to the dunes along sections of South Beach and in loss of nesting habitat on the northern end of North Beach.
- Negative impacts on successful hatchling production at Avoid Island during the 2017-2018 season was limited to a small number of clutches flooded by high tides where they had not been relocated to safer nest habitat.

Management considerations

- Existing management by QPWS at Curtis Island is maintaining flatback turtle clutch loss to predators such as pigs, dogs and foxes at a low level.
- Management of invasive plants in the turtle nesting habitat at Peak Island would befit improved hatchling production.
- Existing management by Trust for Nature at Avoid Island is providing important protected habitat for the eastern Australian nesting population of flatback turtles in an area free of large terrestrial predators of their eggs and well removed from the impacts of urban and industrial development.

CHAPTER 1. INTRODUCTION

This study has been conducted under an agreement between the Gladstone Ports Corporation (GPC) and the Queensland Department of Environment and Science (DES) to continue monitoring of flatback turtle (*Natator depressus*) nesting and hatching at the South End Beach, Curtis Island, Peak Island and Avoid Island for the 2017/18 nesting season. This monitoring is supported by a Gladstone Ports Corporation (GPC) Ecosystem Research and Monitoring Program (ERMP). This is the fifth year of monitoring these rookeries under this program.

These three rookeries are part of the eastern Australian flatback turtle population, also referred to as the eAust flatback stock or management unit (FitzSimmons and Limpus, 2014). This population is distinct from all other flatback rookeries to the west of Torres Strait (Pittard 2010; FitzSimmons and Limpus, 2014).

Curtis Island is a moderately sized rookery that is located near substantial industrial development and potential light pollution. It is one of the index nesting areas that has been monitored annually across decades for this species. Peak Island supports the largest nesting aggregation for flatback turtles within the eAust stock and is an established index beach for long-term monitoring of flatback turtles within the eAust stock. Avoid Island is a moderately sized rookery located towards the northern extent of the population's nesting range (Limpus *et al*. 2002) in a remote area that is not influenced by industrial development or light pollution from the mainland.

The biology of the eAust flatback turtle population has been reviewed (Limpus, 2007; Limpus *et al*. 2013). Monitoring of the rookeries is conducted to determine the size of the nesting population and population trends over time, the proportion of newly recruiting females, the size of females, clutch size, egg size, incubation and emergence success, hatchling size and condition and variability in hatchling production in different areas of the beaches monitored. To assess the impacts of artificial light, data are collected on the orientation ability of females when they ascend the beach to lay eggs and descend afterwards, and of hatchlings as they travel to the water's edge. Additionally, data are collected on beach sand temperatures at nest depth to determine the likely sex of hatchlings.

CHAPTER 2. GENERAL METHODS

Standard Queensland Department of Environment and Science (DES) Aquatic Species Program Turtle Conservation Project methodologies (Limpus *et al*. 1983; Limpus, 1985) were followed for the project to monitor nesting females and their clutches. Statistical procedures follow Zar (1984). Proportional data were presented as the value ± 95% confidence interval.

Monitoring teams included DES staff and Queensland Turtle Conservation (QTC) Volunteers with prior training in the methodologies being implemented.

Nesting activity

Data on nesting activity were recorded at all three rookeries during a minimum of the two-week, mid-season census period:

- At Peak Island from 24 November to 07 December 2017.
- At Curtis Island, daily monitoring began on 24 November until 14 December 2017 and included the standard mid-season census period (see Chapter 3 methods). Intermittent monitoring of the turtle nesting by local volunteer members of the study team occurred throughout the entire nesting season.
- Monitoring at Avoid Island included the standard 14-day census period from 26 November to 9 December 2017. Additional nightly monitoring occurred during the census on all eastern beaches, referred to as South Beach, Middle Beach and North Beach: full monitoring on South Beach was conducted on 20 October, 31 October to 4 November, and 10 to 12 December; only tracks were counted during this time on Middle and North Beach.
- Data from the two week mid-season census are referred to as the ‘census data’.

Nightly monitoring began at least two hours before high tide and continued for at least two hours after low tide, or longer if turtles were still active on the beach. Procedures included:

- Encountered turtles left the beach with a minimum of two titanium tags (manufactured by Stockbrands Australia) in the front left and right flippers at a designated tagging position (Limpus, 1992), generally proximal to the flipper scute closest to the body. If scar tissue from previous tagging made this position unsuitable for tagging, tags were applied distally to this scute.
- Passive Integrated Transponder (PIT) tags were injected into the upper left (or occasionally right) shoulder (just below the carapace) of nesting females. PIT tags were manufactured by Animal Electronic I.D. Systems.
- Curved carapace length (CCL ± 0.1 cm) was measured from the skin/carapace junction at the anterior edge of the nuchal scale, along the midline, to the posterior junction of the two post-vertebral scutes at the rear of the carapace using a flexible fibreglass tape measure. Any barnacles living along the midline of the carapace were removed prior to measuring.
- Any damage to the turtle or unusual features were recorded and photographed if possible.
- A nest tag (flagging tape ~20 cm long) with the date of laying and a tag number of the turtle (Limpus, 1985) was placed in the nest during oviposition for most

clutches. The nest tag enabled identification of individual clutches of eggs when excavated following hatchling emergence some two months later.

- A subset of clutches of eggs were counted and ten eggs were selected to represent a cross-section of eggs from top to bottom of the nest. Each selected egg was weighed (± 0.1 g) on a digital balance and measured for maximum and minimum diameter (± 0.1 mm) with vernier callipers. To minimise movement induced mortality of eggs all handled eggs were returned to their respective nests within two hours of being laid and with the minimum of rotation (Limpus *et al*. 1979).
- Nest locations were recorded using a hand held GPS (global positioning system) unit (± 4 m). Habitat type of the nest location was recorded including the beach profile location and vegetation type near the nest.
- To identify marked nests after hatchling emergence, somewhat different techniques were used at each rookery in addition to GPS locations:
    - At Curtis Island all clutches were marked with two timber marker pegs (25 mm x 25 mm x 400 mm) that were labelled with a unique nest number. One marker peg was placed two hand spans from the nest, and the second maker peg was placed one hand span from the first marker peg, in line with the nest.
    - At Peak Island nests were not mapped and data were collected only from emerged clutches.
    - At Avoid Island, new sector numbers were established on South Beach and North Beach to improve upon the makers put up in 2016. The new markers were aluminium squares with reflective strips and numbers or letters and were attached to trees or posts.

Incubation and emergence success

Nests were excavated after hatchlings had emerged for assessing incubation success and hatchling emergence success. Previously marked nests were located using GPS locations, and measurements from marker trees, posts or pegs and confirmed by the presence of nest tags. Nests were dug no sooner than 24 hours after hatchling emergence or 8 weeks if hatchlings had not emerged. Procedures included:

- If hatchling emergence was observed and when logistically feasible, a sample of 10 hatchlings (+ any live in nest) were weighed (± 0.1 g), measured (± 0.1 mm) with vernier callipers and the scale pattern counted.
- Observations of heat stress were noted that included:
    - dead hatchlings in the neck of the nest that were not otherwise trapped by roots from emerging,
    - dead hatchlings that had emerged but died in the vicinity of the nest, with no signs of predation.
- The number of hatched eggs was determined by counting the number of eggshell fragments that were larger than 50% of that expected from an entire egg.
- Clutches were assessed for any signs of predation by crabs or other animals and counts were made of any hatched live or dead hatchlings within the nest.
- Un-hatched eggs were opened to determine whether the embryo had developed to an observable stage or whether it appeared to be undeveloped.
- Hatching incubation success was calculated as: (hatched eggs/estimated clutch count) x 100%.

- Emergence success was calculated as: (hatched eggs – [live + dead hatchlings]/estimated clutch count) x 100%.
- Counting error, the accuracy of counting broken egg shells was calculated as: estimated clutch count following hatchling emergence minus clutch count made when the eggs were laid.
- The depth to the bottom of the egg chamber was measured (± 5 mm) and observations on the nest environment were made with respect to erosion and water inundation.

Environmental Monitoring

Vemco Minilog II temperature data loggers have been deployed for a number of years at turtle nesting beaches in Queensland to measure sand temperatures at 50 cm depth at 30 min intervals. These temperature recording instruments can record temperature continuously for up to 10 y. Temperature data loggers were deployed at various times and locations at the three rookeries to monitor long-term temperature data in the nesting habitats.

Daily rainfall and air temperature data at selected recording stations were obtained via the Australian Bureau of Meteorology (BOM) website.

Hatchling sex ratio theory

The sex of marine turtle hatchlings is determined by the temperature of the nest presumably during the middle third of incubation (Reed, 1980; Yntema and Mrovosky, 1982). The pivotal temperature, the theoretical temperature that will result in equal proportions of male and female hatchlings for the eAust flatback turtle population is 29.3ºC (Limpus, 2007), with higher temperatures producing females and lower temperatures producing males. If flatback eggs incubate at a constant temperature of 29.3ºC, hatchlings should emerge approximately 52 days after the eggs were laid (EHP unpublished data). Thus incubation duration can also be informative about the sex of hatchlings. Allowing for the time taken for hatchlings to dig to the surface from the hatched eggs, the pivotal period from laying to hatchling emergence to the beach surface should be approximately 54d. Rainfall will influence this as cool rain results in a decline in sand temperatures at nesting beaches. In contrast, sand temperatures increase in the short term in the absence of rain as a result of reduced evaporative cooling within the sand (Reed, 1980).

Turtle orientation

To assess whether the orientation of nesting females and hatchlings was influenced by artificial lights, orientation data were collected at all three rookeries.

- To measure orientation in nesting females, a line was measured 15 m out from the entry point and exit point of the body pit along the up track and return track. Bearings were sighted along these lines and compared to the bearing perpendicular to a bearing sighted along the recent high tide line, which represents the shortest route back to the water.
- The ocean-finding behaviour of hatchling turtles was assessed by measuring from the centre of the nest to 5.0 m along the left and right side of the hatchling track-fan and recording a compass bearing along each of these lines. The average bearing was then compared to the bearing perpendicular to a bearing

sighted along the recent high tide line, which represents the shortest possible route back to the water. This was only possible for nests that were observed with tracks from freshly emerged hatchlings.

These data will be analysed in a separate report (Limpus and Shimada, 2018).

CHAPTER 3. CURTIS ISLAND STUDY

METHODS

Study Area

South End Beach, Curtis Island (23º45'S, 151º18'E), supports a medium density nesting population of the flatback turtle (*Natator depressus*), a turtle found only in Australian continental shelf waters. This large sand island situated off the coast of Gladstone extends for ~100 km to the north. The small South End village lies on the south-eastern tip of the island (Figure 3.1). The majority of the turtle nesting for the island occurs on the adjacent South End Beach which is approximately 5 km in length. In some years, there is occasional nesting by green turtles (*Chelonia mydas*) and/or loggerhead turtles (*Caretta caretta*).

While the rookery has been monitored intermittently since 1969 (Limpus, 1971a), it has been monitored annually since 1994 with support from the Gladstone Ports Corporation (Limpus *et. al*. 2006, 2013, 2017). Curtis Island has one of the longest histories of monitoring of flatback turtle breeding in Australia and hence the world.

Methods specific to Curtis Island

South End Beach was monitored on a daily basis commencing 24 November 2017 until 14 December 2017 for nesting activity, including the two-week mid-season census period: 24 November to 7 December. Monitoring of incubation and emergence success occurred during 15 to 29 January 2018. Local QTC Volunteers provided intermittent monitoring of the beach during 08 October 2017 until 7 May 2018.

The beach was examined once or twice daily depending on tides to count nesting crawls, to locate hatchling emergence and identify daylight nesters. A Suzuki Grand Vitara and a John Deere Gator Side by Side Utility Vehicle were used to patrol the beach (Figure 3.2).

Two Vemco Minilog II temperature data loggers were deployed in open sunny areas within the nesting habitat at opposite ends of South End Beach, Curtis Island during the 2016-2017 breeding season in preparation for down loading of data during the 2017-2018 breeding season.

Rescuing doomed eggs
The Department of Environment and Science conducts an annual project on the Woongarra Coast to rescue doomed turtle eggs laid where they are considered to be at risk of flooding or erosion during incubation (Pfaller *et al.* 2008) or where coastal lighting is likely to disrupt hatchling ocean finding behaviour and cause hatchlings to move inland away from the sea. Doomed clutches of eggs were relocated to safer incubation sites either higher up the dunes or to an adjacent dark beach in response to the identified threats. Eggs are relocated to artificial nests that are 55-60 cm deep with a 50 cm radius "body pit" from which surface vegetation has been cleared within 2 hours of oviposition and with the minimum of rotation (Limpus *et al.* 1979). This

project to rescue doomed eggs on the Woongarra Coast is directed principally at rescuing eggs of the endangered loggerhead turtle.

At Curtis Island, clutches at risk from flooding were rescued by relocating them further up the dune and their eggs counted within two hours of being laid.

Predation monitoring
In contrast to previous years of study, no fox exclusion devices (FEDs) were deployed over clutches of eggs during the 2017-2018 turtle breeding season. During monitoring patrols, tracks or observations of wildlife that have the potential for negatively impacting successful turtle egg incubation were recorded, including cattle, horses, dogs and foxes.

RESULTS

Nesting activity, nesting success and recruitment

A total of 43 flatback turtles were encountered during the entire 2017-2018 breeding season at Curtis Island. Of these, 28 were recorded during the two-week census period. One loggerhead turtle and four green turtles also were recorded nesting during the 2017-2018 breeding season at South End Beach, Curtis Island. Table 3.1 summarises the breeding history of these turtles.

The first flatback nesting crawl occurred on 08 October 2017 and the last nesting crawl and clutch laid on 13 January 2018. The first flatback clutch to emerge for the season was seen on 5 December 2017 (58 d period to emergence) but the date of emergence of hatchlings from the last clutch was not recorded.

The mean nightly numbers of flatback turtle activity during the mid-season census period on South End Beach were 3.4 tracks (SD = 2.209, range = 0-7), 28 different turtles and 35 clutches laid (Figure 3.4A). The mid-season census period encountered 65 ± 14% of the flatback nesting population for the entire season. The mid-season clutch census accounted for 25.2 ± 7.2% of clutches laid for the entire season.

A total of 168 nesting crawls by flatback turtles were recorded on South End Beach from the 08 October 2017 – 28 January 2018 (Figure 3.3). Of these, there were 138 successful beachings that resulted in eggs being laid. This equates to a nesting success of 82.1 ± 5.8% during the entire season. This value was much higher than the nesting success of 72.9 ± 12.6% recorded during the two-week mid-season census.

The proportion of new recruits to the nesting population (first time tagged turtles) was 21 ± 12% of all turtles tagged during the season and 27 ± 16% during the standard mid-season census period (Figure 3.4B).

Turtles coming ashore to attempt nesting during daylight hours occurred infrequently with 5.0% of beachings occurring in daylight hours during the mid-season census period.

Nesting females: size, fecundity

The CCL (cm) of nesting female flatback turtles ranged 85.6 - 97.5 cm at Curtis Island (Table 3.2 and Figure 3.5). As in previous seasons, turtles with a past breeding history (remigrants) had a greater mean CCL (94.7 cm) than new recruit females that were tagged for the first time (91.0 cm).

A total of 33 flatback turtles carrying tags applied in previous breeding seasons were recorded at Curtis Island during the entire breeding season (Table 3.1). All but one of these remigrant turtles had been tagged previously at Curtis Island. The remaining remigrant turtle had nested previously on the Woongarra Coast at Mon Repos for two breeding seasons. The majority of remigrant turtles returned after a two-year remigration interval (mean = 3.42, SD=2.25, range = 1-10, n = 33) (Figure 3.6).

There was an average of 51.6 eggs per clutch for the 31 clutches counted. The number of eggs per clutch is summarised in Table 3.3 and Figure 3.7.

The mean renesting interval between a successful nesting and the subsequent return to lay another clutch was15.5 d (Table 3.3, Figure 3.8). A turtle that did not lay during a nesting crawl usually returned to attempt another nesting on the same night or on the following night (Table 3.3, Figure 3.8).

Health and injuries

In contrast to some years, no nesting flatback turtles died at South End Beach during the 2017 -2018 season. None of the nesting flatback turtles were recorded with fibropapilloma tumours. None were recorded entangled in fishing line or rope. No nesting female turtle was recorded with fresh or recent fractures resulting of injuries since the turtles had been previously recorded nesting at Curtis Island.

Sand temperature monitoring

The temperature data logger located at the southern end of South End Beach in full sun recorded sand temperatures from 2 November 2016 to 11 December 2017. This data logger was redeployed to continue sand temperature monitoring. The second temperature data logger located at the northern end of South End Beach failed to download on 11 December 2017. This faulty data logger was removed and replaced. These data loggers subsequently were not downloaded at the completion of the incubation season and will be retrieved during the 2018-2019 breeding season.

The sand temperature profile from the standard monitoring site on the southern end of South End Beach during the first two months of the 2017-2018 breeding season is summarised in Figure 3.9A.

Sand temperature at 50 cm depth had increased above the minimum temperature for successful incubation (25^{o}C) by the time that the first clutch for the season was laid on 8 October 2017. The high rainfall events of October and early November (Figure 3.9B) will have contributed to the cooling of beach sand at nest depth on South End

Beach, Curtis Island during the first few weeks of the nesting season. Given that the sex of the hatchling is determined during mid incubation and given that the sand temperatures were continuously below the pivotal temperature for the flatback turtle during these first 2 months of the nesting season, it is presumed that the first 27 clutches that were laid by the 11 November 2017 would have produced hatchlings with a strong male bias. These would have been equivalent to at least 20% of the season's egg production resulting in a strongly male biased hatchling sex ratio.

The isolated heavy rainfall events during December-March would have caused brief duration cooling spikes in sand temperature and clutches in mid incubation at these times can be expected to have increased male hatchling production without a significant change in the incubation period to hatchling emergence.

In contrast, the temperatures at nest depth recorded on South End Beach, Curtis Island during the 2016-2017 breeding season were considerably higher than the flatback turtle pivotal temperature for most of the breeding season from approximately the first week of December until the last hatchling emerged. As a result, the 2016-2017 breeding season is expected to have produced a strongly female biased hatchling cohort from Curtis Island (Limpus *et al*. 2017).

Nest and hatchling disturbance and depredation and island fauna

No incubating clutches of turtle eggs were disturbed by the nesting turtles on South End Beach during the 2017-2018 breeding season.

Because no fox tracks were sighted at the start of the nesting season, no fox exclusion devices (FEDs) were placed over clutches this season.

Between 4–12 January 2018, three clutches were predated by an unidentified canid after hatchling emergence and prior to the nests being excavated to determine incubation and emergence success.

No tracks from pigs were observed on South End Beach during breeding season.

No cattle were observed on the beach throughout the 2017-2018 breeding season.

Horses were observed on the beach on thirteen occasions throughout the 2017-2018 breeding season. The majority of horse sightings were on the southern half of South End Beach. Horses foraged on the fore dune and roamed the beach below the high-water mark, usually travelling several hundred metres along the beach before departing over the dune.

No incubating eggs, hatchlings or adult turtles were recorded being impacted by horses or cattle during the 2017-2018 breeding season. However, their presence has the potential for killing eggs and reducing hatchling production via trampling of nests. QPWS is assessing the management of cattle and horses within the Environmental Management Precinct (EMP) and in the South End Conservation Park on Curtis Island.

Estimation of hatchling sex ratio from hatchling emergence data

The mean incubation period to hatchling emergence was 47.5 days (Table 3.4). The changing period to emergence through the breeding season is summarised in Figure 3.10.

The only clutches with a period to emergence longer than 54 days had been laid before mid November.Therefore male hatchlings are expected to have been produced only from among these early season clutches, accounting for less than one third of the season's clutches. In contrast predominantly female hatchlings will have been produced from more than two thirds of the clutches laid during the remainder of the nesting season. A strongly female biased hatchling sex ratio is expected to have been produced from the 2017-2018 breeding season at Curtis Island.

Incubation and emergence success

At Curtis Island, 3 (2 ± 2%) of the 138 *N. depressus* clutches laid during the entire season were laid below the area of potential tidal inundation. These clutches were relocated to more secure incubation habitat higher up the dune within two hours of the eggs being laid, as part of the project's activities to increase hatchling production. As a result of this management action, no flatback clutches were lost to erosion or flooding at South End Beach during the 2017-2018 breeding season.

There was a reasonable accuracy in assessing incubation success by counting the broken egg shells in the clutches from which hatchlings had emerged: mean counting error = 0.08 eggs per nest (SD = 0.95, range = -2 to +3 eggs, n = 25 clutches). This was equivalent to over-counting of eggs by 0.04% per clutch examined after the hatchlings have emerged.

For the mid-season census, Curtis Island flatback clutches successfully incubated without disturbance by roots, vertebrate predators or inundation by wave wash. The mean mid-season incubation success was 74.7% (Table 3.4; Figure 11) and the corresponding hatchling emergence success was 64.2% (Table 3.4; Figure 12). There was a slightly higher incubation success (77.1%) and hatchling emergence success (71.3%) measured across the entire season (Table 3.4).

DISCUSSION

This study examined the flatback turtles nesting on South End Beach, Curtis Island during the 2017-2018 breeding season, a moderate-sized nesting population, within the eAust stock.

This nesting population continues to display strong long-term fidelity to its chosen nesting beach as recorded previously for flatback turtles nesting on the Woongarra Coast (Limpus *et al*. 1984). This fidelity is not absolute however, as illustrated by the female that changed nesting beaches from Mon Repos to Curtis Island this summer.

South End Beach is characterised by a number of features which contribute to its functioning as a high quality turtle rookery:

- Nightly nesting success is high (~80%). There is no significant disturbance of the nesting turtles when they come ashore that results in excessive unsuccessful nesting effort.
- Approaching 100% of clutches of eggs laid on this beach survived to hatch in response to QPWS management of feral predators (pigs, dogs and foxes) and the monitoring team's relocation into safer incubation locations of clutches at risk of less through erosion or flooding.
- The Curtis Island South End dune sands constitute a very good incubation medium. Clutches that had not been interfered with by feral predators or impacted by storm surge or high tide erosion had a high incubation success of 77.1% and an acceptable hatchling emergence rate from the nests of 71.3%.

In contrast, extreme concern should be held regarding other characteristics of this rookery:

- The size of the nesting population during the two-week mid-season census period has approximately halved during the past decade, even though the recruitment of new adults into the nesting population has been increasing during the same period.
- The production of a strongly female biased hatchling sex ratio for the season based on the low mean incubation period from laying to hatchling emergence at the beach surface. This is also supported by early season sand temperatures at nest depth. This hatchling sex ratio from the 2017-2018 season resembles the female biased sex ratio predicted from the 2016-2017 breeding season (Limpus *et al*. 2017). The recurring strongly female biased hatchling sex ratio should be viewed with concern (Hamann *et al*. 2008; Limpus, 2008; Poloczanska *et al*. 2009). Increased effort is warranted to identify if there are other nesting beaches within the breeding range of the eAust flatback turtle genetic stock that consistently produce large numbers of male hatchlings. If not, then management options could be considered that can counter the consequences of global warming to feminise this marine turtle nesting population.
- Flatback turtles do not instinctively know the way to the ocean. As they leave the nest, hatchlings orient to move towards the horizon at the lowest angle of elevation from their viewpoint and they move away from elevated dark horizons (Limpus, 1971b; Limpus and Kamrowski, 2013). The extremely bright sky glow emanating from Gladstone and Port Curtis (Kamrowski *et al*. 2012; Pendoley Environmental, 2012) will have negative impacts on the breeding success of marine turtle nesting on the Curtis Coast:
    - Increased number of hatchlings can be expected to die on Curtis Island as a result of the altered light horizons disrupting the hatchling ocean-finding behaviour. This has been observed in recent years on South End Beach (Limpus *et al*. 2017).
    - It is expected that the bright sky glow inland of the nesting beach will result in an elevated mortality of hatchlings dispersing out to sea from the beaches as has been recorded for green turtle hatchlings dispersing from Heron Island, impacted by the tourist resort and research station lighting (Truscott *et al*. 2017).

- It is expected that with the increased bright sky glow behind South End Beach since the construction since 2010 of the three LNG port facilities on Curtis Island and the Wiggins Island Coal Terminal there will be a reduction in adult female numbers visiting the beach for breeding.

During the 2017-2018 breeding season, monitoring of flatback turtle hatchling fans detected that even under bright moon conditions, hatchlings were being dispersed away from the shortest path to the sea and towards the bright sky glow from Port Curtis and Gladstone (Limpus and Shimada, 2018).

Significant reduction of the intensity of the sky glow created by Gladstone and Port Curtis industrial facilities is warranted.

Trends

The trend in track count numbers, numbers of tagged turtles and number of clutches laid during the standard mid-season census period (Figure 3.4A) has been towards increasing numbers from approximately 2001 until 2008. Since 2008 there has been a continuing downward trend in these indicators of population performance. These data suggest that this population may not be maintaining population stability as was indicated by the capture-mark-recapture analysis of data up to the 2012-2013 breeding season that was reported by Limpus *et al*. (2013).

Annual recruitment of first time breeding turtles into the nesting population (= proportion of first time tagged turtles) appears to have been on the increase since 2001.

Unfortunately there are no studies of the population dynamics of flatback turtles within their dispersed foraging areas that would allow for more comprehensive investigation of these parameters. There are no additional data available to further assess these trends in the dynamics of this breeding population.

CHAPTER 4. PEAK ISLAND STUDY

Study Area

Peak Island, 23.333ºS, 150.933ºE, is a continental island in Keppel Bay and lies approximately 15 km off the mainland coast southeast of Yeppoon in eastern Australia (Figure 4.1). Tenure of the island is "National Park (Scientific)", which is the strongest level of land management protection under the *Nature Conservation Act 1992*. Peak Island is also surrounded by a one-kilometre wide Preservation Zone within the Great Barrier Reef Coast Marine Park and the Great Barrier Reef Marine Park. The island is managed by the Department of Environment and Science (DES) in accordance with the Keppel Bay Islands National Park (Scientific) and adjoining State Waters Management Plan. As a consequence, the turtle nesting habitat of Peak Island and the immediately adjacent inter-nesting habitat are managed to provide the highest level of habitat protection available to any turtle nesting population. The island is closed to visitation by the general public and is uninhabited except by the turtle monitoring team during annual monitoring visits. There is no built structure on the island. The principal nesting beach on Peak Island is on the northwestern corner that faces westerly towards the mainland. Only 300 m of this beach provides access to sand dunes suitable for turtle nesting. The dune nesting habitat on the small beach on the northeastern side of the island is inaccessible because of an erosion bank while the accessible sandy beach on the south-eastern side of the island has rocks under the sand at dune level preventing successful egg chambering.

Peak Island supports one of the largest populations of nesting flatback turtles in the eAust stock (Limpus *et al*. 2013) and is recognised as an index beach for long-term monitoring of flatback turtles within the eAust stock. Census of the Peak Island flatback turtle nesting population commenced in the 1980-1981 breeding season (Limpus *et al*. 1981). Monitoring of turtle nesting at Peak Island was led by Dr C. J. Parmenter of Central Queensland University during 1981-2006 (Parmenter 1993). Monitoring recommenced in 2008 within The Queensland Turtle Conservation Project (Twaddle *et al*. 2014, 2015; Pople *et al*. 2016; Limpus *et al*. 2017).

Methods specific to Peak Island

- At Peak Island the nesting beach is subdivided into 25 m sectors identified by numbered posts to allow comparisons across sectors. Sectors 0-5 are fronted by inter-tidal rocks with a sandy beach above the high tide level. Sectors 14-17 are fronted by extensive inter-tidal rocks which extend to exposed rocky rubble above the high tide level and into the dunes. The remainder of the beach has a sandy approach to the dunes.
- The work program at Peak Island was not designed to collect data for the duration of the flatback turtle nesting season. A two-week, mid-season census was conducted from 24 November – 07 December 2017 and data was collected for emerged clutches during a ten-day trip 16-29 January 2018.
- A Vemco Minilog II temperature data logger that had been buried at a depth of 50 cm in front of the Sector 10 post on 26 November 2014 could not be relocated for downloading. The cord that had secured the data logger to the post was present

but not the data logger. A replacement temperature data logger was set at the same location and at 50 cm depth to record sand temperatures at nest depth at half hour intervals in late January 2017. The temperature data logger was successfully downloaded on 26 November 2017.

RESULTS

Nesting activity, nesting success and recruitment

A total of 158 nesting flatback turtles were recorded during the two-week census period, 24 November – 07 December 2017 (Table 4.1). No other species of turtle was recorded nesting during this period. While 137 females were recorded that had a prior nesting history at Peak Island, 1 flatback turtle was recorded that had been previously recorded nesting at Facing Island, approximately 70 km to the south.

The work program at Peak Island was not designed to define the duration of the flatback turtle nesting season. However, with respect to commencement of hatchling emergence, there was no evidence of hatchling tracks in the beach on arrival on 24 November 2017 and the first emergence of hatchlings was observed on 6 December 2017 (Table 4.2).

The mean nightly census of nesting turtles coming ashore during the mid-season census period was 16.6 tracks, 11.3 different turtles and 11.2 clutches laid (Table 4.2).

There were 232 recorded flatback turtle nesting crawls during the census period (Table 4.2). The frequency distribution of nesting crawls by beach sectors is summarised in Figure 4.2. The majority of successfully nesting turtles came ashore within sectors 7-13, which was fronted by a sandy beach. Nesting success was extremely low in sectors 14-15 (Figure 4.2). The mean nesting success, the proportion of nesting crawls that resulted in eggs being laid by the turtle, was 67.7 ± 6.0% and fluctuated nightly during the census period (Figure 4.3).

The recruitment rate of first time breeding females into the adult nesting population, as measured by the proportion of first time tagged nesting females, was 10.8 ± 4.8% for turtles within the mid-season census period (Figure 4.13).

Nesting females: size and fecundity

The mean CCL (cm) of the nesting female flatback turtles was 93.9 cm (Table 4.3, Figure 4.4). Females that were tagged for their first recorded nesting season, presumed first time breeding turtles, were significantly smaller than remigrant turtles with a past breeding history ($F_{1,201} = 15.61$; $0.05 < p$).

The mean return interval for a turtle returning to attempt to lay eggs following its return to the sea after an unsuccessful nesting crawl was 1.25 days (SD = 1.143, n = 28, range = 0-4 days). Most females returned to re-attempt nesting on the same night or the following night after an unsuccessful nesting attempt.

No turtles were recorded returning to lay an additional clutch during the monitoring period (24 November – 7 December 2017).

The mean remigration interval, the number of years between recorded breeding seasons, for adult female flatback turtles at Peak Island during the 24 November – 7 December 2017 census period was 2.84 years (SD. = 1.23, N = 137) (Table 4.3, Figure 4.5). Most turtles returned on a two or three year remigration.

A total of 157 clutches were laid during the two-week census. The number of eggs per clutch, yolkless and multiyolked eggs, egg diameters, egg weights and nest depths are summarised in Table 4.4 and Figure 4.6. The sampled flatback turtle clutches had on average: 52.0 eggs, 0.1 yolkless eggs and no multiyolked eggs per clutch (n = 17 clutches); with eggs averaging 5.1 cm in diameter and weighing 75.1 g. The nests were on average 34.5 cm deep to the top of the eggs and 53.8 cm to the bottom.

Health and injuries

No nesting flatback turtles were recorded with fresh fracture to the carapace. Numerous nesting flatback turtles had healed injuries from either predator encounters when younger or from damage when dropped on the deck of vessels or from when hit by vessels (Figure 4.7b,d). There were again small numbers of nesting flatback turtles with white patches of exposed bone on the carapace that are presumed to have been caused by abrasion as the turtles have passed through a trawl fishery Turtle Exclusion Device (Figure 4.7a).

Sand temperature monitoring

At Peak Island, sand temperatures at nest depth were recorded, commencing 1 February 2017 and downloaded on 26 November 2017. The data logger was redeployed to continue sand temperature monitoring on 26 November.

The mid-summer flatback turtle nesting season typically coincides with a summer peak annual rainfall. Rainfall results in a decline in sand temperatures at nesting beaches and sand temperatures increase in the short term in the absence of rain (Reed, 1980). In the absence of rain, dry surface sand conditions will favour higher sand temperatures as a result of reduced evaporative cooling within the sand.

In the absence of sand temperature data for most of the turtle breeding season, daily rainfall and air temperature data recorded at the BOM weather stations at Yeppoon and Rosslyn Bay were examined (Figure 4.8). The Australian Bureau of Meteorology (BOM) reported the occurrence of an exceptional period of heatwave conditions impacting coastal central Queensland during the eastern Queensland flatback turtle nesting season of 2017-2018 (Figure 4.9).

The study period during mid to late January 2018 was very hot and dry. Under these conditions the surface sand temperatures, particularly during the middle of the day and early afternoon, will have been high. The combination of elevated temperatures and reduced rainfall resulted in atypically hot beach sand conditions that, in late

January, saw dead flatback hatchlings on the beach surface and just below the surface in the neck of egg chambers over successive days.

Nest and hatchling disturbance and depredation and island fauna

Fourteen nesting turtles were observed digging into existing clutches, which amounted to 6.0 ± 3.1% of nesting activity resulting in clutch destruction with an average clutch destruction rate of 8.9 ± 4.5% of clutches laid during the mid-season census period. On average 10.9 ± 10.0 eggs were disturbed and killed when a nesting turtle dug into an existing nest, equivalent to 21% of a clutch.

Large terrestrial predators (pigs, dogs, foxes, varanid lizards and humans) of turtle eggs are absent from the island. However, an excessive number of clutches were invaded by roots from grasses and vines (65 clutches, equivalent to 47.8 ± 8.4% of clutches examined) with resulting increased incubation failure and entrapment of hatchlings within the nest (Figure 4.7f). There was also some loss of eggs from predation by *Ocypode* crabs and high tide flooding of eggs.

On arrival at the island on 16 January there was a pervasive smell of dead animals. Over the following days, this odour was found to be coming from the excessive number of dead eggs and hatchlings within the turtle nests on the dunes. Hatchlings were observed dying as they crossed the beach from the nests (Figure 4.7e). Numerous hatchlings were not able to right themselves when they fell over. This egg and hatchling mortality was attributed to the local heat wave conditions at the time (Figures 4.8 and 4.9).

At daylight, up to four white bellied sea eagles, *Haliaeetus leucogaster*, patrolled long the beach daily. Later in the morning, small flocks of Torresian crows, *Corvus orru*, would drive off the sea eagles and commence patrolling along the beach and continue throughout the day, utilising trees and elevated positions as resting stations. Crows regularly were observed “dropping” on hatchlings on the beach and carrying the hatchlings in their beaks to feeding stations. This is the first season that crows have been recorded as active predators of the flatback hatchlings at Peak Island. While the rate of hatchling predation by crows remains unquantified, we have the impression that they contributed to a significant level of hatchling loss for the season.

By day and night there were numerous small (less than 1.5 m) carcharinid sharks of multiple species patrolling the shallows against the shoreline. These sharks preyed intensely on hatchlings as they entered the sea. These sharks were also present during the mid-season nesting census.

Incubation and emergence success

A fourteen-day trip to Peak Island from 16 January – 29 January 2018 sampled nests from which hatchlings had emerged to assess incubation and emergence success.

There was a reasonable accuracy in assessing incubation success by counting the broken egg shells in the clutches from which hatchlings had emerged: mean counting error = -0.6 eggs per nest (SD = 1.52, range = -3 to +1 eggs, n = 5

clutches). This was equivalent to under-counting of eggs by 1.3% per clutch examined after the hatchlings have emerged.

Thirty-two nests that had been previously marked at laying and had identification nest tags were located as hatchlings emerged. The dates laid spanned the mid-season census period from 24 November to 7 December 2017. The mean incubation period to hatchling emergence for these clutches was 47.8 days (Table 4.5, Figure 4.11a). The majority of these clutches had a period to hatchling emergence that was below the pivotal period for hatchling emergence (Figure 4.11a) and should have produced hatchlings with a female hatchling bias.

Based on the early season sand temperatures (Figure 4.10), it is expected that there would have been a male biased hatchling production from clutches laid during approximately the first month of the 2017-2018 nesting season.

Hatching success of eggs and emergence success of hatchlings from the nests are summarised in Table 4.5. Clutches laid during the mid-season census period had a mean incubation success of 55.9% and a very poor mean hatchling emergence to the beach surface of 39.1% (61 clutches) during 16 to 29 January 2018 (Figure 4.11b).

Additional clutches, laid mostly before the mid-season census period had a marginally better incubation success and hatchling emergence success (Table 4.5). When clutches laid before and during the mid-season census period are pooled for incubation success, the mean hatching success = 60.5% and hatchling emergence success = 46.9% (n = 134 clutches. Table 4.5).

Given the localised regionally elevated hot weather (Figures 4.8 and 4.9) it is considered that the majority of the clutches emerging during 16 to 29 January and during the following weeks will have been heat stressed. The 2017-2018 breeding season has witnessed the lowest hatching success of clutches and by far the worst hatchling emergence success from the nests recorded at Peak Island since the current monitoring regime commenced in 2008. When this poor hatchling emergence success is considered in association with the elevated, although unquantified death of hatchlings while crossing the beach, and the intense predation of hatchlings by crows and sharks witnessed this summer, overall hatchling dispersal away from the rookery should be the lowest on recorded.

Discussion

Peak Island was not impacted by a cyclone during the 2017-2018 flatback turtle breeding season.

The Peak Island nesting flatback turtles continued to display normal demographic parameters for the eAust stock: mean CCL = 93.9 cm; mean number of eggs in a clutch = 52.0 cm; mean remigration interval = 2.84 yr.

Nesting flatback turtles at Peak Island continued to display a low nesting success, mostly as a result of several sectors of the beach having little or no sand available

for supporting nesting activity. This situation has existed for the last ten breeding seasons.

This season, both incubation success and hatchling emergence success were at the lowest recorded since current studies commenced in 2008. This season's hatching success was 60.2% compared to 88.9% the previous year, and the hatchling emergence success was 46.9% compared to 86.7% the previous year. Root invasion of nests and the localised heat wave conditions in mid to late January were contributing factors to the poor hatchling production. At the same time, the 2017-2018 hatching season appears to have experienced an atypical increase in predation of hatchlings by crows and sharks. We will endeavour to monitor the post emergence predation of hatchlings more precisely next summer. The data indicates that the sand dune environment at Peak Island provided a poor quality incubation environment for flatback turtle eggs. Management of non-native weed species (Limpus and Limpus, 2018) to reduce root invasion of nests may be warranted.

Flatback eggs that incubate at a constant temperature of 29.3^{o}C, the pivotal temperature, should have hatchlings emerging after approximately 53 d (EHP unpublished data). The majority of the clutches from the mid-season census period for which this period to emergence was measured had a period to emergence less than 53 days (Figure 4.11a). Given these results and the heat wave conditions that occurred this summer, it is highly likely that the majority of flatback clutches incubating at Peak Island during the 2017-2018 breeding season had a strongly female-biased sex ratio. However, the early season clutches should have produced a male-biased sex ratio based on the sand temperature at nest depth being below the pivotal temperature (Figure 4.10).

Trends

Limpus *et al*. (2013) identified a downward trend in population size at Peak Island over recent decades. The number of tagged turtles observed this season and in recent seasons suggests that the rate of decline may be slowing but continuing (Figure 4.12).

The recruitment rate (10.8%) of estimated 1st time nesters (turtles not previously tagged) during the census continues to be towards the bottom of the range reported for flatback turtles nesting at Peak Island, Wild Duck Island and the Woongarra Coast (10-20%) reported in Limpus (2007). Given the apparent decline in the annual recruitment of new breeding females into the nesting population over the past nine years (Figure 4.13), this recruitment parameter should continue to be carefully monitored for any further declines. Any continuation of decline in recruitment should be regarded as of high concern for this population.

CHAPTER 5. AVOID ISLAND STUDY

Study Area

This report provides a summary of results from monitoring marine turtle nesting activity at Avoid Island during the 2017-2018 breeding season. Avoid Island was first identified as a significant flatback turtle breeding site during an aerial survey in 1971 (Limpus, 1985) and again in 2000 and 2001 (Limpus *et al*. 2013). The nesting population was first monitored during the mid-nesting season in 2007-2008 (Jones and Venz, 2008). The island's turtle breeding has now been monitored for five consecutive seasons commencing in 2012 with the last four seasons of monitoring supported by GPC ERMP.

Avoid Island, 21.9744ºS, 149.6500ºE, is a continental island located just north of Broad Sound and lying approximately 18 km from the nearest mainland shore and approximately 125 km southeast of the City of Mackay on the mainland coast of eastern Australia. The Queensland Trust for Nature (QTFN) owns the island and manages it as a designated nature refuge. Avoid Island sits within a Habitat Protection Zone of the Great Barrier Reef Coast Marine Park and the Great Barrier Reef Marine Park. The island is closed to visitation by the general public and is uninhabited except by the turtle monitoring team during annual monitoring visits, associated classes visiting for environmental education, and periodic visits by QTFN personnel for maintenance. As a consequence, the turtle nesting habitat of Avoid Island and the immediately adjacent inter-nesting habitat are managed to provide a high level of habitat protection to the turtle nesting population. There is a house, built in the 1970s, on the highest point on the island, and a shed. There are 4wd tracks that circle the island and a grass airstrip, which are maintained with a tractor mower. QTFN installed solar power and two composting toilets on the island in 2015, which substantially improved the living situation.

The Island is approximately 1.6 km long and 0.4 km wide, and has undulating terrain with a rise on the northern end of the island (Figure 5.1). There are three main nesting beaches (South Beach, Middle Beach, North Beach) on the eastern side of the island that are bordered by rocky outcrops. Each beach is fronted by tidal sandy mud flats with scattered rocky shelves. These beaches are backed by dunes, providing nesting habitat on the beach slope and dunes, which are highest at South Beach. Other beaches on the island are either too narrow or rocky to provide suitable nesting habitat, though occasional nesting occurs on West Beach, the largest westerly facing beach.

Avoid Island supports a moderate density of nesting flatback turtles of the EA stock (FitzSimmons and Limpus, 2014) and has been selected as an index beach for long term monitoring of flatback turtles within the EA stock. An initial census of the Avoid Island flatback turtle nesting population was conducted during the 2007-2008 breeding season (Jones and Venz, 2008) and annual monitoring commenced in the 2012-2013 breeding season (FitzSimmons, 2013; FitzSimmons and Limpus, 2014, 2015, 2016; Limpus *et al*. 2017).

Methods specific to Avoid Island

Monitoring at Avoid Island included the standard 14-day census period from 26 November to 9 December 2017 during the mid-season nesting that has been monitored in previous years. Nightly monitoring occurred during the census on all eastern beaches, referred to as South Beach (A3), Middle Beach (A2) and North Beach (A1) (Figure 5.1). Additional monitoring on South Beach occurred on 20 October, 31 October to 4 November, and 10 to 12 December but only tracks were counted during these times on Middle and North Beach.

New sector numbers were established on South Beach and North Beach to improve upon the markers put up in 2016. This was done using aluminium squares with reflective strips and numbers or letters that were attached to trees or posts.

Four temperature data loggers (Vemco Minilog II) were previously established in an open and a shaded location on the top of the 1st dune and on beach, each buried at 50 cm depth.

Students from a conservation biology class run through the University of New South Wales assisted with monitoring of nesting during the mid-season census. Two teams of three or four students, working with one or two experienced people, did nightly monitoring of South Beach, Middle Beach and North Beach. Following the UNSW course, a three-day high school course monitored South Beach for two nights with experienced team leaders. This course was collaborative between QTFN and the Wonders of Science Program of the University of Queensland.

Monitoring of hatchling emergence occurred during 22 January to 3 February 2018 with nests being dug to determine hatching and emergence success.

RESULTS

Nesting activity, nesting success and recruitment

There were 22 tracks from nesting turtles on the South Beach and 4 on North Beach when the monitoring team arrived on the island on 26 November 2018.

A total of 46 flatback turtles were encountered during the 2017-2018 mid-season nesting census and 69 for all nights of monitoring: 13 first time tagged turtles, 56 remigrant turtles recorded nesting back at Avoid Island. No other species of turtle was recorded as nesting during this season.

A total of 85 nesting crawls by flatback turtles were recorded on Avoid Island during the two-week census. Of these, there were 57 successful nests dug with eggs recorded as being laid and two unknown outcomes. This equates to a 67.1 ± 9.5% nesting success for the census period (Table 5.1). During the monitoring done outside of the census, there were an additional 68 nesting crawls and 46 nests with eggs laid, for an overall nesting success of 69.0 ± 7.2%.

The mean nightly number of flatback turtle nesting crawls during the mid-season census period was 6.3 (Table 5.1, Figure 5.4). As in previous years, most nesting activity during the census (76.1% of tracks and 82.3% of clutches laid) occurred on South Beach, which is the largest beach (Figure 5.5). Only two clutches were laid on Middle Beach and nine clutches were laid on North Beach. Although beach erosion from Cyclones *Dylan* in 2014 and *Marcia* in 2015 continued to limit access by turtles to the dunes along sections of South Beach and in loss of nesting habitat on the northern end of North Beach, recent additional sand has raised the beach profile in some areas (Cover photo [top right] and Figure 5.2).

A total of 61 clutches were laid during the two-week census and were marked and mapped for subsequent determination of emergence success. The mean number of clutches laid per night was 4.4 (Table 5.1).

The study has reached the point of being able to estimate the recruitment rate of first time breeding females into the adult nesting population, as measured by the proportion of first time tagged nesting females, commencing in the 2012-2013 breeding season. As expected, this value has declined with each year of tagging during the standard two-week mid-season census: For the 2017-2018 season the mid-season census estimate for new recruits was 23.9% (Figure 5.6) and for the entire monitoring period it was 18.8%.

Nesting females: size, fecundity

The mean CCL of nesting female flatback turtles during all monitoring was 92.9 cm (Table 5.2 and Figure 5.7).

Remigration interval, the number of years between recorded breeding seasons, averaged 2.6 yr (Table 5.2) for the entire monitoring period, with the most common intervals being 2 yr (Figure 5.8).

During the 2017-2018 season all flatback turtles with a past nesting history had nested on Avoid Island in a prior breeding season.

There was an average of 49.7 eggs per clutch laid for the 3 clutches that were counted when laid. Summary data on clutch, egg size and nest depths are given in Table 5.3.

The average re-nesting interval between a successful nesting and the subsequent return to lay another clutch was 13.8 d (Table 5.2, Figure 5.9). An additional 11 turtles that were observed nesting in late October or early November were observed nesting 28-35 days later on (at least) their 3rd nesting. A turtle that did not lay during a nesting crawl usually returned for another nesting attempt on the same night or on the following two nights (Table 5.2, Figure 5.9).

Health and injuries

One of the nesting turtles at Avoid Island had recent fracture damage (Figure 5.10A). No fibropapilloma tumours were observed on any of the turtles. The fractures from

vessel strike such as illustrated in Figure 5.10 are presumed to be occurring mostly in the distant foraging areas from which these turtles originate.

Sand temperature monitoring

Rainfall and air temperature data recorded at the BOM weather station at St Lawrence (Figure 5.11) shows the elevated rainfall during October and November 2017 which resulted in some periods of low sand temperatures prior to early December.

The temperature data loggers were downloaded on 12 December 2017 and 2 February 2018. The data logger in the dune shaded habitat malfunctioned after it was last deployed and the data rejected. Data was successfully downloaded from three other data loggers: upper dune sunny habitat, sector 41; beach sunny habitat, sector 13; beach shaded habitat, sector 27 (Figures 5.12A, B, C).

When the data loggers were initialised in early November, the sand temperature at nest depth was already above the flatback turtle pivotal temperature at all sites. Some of the few clutches laid during October may have been exposed to cooler temperatures. The sand temperatures on both the upper dune and the beach in mid November to early December dropped during brief cooling spikes that brought the sand temperatures below the flatback pivotal temperature. Sand temperatures at all three monitoring sites remained above the flatback pivotal temperature for the remainder of the breeding season after 2 December until at least 2 February when the data loggers were last downloaded (Figure 5.12).

Based on these sand temperature measurements at nest depth, it is expected that the flatback turtle hatchling sex ratio at Avoid Island was strongly skewed to females for almost the entire breeding season.

Nest and hatchling disturbance and depredation and island fauna

No clutches were recorded as having been dug into by a nesting turtle. No mammalian or reptilian terrestrial predators of marine turtle eggs or hatchlings were recorded on Avoid Island. While potential avian predators of turtle hatchlings were present on the island, none were recorded taking turtle hatchlings during this last season. There were 3 clutches during the md-season census period that had eggs predated by crabs, with a mean of 4.7 eggs taken per clutch (SD =5.2, range = 1-12). The crab responsible for this predation was *Ocypode cordimanus*.

Incubation and emergence success

The incubation period to hatchling emergence was obtained for seven clutches from across the entire monitoring period. The average incubation period to hatchling emergence to the beach surface was 46.7 days (Table 5.4).

Three clutches had their eggs counted at laying and again following hatchling emergence. The counts are considered acceptable with a mean error of the clutch count following hatchling emergence compared to the clutch count at laying = -0.67 (SD = 0.58, range = -1 – 0, n = 3).

Hatching success and hatchling emergence success was assessed for 49 clutches that were laid during the mid-season census: hatching success = 62.03%; emergence success = 56.86% while for clutches examined across a wider period of the breeding season: hatching success = 69.19%; emergence success = 64.71% (Table 5.4).

At least 9 clutches were inundated by high tides with a resulting low hatching success and hatchling emergence success of 2.3% (Table 5.4). Additionally, 2 clutches were identified to have been heat stressed, these had an hatching success of 69.9% and an emergence success of 48.2%.

DISCUSSION

Avoid Island supports a moderately sized population of nesting flatback turtles. The island is located towards the northern extremity of the breeding range for the eAust stock. It has been chosen as a control site for comparative monitoring with respect to the Curtis Island and Peak Island rookeries because Avoid Island has no mammalian or reptilian predators of eggs, it is free of uncontrolled human disturbance of the nesting turtles and the nesting and adjacent inter-nesting habitat has not been modified by anthropogenic activities.

This year's study has completed the seventh year of monitoring flatback turtle nesting activity, the last six of which were consecutive. The total number of individually tagged flatback turtles was below the values recorded in previous years. Mean nightly track counts were below average and the total number of clutches was the 2nd lowest during the current sequence of census (FitzSimmons, 2013; FitzSimmons and Limpus, 2014; FitzSimmons and Limpus, 2015; FitzSimmons and Limpus, 2016; Limpus *et al*. 2017) (Figure 5.13).

The proportion of turtles of previously tagged has stabilised, and is within the range recorded for Wild Duck Island of 10-20% (reported in Limpus 2007). This suggests that the proportion of untagged turtles is approaching a representative value for the proportion of new recruits to this rookery.

The nesting turtles at Avoid Island continue to display high fidelity to this island across the breeding seasons.

Revised placement of reflective identification points on trees and posts on South Beach and North Beach helped considerably in marking nest sites at night and in relocating them after hatchling emergence.

Existing management at Avoid Island is providing an important island nesting site that is free of predation by pigs, dogs and foxes on beaches not impacted by urban or industrial development.

Incubation periods ranged from 46-49 days. The pivotal temperature, the theoretical temperature that will produce a 50:50 sex ratio, is 29.3^{o}C for the eastern Australian flatback turtle stock (Limpus, 2007) with warm nests hatchling sooner with a female

bias in the hatchlings. Flatback eggs incubated at constant temperature of 29.3ºC should have the hatchlings emerging at approximately 53 days after the eggs were laid (EHP, unpublished data). All clutches with data on incubation duration emerged in less than 53 days, thus it is highly likely that the majority of the clutches of flatback clutches incubating at Avoid Island during the 2017-2018 breeding season had a strongly female-biased sex ratio. This is consistent with the recorded sand temperatures. Any male hatchlings produced at this island during the 2017-2018 breeding season would have come from the limited number of clutches laid during the early nesting season.

Nesting success was relatively high (70.5%) during the census and similar to previous years. However, hatching success of eggs and hatchling emergence success in this period was among the lowest recorded at 61.6% and 56.3%, respectively. If the entire breeding season is considered, these values rise somewhat to 69.2% and 64.7%, respectively.

The low hatchling production can be attributed in part to nest inundation and heat stress. If the nests affected by this are removed from the estimation, incubation success is 74.5% and emergence success is 68.2%. Factors such as these that are linked to variable weather across the years warrant closer monitoring in future breeding seasons.

6. Acknowledgements

These flatback turtle projects were conducted as part of the Turtle Conservation Project of the Threatened Species Unit, Department of Environment and Science. The project was funded in part by grants from Gladstone Ports Corporation's Ecosystem Research and Monitoring Program and from Eco Logical Australia.

The Curtis Island and Peak Island projects received logistical assistance from the Gladstone Queensland Parks and Wildlife Service staff.

The Avoid Island project was conducted as a cooperative project between the Queensland Trust for Nature (QTFN), the University of New South Wales (UNSW) and the Turtle Conservation Project of the Threatened Species Unit, Department of Environment and Science. Felicity Shapland of QTFN provided logistic support, organised transport and organised accommodation for the field studies. Kevin and Marie English transported supplies by barge and kept the airstrip and paths mowed. Jaz Lawes was convenor of the UNSW course, and did the planning and pre-trip logistics, while Ally Ross ran the course in the field.

These studies could not have been completed without the assistance of the numerous Queensland Turtle Conservation volunteers, who often worked long hours in challenging conditions. The assistance of staff and volunteers is gratefully acknowledged.

7. References

FitzSimmons, N. N. (2013). Avoid Island Flatback Turtle (*Natator depressus*) Nesting Study 2012-2013. Final Report to Queensland Trust for Nature. (20 February 2013).

FitzSimmons, N. N. and Limpus, C. J. (2014). Marine Turtle Nesting Populations: Avoid Island Flatback Turtles, 2013-2014 breeding season. Brisbane: Department of Environment and Heritage Protection, Queensland Government. Report produced for the Ecosystem Research and Monitoring Program Advisory Panel as part of Gladstone Ports Corporation's Ecosystem Research and Monitoring Program. 16 pp.

FitzSimmons, N. N. and Limpus, C. J. (2015). Marine Turtle Nesting Populations: Avoid Island Flatback Turtles, 2014-2015 breeding season. Brisbane: Department of Environment and Heritage Protection, Queensland Government. Report produced for the Ecosystem Research and Monitoring Program Advisory Panel as part of Gladstone Ports Corporation's Ecosystem Research and Monitoring Program. 19 pp.

FitzSimmons, N. N. and Limpus, C. J. (2016). Marine Turtle Nesting Populations: Avoid Island Flatback Turtles, 2015-2016 breeding season. Brisbane: Department of Environment and Heritage Protection, Queensland Government. Report produced for the Ecosystem Research and Monitoring Program Advisory Panel as part of Gladstone Ports Corporation's Ecosystem Research and Monitoring Program. 20 pp.

Hamann, M., Limpus, C. J., and Read, M. A. (2008). Vulnerability of Marine Reptiles in the Great Barrier Reef to Climate Change. Ch.15. in "Climate Change and the Great Barrier Reef: a vulnerability assessment." (Eds. Johnson, J. E. and Marshall, P. A.) Pp. 466-496. (Great Barrier Reef Marine Park Authority: Townsville).

Jones, M. and Venz, H. (2008). Queensland Turtle Conservation Project: Avoid Island Flatback Turtle Study, 2007-2008. Version 1: Report to EPA Tenure Actions Branch and Queensland Trust for Nature. 31 pp.

Kamrowski, R. L., Limpus, C., Moloney, J., and Hamann, M. (2012). Coastal light pollution and marine turtles: assessing the magnitude of the problem. *Endangered Species Research* **19**, 85-98.

Limpus, C. J. (1971a). The flatback turtle, *Chelonia depressa* Garman in southeast Queensland, Australia. *Herpetologica* **27**, 431-436.

Limpus, C. J. (1971b). Sea turtle ocean finding behaviour. *Search* **2**, 385-387.

Limpus, C. J. (1985). A study of the loggerhead turtle, *Caretta caretta*, in eastern Australia. *PhD thesis, University of Queensland*: Brisbane

Limpus, C. J. (1992). Estimation of tag loss in marine turtle research. *Wildlife Research* **19**, 457-69.

Limpus, C. J. (2007). A biological review of Australian marine turtles. 5. Flatback turtle *Natator depressus* (Linneaus). (Queensland Environmental Protection Agency, Brisbane. ISBN 978-0-9803613-2-2.

Limpus, C. J. (2008). Adapting to climate change: a case study of the flatback turtle, *Natator depressus*. In "In Hot Water: preparing for climate change in Australia's coastal and marine systems." (Eds. Poloczanska, E. S., Hobday, A. J., and Richardson, A. J.) Pp. 48-49. Proceedings of conference held in Brisbane, 12-14th November 2007. (CSIRO Marine: and Atmospheric Research: Hobart.)

Limpus C. J. and Kamrowski R. L. (2013). Ocean-finding in marine turtles: the importance of low horizon elevation as an orientation cue. *Behaviour* **150**, 863-893.

Limpus, C. J., Baker, V., and Miller, J. D. (1979). Movement induced mortality of loggerhead eggs. *Herpetologica* **35**, 335-338.

Limpus, C. J., Parmenter, C. J., Parker, R., and Ford, N. (1981). The flatback turtle, *Chelonia depressa*, in Queensland: the Peak Island rookery. *Herpetofauna* **13**, 14-18.

Limpus, C. J., Parmenter, C. J., Baker, V. and Fleay, A. (1983). The Crab Island sea turtle rookery in north eastern Gulf of Carpentaria. *Australian Wildlife Research* **10**, 173-184.

Limpus, C. J., Fleay, A., and Baker, V. (1984). The flatback turtle, *Chelonia depressa* in Queensland: reproductive periodicity, philopatry and recruitment. *Australian Wildlife Research* **11**, 579-87.

Limpus, C. J., Clifton, D., Griffin, K., Kemp, L., Gallagher, L., Gallagher, L., Fisher, S., and Parmenter, C. J. (2002). Survey of marine turtle nesting distribution in Queensland, 2001 and 2002: Broad Sound to Repulse Bay, Central Queensland. (Queensland Parks and Wildlife Service: Brisbane.)

Limpus, C. J., McLaren, M., McLaren, G., and Knuckey, B. (2006). Queensland Turtle Conservation Project: Curtis Island and Woongarra Coast Flatback Turtle studies, 2005-2006. *Conservation Technical and Data Report* **2006**.

Limpus C.J., Parmenter, C.J., and Chaloupka, M. (2013). Monitoring of Coastal Sea Turtles: Gap Analysis 5. Flatback turtles, *Natator depressus*, in the Port Curtis and Port Alma Region. Department of Environment and Heritage Protection Report produced for the Ecosystem Research and Monitoring Program Advisory Panel as part of Gladstone Ports Corporation's Ecosystem Research and Monitoring Program. 26 pp.

Limpus, C. J., FitzSimmons, N. N., Sergeev, J. M., Ferguson, J., Hoffmann, F., Phillot, A., Pople, L., Ross, A., Tompkins, B., Turner, T. and Wenk. L. (2017). Marine turtle nesting populations: flatback turtle, *Natator depressus*, 2016-2017 breeding season at Curtis Peak and Avoid Islands. Brisbane: Department of Environment and Heritage Protection, Queensland Government. Report produced for the Ecosystem Research and Monitoring Program Advisory Panel as part of Gladstone Ports Corporation's Ecosystem Research and Monitoring Program. 70 pp.

Limpus, C. J. and Limpus, D. J. (2018). Plant species within the marine turtle nesting habitat of Peak Island. (Queensland Department of Environment and Science: Brisbane)

Limpus, C. J. and Shimada, T. (2018). Assessing the use to tracks from nesting females and hatchlings for quantifying disrupted ocean finding of flatback turtles, *Natator depressus*. (Queensland Department of Environment and Science: Brisbane)

Parmenter, C. J. (1993). A preliminary evaluation of the performance of passive integrated Transponders and metal tags in a population study of the flatback sea turtle (*Natator depressus*). *Wildlife Research* **20**, 375-381.

Pendoley Environmental (2012). Gladstone Baseline Sky Cam Light Monitoring 2011. Report produced for the Ecosystem Research and Monitoring Program Advisory Panel as part of Gladstone Ports Corporation's Ecosystem Research and Monitoring Program.

Pfaller, J. B., Limpus, C. J., and Bjorndal, K. A. (2008). Nest-site selection in individual loggerhead turtles and consequences of doomed-egg relocation. *Conservation Biology* **23**, 72-80.

Pittard, S.D. (2010). Genetic population structure of the flatback turtle (*Natator depressus*): A nuclear and mitochondrial DNA analysis. *Honour's Thesis, University of Canberra*: Canberra.

Poloczanska, E. S., Limpus, C. J., and Hays, G. C. (2009). Vulnerability of marine turtles to climate change. *Advances in Marine Biology* **56**, 151-211.

Pople, L., Reinhold, L. and Limpus, C. J. (2016). Marine Turtle Nesting Population: Peak Island Flatback Turtles, 2015-2016 breeding season. Brisbane: Department of Environment and Heritage Protection, Queensland Government. Report produced for the Ecosystem Research and Monitoring Program Advisory Panel as part of Gladstone Ports Corporation Ecosystem Research and Monitoring Program.

Reed, P. C. (1980). The sex ratio of hatchling loggerhead turtles - progeny of two nesting adult females. B.Sc.Hon. Thesis, James Cook University of North Queensland: Townsville.

Robins, J. B. (1995). Estimated catch and mortality of sea turtles from the east coast otter trawl fishery of Queensland, Australia. *Biological Conservation* **74**, 157-67.

Robins, J. B. and Mayer, D. G. (1998). Monitoring the impact of trawling on sea turtle populations of the Queensland East Coast. *DPI Project Report Series* **Q098012**, 1-59.

Truscott, Z., Booth D. T., and Limpus C. J. (2017). The effect of on-shore light pollution on sea turtle hatchlings commencing their off-shore swim. *Wildlife Research* **44**(2), 127-134.

Twaddle, H., Limpus, J., Pople, L., Wildermann N., and Limpus, C. J. (2014). Marine Turtle Nesting Population: Peak Island Flatback Turtles, 2013-2014 Breeding Season. Brisbane: Department of Environment and Heritage Protection, Queensland Government. Report produced for the Ecosystem Research and Monitoring Program Advisory Panel as part of Gladstone Ports Corporation's Ecosystem Research and Monitoring Program. 14 pp.

Twaddle, H., French, K., Howe, M., Limpus, G., McLaren, M., Pople, L., Sim, E., and Limpus, C. J. (2015). Marine Turtle Nesting Population: Peak Island Flatback Turtles, 2014-2015 Breeding Season. Brisbane: Department of Environment and Heritage Protection, Queensland Government. Report produced for the Ecosystem Research and Monitoring Program Advisory Panel as part of Gladstone Ports Corporation's Ecosystem Research and Monitoring Program. 19 pp.

Yntema, C. L. and Mrosovsky, N. (1982). Critical periods and pivotal temperatures for sexual differentiation in loggerhead sea turtles . *Canadian Journal of Zoology* **60**, 1012-1016.

Zar, J. H, (1984) Biostatistical Analysis, 2nd ed. (Prentice-Hall : Englewood Cliffs, New Jersey)

TABLES

Table 1. Comparison of reproductive parameters (± standard deviation) recorded for flatback turtles, *Natator depressus*, nesting at the three central Queensland index rookeries during the mid-season census period: 24 November to 7 December 2017. Parameters that are considered to be indicative of poor population performance are shaded.

Data Collected	Curtis Island	Peak Island	Avoid Island
# turtles – total	28	158	>46
Mean tracks/night ± SD	3.4 ± 2.2	16.6 ± 10.8	6.3 ± 5.3
# clutches – total	35	157	62
Nesting success	72.9%	67.7%	67.1%
New recruits to breeding population	21.4%	10.8%	23.9%
Female CCL (cm)	94.1 ± 2.7; n = 28	93.9 ± 2.9; n = 152	92.9 ± 2.90; n = 64
Mean remigration interval (yr)	3.0 ± 1.7; n = 24	2.83 ± 1.2; n = 137	2.60 ± 0.96; n = 53
Mean eggs/clutch	51.4 ± 9.98; n = 21	52.0 ± 8.7; n = 17	49.7 ± 6.9; n = 3
Mean egg diameter (cm); n = # clutches	5.1 ± 0.13; n = 14	5.1 ± 0.16; n = 17	5.2 ± 0.08; n = 3
Mean egg weight (g); n= # clutches	75.2 ± 5.0; n = 14	75.1 ± 6.2; n=17	78.8 ± 2.1; n = 3
Incubation duration from census nests; n = # clutches	47.5 ± 1.7; n = 31	47.8 ± 2.7; n = 32	46.7 ± 1.3; n = 7
Hatching success; n = # clutches	74.7 ± 19.0%; n = 33	55.9 ± 23.3%; n = 61	62.0 ± 36.2%; n = 49
Emergence success; n = # clutches	64.2 ± 26.1%; n = 33	39.1 ± 26.6%; n = 61	56.9 ± 36.7%; n = 49

Curtis Island Tables

Table 3.1. Summary of flatback turtle, *Natator depressus*, tagging census at Curtis Island during the entire 2017-2018 breeding season.

	Flatback turtles	Loggerhead turtles	Green turtles
First time tagged	9	0	2
Remigrant recaptures			
With tags	32	0	1
With tag scars only	1	0	0
Change of colony within 2017-18 season	0	0	0
Change of colony between breeding seasons	1	1	1
Total turtles	**43**	**1**	**4**

Table 3.2. Size of nesting female flatback turtles, *Natator depressus*, at Curtis Island during the entire 2017-2018 breeding season.

	Curved carapace length (cm)			
	Mean	**SD**	**Range**	**N**
Flatback turtles				
First time tagged females	90.95	3.571	85.6-95.1	8
Remigrant females	94.7	2.200	89.6-97.5	30
All females for season	93.84	2.897	85.6-97.5	40
Green turtles				
All females for season	106.4	6.600	98.2-113.3	4
Loggerhead turtles				
All females for season	99.5	-	-	1

Table 3.3. Flatback turtle, *Natator depressus*, clutches, nest descriptions and within season nesting return intervals, at Curtis Island for the entire 2017-2018 breeding season.

	Mean	SD	Range	N
Curtis Island				
Eggs per clutch	51.61	9.983	31-71	31
Yolkless eggs per clutch	0.06	0.250	0-1	31
Multiyolked eggs per clutch	0.10	0.301	0-1	31
Renesting interval (d), following a successful oviposition	15.45	1.864	13-20	11
Return interval (d), following an unsuccessful nesting attempt	0.92	1.188	0-4	13
Nest depth, top (cm)	47.18	8.792	20-60	111
Nest depth, bottom (cm)	55.43	7.556	43-70	28
Egg diameter (mean) (cm)	5.11	0.136	4.82-5.49	140 (14 clutches)
Egg weight (g)	75.23	5.004	63.22-88.87	140 (14 clutches)

Table 3.4. Incubation period, incubation success, and emergence success for undisturbed flatback (*Natator depressus*), green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) turtle clutches at Curtis Island. An undisturbed clutch is defined as one that was not flooded, eroded, or predated by foxes or dogs. Mid-season census and entire season data are included.

	Mean	SD	Range	N
Flatback turtles				
Incubation period (oviposition to emergence)				
• census (d)	47.5	1.704	44-52	32 clutches
• entire season (d)	49.2	3.863	43-60	85 clutches
Success of undisturbed clutches				
• Incubation success, census (%)	74.66	18.973	28.6-100	33 clutches
• Incubation success, entire season (%)	77.04	23.161	0-100	145 clutches
• Emergence success, census (%)	64.16	26.106	19.72-100	33 clutches
• Emergence success, entire season (%)	71.34	27.490	0-100	145 clutches
Success of clutches disturbed by roots				
• Incubation success, entire season (%)	77.46	15.06	51.7-100	13 clutches
• Emergence success, entire season (%)	75.56	16.66	51.7-100	9 clutches
Green turtles				
Incubation period (oviposition to emergence) (d)	54.2	6.723	47-61	5 clutches
Incubation success (%)	78.33	23.656	33.3-100	12 clutches
Emergence success (%)	74.9	23.361	33.3-100	12 clutches
Loggerhead turtles				
Incubation period (oviposition to emergence) (d)	61.5	0.707	61-62	2 clutches
Incubation success (%)	43.61	34.878	6.82-88.33	5 clutches
Emergence success (%)	39.36	33.273	1.52-81.67	5 clutches

Peak Island Tables

Table 4.1. Tagging history of flatback turtles, *Natator depressus*, recorded nesting at Peak Island during the two-week census period, 24 November to 7 December 2017.

Tagging history of turtles	# turtles
First time tagged females (Primary tagged turtles)	17
Recaptures from past nesting seasons at Peak Island	
• Recaptured with tags previously recorded at Peak Island	137
• Recaptured with tag scars only, previously applied tags lost	3
• Recaptured with tags from a different colony between breeding seasons	1
TOTAL	158

Table 4.2. Nightly count of turtle tracks, clutches laid and emerged clutches of flatback turtles, *Natator depressus*, at Peak Island during the two-week census

Date	# tracks	# turtles	# clutches laid	# emerged clutches
24 Nov 2017	25		17	0
25 Nov 2017	5		4	0
26 Nov 2017	16		11	0
27 Nov 2017	20		15	0
28 Nov 2017	8		4	0
29 Nov 2017	10		9	0
30 Nov 2017	2		1	0
1 Dec 2017	33		21	0
2 Dec 2017	5		5	0
3 Dec 2017	12		11	0
4 Dec 2017	22		14	0
5 Dec 2017	14		8	0
6 Dec 2017	39		26	1
7 Dec 2017	21		11	1
Total	232	158	157	2
Mean (S.D)	16.6 ± 10.8	11.29	11.2 ± 6.97	4

Table 4.3. Summary of CCL measurements and remigration intervals of nesting flatback turtles, *Natator depressus*, at Peak Island during the 24 November to 7 December 2017 census period.

	Mean	Std. Dev.	Min	Max	N
	Curved Carapace Length (cm)				
1st breeding season (primary taggings)	92.5	2.31	89.0	96.6	12
All remigrant turtles	94.1	2.93	85.8	103.2	135
All Turtles	93.9	2.90	85.8	103.2	152
	Remigration Interval (yr)				
All remigrant turtles	2.84	1.23	2	8	137

Table 4.4. Flatback turtle, *Natator depressus*, clutches, and nest descriptions at Peak Island, 2017-2018 breeding season.

	Mean	Std. Dev.	Range	N
Eggs per clutch	52.0	8.739	37-70	17
Yolkless eggs per clutch	0.12	0.485	0-2	17
Multiyolked eggs per clutch	0	0	0	17
Nest depth, top (cm)	34.5	6.356	24-45	16
Nest depth, bottom (cm)	53.8	5.747	44-62	17
Egg diameter (cm)	5.14	0.164	4.72-5.54	170 (17 clutches)
Egg weight (g)	75.1	6.23	58.6-91.5	170 (17 clutches)
Eggs/clutch dug from an existing clutch by a nesting turtle	10.9	10.08	1-36	10

Table 4.5. Incubation period Incubation and emergence success and for Flatback turtle, *Natator depressus*, clutches at Peak Island during 24 November – 7 December 2017.

	Mean	Std. Dev.	Range	N
Incubation period (oviposition to emergence) (days)	47.8	2.717	45-59	32
Clutches laid during mid-season census period				
• Hatching success (%)	55.9	23.33	8.16-97.9	61 clutches
• Emergence success (%)	39.1	26.57	0-93.02	61 clutches
Clutches laid mostly outside the mid-season census period				
• Hatching success (%)	64.4	25.50	5.0-97.4	73 clutches
• Emergence success (%)	53.4	31.22	0-97.	73 clutches
Pooling data for all clutches examined				
• Hatching success (%)	60.5	24.81	5.0-97.92	134 clutches
• Emergence success (%)	46.9	29.96	0-97.4	134clutches

Avoid Island Tables

Table 5.1 Nightly census of nesting flatback turtles, *Natator depressus*, at Avoid Island during 26 November – 9 December 2017 (14 nights): nightly track count, observed turtles, observed clutches laid and clutches of hatchlings emerging with mean ± SD calculations.

Date	# tracks	# turtles	# clutches laid	# Emerged clutches
26 Nov	12	5	6	0
27 Nov	21	18	14	1
28 Nov	5	4	2	0
29 Nov	8	5	3	0
30 Nov	5	5	4	0
01 Dec	7	6	5	0
02 Dec	3	3	3	0
03 Dec	1	1	0	0
04 Dec	8	7	6	0
05 Dec	4	3	3	3
06 Dec	7	7	7	0
07 Dec	5	5	5	1
08 Dec	0	0	0	1
09 Dec	0	0	0	1
Total	85	-	57	7
Mean ± SD	6.1 ± 5.4	4.9 ± 4.3	4.1 ± 3.7	0.50 ± 0.82

Table 5.2. Summary of curved carapace length measurements, remigration intervals, renesting intervals, and clutches laid per nesting flatback turtle, *Natator depressus*, at Avoid Island during the 2017-2018 breeding season.

	Mean	Std. Dev.	Range	N
Curved carapace length (cm)				
• 1st breeding season	91.4	2.1	88.5-95.1	13
• known remigrant turtles	93.3	2.9	85.5-100.2	51
All turtles	92.9	2.9	85.5-100.2	64
Remigration interval (yr)				
• entire monitoring period	2.6	0.96	1-5	53
Re-nesting interval (d)				
• following an unsuccessful nesting attempt	1.07	1.03	0-3	15
• following a successful nesting	13.8	0.83	13-16	12

Table 5.3. Summary of clutch and nest data for flatback turtle, *Natator depressus*, at Avoid Island during the 2017-2018 census period.

	Mean	Std. Dev.	Range	N
Eggs per clutch-on laying	49.7	6.9	41-50	3
Egg diameter (cm) – at laying	5.2	0.08	5.1-5.3	30 eggs (3 clutches)
Egg weight (g) – at laying	78.8	2.1	75.4-82.4	30 eggs (3 clutches)
Eggs per clutch-on emergence	48.5	8.2	29-67	48
Yolkless eggs per clutch- on emergence	0.16	0.74	0-5	48
Multiyolk eggs per clutch- on emergence	0	0	0	48
Nest depth, bottom (cm)-on emergence	59.6	9.0	44-97	48

Table 5.4. Summary incubation period to emergence, hatching success and hatchling emergence success for flatback turtle, *Natator depressus*, clutches at Avoid Island during the 2017-2018 census period

	Mean	Std. Dev.	Range	N
Incubation period (period to emergence) (d)				
• Entire monitoring	46.7	1.25	45 - 48	7
Success from clutches laid during mid-season census				
• Incubation success (%)	62.03	36.236	0 - 98.2	49
• Emergence success (%)	56.86	36.715	0 - 98.2	49
Success of clutches impacted across the entire season				
• Incubation success (%)	69.19	31.914	0 - 100	125
• Emergence success (%)	64.71	33.162	0 - 100	125
Success of clutches submerged by high tide/storm surge				
• Incubation success (%)	2.3	4.17	0 - 12	9
• Emergence success (%)	2.3	4.17	0 - 12	9

FIGURES

Curtis Island Figures

a. Curtis Island.

b. South End Beach, looking south from Connor's Bluff.

Figure 3.1. Location of South End Beach, Curtis Island, in relation to Gladstone, Port Curtis and Port Alma.

a. Suzuki Grand Vitara (Photograph by Fiona Hoffmann).

b. John Deere Gator Side by Side Utility Vehicle.

Figure 3.2. Vehicles used for transport of monitoring team and their equipment on South End Beach, Curtis Island during the 2017-2018 breeding season.

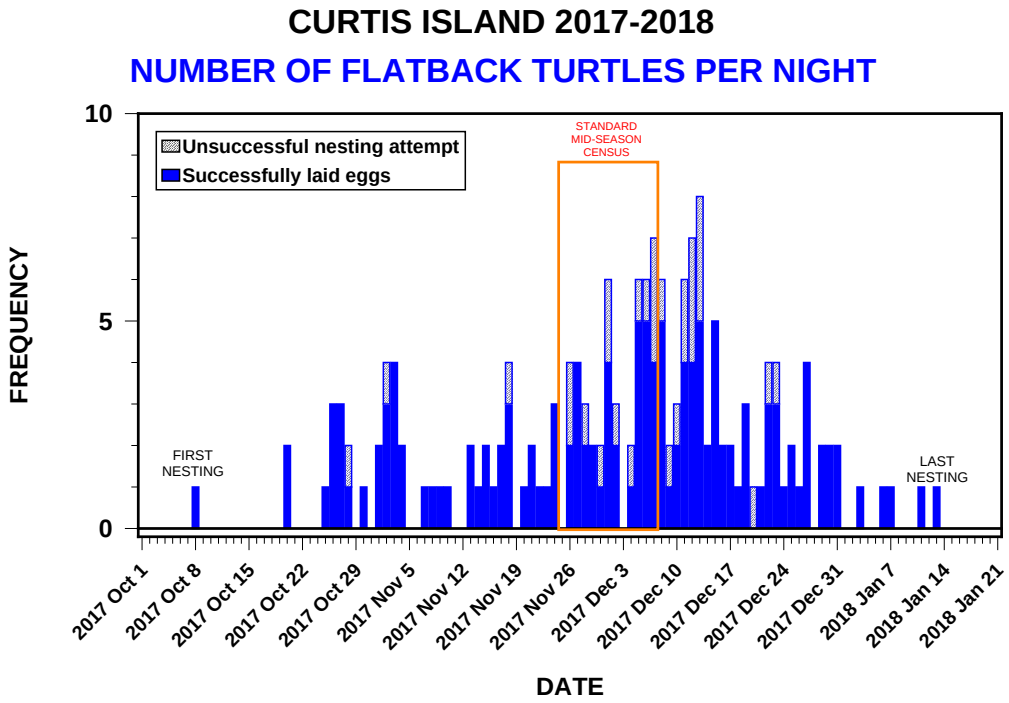
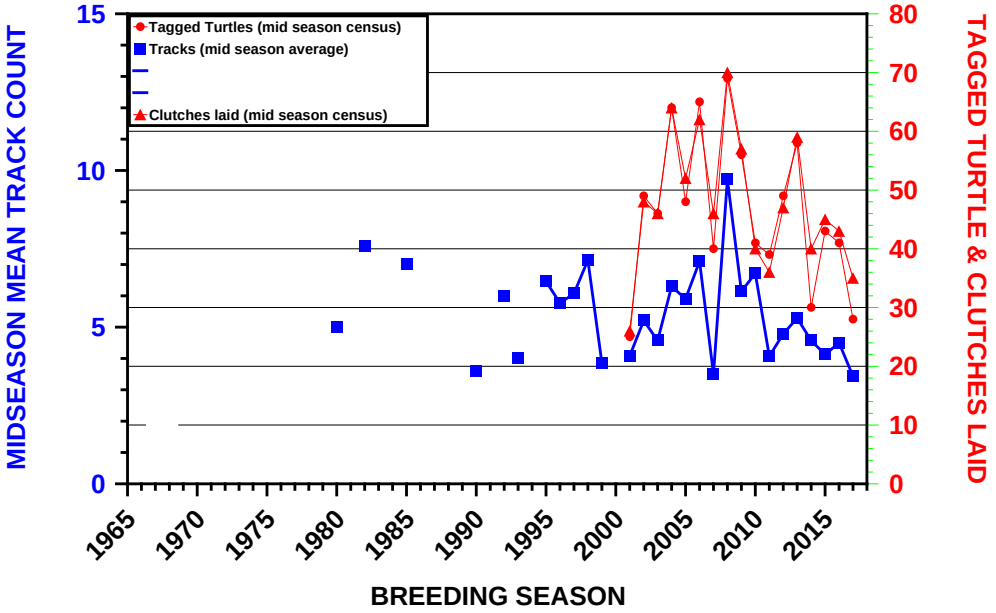
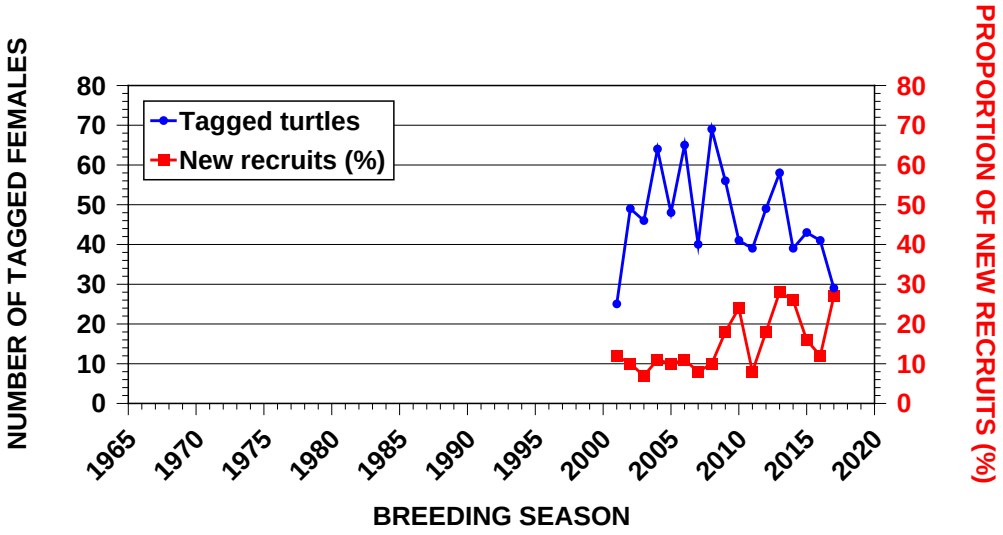


Figure 3.3. Nightly number of flatback turtles, *Natator depressus*, ashore for nesting on South End Beach, Curtis Island during the 2017-2018 nesting season.



a. Yearly comparison of the mean nightly track counts, number of turtles tagged and number of clutches laid. Note that some clutches were laid by turtles that were not encountered.



b. Comparison of numbers of turtles tagged and the proportion of new turtles (recruits) into the annual breeding population.

Figure 3.4. Census of flatback turtle, *Natator depressus*, nesting activity at South End Beach, Curtis Island during the mid-season census population from 1980-2017.

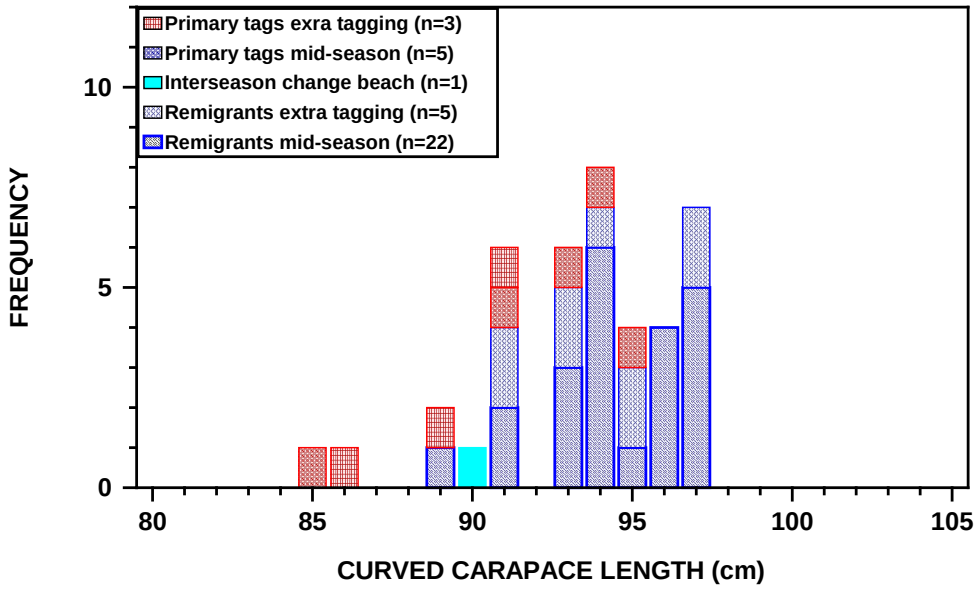


Figure 3.5. Size of nesting flatback turtles, *Natator depressus*, at South End Beach, Curtis Island during the 2017-2018 breeding season.

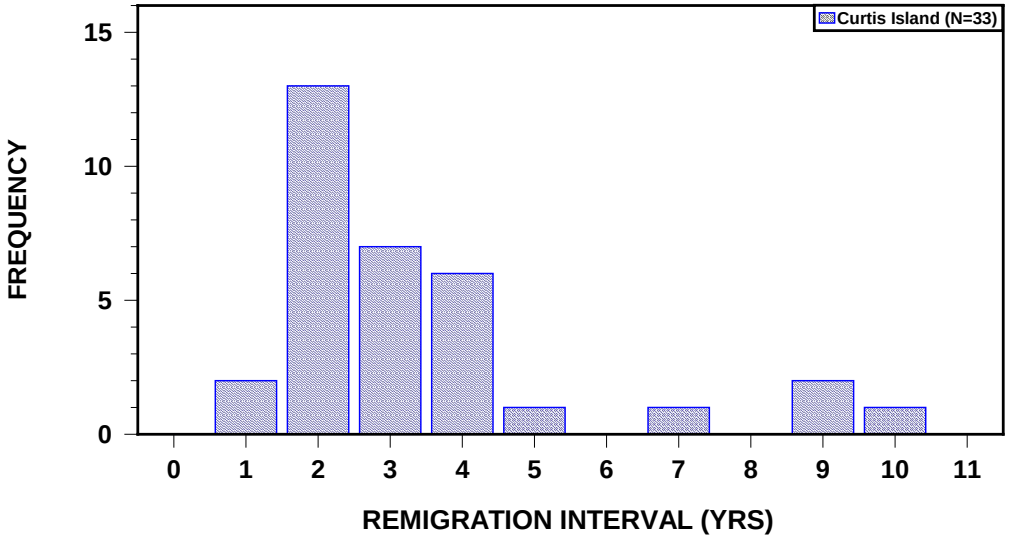


Figure 3.6. Remigration intervals recorded for nesting flatback turtles, *Natator depressus*, at South End Beach, Curtis Island during the 2017-2018 breeding season.

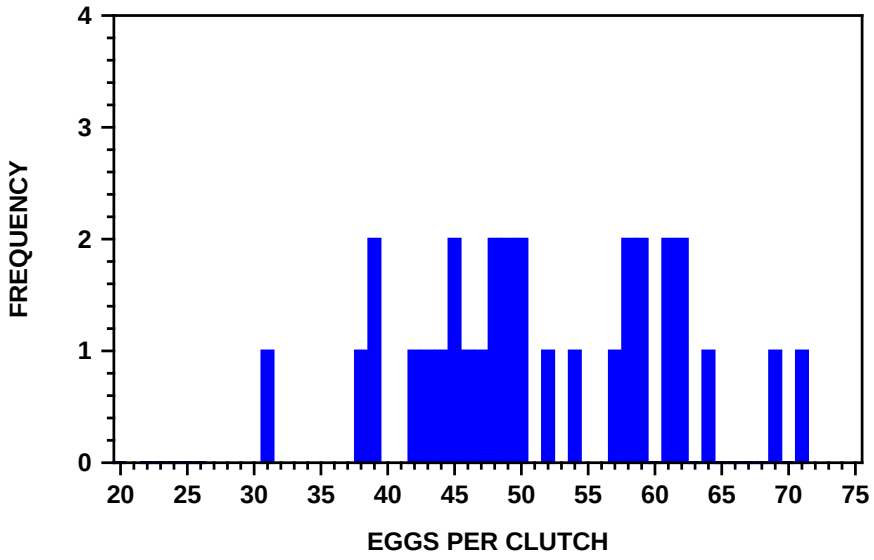


Figure 3.7. Clutch counts recorded for nesting flatback turtles, *Natator depressus*, at South End Beach, Curtis Island during the 2017-2018 breeding season.

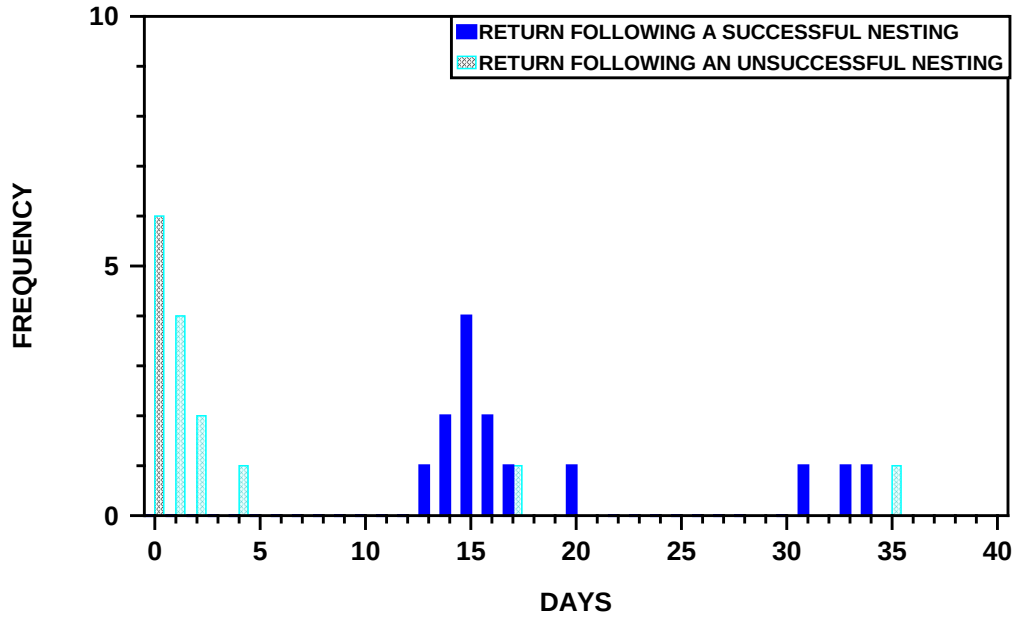
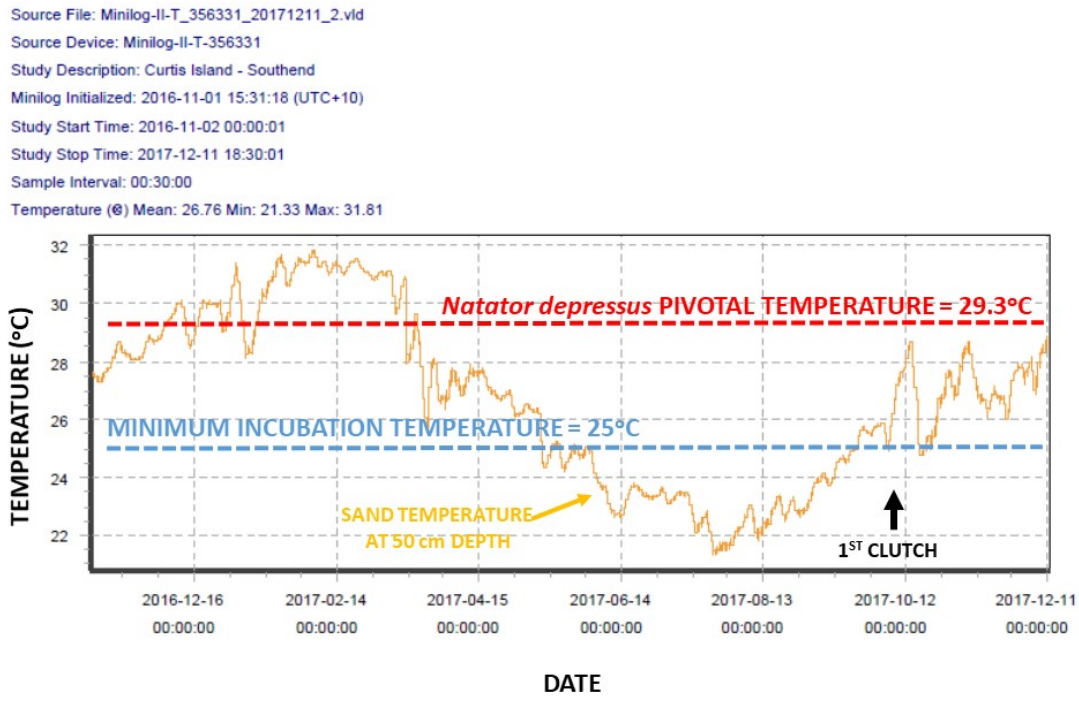
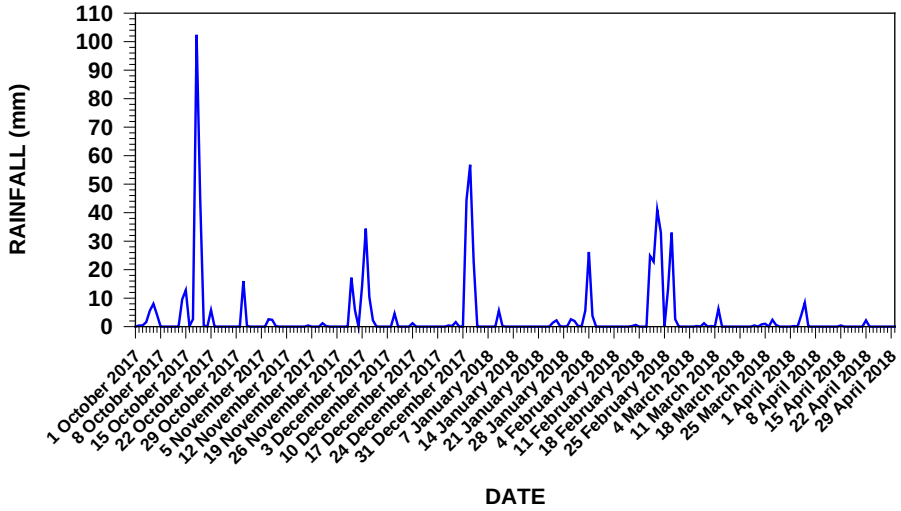


Figure 3.8. Return intervals recorded for nesting flatback turtle, *Natator depressus,* following both successful and unsuccessful nesting attempts at South End Beach, Curtis Island during the 2017-2018 breeding season.



a. Sand temperatures measured at 50 cm depth on the southern end of South End Beach within the turtle nesting habitat in open sun using Vemco Minilog II temperature data logger from 2 November 2016 to 11 December 2017.



b. Summary of daily rainfall data recorded at Gladstone Airport during the 2017-2018 summer turtle nesting season.

Figure 3.9. Summary of sand temperatures at nest depth at South End Beach, Curtis Island and rainfall recorded at Gladstone Airport.

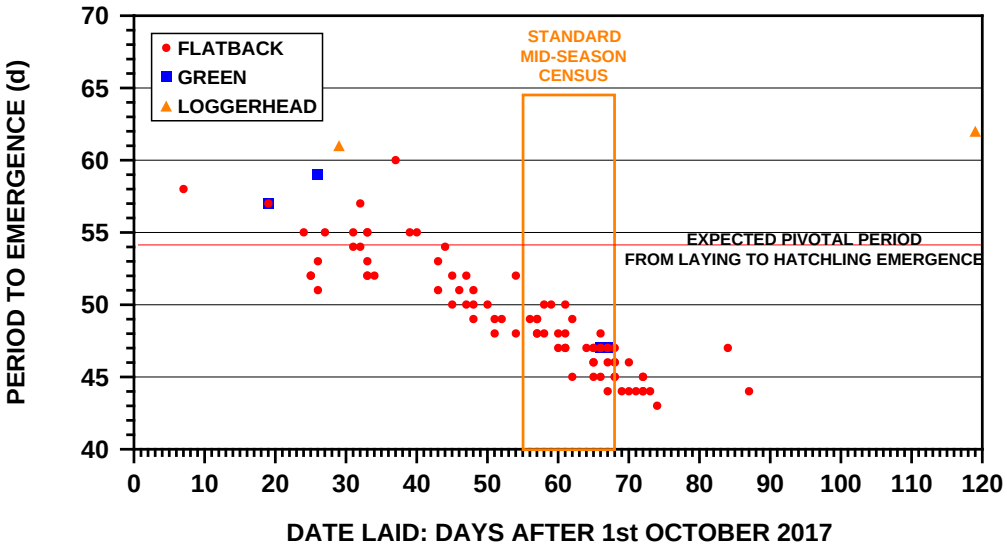


Figure 3.10. Comparison of period to emergence (period from laying to hatchling emergence to the beach surface) for flatback (*Natator depressus*), green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) turtles nesting on South End Beach, Curtis Island, 2017-2018 season.

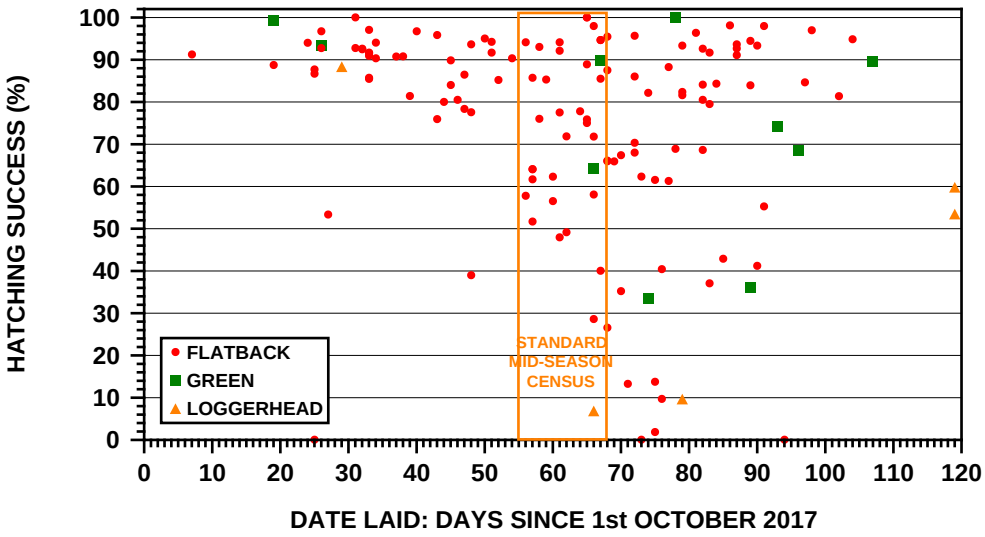


Figure 3.11. Comparison of hatching success (%) for flatback (*Natator depressus)*, green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) turtles nesting on South End Beach, Curtis Island, 2017- 2018 season.

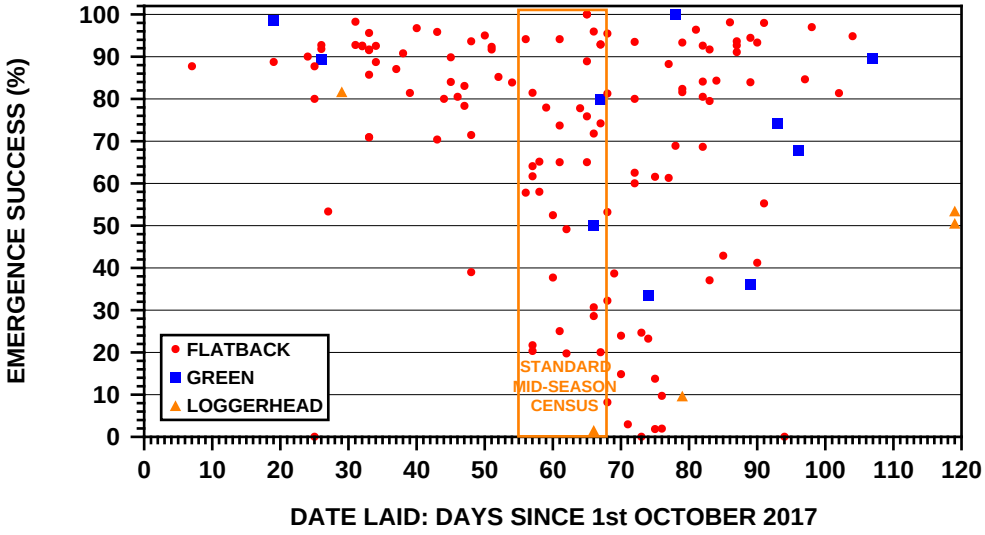
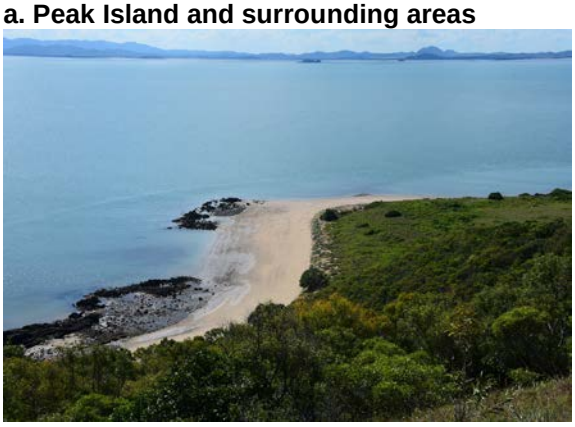


Figure 3.12. Comparison of hatchling emergence success (%) for the 2017-2018 breeding season for flatback (*Natator depressus)*, green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) turtles nesting on Curtis Island.

Peak Island Figures

a. Peak Island and surrounding areas

b. Peak Island



c. View of the nesting beach from near the summit

d. A nesting flatback turtle and the beach profile

e. Peak Island National Park sign

f. Monitoring team camp, Peak Island, January 2018

Figure 4.1. Images of Peak Island, 2017-2018 turtle breeding season.

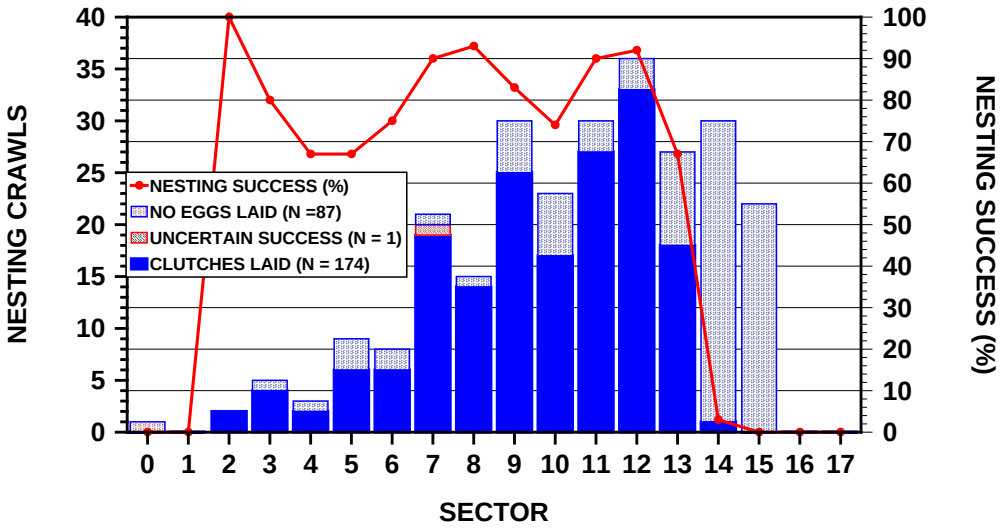


Figure 4.2. Frequency distribution of flatback turtle, *Natator depressus,* nesting crawls (tracks) and nesting success by beach sectors, Peak Island during 24 November – 7 December 2017.

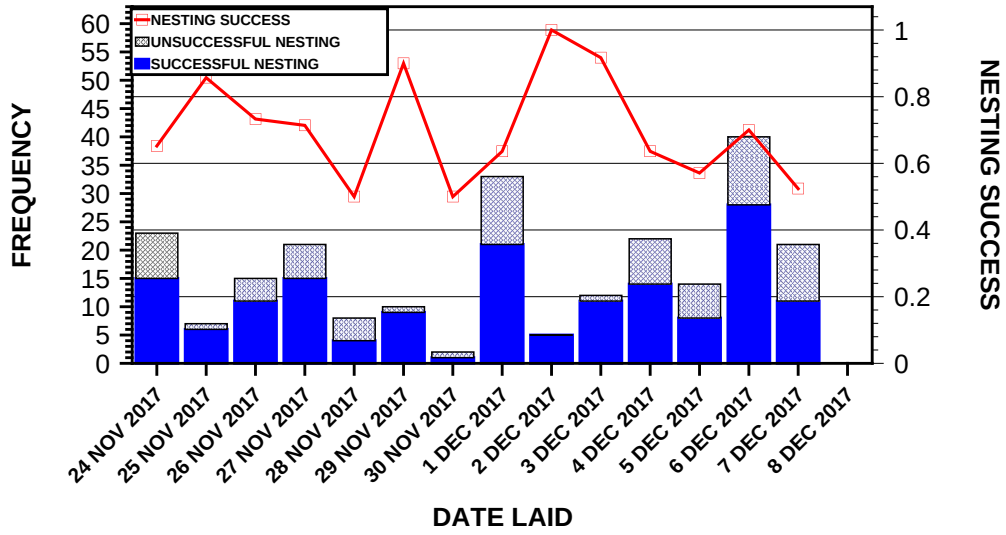


Figure 4.3. Frequency distribution of flatback turtle, *Natator depressus,* nesting crawls (tracks and clutches laid) and nesting success by date, Peak Island during 24 November – 7 December 2017.

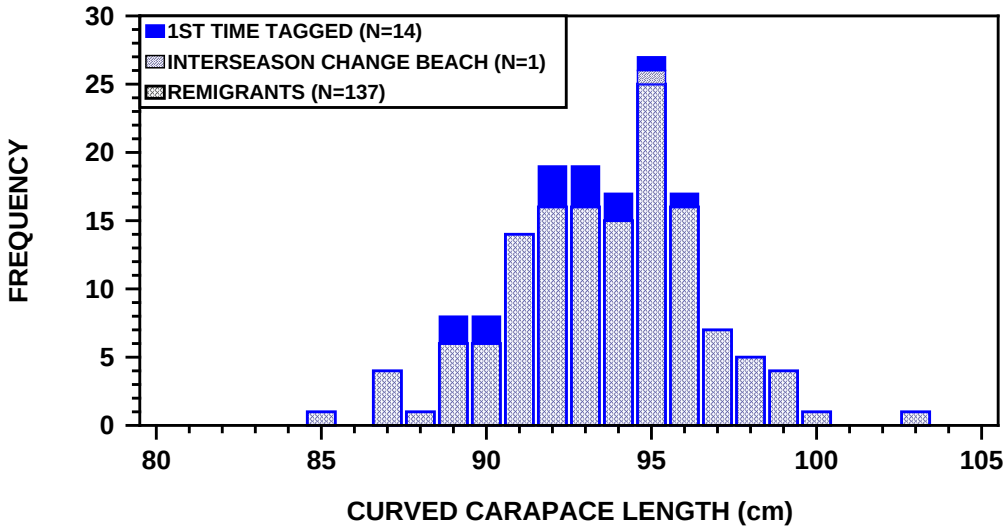


Figure 4.4. Frequency distribution of curved carapace length by breeding experience of flatback turtles, *Natator depressus*, recorded nesting at Peak Island during the 24 November – 7 December 2017.

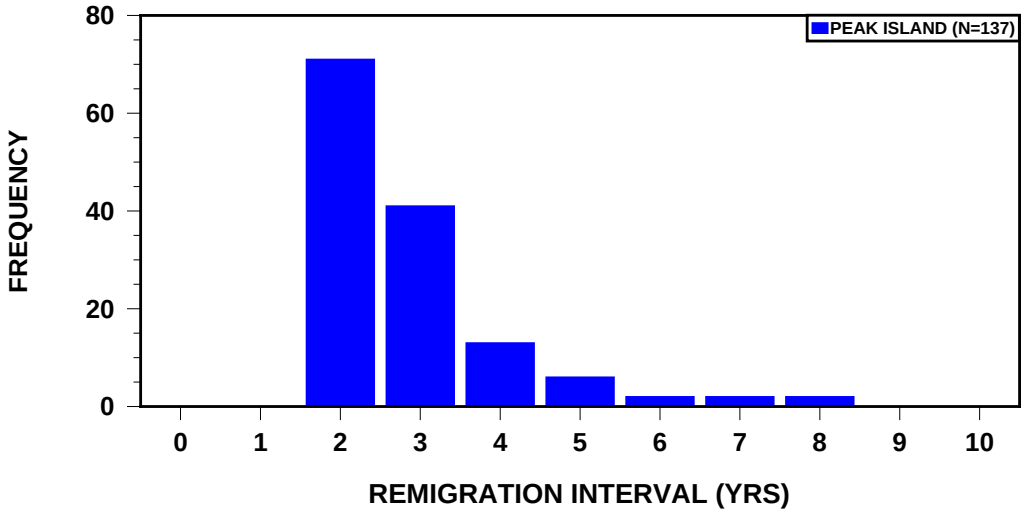


Figure 4.5. Frequency distribution of the number of years between breeding seasons (remigration interval) of flatback turtles, *Natator depressus*, recorded nesting at Peak Island during the 24 November – 7 December 2017.

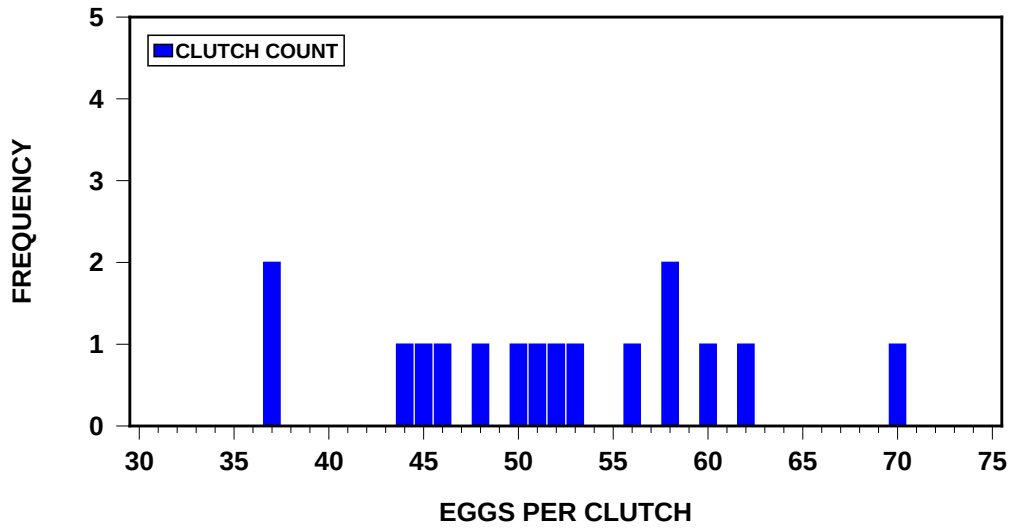


Figure 4.6. Frequency distribution of the number of eggs per clutch of flatback turtles, *Natator depressus*, recorded nesting at Peak Island during the mid-season census period, 24 November – 7 December 2017.

a. Flatback turtle, QA33231, with abrasion exposed bone on the carapace, 27 December 2017.

b. Flatback turtle, Q A85045, with healed fracture to the carapace, 04 December 2017.

c. Flatback turtle, QA33115, with healed bite to the carapace, 04 December 2017. This injury probably occurred when the turtle was very young.

d. Flatback turtle, QA85053, with healed bite to the carapace, 06 December 2017.

e. Hatchlings that died while crossing the beach following a day light emergence of hatchlings, 25 January 2018.

f. Death of a hatchling following entrapment in roots that had invaded the nest, 22 January 2018.

Figure 4.7. Images of carapace damage on nesting flatback turtles at Peak Island, December 2017 and of hatchling mortality during January 2018.

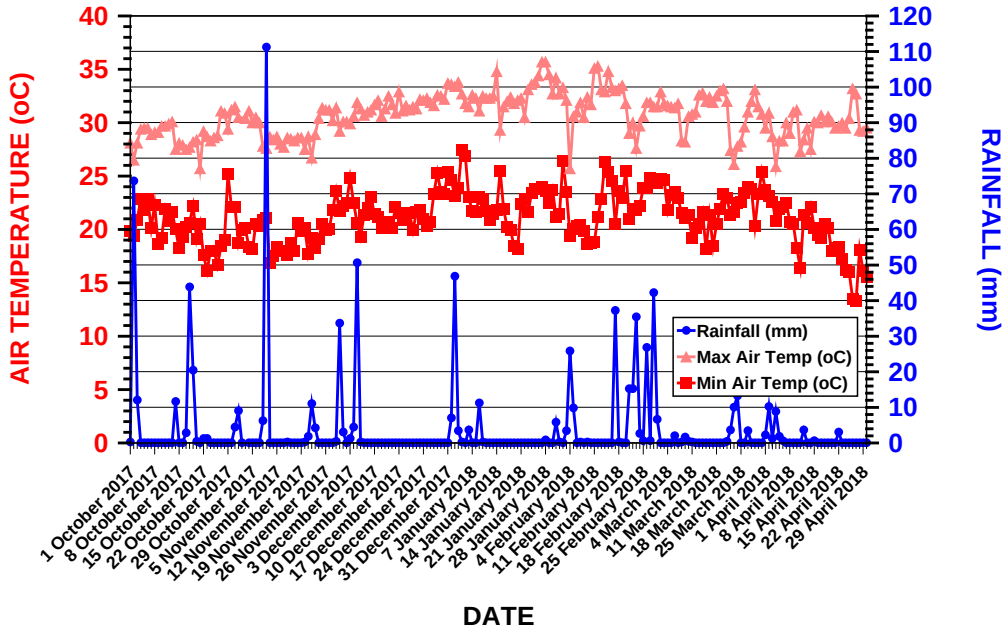


Figure 4.8. Daily rainfall and air temperatures recorded at Yeppoon and Rosslyn Bay during the 2017-2018 flatback turtle, *Natator depressus,* breeding season.

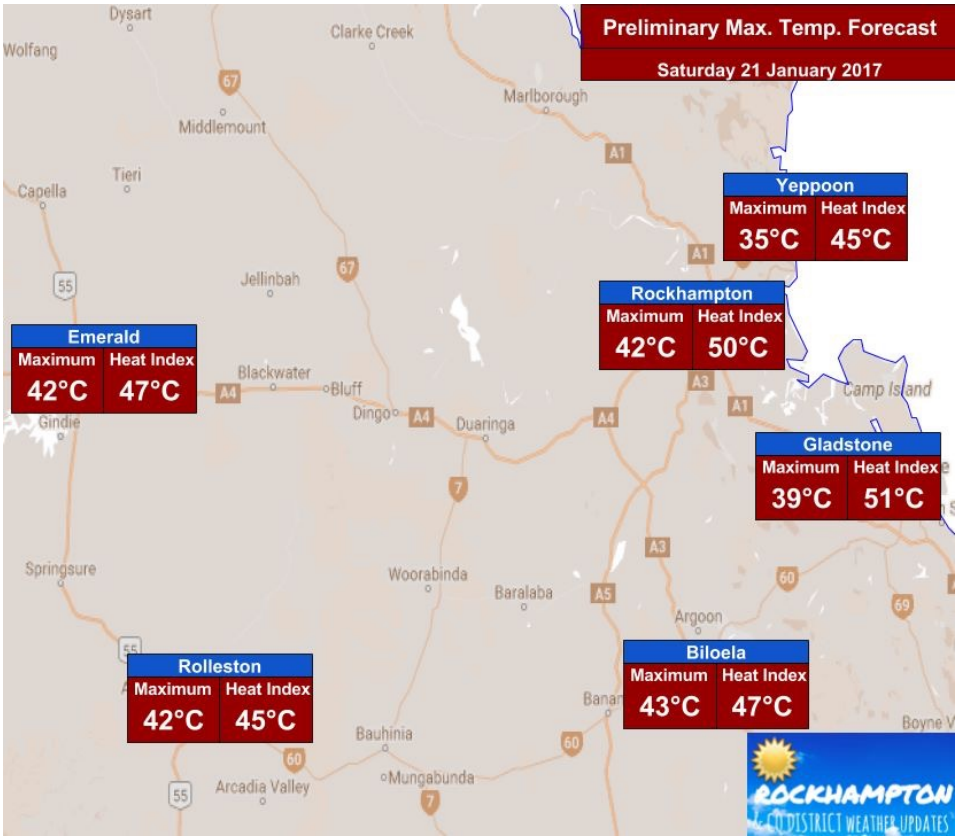


Figure 4.9. Portion of the weather summary for the Rockhampton region on 21 January 2018 during a period of extremely hot weather.

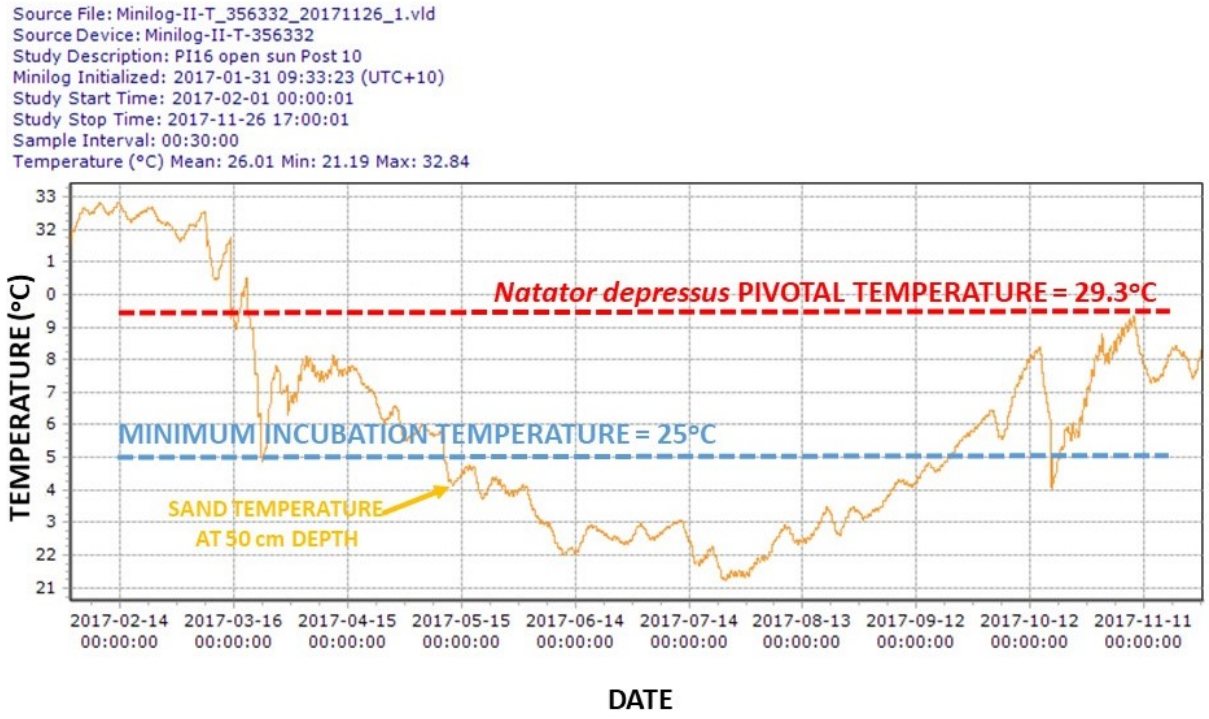
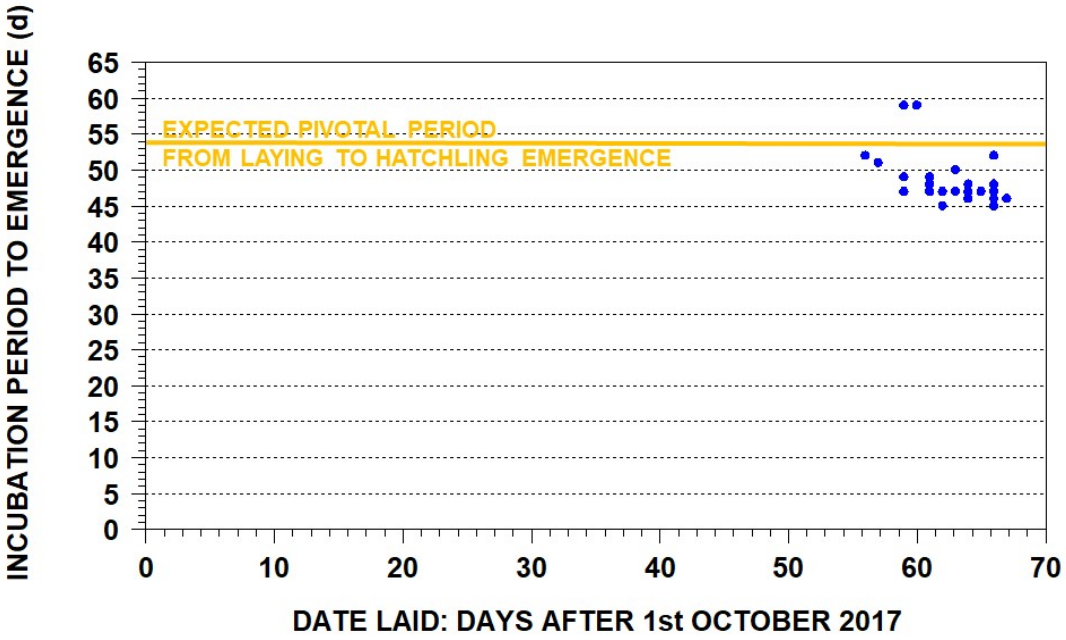
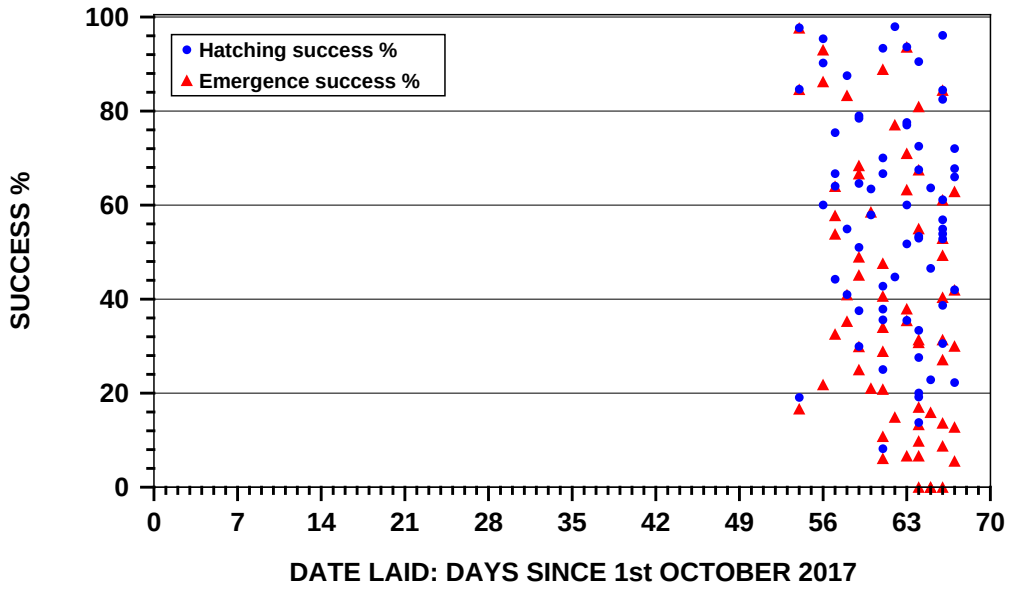


Figure 4.10. Sand temperatures measured at 50 cm depth on the southern end of South End Beach within the turtle nesting habitat in open sun using Vemco Minilog II temperature data logger from 1 February to 26 November 2017.



A. Incubation period, n = 33



B. Hatching and emergence success, n = 65

Figure 4.11. Incubation period (A) and hatching and emergence success (B) for flatback turtle, *Natator depressus*, clutches recorded when laid on Peak Island during the mid-season census period, 24 November to 7 December 2018.

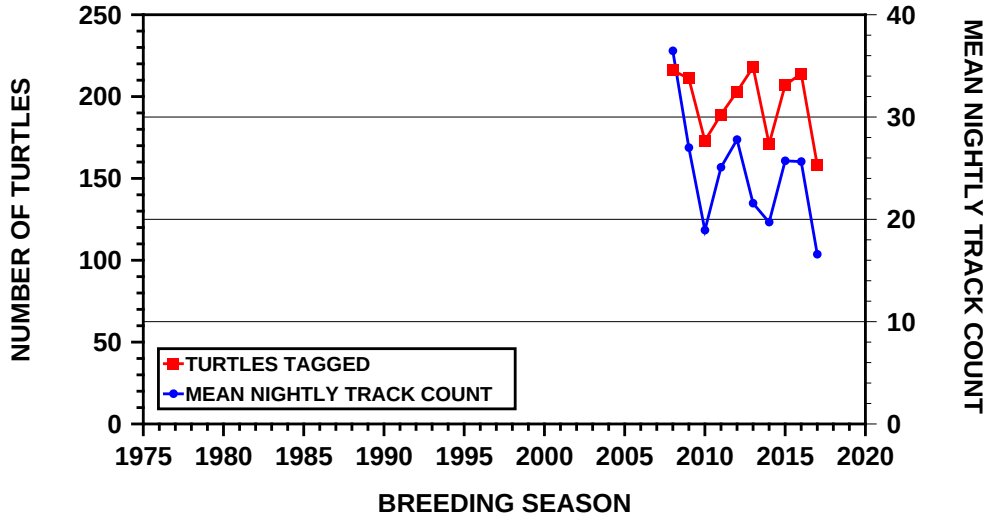


Figure 4.12. Trends in the number of nesting female flatback turtles, *Natator depressus*, tagged during the annual two-week mid-season census (last week of November – first week of December) and the associated mean number of nesting crawls per night during the same period at Peak Island, 2008 to 2017.

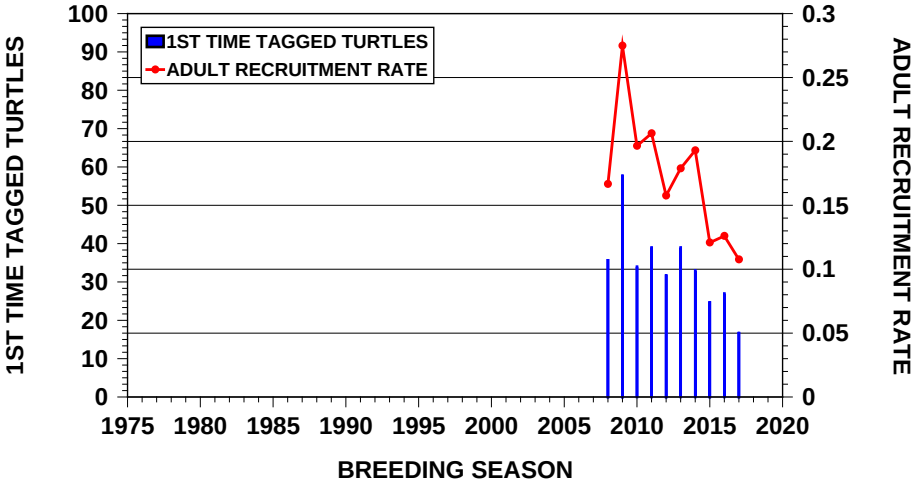


Figure 4.13. Trends in the annual recruitment of new female flatback turtles, *Natator depressus*, to the nesting population at Peak Island, 2008 to 2017 breeding seasons.

Avoid Island Figures

Figure 5.1. Turtle nesting beaches and infrastructure locations at Avoid Island.

a. Remnant dead trees from cyclone damage in recent years, sector 2.

b. Remnant dead trees from cyclone damage in recent years, sector 17. Illustration of new sector numbering.

c. Access to dune nesting habitat, sector 42.

d. Recovery of sand onto the beaches to form a berm along portions of South Beach has created a swale at the base of the dune slope that floods during higher tides.

Figure 5.2. Images illustrating beach habitats at Avoid Island during the 2017-2018 breeding season.

Figure 5.3. Locations of multi-year temperature data loggers in sunny (upper left) and shaded (upper right) flatback turtle, *Natator depressus* nesting locations on the first dune slope, and on the beach slope in a sunny (lower left) and shaded (lower right) locations at Avoid Island.

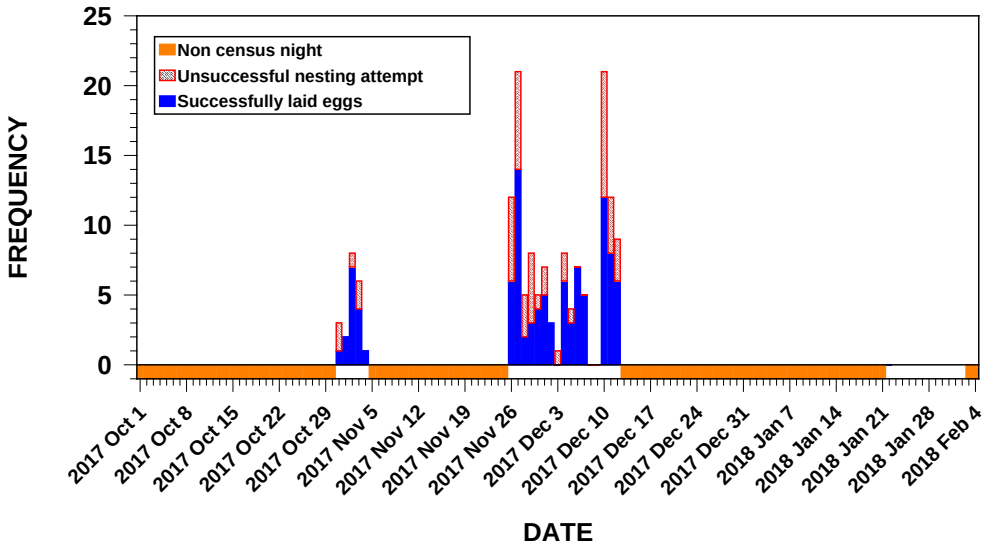


Figure 5.4 Nightly number of track from flatback turtle, *Natator depressus*, nesting on Avoid Island during the 2017-2018 breeding season.

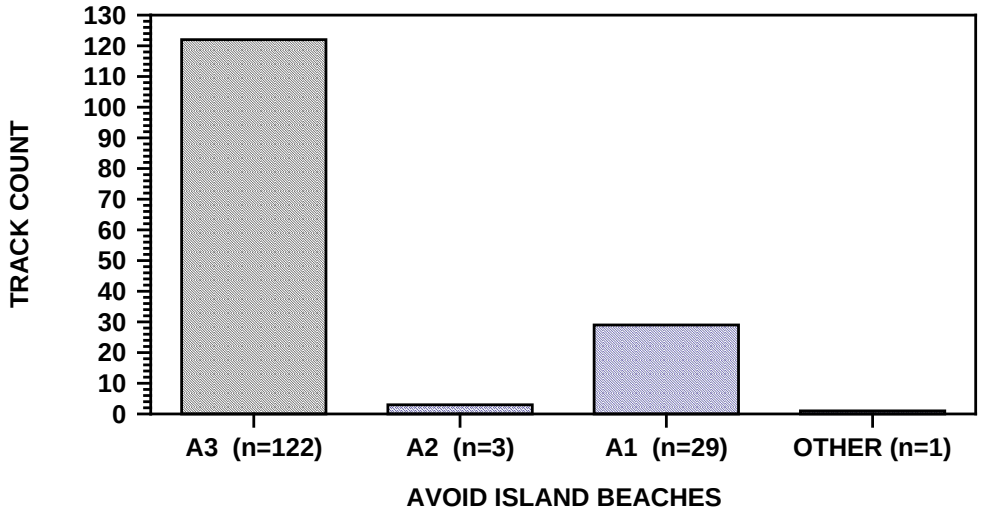


Figure 5.5. Frequency distribution of nesting crawls (tracks) and nesting success of flatback turtles, *Natator depressus*, by beach at Avoid Island during the 2017-2018 breeding season. A1 = North Beach, A2 = Middle Beach, A3 = South Beach.

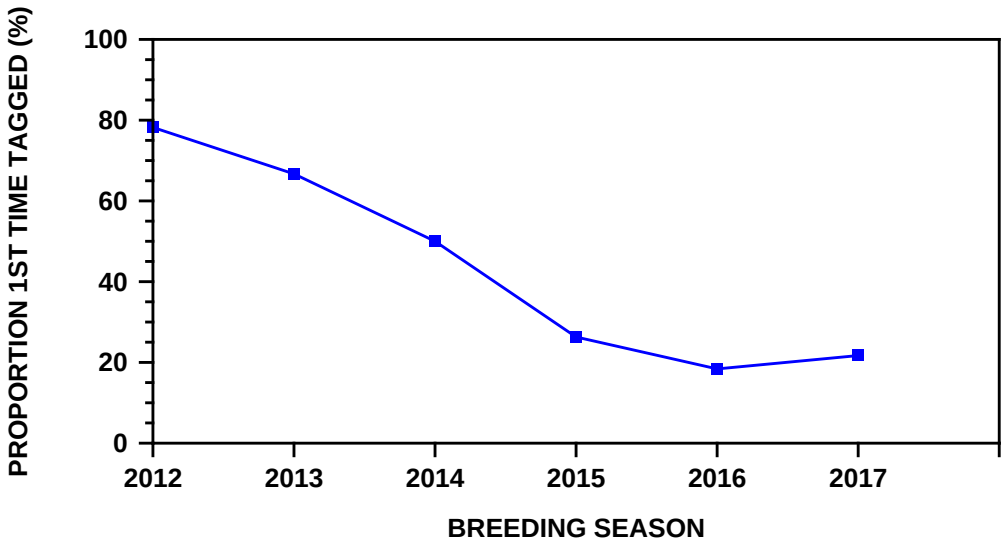


Figure 5.6. Long term trend in the proportion of first time tagged nesting flatback turtles at Avoid Island: 2012-2013 (FitzSimmons, 2013), 2013-2014 (FitzSimmons and Limpus, 2014), 2014-2015 (FitzSimmons and Limpus, 2015), 2015-2016 (FitzSimmons and Limpus, 2016), 2016-2017 (Limpus *et al*. 2017).

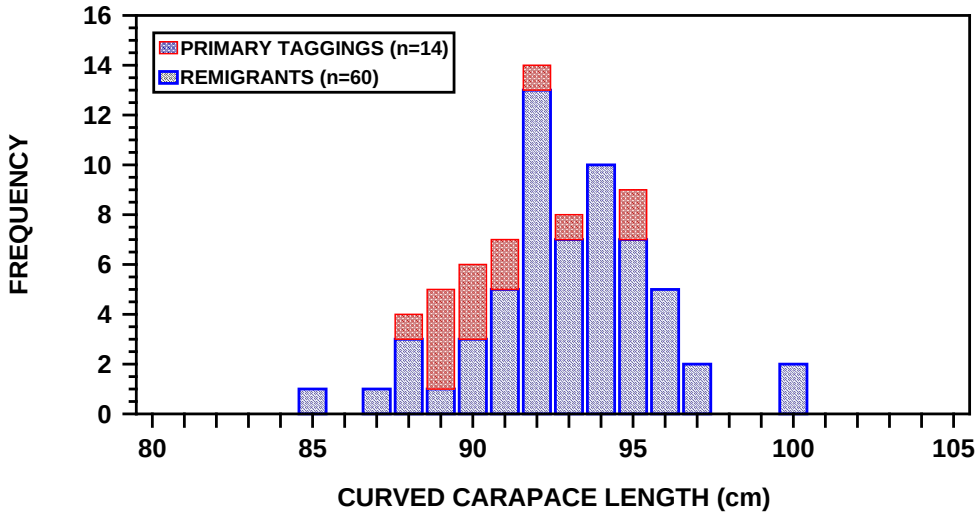


Figure 5.7. Size frequency distribution of nesting flatback turtles, *Natator depressus*, at Avoid Island during the 2017-2018 breeding season.

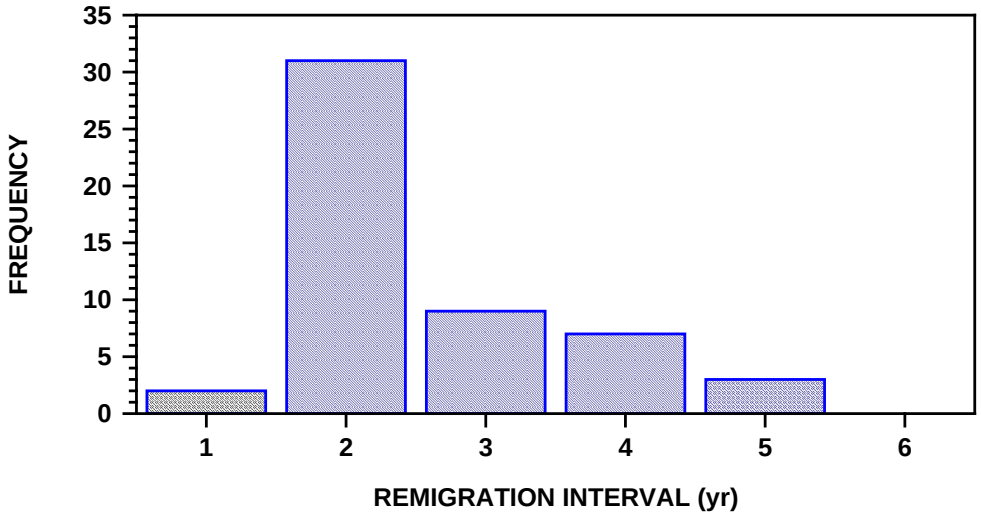


Figure 5.8. Frequency distribution of remigration interval for flatback turtles, *Natator depressus*, at Avoid Island during the entire 2017-2018 breeding season.

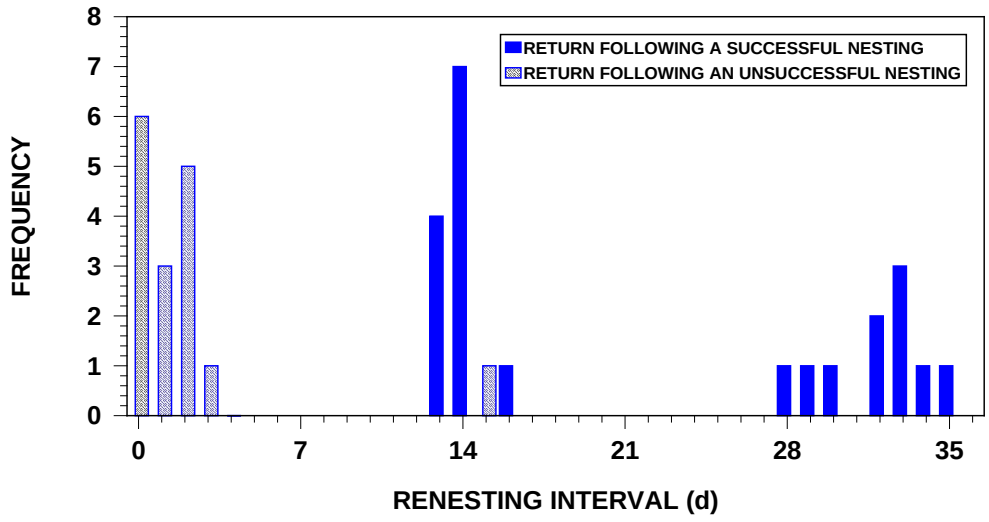


Figure 5.9. Return intervals recorded for nesting flatback turtle, *Natator depressus,* following both successful and unsuccessful nesting attempts at Avoid Island during the 2017-2018 breeding season.

a. **Adult female flatback turtle, QA35855, with recent fracture to the right side of the carapace, 26 November 2017. This injury and the healed fracture at the front of the carapace had occurred since her last recorded nesting in the 2013-2014 season.**

b. **Adult female flatback turtle, QA37477, with old healed propeller damage to the rear of carapace, 4 November 2017.**

Figure 5.10. Example of carapace injuries from anthropogenic sources with nesting flatback turtles at Avoid Island, 2017-2018 breeding season.

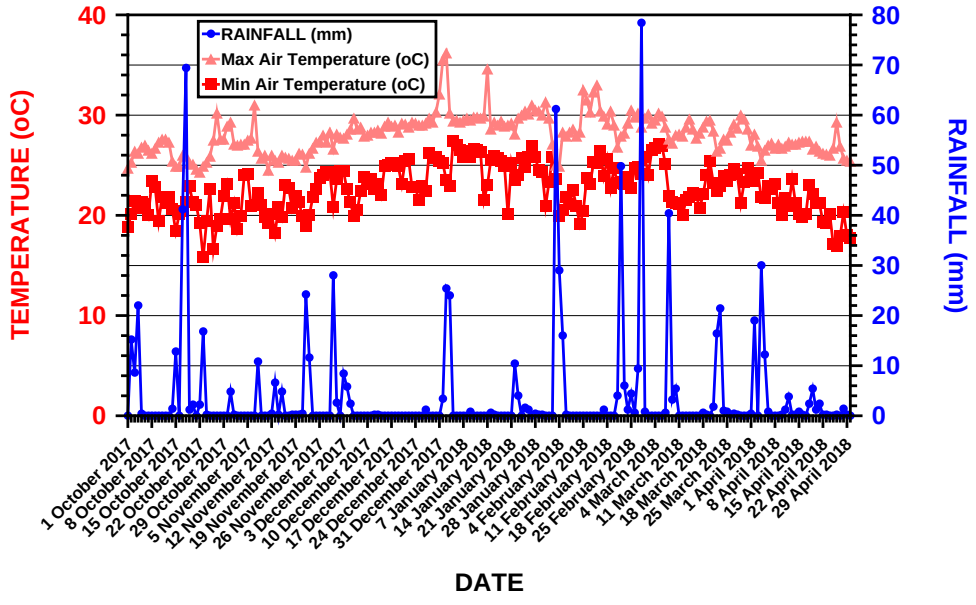


Figure 5.11. Daily rainfall and air temperatures recorded at St Lawrence during the 2017-2018 flatback turtle, *Natator depressus*, breeding season.

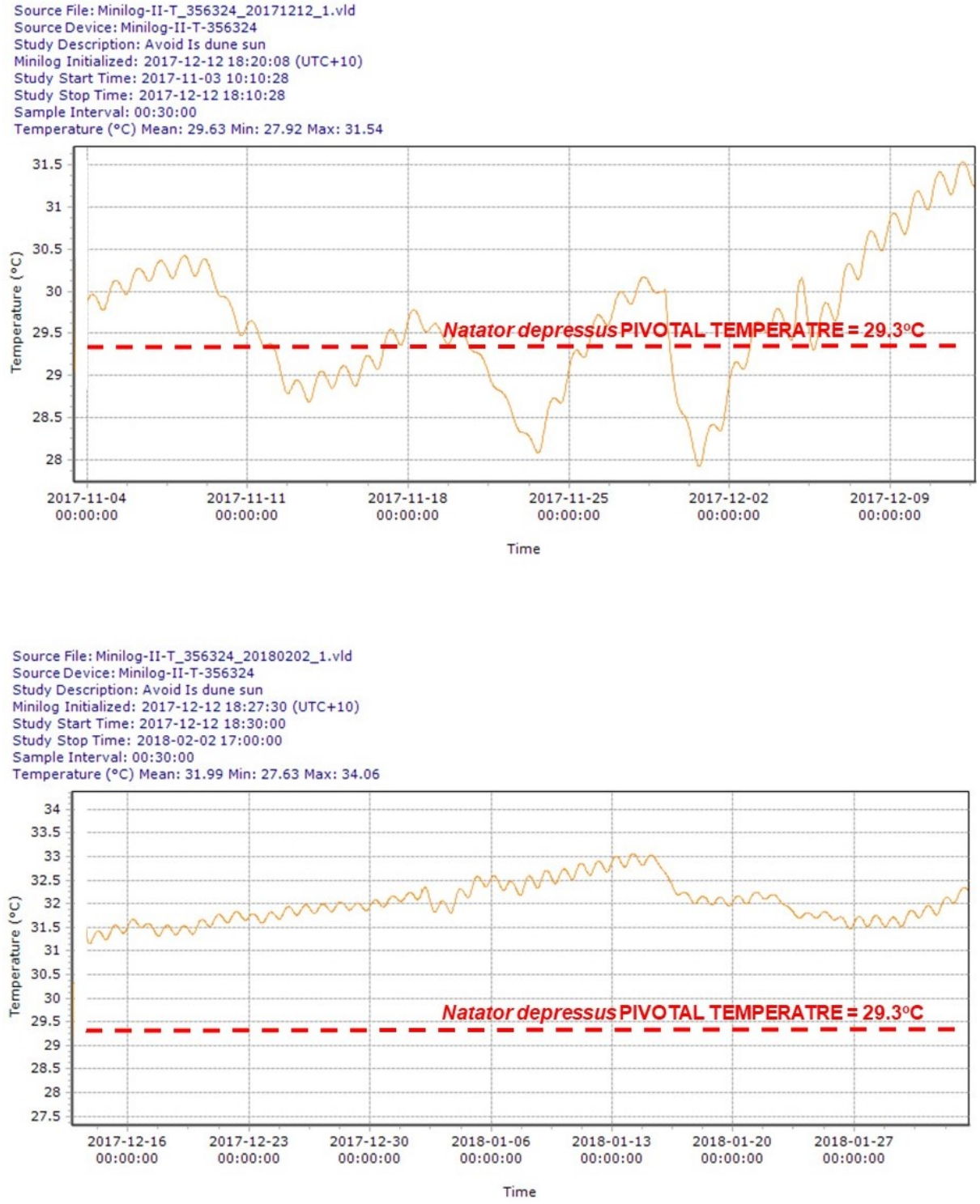
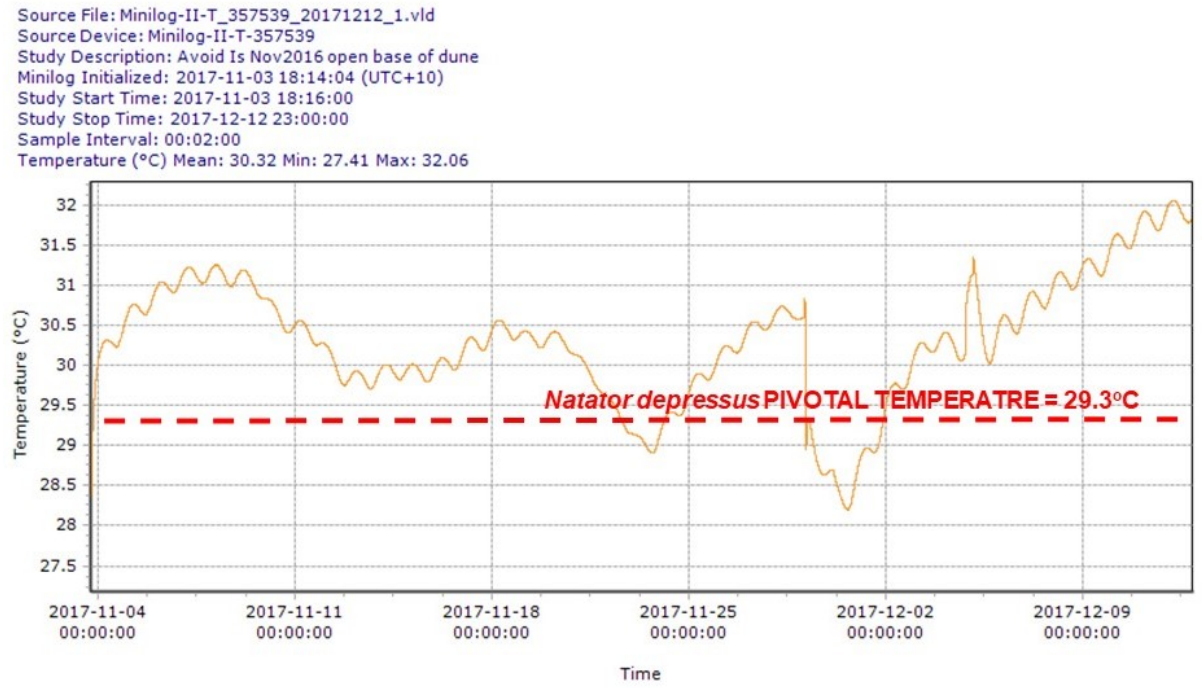


Figure 5.12a. Sand temperature records (2 graphs) from an open sunny area on the dune crest, sector 41, Avoid Island, 12 December 2017 – 21 February 2018.



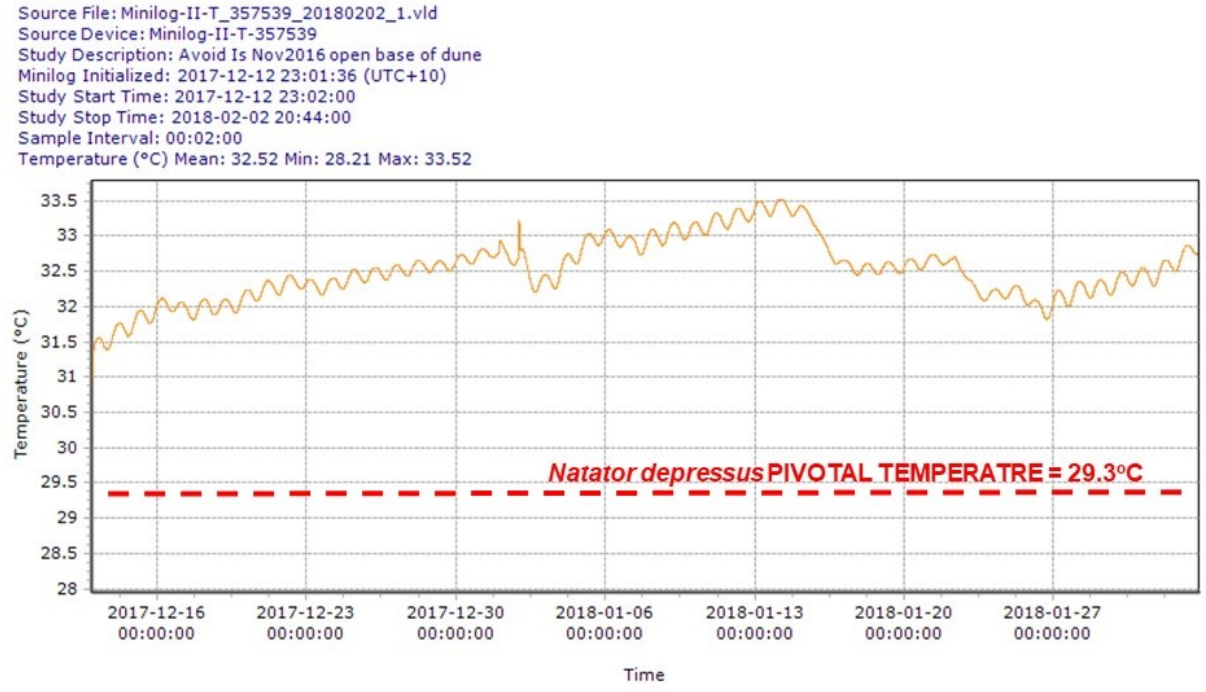


Figure 5.12b. Sand temperature records (2 graphs) from an open sunny area on the beach platform, sector 13, Avoid Island, 3 November 2017 – 21 February 2018.

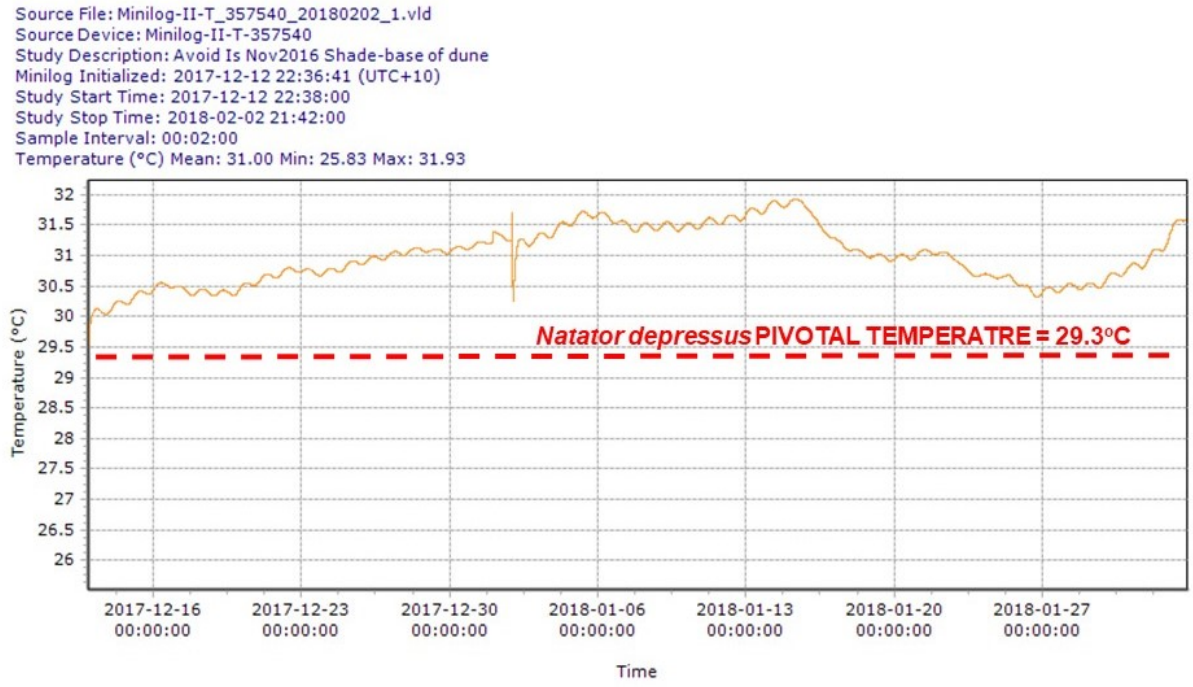


Figure 5.12c. Sand temperature records from a shaded area on the beach platform, sector 27, Avoid Island, 12 December 2017 – 21 February 2018.

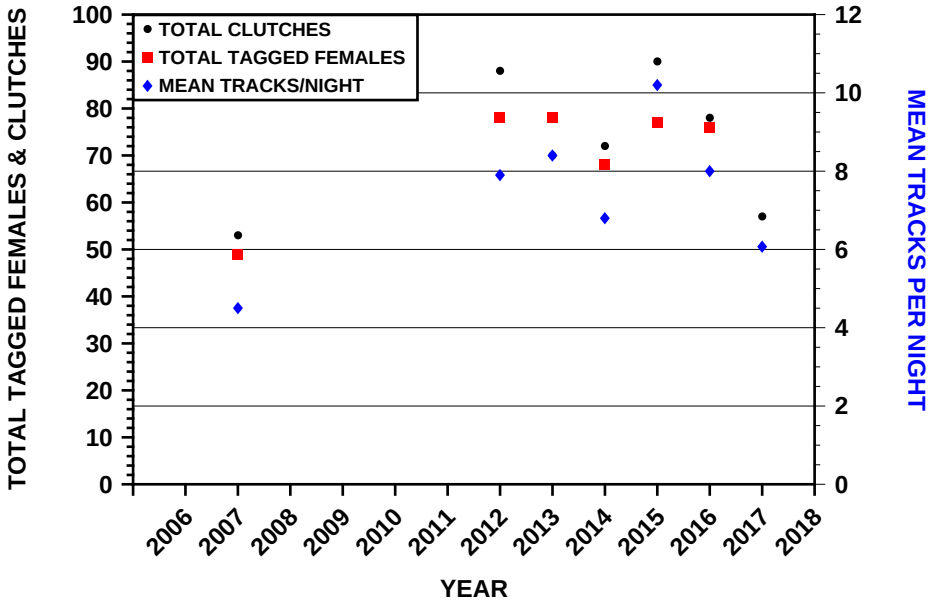


Figure 5.13. Comparison of total number of tagged females, total clutches laid and mean track count per night during the standard mid-season nesting census across breeding seasons for flatback turtle, *Natator depressus*, at Avoid Island.