MARINE TURTLE NESTING POPULATIONS: FLATBACK TURTLE, *NATATOR DEPRESSUS*, 2016-2017 BREEDING SEASON at CURTIS, PEAK AND AVOID ISLANDS




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DEPARTMENT OF ENVIRONMENT AND HERITAGE PROTECTION

Cover photographs:
Scenes from the census of nesting flatback turtles, *Natator depressus,* 2016 – 2017 at Curtis and Avoid Islands. Photographs taken by Nancy FitzSimmons and John Sergeev.

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EXECUTIVE SUMMARY

This report summarises the results of monitoring the eastern Australian flatback turtle nesting population at Curtis, Peak and Avoid Islands during the 2016-2017 breeding season. A two-week mid-season census was conducted at all three islands and full season monitoring was conducted at Curtis and Avoid Islands. This is the first time a full season of data has been collected at Avoid Island.

Number of nesting females and nests

- A total of 41 individual nesting flatback turtles and 43 clutches of eggs were recorded at Curtis Island during the two-week census period (24 November –7 December 2016). Over the entire breeding season 49 individual flatback turtles, 223 nesting crawls and 163 clutches were recorded.

- A total of 214 individual nesting flatback turtles and 209 clutches of eggs were recorded at Peak Island during the two-week census period (24 November –7 December 2016).

- At Avoid Island during the mid-season census period a total of 76 individual flatback turtles, 112 nesting crawls, and 79 clutches were recorded. Over the entire breeding season 92 individual flatback turtles, 394 nesting crawls and 269 clutches 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 12.6% of the recorded turtles is regarded as low for flatback turtles.
- Curtis Island had a similarly low level of recruitment, at 12%, during the census, but new recruits constituted 27% of turtles for the entire season.
- During the mid-season census at Avoid Island 18.4% of nesting turtles were new recruits, and this value rose to 23.9% for the entire season.

Remigration intervals and rookery fidelity

- The most common remigration interval for nesting females at Curtis Island was three years, followed by two or four years. At Peak Island most turtles re-migrated after two years, with several females also returning on three-year intervals. Some turtles returned after one year. 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, followed by three years, and one year.
- Nesting females continue to display high fidelity to each island. Only one nesting female was originally tagged when nesting at a different rookery. That was a female tagged at Wild Duck Island that nested at Avoid Island, as she has done in previous seasons.
- The Curtis Island nesting flatback turtles continue to display a high fidelity to specific nesting beaches with most turtles returning to lay successive clutches of eggs at the same beach, both within and between nesting seasons.

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 and Avoid Islands there was no difference in the size of experienced nesters versus new recruits, within the mid-season census. At Peak Island, new recruits were smaller than returning females and this was also true for turtles at Avoid Island when considering the entire season.
- The first emergence of hatchlings occurred on 17 December on Curtis Island, 30 November 2016 at Peak Island, and 27 November on Avoid Is.
- Mid-season incubation duration was 47.4 days at Curtis Island, 52.7 days at Peak Island and 50.2 days at Avoid Island. Across the entire season, incubation duration was 48.1 days at Curtis Island and 49.6 days at Avoid Island.

Population trends

- This season's mid-season census data support indications that the flatback turtles nesting at Curtis Island may be declining in abundance and recruitment (12.0%) of new females to the population as observed in the last three years. However, higher levels of recruitment (27.0%)were observed for the entire season, indicating that the mid-season census does not provide an accurate estimation of actual recruitment.
- 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 nine breeding seasons.
- The mid-season census at Avoid Island indicated a recruitment level of 18.4%, but for the entire season this rose to 23.9%.

Hatchling production

- Nesting success at Curtis Island rookery had an acceptable nesting success of 73.1%. Incubation success of undisturbed nests (those not inundated or predated by foxes) was 89.0% from mid-season clutches laid and 83.4% across all nests throughout the season. Emergence success from undisturbed clutches was 85.7% from mid-season clutches and 80.2% across the entire nesting season.
- At Peak Island nesting success continued to be low at 53%, as seen in past years. There were 154 nests excavated to assess incubation and emergence success, which were high (mean = 88.8% and 86.7%, respectively).
- At Avoid Island, data were obtained for 80 marked mid-season nests that had an average incubation success of 73.7% and hatchling emergence success of 71.4%. These values were not significantly different between values measured across the entire season (incubation success = 74.8%; hatchling emergence success = 72.7%).

Observed disrupted ocean finding behaviour

- Hatchlings from clutches laid at Curtis Island on the back slope of the first dune or in the depression/swale between first and second dune in sectors 0-5 regardless of moon phase or cloud cover travelled towards the natural lowest light horizon along the length of the swale. They headed predominantly southward, towards the sky glow from Gladstone, until the hatchlings found a break in the dunes and changed direction to head towards the low horizon of the sea.
- Hatchlings from some clutches that emerged from nests on South End Curtis Island displayed disrupted ocean-finding behaviour and headed away from the sea and towards the inland light horizon associated with Gladstone and Port Curtis.

Temperature profiles and weather events

- The abnormal heatwave that impacted south east Queensland during late January – early February 2017 caused elevated mortality at Peak Island of hatchlings digging their way to the surface and of some late stage embryos. The full impact of this heatwave on hatchling production was not possible to determine given that it had not been anticipated and occurred largely after the planned fieldwork.
- Peak Island is expected to have produced a strongly female hatchling sex ratio for the 2016-2017 breeding season.
- Beach erosion from Cyclones Dylan in 2014 and Cyclone 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 2016-2017 season included flooding of eggs where clutches were not laid high up into the dunes and over-heating of eggs and hatchlings during the early 2017 extreme heat wave in south east Queensland.

Management considerations

- Existing management by NPSR at Curtis Island is maintaining flatback turtle clutch loss to predators such as pigs, dogs and foxes at a low level. The nesting turtles and hatchlings at Curtis Island are exposed to sky glow from Gladstone.
- Existing management at Peak 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 in the absence of human interference except for the turtle monitoring activities. The nesting turtles and hatchlings at Peak Island are exposed to sky glow from Yeppoon, Rockhampton and Gladstone.
- Existing management 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 Heritage Protection (EHP) to continue monitoring of flatback turtle (*Natator depressus*) nesting and hatching at the South End Conservation Park, Curtis Island, Peak Island and Avoid Island for the 2016/17 nesting season. This monitoring is supported by the GPC Ecosystem Research and Monitoring Program (ERMP). This is the fourth year of monitoring these rookeries under this program and the first year to monitor the entire season at Curtis Island and Avoid Island.

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 sources of 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 east Australian stock. Avoid Island is a moderately sized rookery located towards the northern extent of the population's nesting range 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 by Limpus (2007) and Limpus *et al*. (2013a). 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. For the entire season monitoring, additional data include the number of clutches laid by females, incubation duration, and variability in parameters across the season. 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.

The sex of marine turtle hatchlings is determined by the temperature of the nest 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 29.3^{o}C (Limpus, 2007), with higher temperatures producing females and lower temperatures producing males. If flatback eggs incubate at a constant temperature of 29.3^{o}C, hatchlings should emerge approximately 53 days after the eggs were laid (EHP unpublished data), thus incubation duration can also be informative about the sex of hatchlings. Rainfall will influence this as the 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) and increased sunlight intensity in the absence of clouds.

CHAPTER 2. GENERAL METHODS

Standard EHP Threatened Species Unit 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 are presented as the value ± 95% confidence interval.

Nesting activity

Data on nesting activity was obtained at all three rookeries during a two-week, mid-season census period. Data from this period is referred to as the 'census data'. At Curtis and Avoid Islands, daily monitoring began on 1 November and continued until most clutches had emerged (see Chapters 3 and 5 methods). Data from this period is referred to as the 'whole season data'. At Peak Island, a 10-day trip collected data on incubation and emergence success (see Chapter 4 methods).

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 recorded nests after hatchling emergence, different techniques were used at each rookery.
    - 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 reflective identification numbers (or letters) were attached to trees or maker posts at 20-30m intervals along the beach. Measurements (± 1 cm) were taken using a 30 m tape measure from the nest to the two nearest markers. If this was not possible, flagging tape with the turtle ID number was placed around nearby tree branches, which were use as the point of measurement.

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/or 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:

- Where time permitted when hatchling emergence was observed, 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.
    - Elevated numbers of dead pipped embryos.
- 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.

Turtle orientation

To assess whether the orientation behavior 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 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.

Sand Temperature 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 data in the nesting habitat.

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 1.1). 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). 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 on 1 November 2016 until 15 March 2017. Local QTC Volunteers provided intermittent monitoring of the beach before this period from 1 October and afterwards until late April. The two-week mid-season census was considered to occur from 24 November – 7 December 2016.

The beach was examined either 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 2).

Two temperature data loggers have been deployed long term on South End Beach, Curtis Island. They are situated within the nesting habitat of the frontal dune within open sunny areas at opposite ends of this crescentic beach.

Rescuing doomed eggs

EHP and National Parks Sport and Racing (NPSR) conduct 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 hatchling 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 50cm 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 relocated further up the dune within two hours of being laid and their eggs counted.

Fox exclusion
Fox exclusion devices (FEDs) made from standard plastic garden mesh were laid horizontally at the beach surface over a series of nests to prevent foxes from digging into clutches of turtle eggs. These plastic mesh (100 mm grid size) panels were approximately 1 x 1 m square. They were placed over clutches of turtle eggs within 2 hrs of the eggs being laid. Each mesh panel was held down by 25 mm x 25 mm x 400 mm timber pegs, one in each corner of the panel.

RESULTS

Nesting activity, nesting success and recruitment

For the first time at Curtis Island, the marine turtle nesting and hatchling emergence has been recorded on South End Beach from the first clutch being laid on 14 October 2016 until the last clutch was excavated on 13 April 2017.

A total of 49 flatback turtles were encountered during the entire 2016-2017 breeding season at Curtis Island. Of these, 41 were recorded during the two-week census period. Thus 83.6% of the total nesting population for the season was observed during the two-week mid-season census. One loggerhead turtle and two green turtles were recorded nesting during the 2016-2017 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 14 October 2016 and the last nesting crawl on 2 February 2017. However, the last flatback clutch was laid on 23 January 2017. The first flatback clutch to emerge for the season was seen on 17 December 2016 and the last flatback clutch emerged on 20 February 2017. There was a zero incubation success for the last three flatback clutches laid for this season (9 – 23 January 2017).

A total of 223 nesting crawls by flatback turtles were recorded on South End Beach from the 14 October 2016 – 13 April 2017 (Figure 3.3). Of these, there were 163 successful beachings that resulted in eggs being laid. This equates to a 73.1% (95% confidence limits = ± 5.8%) nesting success during the entire season. This value was somewhat higher than nesting success than would have been recorded had the normal two week census been undertaken: mid-season nesting success = 63.9% (95% confidence limits = ± 12.1%).

The mean nightly number of flatback turtle activity during the mid-season census period was 4.5 tracks (SD = 4.128, range = 1-11), 41 different turtles and 43 clutches laid (Figure 4). The 43 flatback clutches laid during the standard census period on South End Beach (Figure 4A) equate to 26.4% of the clutches for the entire season.

The proportion of new recruits to the nesting population (first time tagged turtles) was 27 ± 12% of all turtles tagged during the season and 12 ± 10% during the standard mid-season census period (Figure 4B).

Turtles coming ashore to attempt nesting during daylight hours occurred infrequently with 1.4% of beachings occurring in daylight during the entire nesting season.

Nesting females: size, fecundity

The CCL (cm) of nesting female flatback turtles ranged 89.1 to 99.7 cm at Curtis Island (Table 3.2 and Figure 3.5). Turtles with a past breeding history (remigrants) did not have a significantly greater CCL (94.3 cm) than new recruit females (92.6 cm) that were tagged for the first time (one way ANOV: $F_{1,33} = 3.35$, $0.05<p<0.10$).

The recorded mean number of clutches of eggs laid by the nesting flatback turtles during the 2016-2017 breeding season at South End Beach, Curtis Island was 2.65 clutches/female (Table 3.3). Because not every nesting event was identifiable to a specific turtle, the actual mean number of clutches laid per female for the breeding season will have been slightly higher than this recorded value.

There was an average of 52.6 eggs per clutch for the 40 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 was14.7 d (range 12-21) (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).

A total of 35 flatback turtles carrying tags applied in previous breeding seasons were recorded back at Curtis Island this breeding season (Table 3.1). All but one of these remigrant turtles had been previously tagged at Curtis Island and that turtle nested previously at Peak Island. The majority of remigrant turtles returned after a three-year remigration interval (mean = 3.66, s.d.=1.55, range = 2-8, n = 35) (Figure 3.6).

Health and injuries

No nesting flatback turtles died at South End Beach during the 2016 -2017 season. None of the nesting flatback turtles were recorded with fibropapilloma tumours. None were recorded entangled in fishing line or rope.

Two nesting flatback turtles were recorded with recent damage associated with boating activities acquired since they had last been recorded nesting at Curtis Island:

- **K81015**: The damage to this turtle was similar to damage previously seen with turtles that had been dropped from trawl nets onto the deck or sorting tray of trawler (Figure 3.9A. Queensland Turtle Research Data Base).
- **QA37854**: Large shallow propeller cuts to the carapace that occurred since this turtle was last recorded nesting in December 2013 (Figure 3.9B).

Three flatback turtles returned to nest on Curtis Island that had been previously tracked via satellite telemetry using a harness to attach the satellite tag to the turtle:

- T20906: This turtle was tracked in the first flatback satellite telemetry study investigating inter-nesting home range and diving behaviour by Dr J. Sperling (University of Queensland); tag (PTT 3753) deployed in 24 November 2000 and removed when the female returned to lay her next clutch two weeks later. This turtle showed no evidence of carapace damage caused by the telemetry harness.

- **T20452**: This turtle was tracked during a satellite telemetry study within the EIS assessment of the development of LNG terminals within Port Curtis by GHD; tag (PTT 96779) deployed in 22 December 2009. The harness was not removed from the turtle during the nesting season. The turtle has two substantial healed "wounds" (Figure 3.9C) in the rear of the carapace and less severe abrasions on the anterior carapace caused by abrasion/tension of the telemetry harness. This turtle had a 10 mo tracking history.
- **QA30752**: This turtle was tracked during a James Cook University satellite telemetry study commissioned by GPC's ERMP to investigate internesting home range and post-nesting migration; tag (PTT 96779) deployed on 26 November 2013. The harness was not removed from the turtle during the 2013 nesting season. The turtle has two substantial healed "wounds" (Figure 3.9D) in the rear of the carapace and less severe abrasions on the anterior carapace caused by abrasion/tension of the telemetry harness. This turtle had a 3 mo tracking history.

Sand temperature monitoring

The sand temperature profile from the standard monitoring site on the southern end of South End Beach during the 2016-2017 breeding season is summarised in Figure 3.10.

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. The majority of the male hatchlings produced during this season should have been produced during the two brief periods of cooler sand that occurred with periods of heavy rain in early December 2016 and January 2017 respectively and from clutches laid in October and early November.

Nest and hatchling disturbance and depredation and island fauna

Four flatback turtle clutches were covered with fox exclusion devices (FEDs) immediately following the respective clutches being laid during the early nesting season in October before the commencement of the nightly nesting monitoring. Because no nests were predated by foxes during 2015-2016 breeding season at South End Beach, protection of clutches using FEDs was discontinued, commencing 1 November 2016.

During the early part of the nesting season, fox tracks were not observed on South End Beach. However, fox tracks were observed on almost every night between 21 December 2016 – 30 January 2017. Fox tracks typically entered the dune system at the northern end of the beach in close proximity to nests at the top of the dune, and subsequently followed the base of the first dune heading south along the beach. When hatchlings emerged, fox tracks were identified to deviate from the above general path to follow over the top of the hatchling tracks up to the nests.

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

Foxes were recorded digging into incubating flatback clutches on 12 occasions and into emerging flatback clutches on 20 occasions. However only 27 flatback clutches were disturbed by foxes, with 4 clutches being dug into on multiple occasions. This included one clutch of eggs covered by a FED. Two of the non-protected clutches predated by foxes were found with dead hatchlings scattered around the nest (Figure 11A). This flatback clutch destruction rate by feral predators represents a 16.6% clutch loss for the entire season. One additional loggerhead clutch was predated by foxes during this season.

NPSR Marine Parks Rangers recommenced predator control (soft jaw trapping and baiting) in the vicinity of South End Beach for two periods of 10 days from 21 November to 30 November 2016, and 30 January to 8 February 2017. One dog and one fox were trapped and dispatched on 30 January 2017. The stomach content of these animals contained no turtle eggshell or hatchling remains. No sign of fox predation of clutches or hatchlings was recorded after the night of 30 January 2017.

Overall, the trapping, baiting and/or shooting of dogs, pigs and foxes by NPSR that continued on Curtis Island during 2016 and early 2017 has been successful in reducing feral animal predation of clutches of turtle eggs to a sustainable level.

Horses were observed on the beach on sixteen occasions throughout the 2016-2017 breeding season. The majority of horse sightings were on the southern half of South End Beach. Horses were observed feeding on the Spinifex grasses on the fore dune, and roamed the beach below the high-water mark, and often travelled several hundred metres along the beach before exiting over the dune.

Cattle were observed on the beach on three occasions throughout the 2016-2017 breeding season.

No horses or cattle were observed to interfere with incubating eggs, hatchlings or adult turtles during the 2016-2017 breeding season. However, their presence has the potential for killing eggs and reducing hatchling production via trampling of nests. NPSR is assessing the management of cattle and horses within the Environmental Management Precinct (EMP) and in the South End Conservation Park.

Incubation and emergence success

At Curtis Island, 37 (22.7%) of the 163 *N. depressus* clutches laid during the entire season were laid below the area of potential tidal inundation. These clutches which were at risk of loss through flooding/erosion 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 2016-2017 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 and which had not been dug into by foxes: mean counting error = -1.00 eggs per nest (SD = 3.17, range = -16 to +1 eggs, n = 34 clutches). This was equivalent to undercounting of eggs by 1.9% per clutch examined after the clutch has emerged.

For the mid-season census, Curtis Island clutches that successfully incubated without disturbance by foxes or inundation by wave wash, the mean flatback turtle incubation success was 89.0% (Table 3.4; Figure 12) and a hatchling emergence success of 85.7% (Table 3.4; Figure 13) with a mean period to emergence of 47.4 d (Table 3.4; Figure 14). There was a slightly lower incubation success (83.4%) and hatchling emergence success (80.2%) for the total clutch sample across the entire season (Table 3.4).

Not all clutches dug into by foxes were totally predated. It was possible to make counts after hatchling emergence of the remnant clutches previously disturbed by foxes for 10 clutches across the entire breeding season (Table 3.4). For those clutches incubation success was 67.3% and hatchling emergence success was 57.9%.

Orientation

The quantified orientation of hatchlings leaving the nest (hatchling fans) was recorded for a total of 109 clutches for all three species. The quantified orientation of nesting adults as they crossed the beach to nest and returned to the sea was recorded for 42 flatback and green turtles (Table 3.5). These data will be analysed in a separate report.

While monitoring incubation success of clutches, hatchlings tracks were recorded leading away from some natural nests and heading inland away from the sea. Clutches laid behind the first dune or in the depression in sectors 0 to 5, had no immediate visibility of the ocean horizon. In these areas, hatchlings usually turned to head towards the ocean after they followed the depression, often heading south and discovered the break in the first dune at the southern end of sector 1. In the absence of a moon, the bright sky glow created by Gladstone and Port Curtis lighting (Figure 11B) occurred in a similar direction as the orientation of this swale. The following disrupted ocean-finding behaviour was recorded (Figure 11E):

- 30 January 2017: A clutch (K81015, CI120) laid on 12 December on the back of the first dune and which emerged on the 27 January; located in sector 0, at 23.716°S, 151.295°E. There was no moon and 60% cloud cover on the night that these hatchlings emerged from the nest. The tracks of the hatchling fan from this nest ran between compass bearings 187° - 234° away from the water (seaward direction = 78º). An uncounted group of dead hatchlings was found among the grass out from this fan. An additional dead flatback hatchling was found at 23.715°S, 151.294°E by NPSR staff, 88 m from where other dead hatchlings were found (Figure 11C, E). The hatchlings had no injuries consistent with having been taken by a mammalian or bird predators. It is presumed that the hatchlings crawled to the location as a result of disorientation influenced by Gladstone sky glow and eventually was overcome by heat or ants.
- 16 February 2017: Three live green turtle hatchlings were found in the rear dune depression at 6:30am (Figure 11D, E). These hatchlings emerged the previous night from a clutch (QA15147, CI160) laid on 29 December in the first dune swale; located in sector 0, at 23.717°S, 151.295°E. The first hatchling was found at 23.716°S, 151.295°E, 64 m from the nest; the second hatchling was found at 23.716°S, 151.295°E, 40 m from nest; and the third hatchling was found at 23.719°S, 151.295°E, 205 m from the nest. There was a half-moon with 30%

cloud cover on the night that the hatchlings emerged. The ocean horizon was not visible from the nest, but the sky glow from Gladstone was strongly visible. Bird and crab tracks were identified on top of hatchling tracks, indicating the presence of predators, however thick vegetation prevented researchers from identifying the fate of other hatchlings.

DISCUSSION

This study examined the flatback turtles nesting on South End Beach, Curtis Island during the 2016-2017 breeding season, a moderate-sized nesting population, within the eastern Australian stock.

This nesting population continues to display strong long-term fidelity to their chosen nesting beach as has been recorded previously for flatback turtles nesting on the Woongarra Coast (Limpus *et al*. 1984).

The results indicate that 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 (>70%). There is no significant disturbance of the nesting turtles when they come ashore that results in excessive unsuccessful nesting effort.
- There is a high probability (>80%) that clutches of eggs laid on this beach will survive to hatch as a result of NPSR management of feral predators (pigs, dogs and foxes), maintaining flatback turtle clutch loss to predators at a low level.
- Clutches that have not been interfered with by feral predators or impacted by storm surge or high tide erosion have very high incubation success (approaching 90%) and a high level of hatchling emergence from the nests (~85%). The beach sands constitute a very good incubation medium.

In contrast, extreme concern should be held with regard to other characteristics of this rookery:

- The production of a strongly female biased hatchling sex ratio as a result of sand temperatures at nest depth, at temperatures much higher than the pivotal temperature throughout most of the breeding season, should be viewed with concern (Hamann *et al*. 2008; Limpus, 2008; Poloczanska *et al*. 2009). The predicted female biased sex ratio derived from sand temperature measurements during the 2016-2017 breeding season is reinforced by the short mean incubation to emergence period of 47 d recorded over the same time. Increased effort is warranted to identify if there are other nesting beaches within the breeding range of the eastern Australian 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, 1971; 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:

- o Increased number of hatchlings will die on Curtis Island as a result of the altered light horizons disrupting the hatchling ocean-finding behaviour. This is now being observed annually on South End Beach.
- o 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).
- o It is expected that with the increased bright sky glow behind South End Beach since the construction in approximately 2013 of the three LNG terminals and associated port facilities and the Wiggins Island Coal Terminal there will be a reduction in adult female numbers visiting the beach for breeding.

Although it is not the responsibility of GPC ERMP, a 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 4A) has been towards increasing numbers from approximately 2001 until 2008. Since 2008 there has been a 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*. (2013a).

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 until 2013. However, there is the possibility that recruitment to the adult breeding population may be in decline since 2013 (Figure 4B).

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 dynamic of this breeding population.

There are a number of factors that have the potential for contributing to these trends:

- Prior to 2001, flatback turtles were the dominant species of turtle captured in the otter trawl fisheries of eastern Queensland (Robins, 1995; Robins and Mayer, 1998). The long term, low rate of mortality of these turtles caught in the trawl fisheries, would have contributed to an altered population structure for the population.
- Since 2001, Queensland Fisheries Regulations have mandated the compulsory use of turtle exclusion devices (TEDs) in the east coast trawl fisheries. The limited data monitoring available indicates that this change in fisheries management has been effective in greatly reducing the capture and hence

mortality of marine turtles in eastern Queensland trawl fisheries. This change has the potential to have contributed to increased survival of these turtles and hence an increase in numbers of turtles migrating to nesting beaches in eastern Queensland, including Curtis Island.

- The extreme drought conditions over several years in the mid 2000s would have resulted in reduced negative impacts from river run off into coastal waters of the Great Barrier Reef – with reduced negative impacts on the abundance of the benthic invertebrate fauna that are the diet of flatback turtles. It can be reasonably assumed that improved food resources could contribute to increased breeding rates and survivorship.
- Since 2009 to 2013, there has been a series of years with very elevated floods across the entire length of the Great Barrier Reef in association with increased frequency of extreme cyclones that cause habitat damage in coastal waters. The associated negative impacts of widespread repeated turbid water inflow and habitat damage in coastal waters has the potential for damaging the food resources of flatback turtle and hence negatively impacting on survivorship and breeding rates.
- Since 2013, with the construction of the three LNG plants and associated wharf facilities and the Wiggins Island Coal Terminal within Port Curtis, there has been a substantial increase in light pollution over the port. The sky glow over Gladstone is now a prominent feature of the night horizon viewed 80 km off shore at Heron Island. This increase in sky glow has the potential for causing a reduction in the numbers of turtles visiting Curtis Island and adjacent beaches for nesting.

Our challenge is to maintain continued monitoring of the population dynamics of the flatback turtle nesting at Curtis Island while comparable long-term data sets are developed for analysis from the selected control site at Avoid Island. Once such data are available, it is expected that it will be possible to discriminate among the impacts from a number of these factors.

CHAPTER 4. PEAK ISLAND STUDY

Study Area

Peak Island, 23.333ºS, 150.933ºE, is a continental island in Keppel Bay and sits approximately 15 km off the mainland coast southeast of Yeppoon in eastern Australia (Figure 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 area has been managed by the Department of National Parks, Sport and Racing (NPSR) 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. Peak Island has one nesting beach on its northwestern corner that faces westerly towards the mainland. Only 300 m of this beach provides access to sand dunes suitable for turtle nesting. A second accessible sandy beach is on the south-eastern side of the island, but rocks under the sand at dune level prevent successful egg chambering. The third small beach to the east of the main beach (Limpus *et al*. 1981) is backed by rocks forming a cliff that prevents turtles from accessing areas above the high tide level. This third beach is not patrolled for recording of turtle nesting activity.

Peak Island supports one of the largest populations of nesting flatback turtles in the east Australian (EA) stock (Limpus *et al*. 2013) and is recognised as an index beach for long-term monitoring of flatback turtles within the east Australian stock. Census of the Peak Island flatback turtle nesting population commenced in the 1980-1981 breeding season (Limpus *et al*. 1981).

Methods specific to Peak Island

- At Peak Island the nesting beach is subdivided into sectors 25 m in length, 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 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 2016 and a ten-day trip from 23 January – 2 February 2017 collected data on emerged clutches.
- 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.

RESULTS

Nesting activity, nesting success and recruitment

A total of 214 nesting flatback turtles were recorded during the two-week census period, 24 November – 07 December 2016 (Table 4.1). No other species of turtle was recorded nesting during this period. No flatback turtle was recorded with tags that had been recorded nesting at any beach other than Peak Island.

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 2016 and the first emergence of hatchlings was observed on 30 November 2016 (Table 4.2).

The mean nightly numbers for of turtles coming ashore for nesting during the mid-season census period was 25.6 tracks, 17.3 different turtles and 14.9 clutches laid (Table 4.2).

There were 364 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 the nesting turtles came ashore within sectors 8-15, which is not fronted by inter-tidal rocks. First-time nesters and remigrants nested similarly in these areas. Nesting success, the proportion of nesting crawls that resulted in eggs being laid by the turtle, was 53.1 ± 4.9% Nesting success was very low in sectors 14-15 and relatively low in sectors 0-4 (Figure 4.2).

The approximate recruitment rate of first time breeding females into the adult nesting population, as measured by the proportion of first time tagged nesting females, was 12.6 ± 4.4% for turtles within the census period.

Nesting females: size, fecundity

The mean CCL (cm) of the nesting female flatback turtles was 93.9 cm (s.d. = 2.7, range = 82.2-102.7, n = 203) (Table 4.3, Figure 4.3). 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 0.83 days (SD = 0.858, n = 82, range = 0-4 days). Most females returned to re-attempt nesting on the same night or the following night after an unsuccessful nesting attempt. Turtle were recorded taking up to five attempts before successfully laying eggs.

No turtles were recorded returning to lay an additional clutch during the entire period of monitoring (24 November – 7 December 2016).

A total of 209 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 and Figure 5. The sampled flatback turtle clutches had on average: 50.4 eggs, no yolkless eggs and no multiyolked eggs per clutch; with eggs (n = 14 clutches) averaging 5.2 cm in diameter and weighing 76.0 g. The nests were on average 31.5 cm deep to the top of the eggs and 47.6 cm to the bottom.

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 2016 census period was 2.96 years (s.d. = 1.4, N = 184) (Table 4.3, Figure 4.4). Most turtles returned on a two-year interval, and several returned on a three-year interval.

Health and injuries
No records were made for turtles with fractures at Peak Island.

Sand temperature monitoring

As a result of loss of the temperature data logger, there are currently no sand temperature data available for Peak Island for this last breeding season.

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, daily rainfall and air temperature data recorded at the BOM weather stations at Yeppoon and Rosslyn Bay were examined (Figure 6). The Australian Bureau of Meteorology (BOM) reported the occurrence of an exceptional period of heatwave conditions impacting eastern Queensland during the eastern Queensland flatback turtle nesting season of 2016-2017 (BOM, 24 February 2017).

Additionally, the period from mid-January until early March 2017 was very dry with isolated days of 1 mm of rain. Under these conditions the surface sand temperatures, particularly during the middle of the day and early afternoon,
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

Eighteen turtles were observed digging into existing clutches, which amounted to 4.6 ± 2.1% of nesting activity resulting in clutch destruction with an average clutch disturbance rate of 8.6 ± 3.8% of clutches laid during the mid-season census period. Eggs destroyed by nesting turtles digging into pre-existing clutches were counted during 12 disturbance events. On average, 14.3 eggs were disturbed and killed when a nesting turtle dug into an existing clutch, equivalent to an average loss of 28.3% of a clutch. If extrapolated for the entire season, this would be equivalent to a loss of 1.2 eggs per clutch of eggs laid or 2.4% of the seasonal egg production.

Due to the absence of large terrestrial predators (pigs, dogs, foxes, varanid lizards and humans) of turtle eggs on the island, there was only minor loss of eggs within the nest, mostly due to roots growing into clutches and predation of eggs by *Ocypode* crabs.

Occasional hatchlings crossing the beach were attacked by crabs and ants. Potential bird predators of hatchlings recorded during the field studies included beach stone-curlews and white-bellied sea eagles, but no bird depredation of hatchlings was recorded.

Incubation and emergence success

A ten-day trip to Peak Island from 23 January – 2 February 2017 sampled nests from which hatchlings had emerged to access incubation and emergence success.

Twenty-one nests that had been previously marked and had identification tags in them were located as hatchlings emerged. The dates laid spanned the mid-season census period from 26 November to 7 December 2016. The mean incubation period to hatchling emergence for these clutches was 52.7 days (Table 4.5, Figure 4.7a).

Data on 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 88.8% and a mean hatchling emergence to the beach surface of 86.7% (36 clutches) during 23 January – 2 February 2017 (Table 4.5, Figure 4.7b).

Additional clutches assessed for incubation success included clutches laid outside the mid-season census period. The pooled results from all clutches (n = 154 clutches) were lower: mean incubation success = 79.0%, emergence success = 68.3% (Table 4.5, Figure 4.7b).

Thirty-three of the 34 emerged clutches were recorded with atypically elevated unhatched eggs that could be the result of either inundation or heat stress. Heat-stressed clutches were detected mostly after 26 January 2017 indicating that they were most likely laid after the mid-season census period. These clutches with elevated unhatched eggs (typically eggs that died at pipping) had a mean incubation success of 76.8% and a mean emergence success of 56.4% (Table 4.5, Figure 4.8).

There was poor incubation success of eggs that remained in nests after clutch disturbance by nesting turtles. In the five affected clutches, eggs had a mean incubation success of 44.1% and mean emergence success of 25.3% (Table 4.5).

Turtle orientation

During the 2016-2017 season night lighting was documented photographically again during the census period. The most predominant lighting visible from the nesting beach was from Gladstone, Rockhampton and the Keppel Bay coast as reported by Twaddle *et al*. (2015). As determined from last season, Sectors 1-9 in the southern part of the nesting beach are shielded from the Gladstone glow by the lower peak of the island. Additionally, nests here are also more likely to be laid on the slope or beach, so have a more direct path to the sea than those laid further back in the dunes. Sectors 10-11 are exposed to both the Gladstone and the Rockhampton glows and Sectors 12-15 are exposed to the lights of the Keppel Coast.

This season, data were collected on orientation of tracks from 48 nesting females and 44 hatchling track fans. The statistical analyses of these data will be completed along with analysis of similar data from multiple nesting beaches including Avoid Island and Curtis Island in a later report.

Discussion

The Peak Island nesting flatback turtles continue to display normal demographic parameters for the eastern Australian stock: mean CCL = 93.9 cm; mean number of eggs in a clutch = 50.4 cm; mean remigration interval = 2.96 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 past nine breeding seasons.

The high incubation success (88.9%) and high hatchling emergence success (86.7%) indicate that the sand dune environment at Peak Island provides a good quality incubation environment for flatback turtle eggs.

Peak Island was not impacted by a cyclone during the 2016-2017 flatback turtle breeding season.

However, the heatwave that impacted SE Queensland in late January and February 2017 coincided with the hatchling emergence from clutches laid after the mid-season census period. The sampling of clutches emerging at that time detected an elevated mortality of hatchlings at or near the beach surface in the neck of the egg chamber and an increased mortality of eggs during the later stages of incubation. These data indicate that heat stressed clutches with poor hatchling emergence success would have continued to occur after the study team left Peak Island on 2 February 2017. This heat wave impact on marine turtle hatchling production was a new phenomenon that the study team has not observed at any of our monitored beaches in previous years. This issue is one to be considered in future planning and management of marine turtle hatchling production.

Flatback eggs that incubate at a constant temperature of 29.3^{o}C, the pivotal temperature, should have hatchlings emerging after approximately 53 days (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 4.7A). Given these results and the heat wave conditions that occurred this summer, it is highly likely that the majority of the clutches of flatback clutches incubating at Peak Island during the 2016-2017 breeding season had a strongly female-biased sex ratio. However, the early season clutches should have produced a male-biased sex ratio.

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 (Figure 4.9).

The recruitment rate (12.6%) 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 eight years (Figure 4.10), 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 2016-2017 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's 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 East Australian (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, FitzSimmons and Limpus, 2015; FitzSimmons and Limpus, 2016).

Methods specific to Avoid Island

- Monitoring at Avoid Island included the standard 14-day census period from 20 November – 3 December 2016 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, Middle Beach and North Beach.

- This was the first year in which turtle nesting and hatching was monitored for effectively the entire breeding season. Monitoring of beaches began on 28 October 2016 and ceased on 1 March 2017. Outside of the census period, nightly monitoring occurred on South Beach and Middle Beach. North Beach was patrolled in the morning to count tracks and identify and map nests.

- The entire season monitoring provided data on incubation duration has not been adequately quantified in previous years. This also allowed comparison of incubation and emergence success throughout the season.

- For the first time, sectors were established on South Beach and North Beach to aid in relocating marked nests. This was done using aluminium squares with reflective strips and numbers or letters that were attached to trees or posts (Figure 5.2).

- Two temperature data loggers (Vemco Minilog II) were previously established in an open and a shaded location on the top of the 1st dune. Two additional data loggers were placed in open and shaded location on beach at the base of the dunes on 3 Nov 2016, each buried at 50 cm depth (Figure 5.3).

- During the mid-season census, monitoring was conducted in conjunction with students from a conservation biology class run through the University of New South Wales. Two teams of three or four students, working with one or two experienced people, did nightly monitoring of South Beach (A3), Middle Beach (A2) and North Beach (A1). 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. Additional nightly monitoring of South and Middle beaches was done throughout the nesting season with volunteers and an experienced team leader, and daily track and nest assessments were done on North Beach.

RESULTS

Nesting activity, nesting success and recruitment

A whole of nesting season monitoring was attempted for the first time at Avoid Island during the 2016-2017 breeding season. There were 17 tracks from nesting turtles, all on the South Beach when the monitoring team arrived on the island on 27 October 2017. The last nesting crawl occurred on 23 January 2017. Hatchling emergence was monitored from the first emergence of hatchlings on 27 November 2016 until the end of February 2017. The last few clutches laid were not monitored for hatchling emergence.

A total of 92 flatback turtles were encountered during the entire 2016-2017 breeding season at Avoid Island. Of these, 78 were recorded during the two-week census period, 20 November – 3 December 2016. Thus 84.8% of the total nesting population for the season was observed during the two-week mid-season census. No other species of turtle was recorded as nesting during this season.

A total of 394 nesting crawls by flatback turtles were recorded on Avoid Island from 27 October 2016 – 28 February 2017. Of these, there were 269 successful nests dug with eggs recorded as being laid and 21 unknown outcomes. This equates to a 72.1% nesting success for the entire season. During the mid-season census there were 112 nesting crawls and 79 nests with eggs laid (Table 5.1), for a nesting success of 71.1%.

The mean nightly number of flatback turtle nesting crawls during the mid-season census period was 8.0 (s.d. = 4.0, n = 14, range = 2 – 15; Table 5.1, Figure 5.4). As in previous years, most nesting activity during the census (91.1% of tracks and 93.7% of clutches laid) occurred on South Beach (A3), which is the largest beach (Figure 5.6). Only one clutch was laid on Middle Beach and four clutches were laid on North Beach. Beach erosion from Cyclones Dylan in 2014 and Cyclone Marcia in 2015 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.

A total of 79 clutches were laid during the two-week census and were marked and mapped for determining emergence success. The mean number of clutches laid per night was 5.6 (SD = 2.2, n = 14, range = 2-10; Table 5.1).

The study is nearing 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. As expected, this value has declined with each year of tagging during the standard two-week mid-season census: 78.2% in 2012-2013 (FitzSimmons, 2013), 66.7% in 2013-2014 (FitzSimmons and Limpus, 2014), 50.0% in 2014-2015 (FitzSimmons and Limpus, 2015) and 26.3% in 2015-2016. This value continued to decline in 2016-2017, with 18.4 ± 8.7% of turtles previously untagged. When considering the entire season, the proportion of first time tagged turtles rose to 23.9 ±8.7% of all turtles tagged

Nesting females: size, fecundity

The mean curved carapace length of nesting female flatback turtles for the entire season was 93.5 cm (s.d. = 2.5, range= 87.8 to 99.0 cm; Table 5.2 and Figure 5.6). There was no significant difference in the size of nesting females during the mid-season census period and those recorded during the entire breeding season. For turtles measured across the entire season remigrant turtles were on average 1 cm shorter than remigrant females and this difference was significant (t-test, p = 0.049).

Remigration interval, the number of years between recorded breeding seasons, averaged 2.3 yr (s.d.= 0.88, range = 1-4; Table 5.2) for the entire season, with the most common intervals being 2 or 3 years (Figure 5.7). There was no significant difference in the remigration interval recorded for females nesting during the mid-season census period and those recorded during the entire breeding season.

During the 2016-2017 season all flatback turtles with a past nesting history had nested on Avoid Island in a prior breeding season. One turtle, T38567 that had been tagged originally at Wild Duck Island in 1988, and subsequently recorded nesting in the 2012-2013 season at Avoid Island, returned again to nest at Avoid Island this season. This turtle has a breeding history of at least 30 years and is estimated to be at least 50 years old.

There was an average of 42 eggs per clutch laid for the 8 clutches that were counted when laid (s.d. = 6.1, range = 32-49; Table 5.3). Summary data on 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 13.9 d (s.d. = 1.2, range -12-17 d; n = 112; Table 5.2, Figure 5.8). 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 5.2, Figure 5.8). Turtles with re-nesting intervals >17 days (Figure 5.8) indicate turtles that were missed during their previous nesting, either while nesting on Avoid Island or at another beach.

The recorded mean number of clutches of eggs laid by the nesting flatback turtles during the 2016-2017 breeding season at Avoid Island was 2.7 clutches (s.d. = 1.0, range = 1-5, n = 92; Table 5.2). Because not every nest laid was identified to a specific turtle, if these nests were laid by females before they were first identified for the season, or if they were laid after females were last observed nesting, then actual clutch numbers for those females would be higher.

Health and injuries

None of the nesting turtles at Avoid Island displayed recent tissue damage or fractures. No fibropapilloma tumours were observed on any of the turtles.

Sand temperature monitoring

The Australian Bureau of Meteorology (BOM) reported the occurrence of an exceptional period of heatwave conditions impacting eastern Queensland during the eastern Queensland flatback turtle nesting season of 2016-2017 (BOM, 24 February 2017). For comparative purposes, daily rainfall and air temperature data recorded at the BOM weather stations at St Laurence were examined (Figure 5.9). The period from mid-January until early March 2017 was very dry with isolated days with a few millimetres of rain and was also the period of elevated daily air temperatures for the summer. Under these conditions the surface sand temperatures, particularly during the middle of the day and early afternoon, can be expected to reach lethal levels for turtle hatchlings.

Data were downloaded on 3 Dec 2016 as a quality check. It was found that the temperature logger in the sunny location at the top of the 1st dune had failed. Data were obtained up to 3 December 2016 from the two temperature loggers placed at the base of the dunes (Figure 5.10a,b). However, the 'stand-alone' downloading hardware failed to reinstate data collection as designed, so unknowingly, no further data were collected. Data from the temperature logger in the shady location on the top of the 1st dune were collected for the entire season (Figure 5.10c). This was possible because when the data were checked, they were downloaded via computer and manually reactivated.

Sand temperatures in the open, mostly sunny area at the base of the dune reached the pivotal temperature (29.3°C) for flatback turtles in the second week of November and stayed above it until the recording stopped on 4 December 2017 (Figure 5.10A). Sand temperatures in the shaded area at the base of the dune reached the pivotal temperature briefly in mid-November. After a brief period below the pivotal temperature, it rose above pivotal temperature in the last week of December (Figure 5.10B). In the shaded location at the top of the 1st dune, sand temperatures at nest depth remained below the pivotal temperature for flatback turtles for the entire breeding season (Figure 5.10A).

Nest and hatchling disturbance and depredation and island fauna

Three clutches were recorded as having been dug into by a nesting turtle. Two of these clutches were assessed for incubation success and had an incubation success = 64.6% and hatchling emergence success = 60.7% (Table 5.4). At least 30 clutches had eggs that were identified as having been predated by crabs with a mean 1.8 eggs taken per clutch (s.d. =1.34, range = 1-5). The principle crab responsible for this predation was *Ocypode cordimanus*.

Incubation and emergence success

The incubation period to hatchling emergence was measured from 172 clutches from across the entire season and from 60 clutches laid during the mid season census period. The incubation period to hatchling emergence for clutches laid during the mid-season census period was 50.2 d (s.d. = 2.7, range 45-57) in comparison to 49.6 d (s.d. = 2.5, range = 42-59) from across the entire nesting season (Table 5,4 Figure 5.11). These values were not significantly different.

Incubation success and hatchling emergence success was assessed for 325 of the 327 clutches recorded from across the entire season and for 80 nests laid mid-season (Table 5.4, Figures 5.12, 5.13). For this period incubation success was 74.7% (s.d.= 29.0, range 0-100). This was not significantly different from the incubation success from clutches laid during the mid-season census (73.7%, s.d.= 31.2, range = 0-100). Similarly, there was no significant difference between emergence success for the entire season (72.7%, s.d. = 29.6, range 0-100) and mid-season census (71.4%, s.d. = 32.2, range = 0-100).

Throughout the season some incubating clutches were impacted by external factors that reduced their hatching success. At least six clutches were inundated by high tides (e.g., Figure 5.14) with a resulting low hatching success and hatchling emergence success of 9.3%.

While it was not possible to accurately identify all clutches impacted by the heat wave, given the mosaic of shade and sunny areas within the nesting habitat, 12 clutches were identified to have been heat stressed during the heat wave period based on elevated death of eggs at pipping, death of hatchlings in the dry sand above the eggs and/or dead hatchlings on the beach surface. These had an hatching success of 50.6% (s.d. = 33.8, range = 2.0 – 95.5) and an emergence success of 40.0% (s.d.= 33.1, range = 1.85 – 91.1) (Table 5.4).

Turtle orientation

During the two-week census orientation data were collected on the tracks of 94 nesting females. For the entire season, data were collected from 162 emerged clutches. A detailed analysis of adult female and hatchling orientation measures based on tracks will be the subject of a separate future report addressing turtle orientation with respect to horizons at multiple study sites.

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 eastern Australian 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 sixth year of monitoring flatback turtle nesting activity, the last five of which were consecutive. The numbers of individually tagged flatback turtles, mean nightly track counts and the total number of clutches during the two-week census of the 2016-2017 breeding season were within the range of values recorded for the mid-season census of the previous four seasons (FitzSimmons, 2013; FitzSimmons and Limpus, 2014; FitzSimmons and Limpus, 2015; FitzSimmons and Limpus, 2016) (Figure 5.15). No explanation is offered for the low census values recorded during the 2007-2008 season (Jones and Venz, 2008).

The proportion of turtles of previously tagged has continued to fall each season, and is now within the range recorded for Wild Duck Island of 10-20% (reported in Limpus 2007). In the 2015-2016 breeding season, there were 26.3% untagged turtles, and in 2016-2017, this declined by another ~8% to 18.4%. 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. There was no significant difference in the remigration interval recorded for females nesting during the mid-season census period and those recorded during the entire breeding season, with most returning at 2-3 yr intervals.

There was no significant difference in the size of nesting females during the mid-season census period and those recorded during the entire breeding season. Comparing remigrant and newly recruiting females for the entire season indicated the new recruits to be significantly smaller, by 1 cm on average.

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.

The mean incubation period for the entire season was 50 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 29.3^{o}C should have the hatchlings emerging at approximately 53 days after the eggs were laid (EHP, unpublished data). The majority of the clutches emerged in less than 53 days, this it is highly likely that the majority of the clutches of flatback clutches incubating at Avoid Island during the 2016-2017 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 2016-2017 breeding season would have come from the limited number of clutches laid during the early nesting season that had period to emergence values greater than 53 days.

Although nesting success was relatively high (>70%), incubation success of eggs and hatchling emergence success from nests for the entire season was low at 73.7% and 71.4%, respectively, and these values were not significant different from those of clutches laid during the mid-season census.

The low hatchling production can be attributed to a number of factors including:

- Beach erosion from tropical cyclones *Dylan* in 2014 and *Marcia* in 2015 was still apparent in the relatively steep dune profile along much of South Beach. Additionally, a lower profile of the beach allows for inundation of several nests that is difficult to quantify. On North Beach, the northern end of the beach continues to have inundation of all clutches laid below the 1st dune on the higher tides (Figure 5.14).
- The heat wave during late January and February 2017 associated with a protracted period of low rainfall caused elevated mortality of eggs and hatchlings within nests.

Factors such as these that are linked to variable weather across the years warrant closer monitoring in future breeding seasons.

Chapter 6. Rockery Comparisons

Comparison of the three rookeries: mid-season census

A summary of the results from the two-week, mid-season monitoring are given in Table 6.1, refer to the rookery-specific chapters for additional information.

Peak Island had more than twice the number of turtles as Avoid Island, which had more than twice the number of turtles as Curtis Island. The only other rookery of the eAust flatback population with substantial number of flatbacks is Wild Duck Island, which is in between the rookeries at Peak and Avoid islands. The proportion of first time tagged turtles at Avoid Island was somewhat higher than Curtis and Peak Islands, which may indicate that the proportion of new recruits has not yet stabilised after five consecutive years of mid-season tagging.

The size of the females is the same across rookeries, though clutch size and egg size were somewhat smaller at Avoid Island. Remigration interval was also somewhat smaller at Avoid Island due to the shorter period of study at this rookery and in part to a greater proportion of turtles remigrating after one year. The number of clutches for the entire season was similar for Curtis Island and Avoid Island.

Nesting success was lowest at Peak Island due to a lack of sand in some sectors, and similar nest success was measured at Avoid and Curtis Islands. The Peak and Curtis rookeries had similar incubation and emergence success, which was reduced at Avoid Island. One reason for this may be the Avoid Island beach profile has not rebuilt sufficiently since Cyclones Dylan (2014) and Marcia (2016) and that several nests were inundated during high tides.

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References

Bureau of Meteorology (24 February 2017). Exceptional Climate Statement 61 – exceptional heat in southeast Australia in early 2017.

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. Xx 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. (1971). 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: Broadsound 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.

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. 1-43 pp.

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's Ecosystem Research and Monitoring Program. 21 pp.

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

Curtis Island Tables

Table 3.1. Summary of flatback turtle tagging census at Curtis Island during the entire 2016-2017 breeding season.

	Flatback turtles	Loggerhead turtles	Green Turtles
First time tagged	13	0	0
Remigrant recaptures			
With tags	34	1	1
With tag scars only	0	0	1
Change of colony within 2016-17 season	1	0	0
Change of colony between breeding seasons	1	0	0
Total turtles	**49**	**1**	**2**

Table 3.2. Size of nesting female flatback turtles at Curtis Island during the entire 2016-2017 breeding season.

	Curved carapace length (cm)			
	Mean	**SD**	**Range**	**N**
Flatback turtles				
First time tagged females	92.55	2.285	89.1-95.8	10
Remigrant females	94.21	2.473	89.6-99.7	35
All females for season	93.85	2.480	89.1-99.7	46
Green turtles				
All females for season	99.50	2.970	97.4-101.6	2
Loggerhead turtles				
All females for season	91.5	-	-	1

Table 3.3. Flatback turtle clutches, nest descriptions and within season nesting return intervals, at Curtis Island, 2016-2017 for the entire breeding season.

	Mean	SD	Range	N
Curtis Island				
Total clutches per individual / season	2.65	0.92	1-4	46
Eggs per clutch	52.63	8.427	21-68	40
Yolkless eggs per clutch	0.08	0.267	0-1	40
Multiyolked eggs per clutch	0	0	0	40
Renesting interval (d), following a successful oviposition	14.7	1.703	12-21	71
Return interval (d), following an unsuccessful nesting attempt	0.6	0.507	0-1	19
Nest depth, top (cm)	40.10	8.100	23-59	97
Nest depth, bottom (cm)	56.81	5.903	47-71	36
Egg diameter (mean) (cm)	5.21	0.128	4.90-5.45	30 (3 clutches)
Egg weight (g)	76.33	4.730	65.30-85.55	30 (3 clutches)

Table 3.4. Incubation period, incubation success, and emergence success for undisturbed flatback, green and loggerhead turtle clutches at Curtis Island. These clutches include those protected by fox exclusion devices. 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 provided.

	Mean	SD	Range	N
Flatback turtles				
Incubation period (oviposition to emergence)				
• census (d)	47.40	2.163	44-53	29 clutches
• entire season (d)	48.07	2.635	43-61	122 clutches
Success of undisturbed clutches				
• Incubation success, census (%)	89.02	15.774	0-100	37 clutches
• Incubation success, entire season (%)	83.38	20.673	0-100	151 clutches
• Emergence success, census (%)	85.70	15.875	0-98.08	37 clutches
• Emergence success, entire season (%)	80.24	21.201	0-100	151 clutches
Success of clutches disturbed by foxes				
• Incubation success, entire season (%)	67.26	26.451	23.8-94.1	10 clutches
• Emergence success, entire season (%)	57.91	31.538	10.0-94.12	10 clutches
Green turtles				
Incubation period (oviposition to emergence) (d)	51.33	9.452	44-62	3 clutches
Incubation success (%)	56.64	45.649	0-98.65	6 clutches
Emergence success (%)	55.55	45.396	0-98.65	6 clutches
Loggerhead turtles				
Incubation period (oviposition to emergence) (d)	48	-	-	1 clutch
Incubation success (%)	76.33	14.466	60.32-88.46	3 clutches
Emergence success (%)	20.02	28.741	2.08-53.17	3 clutches

Table 3.5. Number of track orientations recorded across all three species of turtles nesting at Curtis Island during the entire 2016-2017 nesting and hatching season.

	Nesting	Hatchling
Flatback turtles	39	106
Green turtles	3	2
Loggerhead turtles	0	1

Peak Island Tables

Table 4.1. Tagging history of flatback turtles recorded nesting at Peak Island during the two-week census period, 24 November –7 December 2016.

Tagging history of turtles	# turtles
First time tagged females (Primary tagged turtles)	27
Recaptures from past nesting seasons at Peak Island	
• Recaptured with tags previously recorded at Peak Island	184
• Recaptured with tag scars only, previously applied tags lost	3
TOTAL	214

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

Date	# tracks	# clutches laid	# emerged clutches
24 Nov 2016	52	25	0
25 Nov 2016	3	3	0
26 Nov 2016	27	13	0
27 Nov 2016	53	24	0
28 Nov 2016	46	28	0
29 Nov 2016	10	6	0
30 Nov 2016	19	15	1
1 Dec 2016	48	35	1
2 Dec 2016	40	25	0
3 Dec 2016	22	15	1
4 Dec 2016	11	4	0
5 Dec 2016	20	12	2
6 Dec 2016	6	3	0
7 Dec 2016	2	1	0
Total	359	209	5
Mean (s.d.)	25.6 (18.8)	14.9 (10.9)	

Table 4.3. Summary of CCL measurements and remigration intervals of nesting flatback turtles, *Natator depressus*, at Peak Island during the 25 November – 7 December 2016 census period.

	Mean	Std. Dev.	Min	Max	N
	Curved Carapace Length (cm)				
1st breeding season (primary taggings)	91.9	2.89	82.2	98.1	25
All remigrant turtles	94.2	2.57	88.1	102.7	178
All Turtles	93.9	2.71	82.2	102.7	203
	Remigration Interval (yr)				
All remigrant turtles	2.96	1.40	1	8	184

Table 4.4. Flatback turtle, *Natator depressus*, clutches, and nest descriptions at Peak Island, 2016-2017 breeding season.

	Mean	SD	Range	N
Eggs per clutch	50.4	6.2	42-65	17
Yolkless eggs per clutch	0	0	0	17
Multiyolked eggs per clutch	0	0	0	17
Nest depth, top (cm)	31.5	5.0	25-40	8
Nest depth, bottom (cm)	47.6	7.2	37-57	11
Egg diameter (cm)	5.20	0.136	4.8-5.5	140 (14 clutches)
Egg weight (g)	76.0	5.54	59.7-90.8	140 (14 clutches)
Eggs/clutch dug from an existing clutch by a nesting turtle	14.3	9.64	2-34	12

Table 4.5. incubation period Incubation and emergence success for flatback turtle clutches at Peak Island during 24 November – 7 December 2016.

	Mean	Std. Dev.	Range	N
Incubation period (oviposition to emergence) (days)	52.67	3.825	48-61	21
Clutches laid during mid-season census period				
• Incubation success (%)	88.84	8.776	57.8-100	36clutches
• Emergence success (%)	86.68	11.465	48.4-100	36 clutches
All clutches examined				
• Incubation success (%)	79.01	19.873	2.3-100	154 clutches
• Emergence success (%)	68.26	27.067	0-100	154 clutches
Clutches identified with heat stress to hatchlings or eggs				
• Incubation success (%)	76.80	17.930	31.8-100	33 clutches
• Hatchling emergence success (%)	56.35	24.546	0-95.6	33 clutches
Clutches dug into by nesting turtles				
• Incubation success (%)	44.08	26.180	2.25-77.4	5 clutches
• Emergence success (%)	25.33	29.478	0-71.4	5 clutches

Avoid Island Tables

Table 5.1 Nightly census of nesting flatback turtles, *Natator depressus*, at Avoid Island during 20 November – 3 December 2016: track count, observed clutches laid and clutches of hatchlings emerging.

Date	# tracks	# turtles	# clutches laid	# Emerged clutches
20 Nov	15	7	8	0
21 Nov	8	6	5	0
22 Nov	7	6	7	0
23 Nov	2	2	2	0
24 Nov	6	5	5	0
25 Nov	12	10	7	0
26 Nov	8	7	6	0
27 Nov	11	7	7	1
28 Nov	12	9	6	0
29 Nov	10	8	6	0
30 Nov	5	5	5	0
01 Dec	3	3	3	0
02 Dec	11	11	10	1
03 Dec	2	2	2	0
Total	112	88	79	2
Mean (s.d)	8.0 (4.0)	6.3 (2.7)	5.6 (2.2)	n/a

Table 5.2. Summary of curved carapace length measurements, remigration intervals, renesting intervals, and clutches laid per female nesting flatback turtles, *Natator depressus*, at Avoid Island during the 2016-2017 breeding season.

	Mean	SD	Range	N
Curved carapace length (cm)				
Entire season				
• 1st breeding season & previously untagged remigrants (primary taggings)	92.67	1.878	89.1-95.7	21
• known remigrant turtles	93.71	2.658	87.8-99.0	70
All turtles	93.47	2.529	87.8-99.0	91
Mid-season census				
• 1st breeding season & previously untagged remigrants (primary taggings)	93.31	1.727	91.1-95.7	14
• known remigrant turtles	93.63	2.613	87.8-99.0	62
All turtles	93.57	2.467	87.8-99.0	76
Remigration interval (yr)				
• entire season	2.32	0.883	1-4	69
• mid-season census	2.41	0.909	1-4	63
Clutches laid per female (yr)				
• entire season	2.73	1.049	1-5	92
Re-nesting interval (d)				
• following an unsuccessful nesting attempt	0.72	0.741	0-3	36
• following a successful nesting	13.92	1.156	12-17	112

Table 5.3. Summary from all of the breeding season for clutch and nest data for flatback turtle, *Natator depressus*, at Avoid Island 2016-2017 breeding season. * Yolkless eggs were counted at hatchling emergence in two clutches not counted when laid (2 – 7 eggs per clutch).

	Mean	SD	Range	N
Eggs per clutch	42	6.141	32-49	8
Yolkless eggs per clutch*	0	0	0	8
Multiyolk eggs per clutch	0.1	0.316	0-1	8
Nest depth, top (cm)	48.5	3.873	45-54	4
Nest depth, bottom (cm)	59.8	7.757	43-69	10
Egg diameter (cm)	4.77	0.712	3.27-5.37	100 eggs (10 clutches)
Egg weight (g)	72.02	5.125	58.9-79.7	100 eggs (10 clutches)

Table 5.4. Summary of data recorded after hatchling emergence for the flatback turtle, *Natator depressus*, clutches at Avoid Island, 2016-2017 nesting season.

	Mean	SD	Range	N
Incubation period (period to emergence) (d)				
• Mid-season census	50.2	2.7	45-57	60
• Entire season	49.6	2.5	42-59	172
Success from clutches laid during mid-season census				
• Incubation success (%)	73.7	31.2	0-100	80
• Emergence success (%)	71.4	32.2	0-100	80
Success from clutches from entire season				
• Incubation success (%)	74.8	29.0	0-100	325
• Emergence success (%)	72.7	29.6	0-100	325
Subset of clutches from within entire season				
Success of clutches impacted by heat wave				
• Incubation success (%)	50.6	33.8	2.0-95.5	12
• Emergence success (%)	40.0	33.1	1.85-91.11	12
Success of clutches submerged by high tide				
• Incubation success (%)	9.26	16.445	0-41.27	6
Success of remnant clutches dug into by nesting turtles				
• Incubation success (%)	64.6	37.7	37.9-91.3	2
• Emergence success (%)	60.7	38.7	33.3-88.0	2

Table 6.1 Summary of data collected on flatback turtles, Natator depressus, nesting at three index rookeries, Curtis, Peak and Avoid Islands, during the 2016 two-week, mid-season monitoring.

Data Collected (mean)	Curtis Island	Peak Island	Avoid Island
# turtles - total	41	214	88
Mean tracks/night	4.5 (4.1)	25.6 (18.8)	8.0 (4.0)
# clutches - total	43	209	79
Nesting success %	73.1	53.1	72.1
% new recruits	12.0	12.6	18.4
Female CCL	93.9 (92.5); n = 46	93.9 (2.7); n = 178	93.6 (2.5); n = 76
Remigration interval (yr)	3.7 (1.6); n = 35	2.96 (1.4) n = 184	2.41 (0.91); n = 63
Clutch size	52.6 (8.4); n = 40	50.4 (6.2); n = 17	42 (6.1); n = 8
Egg Size-cm n = # clutches	5.2 (0.13); n = 3	5.2 (0.13); n = 14	4.8 (0.71); n = 10
Egg Size- weight n= # clutches	76.3 (4.7); n = 3	76.0 (5.5); n=14	72.0 (5.1); n = 10
Incubation success %; n = # clutches	89.0 (15.8); n = 37	88.8 (8.8); n = 36	73.7 (31.2); n = 80
Emergence success %; n = # clutches	85.7(15.9); n = 37	86.7 (11.5); n = 36	71.4 (32.2); n = 80
Incubation duration (census nests); n = # clutches	47.4 (2.2); n = 29	52.7 (3.8); n = 21	50.2 (2.7); n = 60
# clutches laid/female	2.7 (0.9); n = 46	n/a	2.7 (1.0); n = 92

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 2016-2017 breeding season.

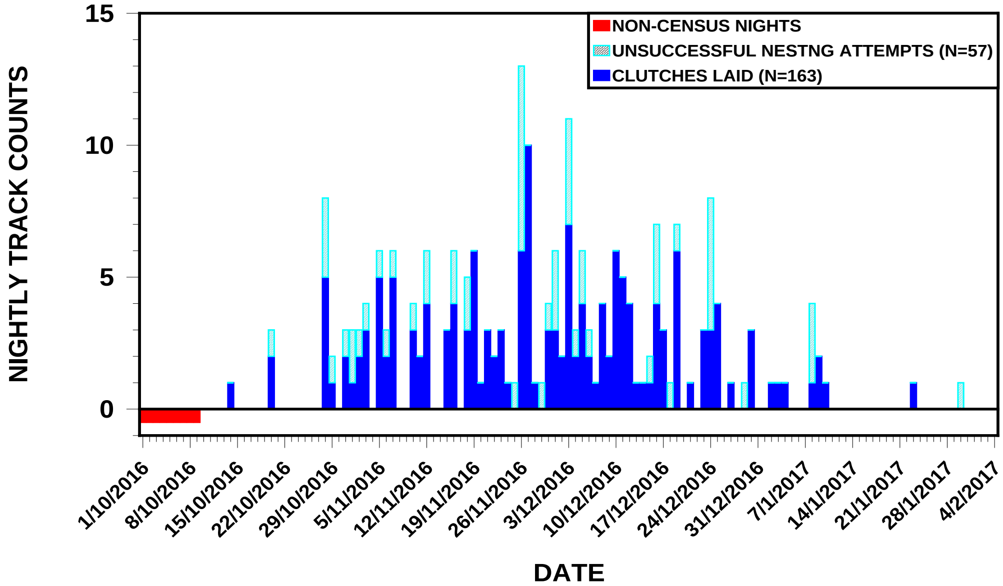
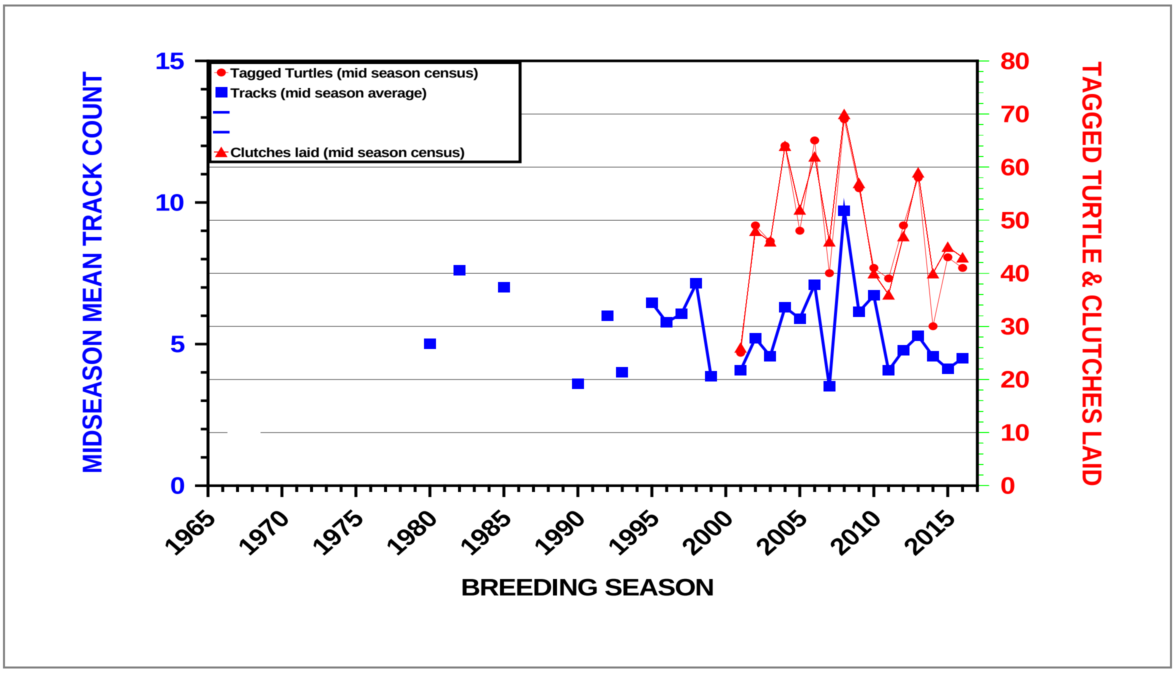
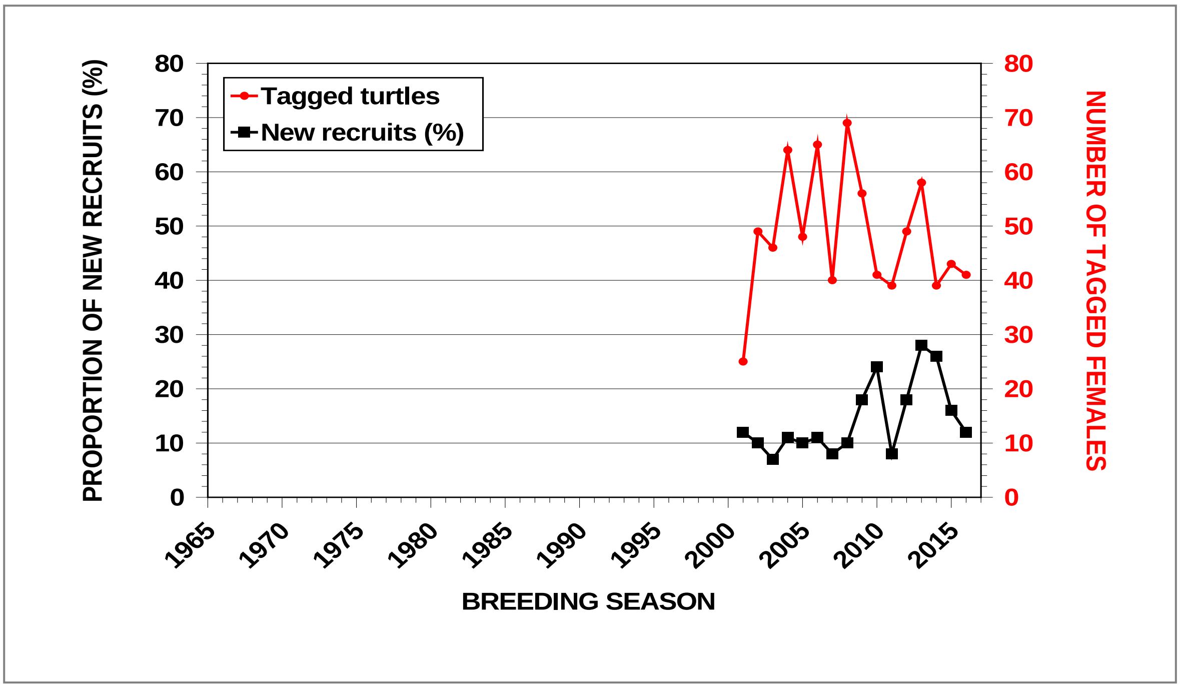


Figure 3.3. Nightly number of flatback turtles, *Natator depressus*, ashore for nesting on South End Beach, Curtis Island during the 2016-2017 nesting season.



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 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 1980-2016.

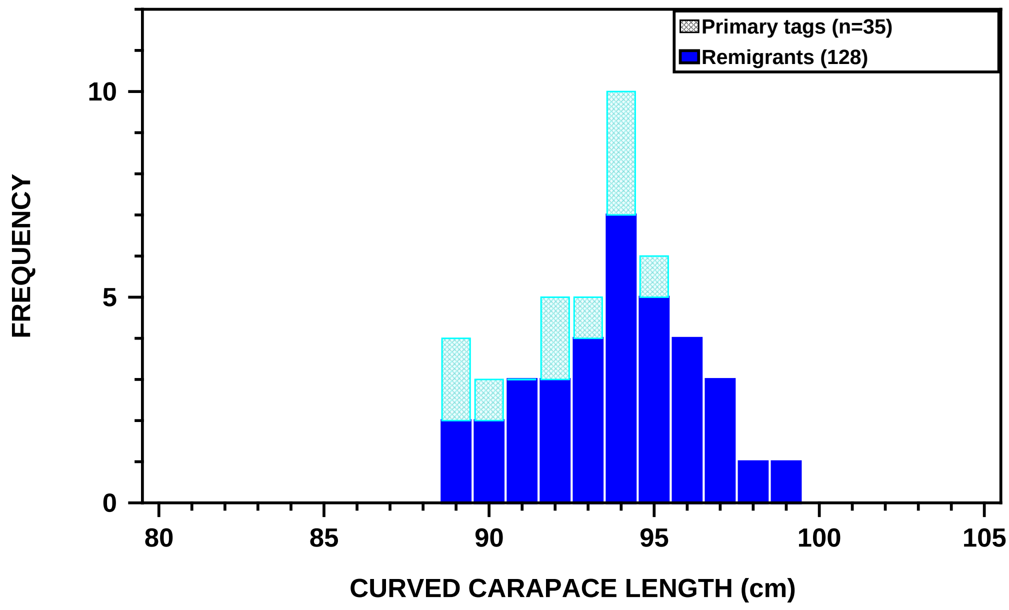


Figure 3.5. Size of nesting flatback turtles, *Natator depressus*, at South End Beach, Curtis Island during the 2016-2017 breeding season.

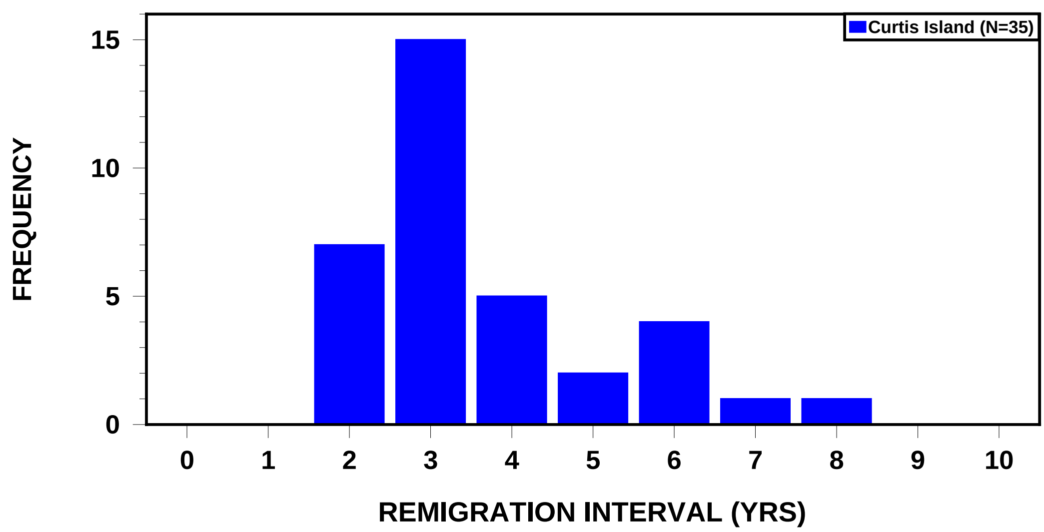


Figure 3.6. Remigration intervals recorded for nesting flatback turtles, *Natator depressus*, at South End Beach, Curtis Island during the 2016-2017 breeding season.

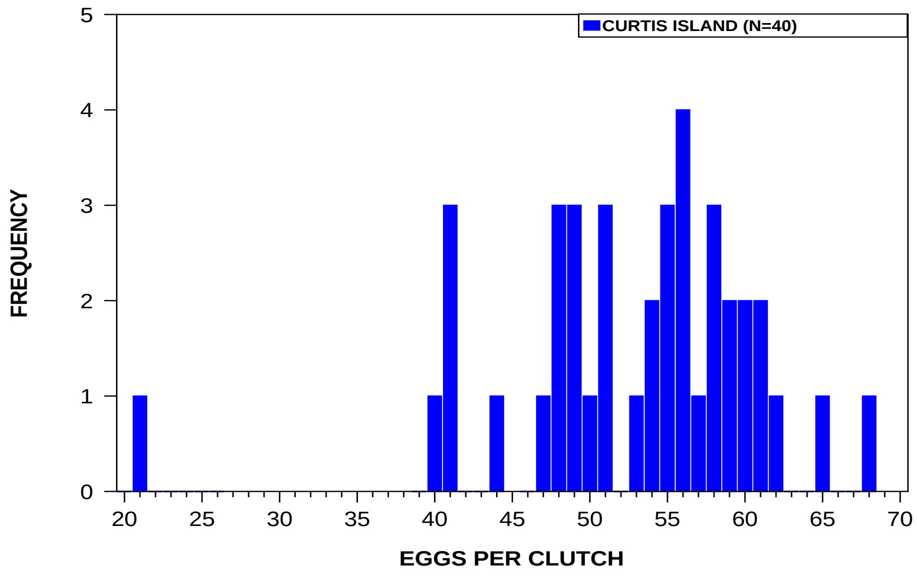


Figure 3.7. Clutch counts recorded for nesting flatback turtles, *Natator depressus*, at South End Beach, Curtis Island during the 2016-2017 breeding season.

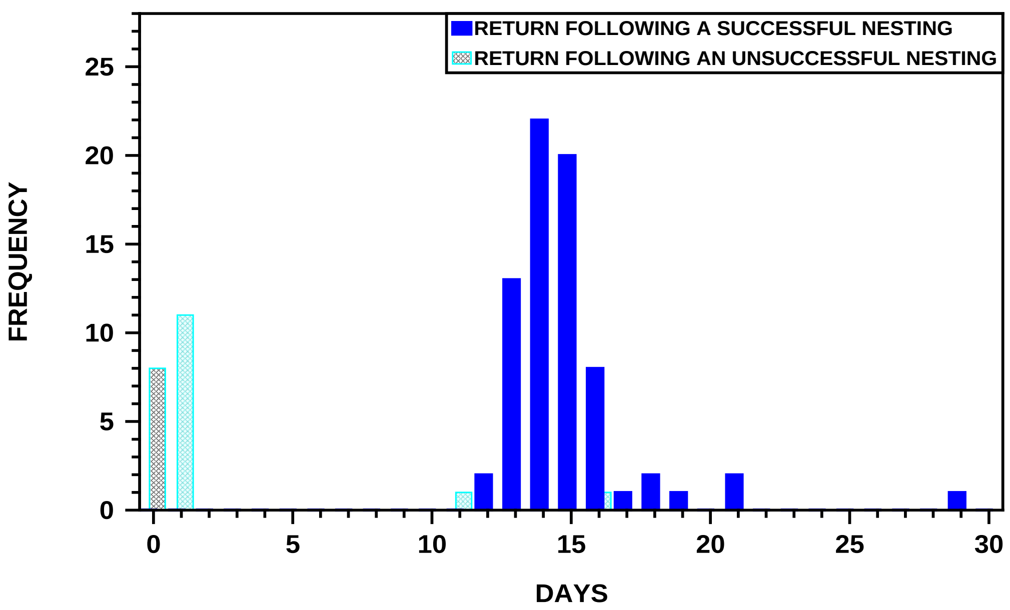


Figure 3.8. Return intervals recorded for nesting flatback turtle, *Natator depressus,* following both successful and unsuccessful nesting attempts at South End Beach, Curtis Island during the 2016-2017 breeding season.

A. K81015: Recent carapace damage presumed to have occurred when the turtle was dropped from a net onto the deck of a vessel.

B. QA37854: Propeller cuts to the carapace that have occurred since this turtle was last recorded nesting in December 2013.

C. T20452: Damage to the rear carapace caused by satellite tag harness deployed on 22 December 2009.

D. QA30752: Damage to the rear carapace caused by satellite tag harness deployed on 26 November 2013.

Figure 3.9. Examples of injured flatback turtles, *Natator depressus*, recorded nesting on South End Beach, Curtis Island, 2016-2017 breeding season.

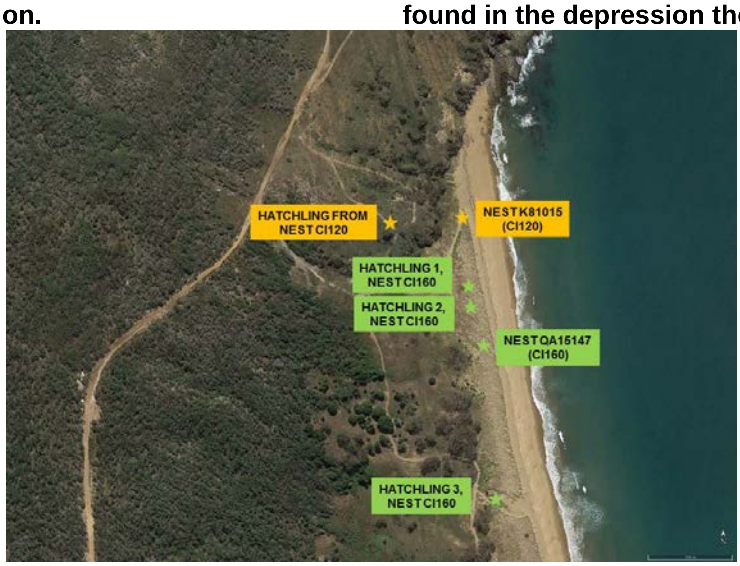
Figure 3.10. Sand temperatures measured at 50 cm depth on the southern end of South End Beach within the turtle nesting habitat in open sun using Vemco Minilog II temperature data logger from 2 November 2016 to 15 March 2017.

A: Photo of sixteen dead, fox predated hatchlings, dug from CI 047 nest prior to emergence.

B: Sky glow from lighting at Gladstone and surrounding Port Curtis, viewed from the northern end of South End Beach, Curtis Island, on a moonless night.

C: Photo of dead flatback hatchling from nest K81015 (CI120), found on 30 January 2017, inland from sector 0, after disorientation.

D: Photo of multiple green turtle hatchling tracks from nest QA15147 (CI160) behind the frontal dune, sector 1. Three hatchlings were found in the depression the next morning.



E. Locations where hatchlings from clutches laid by K81015 and QA15147 were found.

Figure 3.11. Images highlighting the problems caused by introduced predators and sky glow at South End Beach, Curtis Island to flatback turtles, *Natator depressus*.

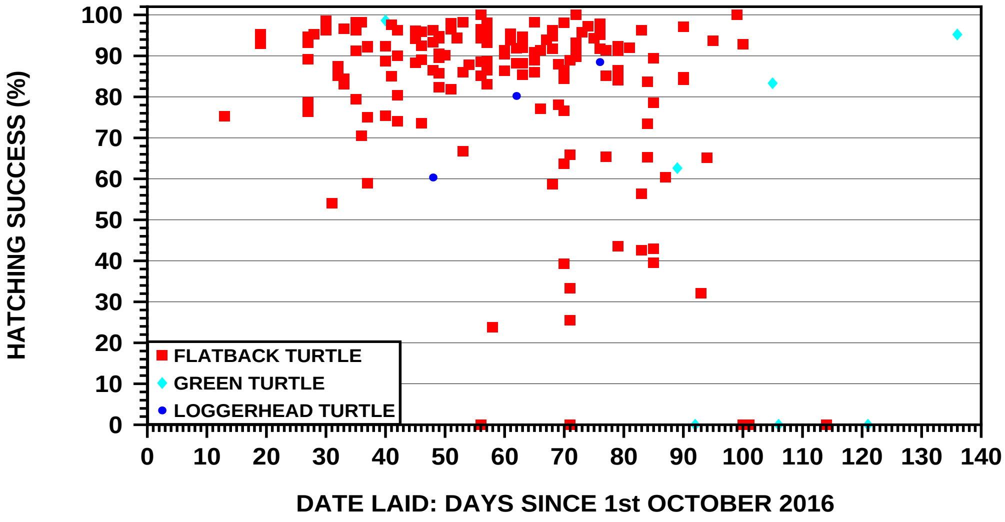


Figure 3.12. Comparison of hatching success (%) for flatback, *Natator depressus*, green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) turtles nesting on South End Beach, Curtis Island, 2016- 2017 season.

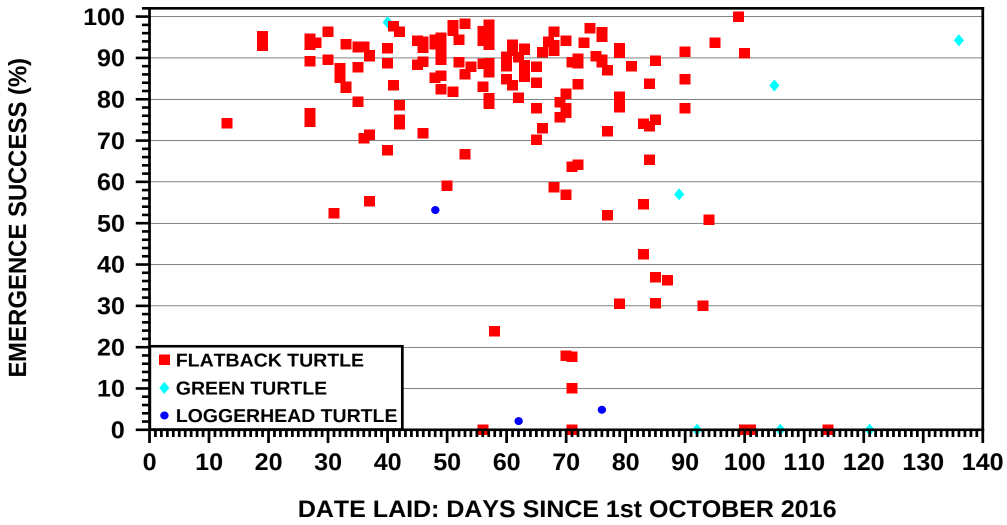


Figure 3.13. Comparison of hatchling emergence success (%) for the 2016-2017 breeding season for flatback, *Natator depressus*, green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) turtles nesting on Curtis Island.

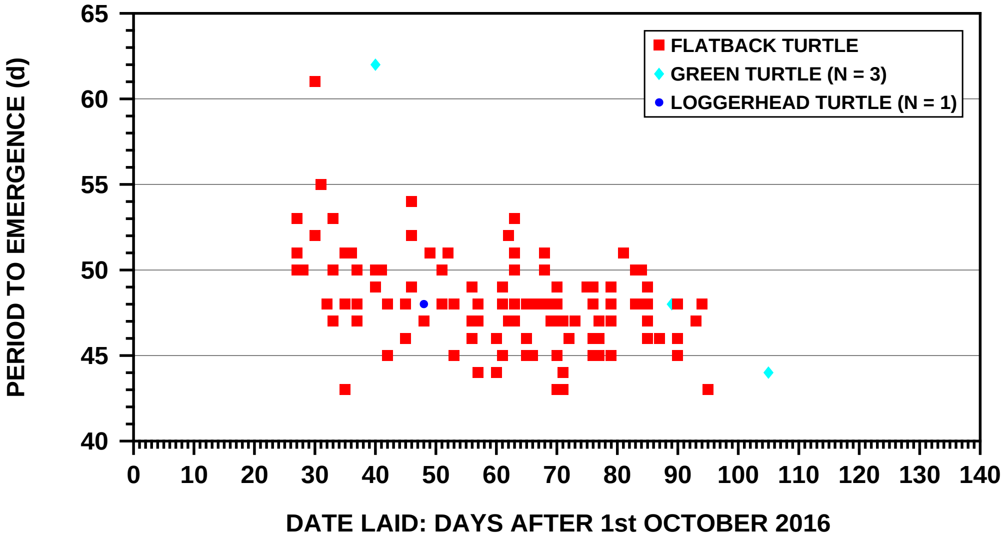


Figure 3.14. Comparison of period to emergence (period from laying to hatchling emergence to the beach surface) for turtle nesting on South End Beach, Curtis Island, 2016-2017 season.

Peak Island Figures

1a. Peak Island and surrounding areas

1b. Peak Island

Figure 4.1. Maps of Peak Island

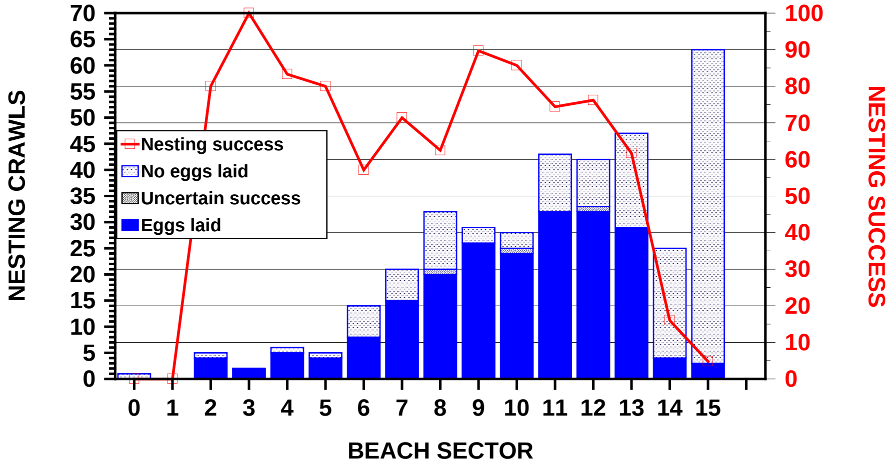


Figure 4.2. Frequency distribution of flatback turtle, *Natator depressus,* nesting crawls (tracks) and nesting success by beach sectors, Peak Island during 24 November – 7 December 2016.

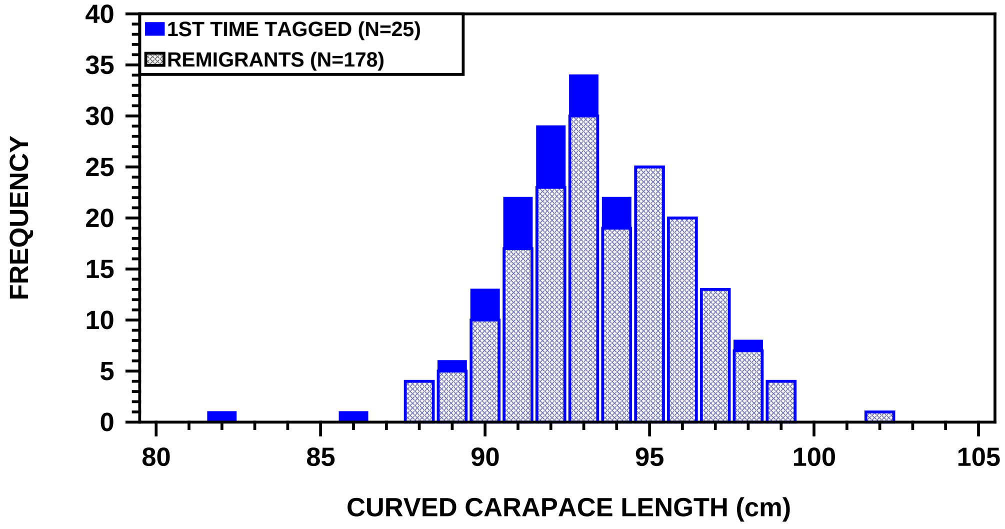


Figure 4.3. Frequency distribution of curved carapace length by breeding experience of flatback turtles, *Natator depressus*, recorded nesting at Peak Island during the 24 November – 7 December 2016.

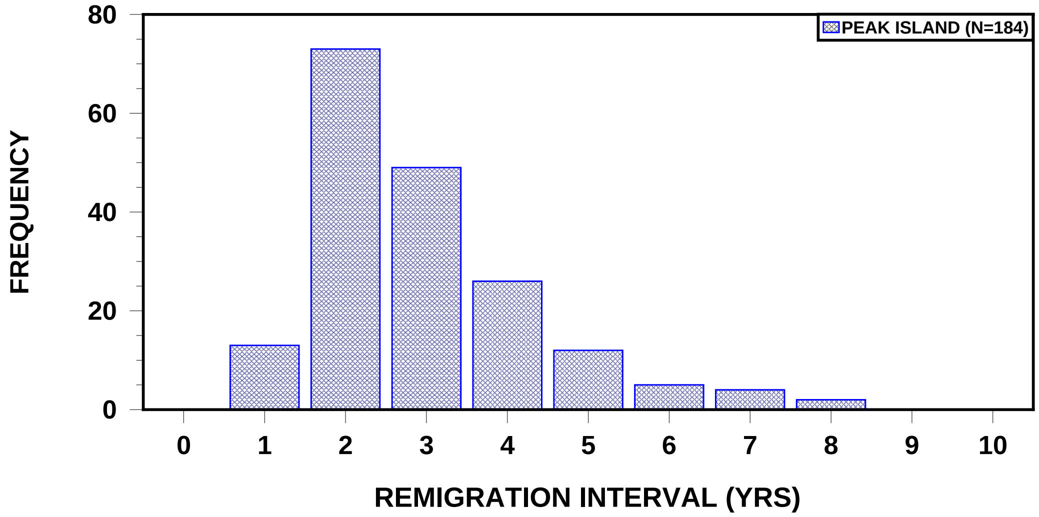


Figure 4.4. Frequency distribution of the number of years between breeding seasons (remigration interval) of flatback turtles, *Natator depressus*, recorded nesting at Peak Island during the 24 November – 7 December 2016.

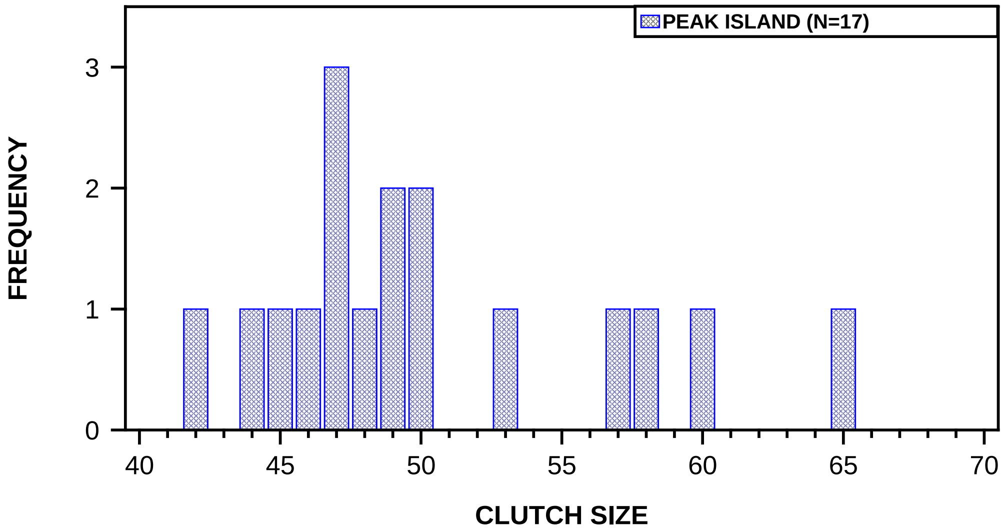


Figure 4.5. Frequency distribution of the number of eggs per clutch of flatback turtles, *Natator depressus*, recorded nesting at Peak Island during the 24 November – 7 December 2016.

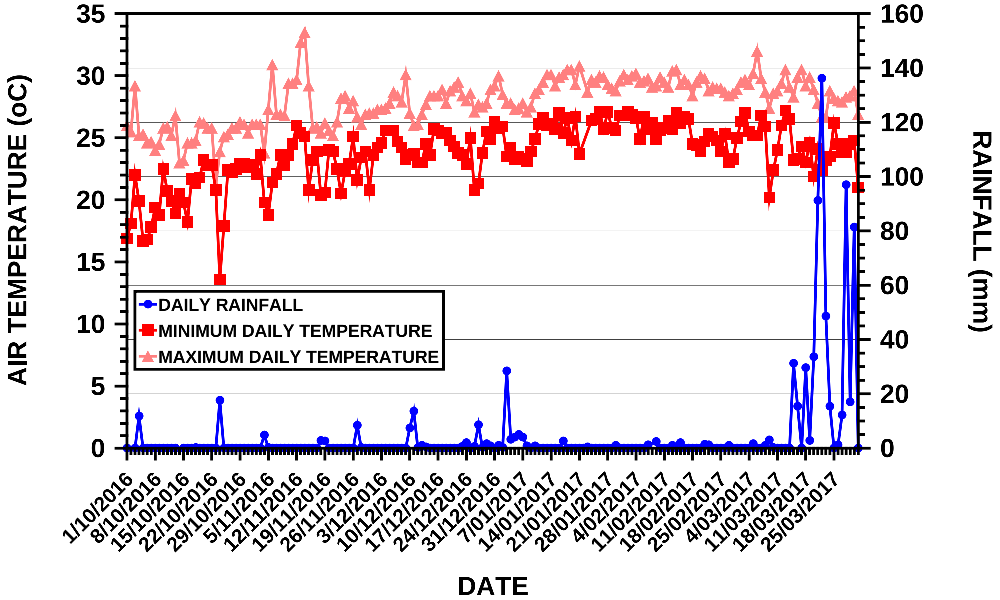
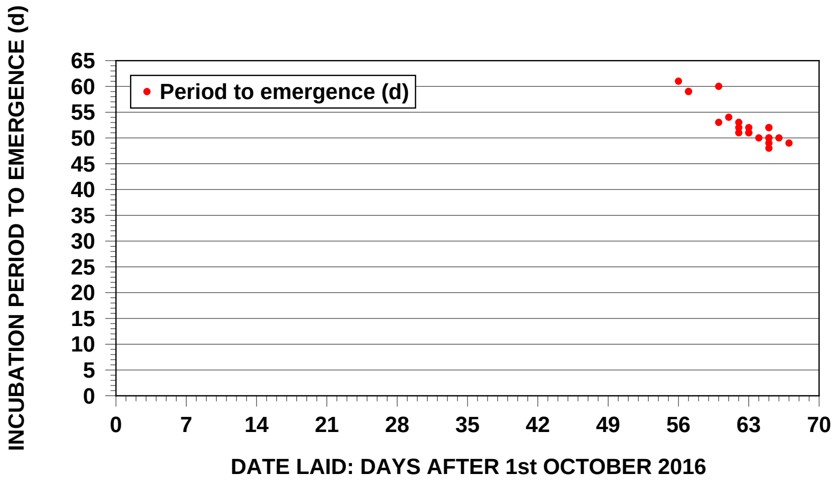
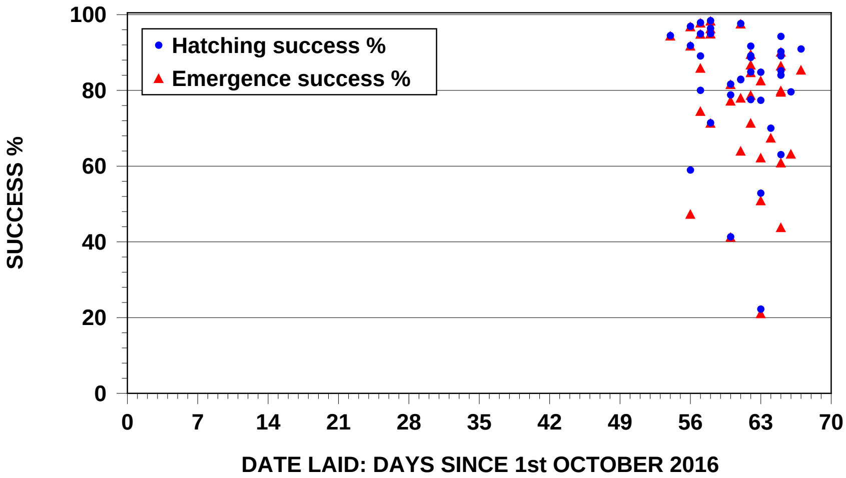


Figure 4.6. Daily rainfall and air temperatures recorded at Yeppoon and Rosslyn Bay during the 2016-2017 flatback turtle, *Natator depressus,* breeding season.

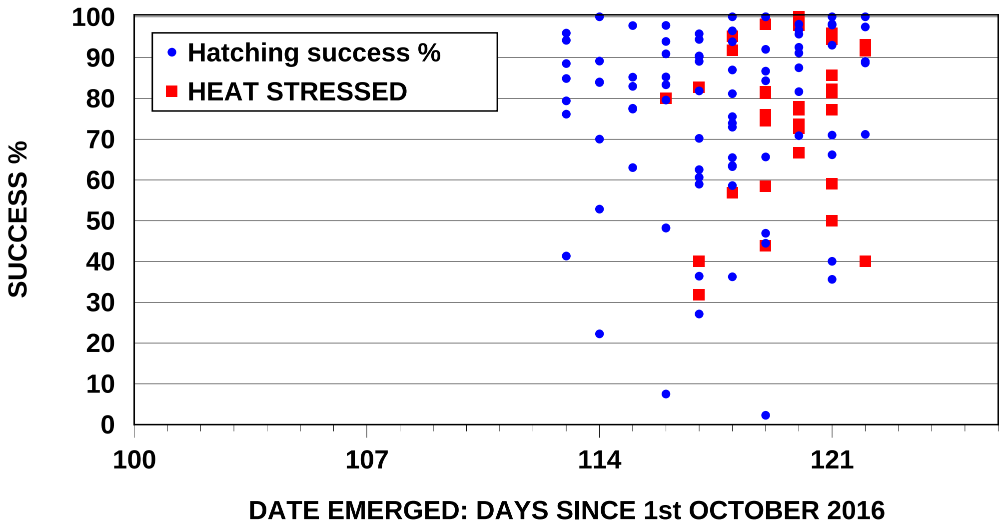


A. Incubation period, n = 21

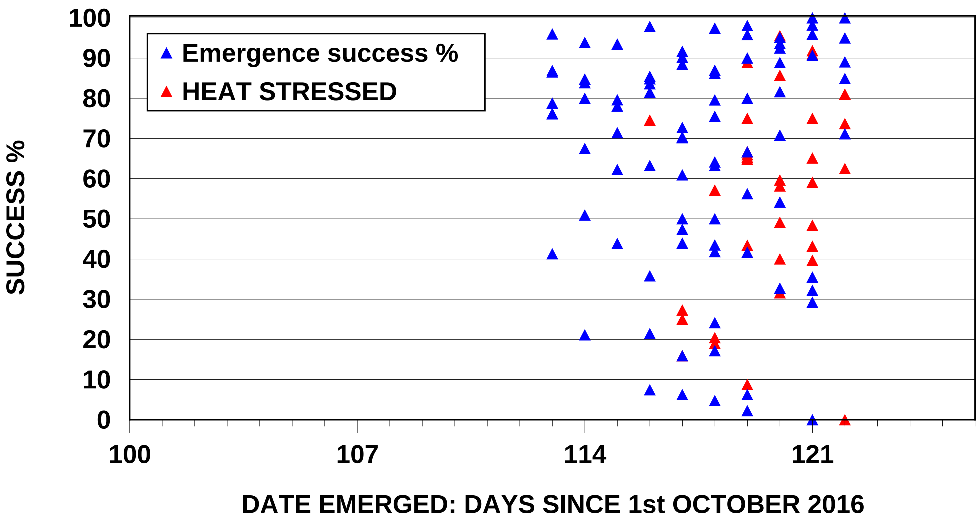


B. Incubation and emergence success, n = 36

Figure 4.7. Incubation period (A), incubation and emergence success (B) for flatback turtle, *Natator depressus*, clutches recorded at nesting at Peak Island during the mid-season census period, 24 November – 7 December 2017.



A. Incubation success



B. Emergence success

Figure 4.8. Comparison of incubation and emergence success from identified heat-stressed clutches and all other clutches identified to date of flatback turtle, *Natator depressus* hatchling emergence at Peak Island during 23 January – 2 February 2017.

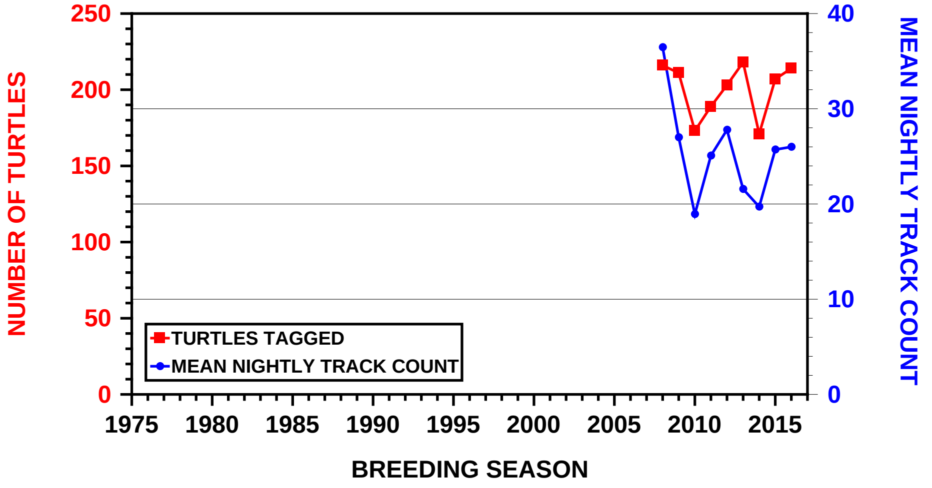


Figure 4.9. Trends in the number of nesting female flatback turtles, *Natator depressus*, tagged during the annual two-week mid-season census (last week of November – first week of December) and the associated mean number of nesting crawls per night during the same period at Peak Island, 2008 to 2016 nesting seasons.

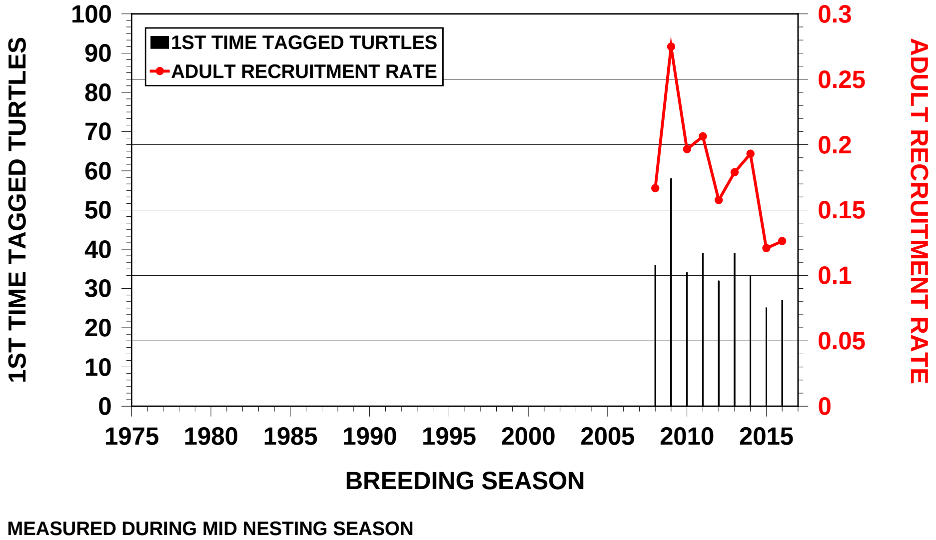


Figure 4.10. Trends in the annual recruitment of new female flatback turtles, *Natator depressus*, to the nesting population at Peak Island, 2008 to 2016 nesting seasons.

Avoid Island Figures

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

Figure 5.2. Researchers Bill Tompkins, Jay Streatfield and Quintin Diou-Cass installing reflective identification markers on trees and posts at Avoid Island during the 2016-2017 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.

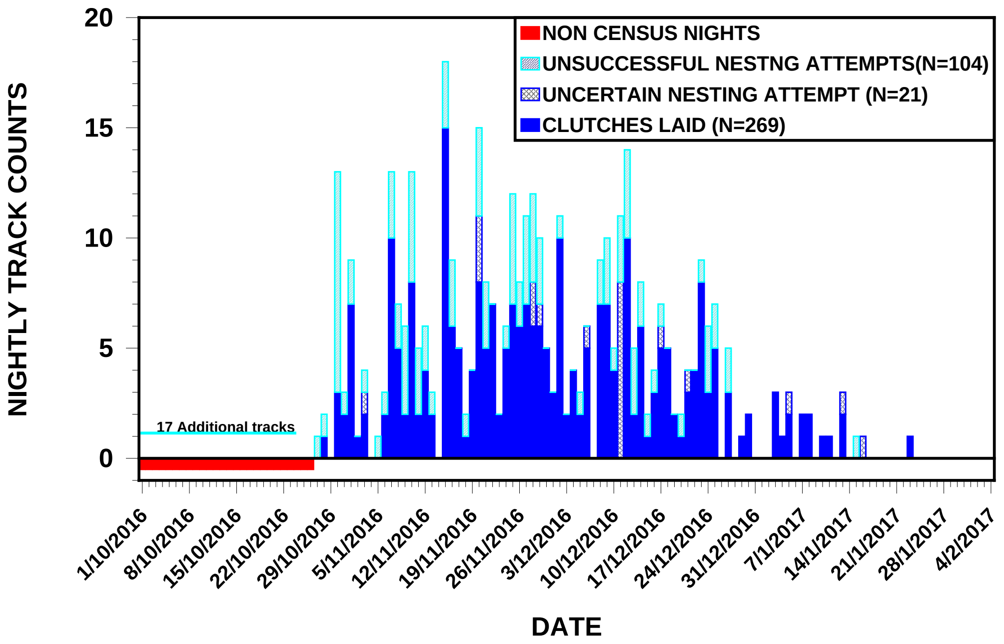


Figure 5.4 Nightly track number of flatback turtle, *Natator depressus*, nesting on Avoid Island during the entire 2016-2017 breeding season.

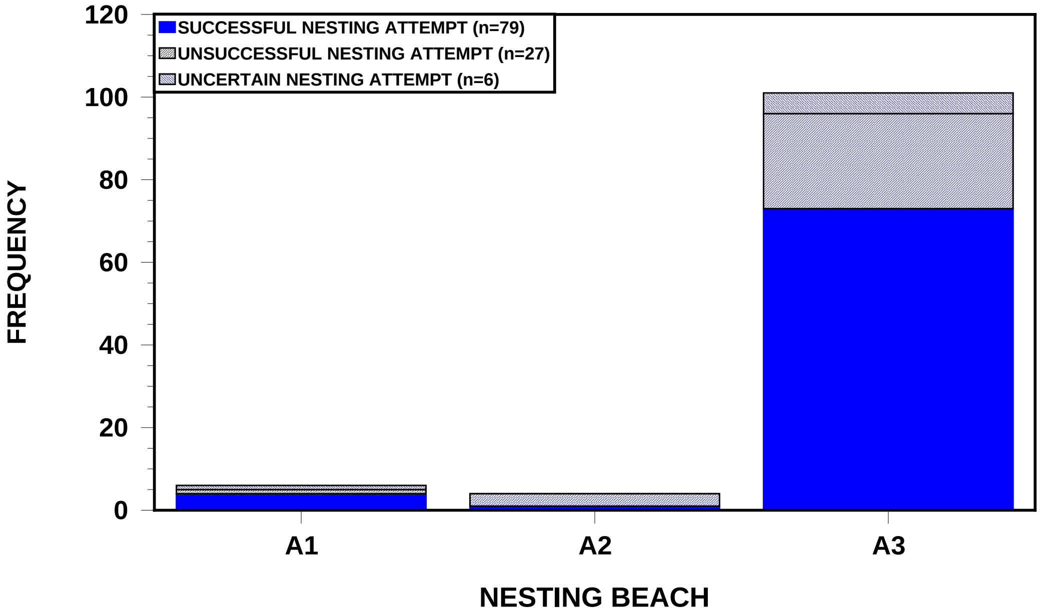


Figure 5.5. Frequency distribution of nesting crawls (tracks) and nesting success of flatback turtles, *Natator depressus*, by beach at Avoid Island during 20 November – 3 December 2016. A1 = North Beach, A2 = Middle Beach, A3 = South Beach.

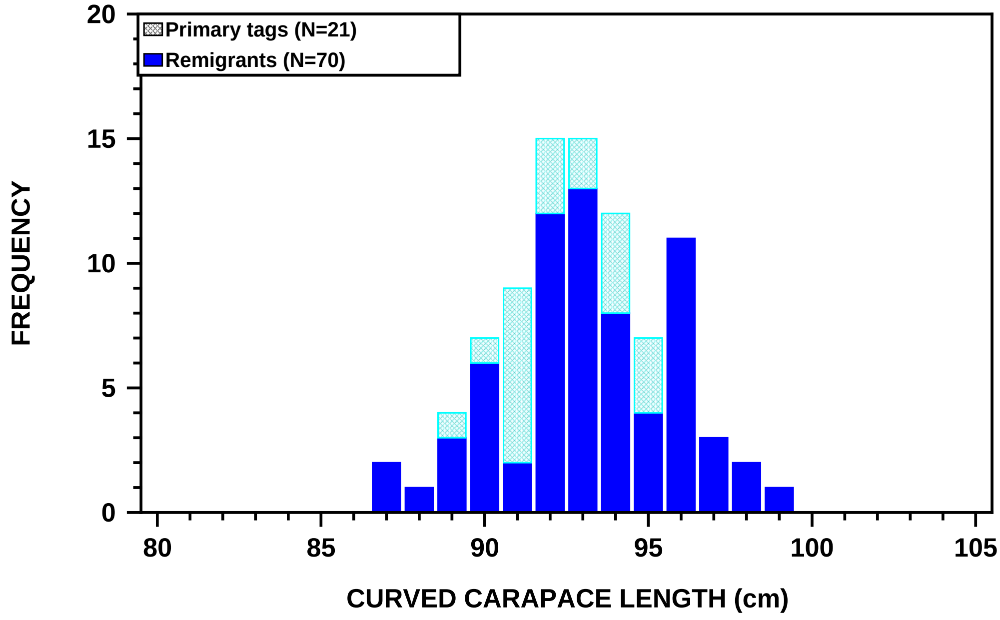


Figure 5.6. Size frequency distribution of nesting flatback turtles, *Natator depressus*, at Avoid Island during the 2016-2017 breeding season.

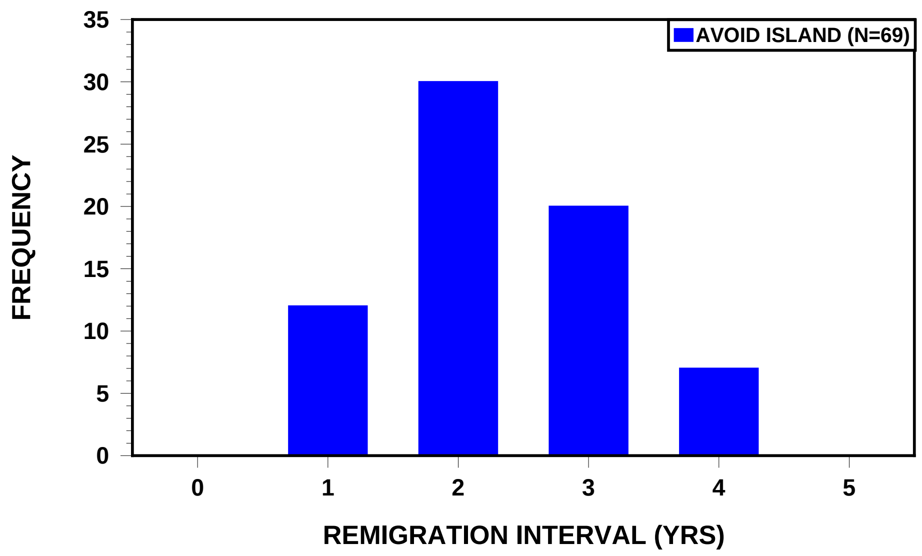


Figure 5.7. Frequency distribution of remigration interval for flatback turtles, *Natator depressus*, at Avoid Island during the entire 2016-2017 breeding season.

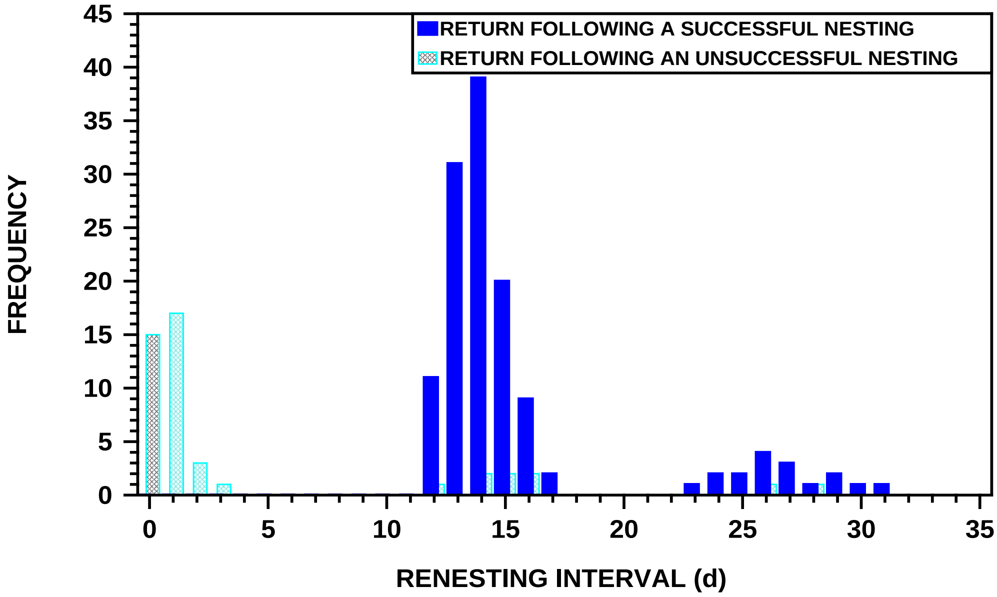


Figure 5.8. Return intervals recorded for nesting flatback turtle, *Natator depressus,* following both successful and unsuccessful nesting attempts at Avoid Island during the 2016-2017 breeding season.

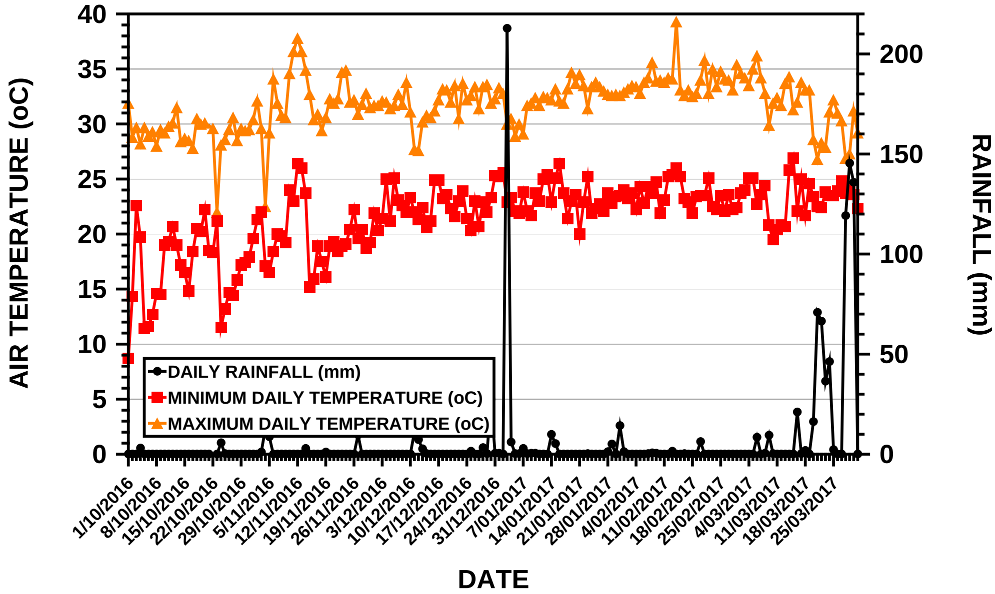
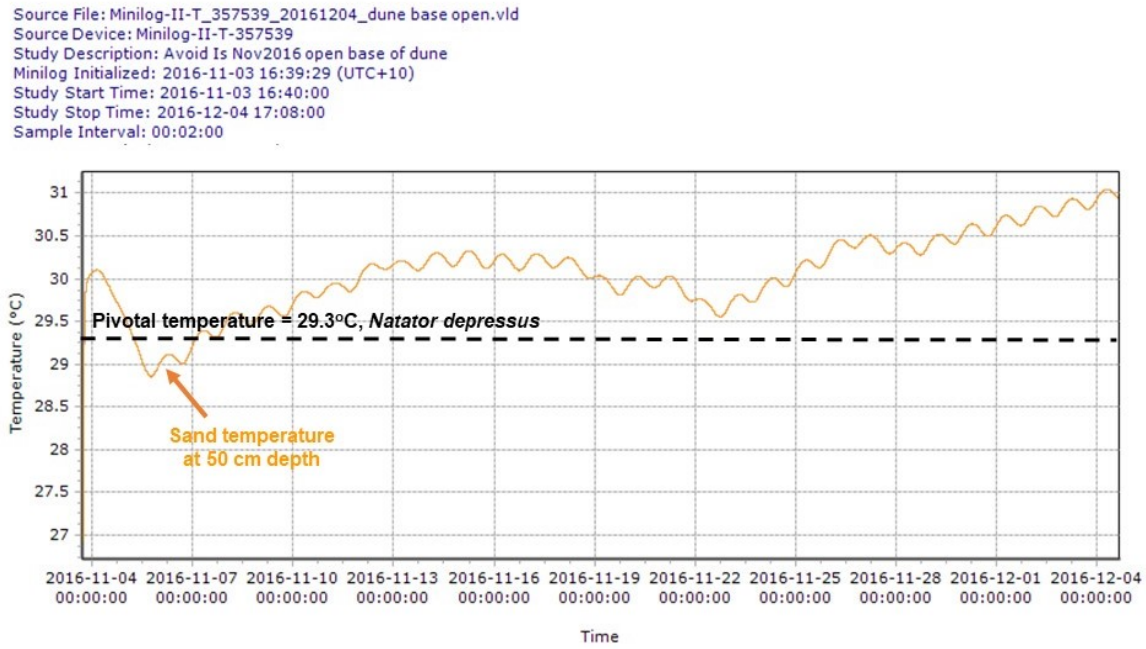
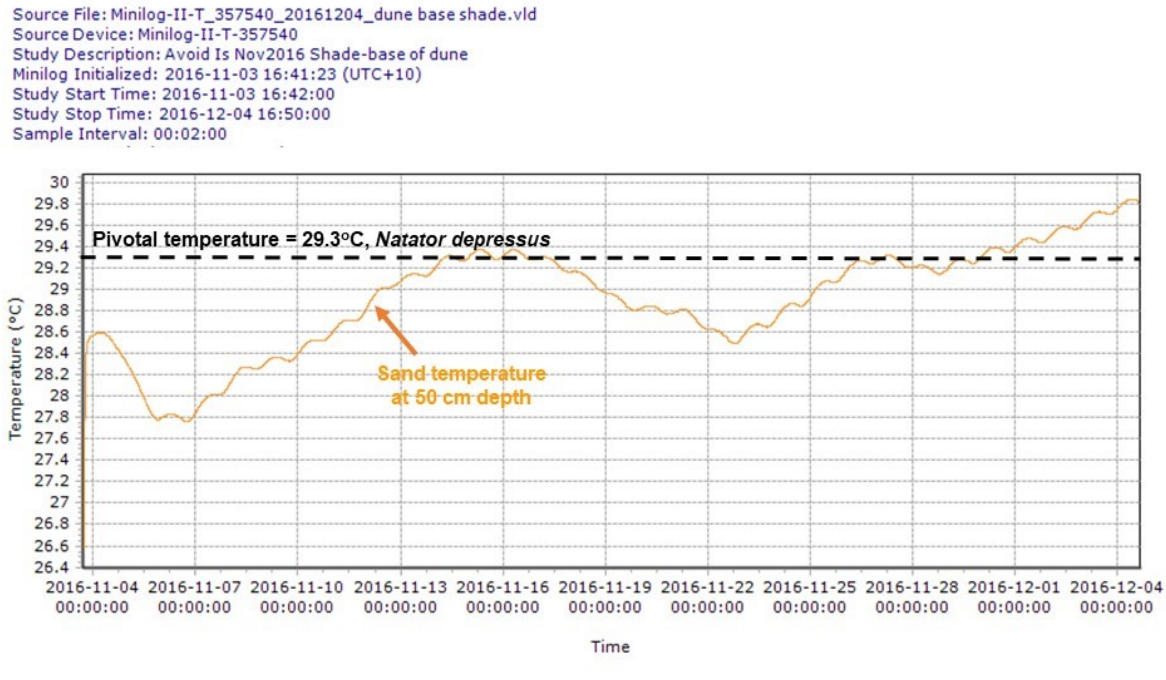


Figure 5.9. Daily rainfall and air temperatures recorded at St Laurence during the 2016-2017 flatback turtle breeding season.

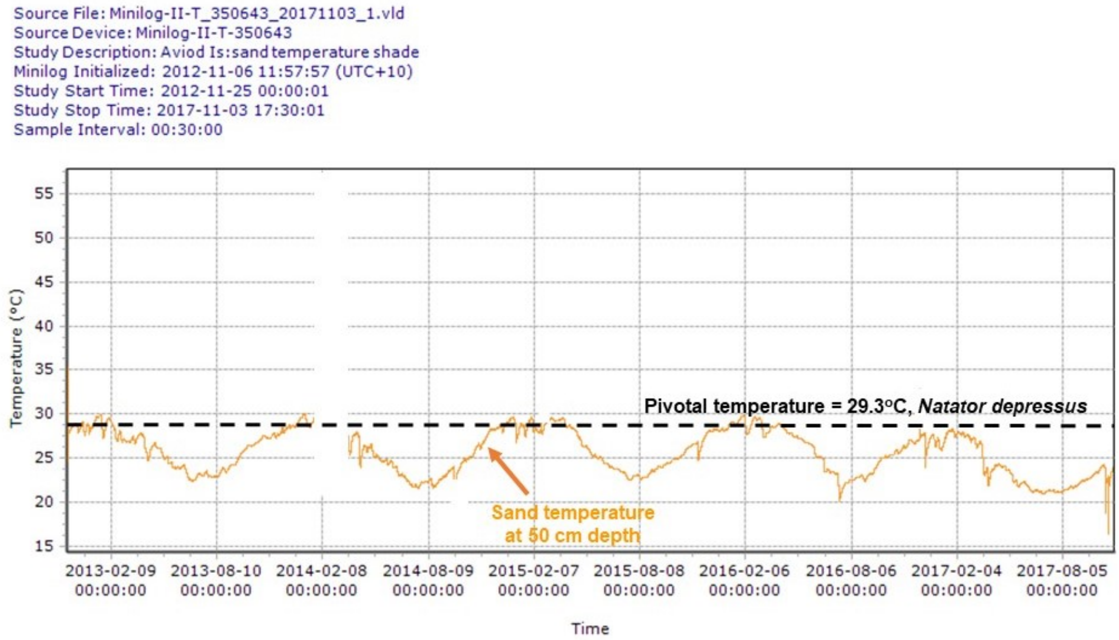


A. Base of dune in open sun.



B. Base of dune in shade.

Figure 5.10. Sand temperatures at 50 cm depth recorded in nesting habitat at Avoid Island during the 2016-2017 flatback turtle, *Natator depressus*, breeding season.



C. Top of 1st dune, in shade, including sand temperature data since November 2012.

Figure 5.10. Continued.

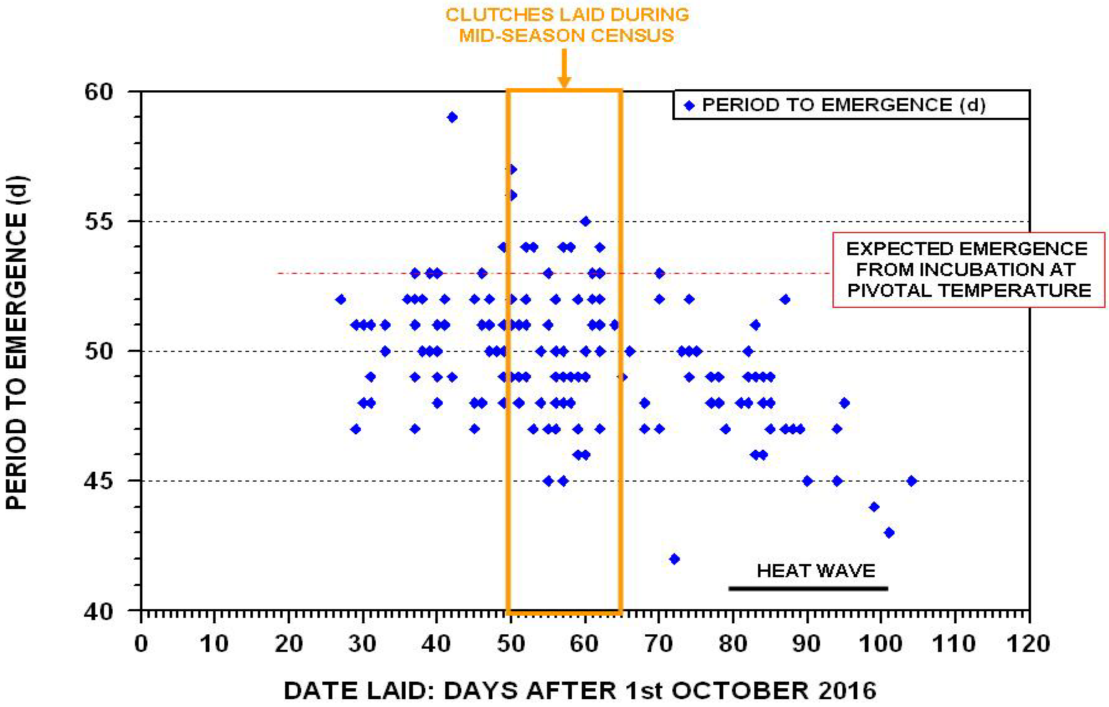


Figure 5.11. Comparison of period to emergence (incubation period from laying to hatchling emergence to the beach surface) for flatback turtle, *Natator depressus*, clutches laid at Avoid Island, 2016-2017 breeding season. Clutches laid during the mid-season census period are identified. The period of heat wave conditions in

south east Queensland is identified. The expected period to emergence of clutches incubating at the pivotal temperature (29.3ºC) is shown.

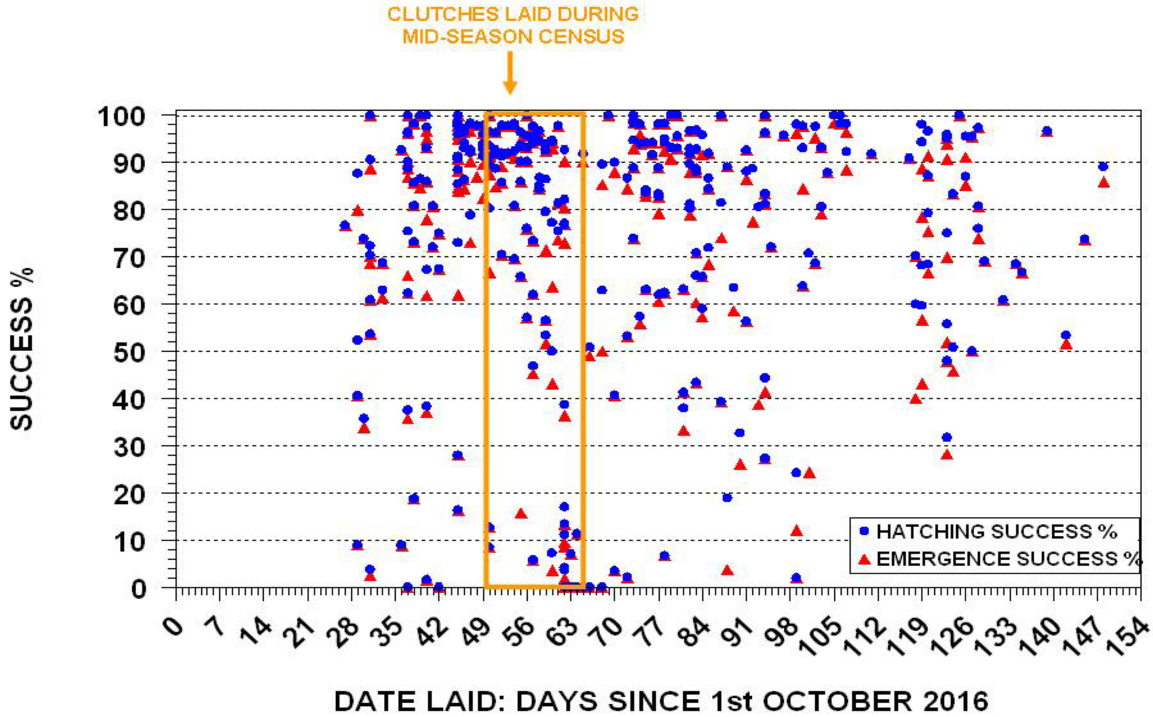


Figure 5.12. Comparison of incubation success by date laid for flatback turtle, *Natator depressus*, clutches at Avoid Island, 2016-2017 breeding season. Clutches laid during the mid-season census period are identified.

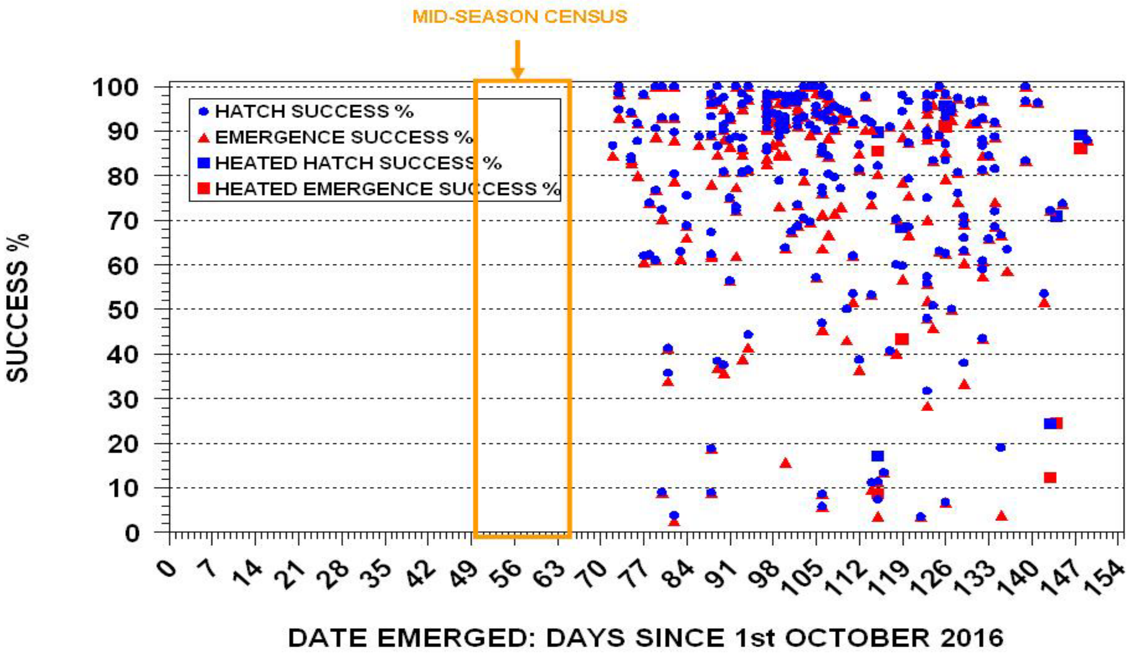


Figure 5.13. Comparison of hatchling incubation success by date of hatchling emergence for flatback turtle, *Natator depressus*, clutches at Avoid Island, 2016-2017 breeding season.

Figure 5.14. Beach profile of South Beach (left) and North Beach (right) at Avoid Island, during a period of King tides, November 2016.

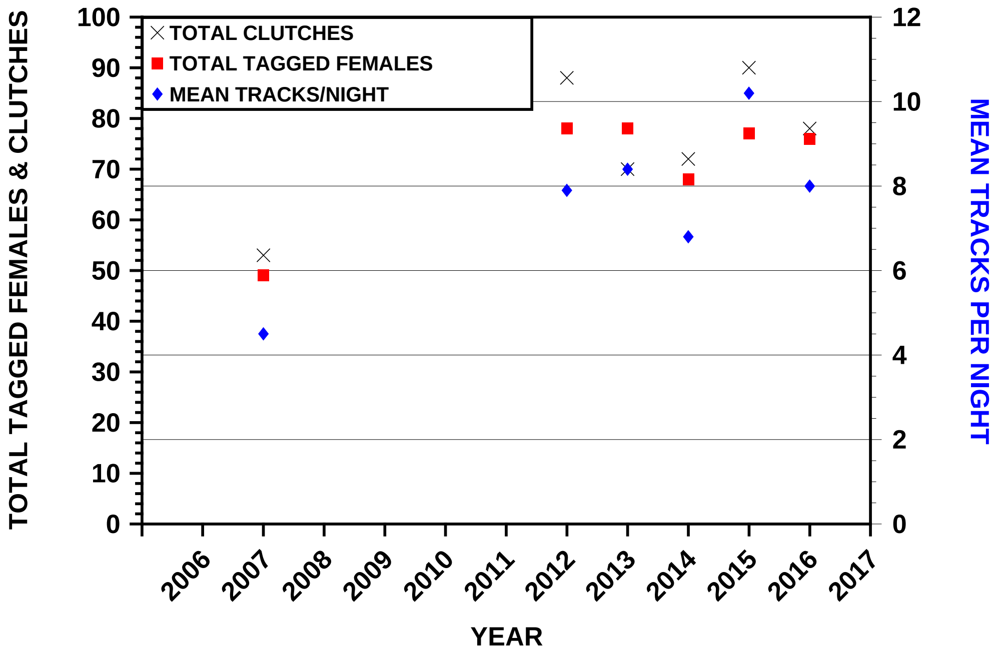


Figure 5.15. Comparison of total number of tagged females, total clutches laid and mean track count per night during the standard mid-season nesting census across breeding seasons for flatback turtle, *Natator depressus*, at Avoid Island.