FLATBACK TURTLE, *Natator depressus*, 2018-2019 BREEDING SEASON, AT CURTIS, PEAK AND AVOID ISLANDS




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Cover photographs:
Scenes from the census of nesting flatback turtles, *Natator depressus,* 2018 – 2019 at Curtis, Peak and Avoid Islands. Photographs taken by, Duncan Limpus and Maree McLaren.

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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 2018-2019 breeding season. A two-week mid-season census was conducted at all three islands. A greater extent of the entire breeding season was monitored at Curtis Island. Table 1 provides a comparison of reproductive parameters recorded at these three central Queensland flatback turtle index beaches with high-lighting of those parameters that are considered to be indicators of poor population performance.

Number of nesting females and nests

- A total of 40 nesting crawls from 30 individual nesting flatback turtles and 30 clutches of eggs laid were recorded at Curtis Island during the two-week census period (24 November –7 December 2018).

- A total of 236 nesting crawls from 122 individual nesting flatback turtles and 114 clutches of eggs laid were recorded at Peak Island during the two-week census period (24 November –7 December 2017).

- A total of 49 nesting crawls, 29 individual nesting flatback turtles and 31 clutches were recorded at Avoid Island during the two-week census period. During an extra nine days of monitoring during 30 Oct - 4 Nov and 8-10 Dec, 3 additional individual flatback turtles and 11 clutches were recorded.

Recruitment of new females into the annual breeding population

- Curtis Island had a moderate level of recruitment, at 16%, during the census.
- Recruitment of new nesting females into the breeding population during the census period has been declining at Peak Island and the value of 10.7% of the recorded turtles is regarded as low for flatback turtles.
- During the mid-season census at Avoid Island 17.2% of nesting turtles were new recruits, and this value decreased to 15.6% when including the additional days of monitoring.

Remigration intervals and rookery fidelity

- The most common remigration interval for nesting females at Curtis Island was two years, followed by three or four years. At Peak Island most turtles re-migrated after two or three year intervals but some turtles were observed returning after up to 10 years. It is possible that we failed to record their nesting during the intervening years because of the brief annual census. At Avoid Island, most turtle re-migrated after two or three years.
- Nesting females continue to display high fidelity to each island. No recaptured females were originally tagged while nesting at a different rookery.

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 and hatchling size.

- At Curtis, Peak and Avoid Islands, new recruits to the nesting population were smaller than females with a past breeding history.
- The length of the nesting season was recorded at Curtis Island with nesting commencing on 17 October 2018 and the last clutch laid on 17 January 2019.
- The first emergence of hatchlings occurred on 8 December 2018 on Curtis Island. Commencement of hatchling emergence was not recorded at Peak and Avoid Islands.
- The average incubation period from laying to hatchling emergence to the beach surface was 48.2 days at Curtis Island, 48.2 days at Peak Island and 49.8 days at Avoid Island.

Population trends

- At Curtis Island the size of the nesting population during the two-week mid-season census period has approximately halved during the past decade, even though the recruitment of new adults into the nesting population has been increasing at a low rate over the same period.
- At Peak Island the mid-season census counts of mean numbers of nesting crawls and the mean number of clutches laid suggest that the nesting population may still be declining at a slow rate across the last 11 breeding seasons.
- At Avoid Island the mid-season census count (n = 29) was considerably lower than in the previous six seasons (mean = 72.7; range 60-78) and warrants additional monitoring.

Hatchling production

- Curtis Island: Nesting success was 75%. Hatching success of eggs exceeded 80% across all nests throughout the season. Emergence success was 78% across the entire nesting season.
- Peak Island: Nesting success was very low at 48.3%. There was a good increase in incubation success at Peak Island this past summer, with a mean hatching success of 80.3% and a hatchling emergence success from the nests of 73.1% from the 136 clutches examined. These improved incubation results from natural nests are attributed to lower sand temperatures as a result of increased rainfall and reduced root invasion of the nests.
- Avoid Island: Data were obtained for 21 marked mid-season nests, with results indicating a low average hatching success of 61.4% and hatchling emergence success of 59.6%. If including additional nests that were either marked earlier in the season, or encountered after emergence, the values rose somewhat: hatching success = 63.4%; hatchling emergence success = 61.5%.

Temperature profiles and weather events

- Although Australia experienced a record level of heatwave conditions during the 2018-2019 east coast flatback turtle breeding season, sand temperatures at nest depth were lower at all three beaches compared to sand temperatures in the 2017-2018 summer. This was a consequence of the intermittent elevated rainfalls throughout the 2018-2019 season from three cyclones in the Coral Sea.
- These cyclones did not pass close enough with sufficient intensity to cause significant erosion of nesting habitat at any of the monitored rookeries.
- Based on sand temperature measurements and incubation period to hatchling emergence values, it is predicted that a female biased hatchling sex ratios will

have been produced at all three census islands but that this female bias will not have been as strong as in the previous two summers.

- Negative impacts on successful hatchling production at Avoid Island during the 2018-2019 season was influenced by flooding during high tides. Several areas of South and North Beach have developed depressed areas within the nesting habitat that collect water during the higher high tides. This was recorded as a problem for 19.6% of nests that were dug.

Management considerations

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

CHAPTER 1. INTRODUCTION

This study has been conducted under an agreement between the Gladstone Ports Corporation (GPC) and the Queensland Department of Environment and Science (DES) to continue monitoring of flatback turtle (*Natator depressus*) nesting and hatching at the South End Beach, Curtis Island, Peak Island and Avoid Island for the 2018/19 breeding season (Figure 1.1). This monitoring is supported by a Gladstone Ports Corporation (GPC) Ecosystem Research and Monitoring Program (ERMP). This is the sixth year of monitoring these rookeries under this program.

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

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

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

CHAPTER 2. GENERAL METHODS

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

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

Nesting activity

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

- At Curtis Island, daily monitoring began on 24 November until 14 December 2018 and included the standard mid-season census period (see Chapter 3 methods). Intermittent monitoring of the turtle nesting by local volunteer members of the study team occurred throughout the entire nesting season.
- At Peak Island from 24 November to 07 December 2018.
- Monitoring at Avoid Island included the standard 14-day census period from 24 November to 7 December 2018, with nightly monitoring on all eastern beaches, referred to as South Beach, Middle Beach and North Beach. Additional monitoring on South Beach was conducted on 31 Oct to 4 Nov, and 8 to 10 Dec; during this time only tracks and nests were counted on Middle and North Beach.
- Data from the two week mid-season census are referred to as the ‘census data’.

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

- Encountered turtles left the beach with a minimum of two titanium tags (manufactured by Stockbrands Australia) in the front left and right flippers at a designated tagging position (Limpus, 1992), generally proximal to the flipper scute closest to the body. If scar tissue from previous tagging made this position unsuitable for tagging, tags were applied distally to this scute.
- Passive Integrated Transponder (PIT) tags (Parmenter, 1993) 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 or Smartrac .
- Curved carapace length (CCL ± 0.1 cm) was measured from the skin/carapace junction at the anterior edge of the nuchal scale, along the midline, to the posterior junction of the two post-vertebral scutes at the rear of the carapace using a flexible fibreglass tape measure. Any barnacles living along the midline of the carapace were removed prior to measuring.
- Any damage to the turtle or unusual features were recorded and photographed if possible.
- A nest tag (flagging tape ~20 cm long) with the date of laying and a tag number of the turtle (Limpus, 1985) was placed in the nest during oviposition for most

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

- A subset of clutches of eggs were counted and ten eggs were selected to represent a cross-section of eggs from top to bottom of the nest. Each selected egg was weighed (± 0.1 g) on a digital balance and measured for maximum and minimum diameter (± 0.1 mm) with Vernier callipers. To minimise movement induced mortality of eggs all handled eggs were returned to their respective nests within two hours of being laid and with the minimum of rotation (Limpus *et al*. 1979).
- Nest locations were recorded using a hand held GPS (global positioning system) unit (± 4 m). Habitat type of the nest location was recorded including the beach profile location and vegetation type near the nest.
- To identify marked nests after hatchling emergence, somewhat different techniques were used at each rookery in addition to GPS locations:
    - At Curtis Island all clutches were marked with two timber marker pegs (25 mm x 25 mm x 400 mm) that were labelled with a unique nest number. One marker peg was placed two hand spans from the nest, and the second maker peg was placed one hand span from the first marker peg, in line with the nest.
    - At Peak Island nests were not mapped and data were collected only from emerged clutches.
    - At Avoid Island, the new sector numbers established in 2017 on South Beach and North Beach continued to be used.

Incubation and emergence success

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

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

- Counting error, the accuracy of counting broken egg shells was calculated as: estimated clutch count following hatchling emergence minus clutch count made when the eggs were laid.
- The depth to the bottom of the egg chamber was measured ($\pm$ 5 mm) and observations on the nest environment were made with respect to erosion and water inundation.

Environmental Monitoring

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

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

The Australian Bureau of Meteorology has identified the summer of 2018-2019 as the hottest summer since recording commenced in 1910 (Figure 2.1. Bureau of Meteorology, 2019):

- An unusual extended period of heatwaves over much of Australia began in early December 2018 and continued through January 2019. February was less extreme but still substantially hotter than average. Persistent thermal lows and no significant synoptic systems to change the air mass resulted in northern Australia seeing near-ideal conditions for heat build-up. Very large areas of Australia experienced exceptionally high temperatures during the last week of December, extending from the northwest of the country to the inland southeast. Temperatures remained very high for multiple days, with the event generally more of a standout for the persistence of the heat than for absolute extremes. Individual daily temperature records, were observed across northern, central and eastern Australia, including 49.3 °C at Marble Bar in the northwest Western Australia on the 27th; the third-highest temperature on record anywhere in Australia during December.
- An extreme heatwave on the tropical Queensland coast occurred during 24 – 30 January 2019. The areas affected by the extreme heatwave encompassed from around Lockhart River in far north of Cape York Peninsula to the Capricornia coast near Yeppoon, extending west to tropical inland districts. Most of northern and eastern Queensland experienced a low intensity heatwave during this period, while on the east coast, much of the far north tropical to central coasts and adjacent inland districts, experienced a severe heatwave.

The 2018−2019 summer was the hottest on record for Australia by a margin of 0.86 °C, and was also the hottest for New South Wales, Victoria, Western Australia and the Northern Territory. January 2019 was the hottest month on record nationally by a margin of 0.99 °C, and was also the hottest month on record for every State and Territory except South Australia and Western Australia.

Three cyclones brought periods of elevated rainfall with associated drops in sand temperatures on the beaches and increased wave washover and or erosion of nesting habitat along the central Queensland Coast during the 2018-2019 marine turtle breeding season within this summer of intermittent heatwave conditions: In the absence of elevated rainfall, beach sand temperatures were expected to be elevated with resulting potential to feminise hatchlings and increase egg mortality.

- **Early December 2018, Severe tropical cyclone *Owen*** (Figure 2.2a): A tropical low developed into TC *Owen* over the Coral Sea on 2 December but was downgraded while still well off the north Queensland coast on 4 December. The low (ex-TC *Owen*) moved west towards northern Queensland and crossed the coast near Port Douglas, north of Cairns, at around 3 am on 10 December causing heavy rainfall. The system passed into the Gulf of Carpentaria, and regained its cyclone strength and intensified to severe cyclone (category 3) *Owen* near the Gulf's southwest coast before turning back east and making landfall near Kowanyama on the western side of the Peninsula early on 15 December (see the preliminary report for more details). *Owen* produced steady heavy rainfall on its second pass, resulting in localised flash flooding. There were daily totals over 300 mm near Ingham on the east coast, including 678 mm at Halifax (a new December daily rainfall record for Australia).
- **Late December 2018, Tropical cyclone *Penny*** (Figure 2.2b): TC *Penny* made landfall along the west coast of Cape York Peninsula, near Weipa, late on New Year's Day 2019, as a category 1 strength system. The most significant impacts during this event were not directly associated with *Penny*, but more so with the monsoon that was active to the north of the Australian continent at the time. There were reports of multiple fatalities in Papua New Guinea and the Solomon Islands due to the impacts of monsoonal rain and winds during late December and early January. The tropical low that became *Penny* was first identified and tracked in the northwest Coral Sea, offshore of Lockhart River, on 28 December. In the days leading up to New Year's Eve, the low drifted slowly west across Cape York Peninsula and towards the northern Gulf of Carpentaria. The low quickly showed signs of development within 24 hours of moving over northern Gulf of Carpentaria waters and by the end of 31 December the system began to adopt a track back towards the east under the influence of the monsoonal flow to the north of the system. As the environment around the Gulf of Carpentaria was conducive for development, the low was able to form into a tropical cyclone and was subsequently named *Penny* at 7am AEST on New Year's Day, approximately 100km west of Weipa. A 0.8 metre storm surge was recorded by the Weipa storm tide gauge on 1 January, which lead to a marginal exceedance of the Highest Astronomical Tide level. Large waves were also observed for a brief period at the Weipa wave monitoring gauge. Following landfall, *Penny* continued to track in an eastwards direction across Cape York Peninsula and emerged over the northwest Coral Sea on 2 January. The environment in the Coral Sea was conducive for development and as a result Penny was able to reform into a tropical cyclone by 4pm AEST on 2 January. Over the next few days, *Penny* tracked further across the Coral Sea and peaked as a category 2 strength system on 4 January. By 5 January, *Penny* was slowly weakening and downgraded to a tropical low as it became removed from the monsoonal flow to the north of the system and as drier mid-level air began to entrain into the circulation. The remnants of *Penny* tracked back towards the Queensland east coast over the next few days and the system once more

made landfall near Bowen on 9 December. Heavy rainfall occurred in areas of central and northern Queensland on the days following landfall, including a day where Strathbogie (south of Ayr and west of Bowen) received 432mm in the 24 hours to 9am on 10 January.

- **Mid-Late February 2019, Severe Tropical Cyclone *Oma*** (Figure 8C): During 18-23 February, the central Queensland Coast was exposed to elevated spring high tide levels ranging 4.34 – 5.12 m (Marmatcia, 2018). These elevated tidal levels coincided with the wind driven storm surge from TC *Oma* as it travelled out of north eastern New Caledonia as a category 3 cyclone and degraded through category 2 and 1 to a tropical low as it passed some 800 km to the east of Gladstone . This resulted in actual high tide levels at that time being up to approximately 1 m higher than predicted.

Hatchling sex ratio theory

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

CHAPTER 3. CURTIS ISLAND STUDY

METHODS

Study Area

South End Beach, Curtis Island (23°45'S, 151°18'E), has supported a medium density nesting population of the flatback turtle (*Natator depressus*), a turtle found only in Australian continental shelf waters. This large sand island situated off the coast of Gladstone extends for ~100 km to the north. The small South End village lies on the south-eastern tip of the island (Figure 3.1). The majority of the turtle nesting for the island occurs on the adjacent South End Beach which is approximately 5 km in length. In some years, there is occasional nesting by green turtles (*Chelonia mydas*) and/or loggerhead turtles (*Caretta caretta*).

While the rookery has been monitored intermittently since 1969 (Limpus, 1971a), it has been monitored annually since 1994 with support from the Gladstone Ports Corporation (Limpus *et. al*. 2006, 2013, 2017, 2018). Curtis Island has one of the longest histories of monitoring of flatback turtle breeding in Australia and hence the world.

Methods specific to Curtis Island

South End Beach was monitored on a daily basis commencing 24 November until 14 December 2018 for nesting activity, including the two-week mid-season census period: 24 November to 7 December. Monitoring of incubation and emergence success occurred during 19 January to 4 February 2019. Local QTC Volunteers provided intermittent monitoring of the beach during 10 October 2018 until 10 March 2019.

The beach was examined once or twice daily depending on tides to count nesting crawls, to locate hatchling emergence and identify daylight nesters. A Suzuki Grand Vitara was used to patrol the beach (Figure 3.2).

Two Vemco Minilog II temperature data loggers have been deployed in open sunny areas within the nesting habitat at opposite ends of South End Beach, Curtis Island since the 2016-2017 breeding season. These temperature data loggers were set at 50 cm below the beach surface in open sandy areas.

Rescuing doomed eggs
The Department of Environment and Science supports the rescue of doomed turtle eggs for highly threatened populations when eggs are laid in areas considered to be at risk of flooding or erosion during incubation (Pfaller *et al.* 2008). Eggs may also be rescued where coastal lighting is likely to disrupt hatchling ocean finding behaviour and cause hatchlings to move inland away from the sea. On Curtis Island, 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 (within two hours of oviposition and with the minimum of rotation) to artificial nests that are 55-60 cm deep with a 50 cm radius "body pit" from which surface vegetation

has been cleared within 2 hours of oviposition and with the minimum of rotation (Limpus *et al.* 1979).

Predation monitoring
No fox exclusion devices (FEDs) were deployed over clutches of eggs during the 2018-2019 turtle breeding season. During monitoring patrols, tracks or observations of wildlife that have the potential for negatively impacting successful turtle egg incubation were recorded, including cattle, horses, dogs and foxes.

RESULTS

Nesting activity, nesting success and recruitment

A total of 27 tagged flatback turtles were encountered during the entire 2018-2019 breeding season at Curtis Island. Thirty separate turtles, including three turtles missed for tagging, laid eggs during the two-week mid-season census period. One green turtle and one loggerhead turtle were recorded nesting during the 2018-2019 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 17 October 2018 and the last nesting crawl and clutch laid on 17 January 2019. Hatchlings emerged from the first flatback clutch laid for the season on 8 December 2018 (52 d period to emergence) but the date of emergence of hatchlings from the last clutch was not recorded.

The mean nightly numbers of flatback turtle activity during the mid-season census period on South End Beach were 2.6 tracks (SD = 2.13, range = 0-7, 14 nights), 30 different turtles and 30 clutches laid (Figure 3.4a).

A total of 40 nesting crawls by flatback turtles were recorded on South End Beach during the two-week mid-season census (Figure 3.3). Of these, there were 30 successful beachings that resulted in eggs being laid. This equates to a nesting success of 75 ± 13% during the census period.

The proportion of new recruits to the nesting population (first time tagged turtles) was 16 ± 14% of turtles tagged during the standard mid-season census period (Figure 3.4b).

Turtles coming ashore to attempt nesting during daylight hours occurred intermittently with 13.3 ± 7.3% of beachings occurring in daylight hours during the mid-season census period.

Nesting females: size, fecundity

The CCL (cm) of nesting female flatback turtles ranged 88.6 – 99.0 cm at Curtis Island (Table 3.2 and Figure 3.5). As in previous seasons, turtles with a past breeding history (remigrants) had a greater mean CCL (95.0 cm) than new recruit females that were tagged for the first time (90.6 cm) ($F_{1,22} = 14.24$; $0.005 < p < 0.002$).

Twenty-one flatback turtles with tags applied in previous breeding seasons were recorded at Curtis Island during the 2018-2019 breeding season. All had been tagged originally at Curtis Island (Table 3.1). These remigrant turtles mostly returned after a two-year remigration interval (mean = 3.35 yr, SD = 1.14, range = 2-6, n = 20) (Figure 3.6).

There was an average of 52.1 eggs per clutch for the 31 clutches counted. The number of eggs per clutch is summarised in Table 3.3 and Figure 3.7.

The mean renesting interval between a successful nesting and the subsequent return to lay another clutch was14.1 d (Table 3.3, Figure 3.8). A turtle that did not lay during a nesting crawl usually returned to attempt another nesting on the same night or on the following night (Table 3.3, Figure 3.8).

Health and injuries

In contrast to some years, no nesting flatback turtles died at South End Beach during the 2018 -2019 season. None of the nesting flatback turtles were recorded with fibropapilloma tumours. None were recorded entangled in fishing line or rope. No nesting female turtle was recorded with fresh or recent fractures resulting of injuries since the turtles had been previously recorded nesting at Curtis Island.

Sand temperature monitoring

The temperature data logger located at the southern end of South End Beach in full sun recorded sand temperatures from 2 November 2016 to 23 January 2019 (Figure 3.9a). The temperature data logger located at the northern end of South End Beach in full sun recorded sand temperatures from 13 December 2017 to 23 January 2019 (Figure 3.9b). These data loggers were redeployed to continue sand temperature monitoring.

Although the Australian Bureau of Meteorology has identified the 2018-2019 summer as the hottest on record (Figure 2.1), sand temperatures were not excessively high at South End Curtis Island in response to elevated rainfalls associated with the three tropical cyclones in the Coral Sea during the flatback turtle breeding season (Figure 3.10).

Sand temperature at 50 cm depth had increased above the minimum temperature for successful incubation (25°C) by the time that the first clutch for the season was laid on 17 October 2018. The high rainfall events of October, November and December will have contributed to the cooling of beach sand at nest depth on South End Beach, Curtis Island during the first months of the nesting season. Given that the sex of the hatchling is determined during mid incubation and given that the sand temperatures were often below the pivotal temperature for the flatback turtle during these first 2 months of the nesting season, it is presumed that the first 27 clutches that were laid by the 11 November 2018 would have produced hatchlings with a strong male bias. These would have been equivalent to at least 20% of the season’s egg production with a strongly male biased hatchling sex ratio.

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

In contrast, the temperatures at nest depth recorded on South End Beach, Curtis Island during the 2016-2017 and 2017-2018 breeding seasons 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. Based on sand temperature data, the 2016-2017 and 2017-2018 breeding seasons are expected to have produced a more strongly female biased hatchling cohort from Curtis Island (Limpus *et al*. 2017, 2018) when compared to the 2018-2019 breeding season.

Nest and hatchling disturbance and depredation and island fauna

No disturbance of incubating clutches of turtle eggs by nesting turtles on South End Beach was recorded during the 2018-2019 breeding season.

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

During the 2018-2019 season, no clutches were predated by canids.

No tracks from pigs or cattle were observed on Southend beach throughout the 2018-2019 breeding season. There were only isolated observations of horses on the beach throughout the 2018-2019 breeding season. No incubating eggs, hatchlings or adult turtles were recorded being impacted by feral mammals during the 2018-2019 breeding season.

Estimation of hatchling sex ratio from hatchling emergence data

The mean incubation period to hatchling emergence was 48.2 d (Table 3.4). The changing period to emergence through the breeding season is summarised in Figure 3.11.

There were no clutches with a period to emergence longer than 54 d recorded during this summer. As a consequence, in contrast with the prediction from the sand temperature data, few male hatchlings are expected to have been produced during the 2018-2019 breeding season, even from among the first clutches laid for the season. A strongly female biased hatchling sex ratio is expected to have been produced from the 2018-2019 breeding season at Curtis Island.

Incubation and emergence success

At Curtis Island, 5 (5 ± 5%) of the 91 *N. depressus* clutches recorded being laid across the entire season were laid below the area of potential tidal inundation. These clutches were relocated to more secure incubation habitat higher up the dune within two hours of the eggs being laid, as part of the project's activities to increase hatchling production. As a result of this management action, no flatback clutches appear to have been lost to erosion or flooding at South End Beach during the 2018-2019 breeding season.

There was a reasonable accuracy in assessing incubation success by comparison of counts of eggs as the clutch was laid and counting the broken egg shells in the clutches from which hatchlings had emerged: mean counting error = -0.28 eggs per clutch (SD = 0.89, range = -3 to +2 eggs, n = 32 clutches). This was equivalent to under-counting of eggs by 0.50% per clutch examined after the hatchlings have emerged.

For the mid-season census, Curtis Island flatback clutches successfully incubated without disturbance by vertebrate predators or inundation by wave wash. The mean mid-season incubation success was 86.7% (Table 3.4; Figure 3.12) and the corresponding hatchling emergence success was 81.8% (Table 3.4; Figure 3.13). There was a slightly lower incubation success (81.7%) and hatchling emergence success (78.0%) measured across the entire season (Table 3.4).

DISCUSSION

This study examined the flatback turtles nesting on South End Beach, Curtis Island during the 2018-2019 breeding season, which is now a small-sized nesting population, within the eAust stock.

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

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

- Nightly nesting success was high (75%). There is no significant disturbance of the nesting turtles when they come ashore that resulted in excessive unsuccessful nesting effort.
- Approaching 100% of clutches of eggs laid on this beach survived to hatch in response to QPWS management of feral predators (pigs, dogs and foxes) and large grazing stock (cattle and horses) and the monitoring team's relocation into safer incubation locations of clutches at risk of loss through erosion or flooding.
- The Curtis Island South End dune sands constitute a very good incubation medium. Clutches that had not been interfered with by feral predators or impacted by storm surge or high tide erosion had a high incubation success of >80% and an acceptable hatchling emergence rate from the nests of >75%.

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

- The size of the nesting population during the two-week mid-season census period has approximately halved during the past decade (Figure 3.4a), even though the recruitment of new adults into the nesting population has been increasing during the same period, but at a lower rate (Figure 3.4b). In addition, based on flipper tag recoveries, there is no indication of substantial numbers of tagged flatback turtles from Curtis moving to nesting at other monitored beaches in south and central Queensland.

- A predicted strongly female biased hatchling sex ratio for the season could be based on the low mean incubation period from laying to hatchling emergence at the beach surface. This female biased sex ratio prediction is not as strong when sand temperatures at nest depth are considered. Based on sand temperatures (Figure 3.9b), the hatchling sex ratio predicted from the 2018-2019 season sand temperature data may not have been as female biased as predicted from the 2016-2017 and the 2017-2018 breeding seasons (Limpus *et al*. 2017). The recurring strongly female biased hatchling sex ratio should be viewed with concern (Hamann *et al*. 2008; Limpus, 2008; Poloczanska *et al*. 2009). Increased effort is warranted for identifying if there are other nesting beaches within the breeding range of the eAust flatback turtle genetic stock that consistently produce large numbers of male hatchlings. If not, then management options could be considered that can counter the consequences of global warming to feminise this marine turtle nesting population.
- Flatback turtles do not instinctively know the way to the ocean. As they leave the nest, hatchlings orient to move towards the horizon at the lowest angle of elevation from their viewpoint and they move away from elevated dark horizons (Limpus, 1971b; Limpus and Kamrowski, 2013). The extremely bright sky glow emanating from Gladstone and Port Curtis (Kamrowski *et al*. 2012; Pendoley Environmental, 2012) will have negative impacts on the breeding success of marine turtle nesting on the Curtis Coast:
    - It is expected that the bright sky glow inland of the nesting beach will result in an elevated mortality of hatchlings dispersing out to sea from the beaches as has been recorded for green turtle hatchlings dispersing from Heron Island, impacted by the tourist resort and research station lighting (Truscott *et al*. 2017).
    - It is expected that with the increased bright sky glow behind South End Beach since the construction since 2010 of the three LNG port facilities on Curtis Island and the Wiggins Island Coal Terminal there will be a reduction in adult female numbers visiting the beach for breeding.

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

Trends

The trend in track count numbers, numbers of tagged turtles and number of clutches laid during the standard mid-season census period (Figure 3.4a) had been towards increasing numbers from approximately 2001 until 2008. Since 2008 there has been a continuing downward trend in these indicators of population performance. These data suggest that this population may not be maintaining population stability as was indicated by the capture-mark-recapture analysis of data up to the 2012-2013 and 2016-2017 breeding seasons that was reported by Limpus *et al*. (2013, 2017).

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

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

CHAPTER 4. PEAK ISLAND STUDY

Study Area

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

Peak Island has supported one of the largest populations of nesting flatback turtles in the eAust stock (Limpus *et al*. 2013) and is recognised as an index beach for long-term monitoring of flatback turtles within the eAust stock. Census of the Peak Island flatback turtle nesting population commenced in the 1980-1981 breeding season (Limpus *et al*. 1981). Monitoring of turtle nesting at Peak Island was led by Dr C. J. Parmenter of Central Queensland University during 1981-2006 (Parmenter 1993). Monitoring recommenced in 2008 within The Queensland Turtle Conservation Project and has continued to the present with funding support from the GPC ERMP (Twaddle *et al*. 2014, 2015; Pople *et al*. 2016; Limpus *et al*. 2017, 2018).

Methods specific to Peak Island

- At Peak Island the nesting beach is subdivided into 25 m sectors identified by numbered posts to allow comparisons across sectors. Sectors 0-5 are fronted by inter-tidal rocks with a sandy beach above the high tide level. Sectors 14-17 are fronted by extensive inter-tidal rocks which extend to exposed rocky rubble above the high tide level and into the dunes. The remainder of the beach has a sandy approach to the dunes.
- The work program at Peak Island was not designed to collect data for the full duration of the flatback turtle nesting season. A two-week, mid-season census was conducted from 24 November – 07 December 2018 Because of adverse weather the monitoring team was unable to leave the island on 8 December and continued to monitor the nesting population for an additional three nights until the

team departed the island on 11 December 2018. Data were collected from emerged clutches during an eleven-day trip 17-31January 2019.

- A Vemco Minilog II temperature data logger that had been buried at a depth of 50 cm in front of the Sector 10 post on 26 November 2014 could not be relocated for downloading. The cord that had secured the data logger to the post was present but not the data logger. A replacement temperature data logger was set at the same location and at 50 cm depth to record sand temperatures at nest depth at half hour intervals in late January 2017. The temperature data logger was successfully downloaded on 26 November 2017 and on 29 January 2019.

RESULTS

Nesting activity, nesting success and recruitment

A total of 121 tagged\nesting flatback turtles were recorded during the two-week census period, 24 November – 07 December 2018 (Table 4.1). This is the lowest number of flatback turtles recorded nesting during the standard mid-season census period since DES took over the leadership of the census studies in 2008. No other species of turtle was recorded nesting during this period. There were 106 females that had been recorded with a prior nesting history at 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 2018 and no evidence of hatchling emergence was found during 24 November – 11 December 2018 (Table 4.2).

The mean nightly census of nesting turtles coming ashore during the mid-season census period was 17.6 tracks, 8.7 different turtles and 4.3 clutches laid (Table 4.2).

There were 236 recorded flatback turtle nesting crawls during the census period (Table 4.2). The frequency distribution of nesting crawls by beach sectors is summarised in Figure 4.2. The majority of successfully nesting turtles came ashore within sectors 7-13, which was fronted by a sandy beach. Nesting success was fair to good in sectors 8-13 and extremely low in sectors 14-16 (Figure 4.2). The mean nesting success, the proportion of nesting crawls that resulted in eggs being laid by the turtle, was 48.3 ± 6.4% and fluctuated nightly during the census period (Figure 4.3). Nesting female came ashore during daylight hours on 5.7 ± 2.8% of the beachings recorded (n = 15).

The recruitment rate of first time breeding females into the adult nesting population, as measured by the proportion of first time tagged nesting females, was 10.7 ± 5.5% for turtles within the mid-season census period (Figure 4.12).

Nesting females: size and fecundity

The mean CCL (cm) of the nesting female flatback turtles was 93.5 cm (Table 4.3, Figure 4.4). Females that were tagged for their first recorded nesting season, presumed first time breeding turtles, were significantly smaller than remigrant turtles with a past breeding history ($F_{1,113} = 1.412$; $0.002 < p < 0.005$).

The mean return interval for a turtle returning to attempt to lay eggs following its return to the sea after an unsuccessful nesting crawl was 1.2 days. Most females returned to re-attempt nesting within two nights after an unsuccessful nesting attempt (Table 4.3; Figure 4.5a).

Nesting females that had successfully laid a clutch were recorded returning to lay an additional clutch during the following 13.3 days (Table 4.3; Figure 4.5a).

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 2018 census period was 3.3 yr (Table 4.3, Figure 4.5b). Most turtles returned on a two or three year remigration interval.

A total of 114 clutches were laid during the two-week census. The number of eggs per clutch, yolkless and multiyolked eggs, egg diameters, egg weights and nest depths are summarised in Table 4.4 and Figure 4.6. The sampled flatback turtle clutches had on average: 51.6 eggs, 0.1 yolkless eggs and 0.4 multiyolked eggs per clutch (n = 29 clutches); with eggs averaging 5.2 cm in diameter and weighing 76.8 g. The nests were on average 35.3 cm deep to the top of the eggs and 56.4 cm to the bottom.

Health and injuries

QA9642, 23 November 2018: Fell on her back when returning across an erosion bank; rescued by monitoring team.

No nesting flatback turtles were recorded with fresh fracture to the carapace. Four nesting flatback turtles had healed injuries from past damage caused by vessels strike.

Sand temperature monitoring

At Peak Island, sand temperatures at nest depth were recorded, commencing 1 February 2017, until 29 January 2019 (Figure 4.7). The data logger was redeployed to continue sand temperature monitoring. These sand temperatures recorded at approximately nest depth during October–January, during a major part of the 2018-2019 flatback turtle incubation period, were below the pivotal temperature of 29.3^{o}C for the eAust flatback turtle population for many weeks during October–December. The 2018-2019 sand temperatures were cooler than for the same period during the 2017-2018 breeding season. As a consequence, based on these sand temperature records, the Peak Island flatback hatchling sex ratio from the 2018-2019 breeding season is not expected to be extremely female biased as has occurred during the previous two breeding seasons.

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.

The Australian Bureau of Meteorology (BOM) reported the occurrence of an exceptional period of heatwave conditions impacting coastal central Queensland during the eastern Queensland flatback turtle nesting season of 2018-2019 (Figure 2.1). In support of sand temperature data across the turtle breeding season, daily rainfall data recorded at the BOM weather station at Yeppoon were examined (Figure 4.8). The cooling spikes in sand temperature in early to mid December and early January coincide with the elevated rainfall at those times.

Mid to late January 2018 was very hot between two elevated rainfall events in early-January and in early February. Under these conditions the surface sand temperatures, particularly during the middle of the day and early afternoon, will have been high. The combination of elevated temperatures and reduced rainfall during the brief heatwave conditions 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 several days (Figure 4.9a).

Nest and hatchling disturbance and hatchling depredation and island fauna

Ten nesting turtles were observed digging into existing clutches, which amounted to 7.8 ± 4.6% of nesting activity resulting in clutch destruction.

Unlike the situation with the team's arrival in January 2018, there was no pervasive smell of dead eggs and hatchlings as the team arrived at the island on 17 January 2019. During the latter part of the visit, hatchlings were observed dying as they crossed the beach from the nests. Numerus hatchlings were not able to right themselves when they fell over (Figure 4.9a). This hatchling mortality was attributed to the local heatwave conditions at the time. At the same time dead hatchlings were found in the neck of the egg chamber and dead pipped embryos were recorded. Eleven clutches negatively impacted by heatwave conditions and resulting increased incubation failure were identified (equivalent to 8.1 ± 4.6% of clutches examined).

Large terrestrial predators (pigs, dogs, foxes, varanid lizards and humans) of turtle eggs remain absent from this island. However, an excessive number of clutches were invaded by roots from grasses and vines (35 clutches, equivalent to 25.7 ± 7.3% of clutches examined) with resulting increased incubation failure and entrapment of hatchlings within the nest (Figure 4.9b). There was also some loss of eggs from predation by *Ocypode* crabs (*O. cordimanus*, Figure 4.9e) and flooding of eggs by high tides.

A pair of beach thick-knees, *Esacus magnirostris*, were recorded as nocturnal predators of flatback hatchlings as they crawled from the nest to the sea (Figure 4.9c). At daylight, two adult white bellied sea eagles, *Haliaeetus leucogaster*, patrolled long the beach daily and were recorded preying on hatchligs as they crawled to the sea (Figure 4.9d). Ghost crabs, *O. ceratothalmus* and *O.cordimanus,* was recorded as a predator of flatback turtle hatchlings crossing the beach (Figure 4.9e).

In contrast with the 2017-2018 hatchling emergence period, there were no Torresian crows, *Corvus orru*, recorded at Peak Island during 17-31 January 2019, high-lighting again the atypical intense depredation of hatchlings by crows in the 2017-2018 breeding season.

By day and night there were numerous small (less than 1.5 m) carcharinid (whaler) sharks of multiple species patrolling the shallows against the shoreline (Figure 4.9f). These sharks preyed on hatchlings as they entered the sea.

Hatchling mortality rates from the above sources of avian, crab and shark depredation and other mortality sources for hatchlings as the left their nests and crossed to the sea were not quantified at Peak Island during the 2018-2019 breeding season.

Incubation and emergence success

A fourteen-day trip to Peak Island from 17 – 31 January 2019 sampled nests from which hatchlings had emerged to assess incubation and emergence success.

There was a reasonable accuracy in assessing incubation success by counting the broken egg shells in the clutches from which hatchlings had emerged: mean counting error = -0.9 eggs per nest (SD = 3.22, range = -9 to +1 eggs, n = 9 clutches). This was equivalent to under-counting of eggs by -1.7% per clutch examined after the hatchlings have emerged.

Eleven nests that had been previously marked at laying and had identifying nest tags were located as hatchlings emerged. The dates laid spanned the mid-season census period from 24 November to 7 December 2018. The mean incubation period to hatchling emergence for these clutches was 51.2 days (Table 4.5, Figure 4.10a). The majority of this small sample of clutches had a period to hatchling emergence that was equal to or above the pivotal period for hatchling emergence (Figure 4.10a). This is indicative of a reasonable proportion of male hatchlings having been produced at Peak Island during the 2018-2019 incubation season.

This conclusion is consistent with the conclusion drawn from the early season sand temperature data (Figure 4.7). It is expected that there would have been a male biased hatchling production from clutches laid during approximately the first two months of the 2018-2019 nesting season.

Hatching success of eggs and emergence success of hatchlings from the nests are summarised in Table 4.5. Clutches laid during the mid-season census period and emerging during 17-29 January 2019 had a good mean incubation success of 82.8% and a reasonably good mean hatchling emergence to the beach surface of 73.3% (16 recorded clutches. Figure 4.10b).

Additional clutches, laid mostly before the mid-season census period had a marginally better incubation success and hatchling emergence success (Table 4.5). When clutches laid before and during the mid-season census period are pooled for incubation success, the mean hatching success = 80.3% and hatchling emergence success = 73.1% (n = 136 clutches. Table 4.5).

Discussion
Peak Island was not directly impacted by a cyclone during the 2018-2019 flatback turtle breeding season but received elevated rainfall as a consequence of the three cyclones within the breeding season.

The Peak Island nesting flatback turtles continued to display normal demographic parameters for the eAust stock: mean CCL = 93.5 cm; mean number of eggs in a clutch = 52 cm; mean remigration interval = 3.33 yr (Tables 4.3, 4.4).

Nesting flatback turtles at Peak Island continued to display a low nesting success, mostly as a result of several sectors of the beach having little or no sand available for supporting nesting activity. This situation has existed for the last ten breeding seasons.

The improved hatching success and hatchling emergence success during the 2018-2019 breeding season compared to the very low measure of these parameters during the 2017-2018 breeding season is consistent with the consequences of the overall lower sand temperatures recorded at Peak island within the 2018-2019 breeding season (Table 4.5, Figure 4.7 and comparable data in Limpus *et al*. 2018).

In spite of the record heatwave year reported (Bureau of Meteorology, 2019), the associated elevated rainfall from three cyclones resulted in improved hatchling emergence success compared to recent years.

The removal of some of the weed vegetation within the nesting habitat by the monitoring team and QPWS staff since the 2018 incubation monitoring has probably contributed to the reduced proportion of clutches negatively impacted by roots growing among the incubating eggs compared to that recorded in the 2017-2018 season (Limpus *et al*. 2018, Limpus and Limpus, 2018). This weed management should have als contributed to the improved hatchling emergence success of 2018-2019.

Given the complexity of quantify hatchling sex ratios from a nesting beach:

- There is currently no reliably documented methodology for determining the gender of live hatchlings captured as they leave the beach;
- There is variable sand temperatures within the nesting habitat of individual beaches influenced by, including, elevation above the water table, extent of shading from vegetation, aspect towards the sun, sand colour;
- Intra and Inter seasonal variation in sand temperatures at nest depth in response to regional air temperature variability; rainfall variability, cloud cover;

it is not possible to provide a precise quantification of hatchling sex ratios from any one nesting beach.

The sex ratio from within a single clutch could be reliably predicted if a temperature data logger provided temperature data during the mid incubation period. However, it would be impracticable to attempt this quantification of every clutch laid during an extended sampling period. Thus only general comments can be made regarding expected sex ratios when based on small samples of period to hatchling emergence data and beach sand temperature data from a few isolated temperature data loggers.

Flatback eggs that incubate at a constant temperature of 29.3°C, the pivotal temperature, should have hatchlings emerging after approximately 53 d (Limpus, 2007). With the majority of the clutches at Peak Island from the mid-season census period for which this period to emergence was measured having a period to emergence equal to or greater than 53 days (Figure 4.10a), this indicates that a reasonable proportion of male hatchlings should have hatched at Peak Island this last summer. This contrasts with the excessively female biased hatchling production that should have resulted from the 2017-2018 breeding season.

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 this decline is continuing (Figure 4.11).

The recruitment rate (10.7%) of estimated 1st time nesters (turtles not previously tagged) during the census continues to be at 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 Peak Island nesting population over the past eleven years (Figure 4.12), this recruitment parameter should continue to be monitored. This 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 2018-2019 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 six consecutive seasons commencing in 2012 with the last five seasons of monitoring supported by GPC ERMP.

Avoid Island, 21.9744^{o}S, 149.6500^{o}E, 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 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, which are highest at South Beach. Nesting activity occurs on the beach slope and dunes. 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 (eAust) stock (FitzSimmons and Limpus, 2014) and has been selected as an index beach for long term monitoring of flatback turtles within the EA stock. An initial census of the Avoid Island flatback turtle nesting population was conducted during the 2007-2008 breeding season (Jones and Venz, 2008) and annual monitoring commenced in the 2012-2013 breeding season (FitzSimmons, 2013; FitzSimmons and Limpus, 2014, 2015, 2016; Limpus *et al*. 2017, Limpus *et al.* 2018).

Methods specific to Avoid Island

Monitoring at Avoid Island included the standard 14-day census period from 24 November to 7 December 2018 during the mid-season as in previous years. Nightly monitoring occurred during the census on all eastern beaches, referred to as South Beach (A3), Middle Beach (A2) and North Beach (A1) (Figures 5.1, 5.2). Additional nightly monitoring on South Beach occurred from 31 October to 4 November, and 8 to 10 December. During these times only track and nest counts were done on Middle and North Beach.

Sector numbers established in 2017 on South Beach and North Beach continued to be used.

Four temperature data loggers (Vemco Minilog II) were previously established in open and shaded locations on the top of the 1st dune and on the upper beach slope, each buried at 50 cm depth (Figure 5.3).

Monitoring of the nesting females and hatchling emergence was conducted by teams of volunteers and experienced team leaders. Additionally, a three-day high school course monitored hatchling emergence on South Beach with experienced team leaders. This course was collaborative between QTFN and the Wonder of Science Program of the University of Queensland.

Monitoring of hatchling emergence occurred during 11 - 25 January 2019, with nests being dug to determine hatching and emergence success.

RESULTS

Nesting activity, nesting success and recruitment

Outside of the census period there were 12 turtle tracks on South Beach, two on North Beach and two on Middle Beach, and an estimated nine nests laid, prior to the team arrival on 31 October 2018.

Immediately prior the census period there were 38 turtle tracks on South Beach, eight on North Beach and one on Middle Beach, and an estimated 25 nests laid, prior to the team's return on 24 November 2018.

Upon arrival for monitoring hatchling emergence there were approximately seven sets of tracks that appeared to have been made within the previous two weeks, with three nests identified. Additionally, one turtle emerged, but did not nest on 16 Jan 2019.

A total of 29 individual flatback turtles were encountered during the 2018-2019 census and 32 turtles recorded for all nights of monitoring. There were five first time tagged turtles, which gives an estimated 17.2% recruitment rate during the census. No other species of turtle was recorded as nesting during this season.

A total of 49 nesting crawls by flatback turtles were recorded on Avoid Island during the two-week census. Of these, there were 31 successful nests dug with eggs recorded as being laid and two unknown outcomes. This equates to a 67.1 ± 9.5% nesting success for the census period (Table 5.1). During the monitoring done outside of the census, there were an additional 68 nesting crawls and 46 nests with eggs laid, for an overall nesting success of 63.3%.

The mean nightly number of flatback turtle nesting crawls during the mid-season census period was 3.5 (Table 5.1, Figure 5.4). As in previous years, most nesting activity during the census occurred on South Beach (75.5% of tracks and 74.2% of clutches laid), which is the largest beach (Figure 5.5). There were eight clutches laid on North Beach and none on Middle Beach during the census.

Access by turtles to the dunes along South Beach continues to be limited, with only two nests laid on the dunes. Beach nesting habitat was adversely affected by tidal washover (Figure 5.2), which resulted in prolonged inundation of some nests and decreased incubation success.

A total of 31 clutches were laid during the two-week census and were marked and mapped for subsequent determination of emergence success. The mean number of clutches laid per night was 2.3 (Table 5.1).

The study has reached the point of being able to estimate the recruitment rate of first time breeding females into the adult nesting population, as measured by the proportion of first time tagged nesting females, commencing in the 2012-2013 breeding season. As expected, this value has declined with each year of tagging during the standard two-week mid-season census: For the 2018-2019 season the mid-season census estimate for new recruits was 17.2% (Figure 5.6) and for the entire monitoring period it was 15.6%.

Nesting females: size, fecundity

The mean CCL of nesting female flatback turtles during all monitoring was 93.4 cm (Table 5.2 and Figure 5.7). First time breeding females were significantly smaller than turtles with a past breeding history (($F_{1,30} = 16.55$; $0.001 < p$)

Remigration interval, the number of years between recorded breeding seasons, averaged 3.0 yr (Table 5.2) for the entire monitoring period, with the most common intervals being 2 yr (Figure 5.8).

During the 2017-2018 season all but one flatback turtle with a past nesting history had nested on Avoid Island in a prior breeding season. Turtle T38567 was first tagged by Dr. John Parmenter's team on Wild Duck Island in 1988 and has been encountered at Avoid Island in 2007, 2012 and 2016.

Re-nesting intervals between a successful nesting and the subsequent return to lay another clutch were recorded for three turtles, which returned 12 or 13 days later (Table 5.2, Figure 5.9). An additional three turtles that were observed nesting in late October or early November were observed nesting 29-31 days later on (at least) their 3rd nesting. Three turtles that did not lay during a nesting crawl returned for another nesting attempt on the same night or on the following night (Table 5.2, Figure 5.9).

Health and injuries

No recent fracture damage was observed on nesting turtles. One turtle had healed scars from propeller cuts, and one turtle was missing half of a front flipper. No fibropapilloma tumours were observed on any of the turtles.

Sand temperature monitoring

Rainfall and air temperature data recorded at the BOM weather station at Carmilla (Figure 5.11) shows intermittent elevated rainfall throughout the entire 2018-2019 breeding season which resulted in generally lower sand temperatures at nest depth during this breeding season.

The temperature data loggers were downloaded on 2 November 2018 and 24 January 2019. The data logger in the shaded dune habitat malfunctioned prior to the nesting season and the data were rejected. Data were successfully downloaded from three other previously placed data loggers: sunny dune habitat, sector 41; sunny beach slope habitat, sector 13; shaded dune habitat, sector 27 (Figure 5.11a, b, c). An additional, temporary data logger was placed at North Beach, on the open beach below the higher high tide level, approximately two metres away from a nest.

At the beginning of the nesting season the data loggers reached pivotal temperature (29.3°C) for flatback turtles at different dates: 25 October for sunny dune and sunny beach slope, and 8 November for shaded beach slope habitats. Three periods of heavy rain brought temperatures below the pivotal temperature for variable lengths of time of approximately: 6 days (sunny dune), 11 days (sunny beach slope), 14 days (open beach at North Beach) and 24 days (shaded beach slope). For the remaining time periods, temperatures at nest depth were above pivotal temperature at all sites.

Based on these sand temperature measurements at nest depth, it is expected that the flatback turtle hatchling sex ratio at Avoid Island was strongly skewed to females for most of the breeding season. Cooler spikes due to rain would have produced some male hatchlings in all nesting habitat.

Nest and hatchling disturbance and depredation and island fauna

No clutches were recorded as having been dug into by a nesting turtle. No mammalian or reptilian terrestrial predators of marine turtle eggs or hatchlings were recorded on Avoid Island. While potential avian predators of turtle hatchlings were present on the island, none were recorded taking turtle hatchlings during this season. There were 3 clutches during the mid-season census period that had eggs predated by crabs, with a mean of 0.4 eggs taken per clutch (SD =1.0, range = 1-4). The crab species responsible for this predation was *Ocypode cordimanus*.

Incubation and emergence success

The incubation period to hatchling emergence was obtained for 18 clutches from across the entire monitoring period. The average incubation period to hatchling emergence to the beach surface was 49.8 d (SD = 3.2, range = 45-60) (Table 5.4).

Hatching success and hatchling emergence success was assessed for 21 clutches that were laid during the mid-season census: hatching success = 64.0%; emergence success = 61.0%. For all clutches examined across a wider period of the breeding season: hatching success = 63.4%; emergence success = 61.5% (Table 5.4).

At least 10 clutches were inundated by high tides, which resulted in a low hatching success of 3.6% and a low hatchling emergence success of 3.5% (Table 5.4). Six of the 10 nests identified as inundated had 0% success.

DISCUSSION

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

This year's study has completed the eighth year of monitoring flatback turtle nesting activity, the last seven of which were consecutive. The total number of individually tagged flatback turtles was considerably below the values recorded in previous years. Mean nightly track counts were considerably below average and the total number of clutches was the lowest during all census years (Jones, M. and Venz, H. 2008, FitzSimmons, 2013; FitzSimmons and Limpus, 2014; FitzSimmons and Limpus, 2015; FitzSimmons and Limpus, 2016; Limpus *et al*. 2017) (Figure 5.12).

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

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

Revised placement of reflective identification points on trees and posts on South Beach and North Beach in 2017 continued to help considerably in marking nest sites at night and in relocating nests after hatchling emergence.

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

Incubation periods ranged from 45-60 days. The pivotal temperature, the theoretical temperature that will produce a 50:50 sex ratio, is 29.3°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°C should have the hatchlings emerging at approximately 53 days after the eggs were laid (EHP, unpublished data). Of the 18 clutches with data on incubation duration, all but one emerged in less than 53 days, thus it is highly likely that the majority of the clutches of flatback clutches incubating at Avoid Island during the 2017-2018 breeding season had a strongly female-biased sex ratio. This is consistent with the recorded sand temperatures. Any male hatchlings produced at this island during the 2018-2019 breeding season would have come from the limited number of clutches laid during the early nesting season and those clutches that were in the critical developmental period for determining sex when heavy rainfall decreased the sand temperatures.

Nesting success was relatively high (67.1%) during the census and similar to previous years. However, hatching success of eggs and hatchling emergence success in this period remains low at 64.0% and 61.0%, respectively.

The low hatchling production can be attributed in part to nest inundation. The extent to which this is an issue depends upon how weather events shape the beach profile, and whether turtles access the higher beach slope or dunes. Factors such as these that are linked to variable weather across the years warrant closer monitoring in future breeding seasons.

6. Acknowledgements

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

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TABLES

Table 1. Comparison of reproductive parameters (± standard deviation) recorded for flatback turtles, *Natator depressus*, nesting at the three central Queensland index rookeries during the mid-season census period: 24 November to 7 December 2018. Parameters that are considered to be indicative of poor population performance are shaded.

Data Collected	Curtis Island	Peak Island	Avoid Island
# turtles – total	30	122	29
Mean tracks/night ± SD	2.6 ± 2.1	17.5 ± 9.52	3.5 ± 4.5
# clutches – total	30	114	32
Nesting success	75.0%	48.3%	65.3%
New recruits to breeding population	16.0%	10.8%	17.2%
Female CCL (cm)	94.3 ± 1.6; n = 25	93.5 ± 2.8; n = 116	93.2 ± 2.5; n = 28
Mean remigration interval (yr)	3.4 ± 1.1; n = 20	3.3 ± 1.7; n = 108	3.0 ± 1.4; n = 24
Mean eggs/clutch	52.1 ± 8.76; n = 31	51.6 ± 8.1; n = 29	n.a.
Mean egg diameter (cm); n = # clutches	5.18 ± 0.14; n = 28	5.2 ± 0.11; n = 250 (25 clutches)	n.a.
Mean egg weight (g); n= # clutches	77.0 ± 5.59 n = 28	76.8 ± 7.2; n = 250 (25 clutches)	n.a.
Incubation duration from census nests; n = # clutches	48.4 ± 1.8; n = 14	51.2 ± 3.0; n = 16	49.8 ± 3.3; n = 17
Hatching success; n = # clutches	86.7 ± 14.9%; n = 14	82.8 ± 12.53%; n = 16	61.4 ± 36.5%; n = 15
Emergence success; n = # clutches	81.8 ± 20.2%; n = 31	73.3 ± 19.8%; n = 16	59.6 ± 35.5%; n = 15

Curtis Island Tables

Table 3.1. Summary of flatback turtle, *Natator depressus*, tagging census at Curtis Island during the entire 2018-2019 breeding season.

	Flatback turtles	Loggerhead turtles	Green turtles
First time tagged	5	0	0
Remigrant recaptures			
With tags	21	0	1
With tag scars only	1	0	0
Change of colony within 2018-19 season	0	0	0
Change of colony between breeding seasons	0	0	0
Total turtles	**27**	**0**	**1**

Table 3.2. Size and remigration interval of nesting female turtles at Curtis Island during the entire 2018-2019 breeding season.

	Curved carapace length (cm)			
	Mean	**SD**	**Range**	**N**
Flatback turtles				
First time tagged females	90.63	1.552	89.1-92.2	4
Remigrant females	95.02	2.172	88.6-99.0	20
All females for season	94.32	2.5971	88.6-99.0	25
Green turtles				
All females for season	99.1	-	-	1
	Remigration interval (yr0			
	Mean	**SD**	**Range**	**N**
Flatback turtles	3,35	1.137	2-6	20
Green turtles	9	-	-	1

Table 3.3. Flatback turtle, *Natator depressus*, clutches, nest descriptions and within season nesting return intervals, at Curtis Island for the entire 2018-2019 breeding season.

	Mean	SD	Range	N
Eggs per clutch	52.06	8.760	29-70	31
Yolkless eggs per clutch	0.16	0.523	0-2	31
Multiyolked eggs per clutch	0.0	-	-	31
Renesting interval (d), following a successful nesting	14.11	1.453	13-17	9
Return interval (d), following an unsuccessful nesting attempt	0.80	1.304	0-3	5
Nest depth, top (cm)	42.78	8.661	22-60	60
Nest depth, bottom (cm)	57.03	5.997	42-70	33
Egg diameter (mean) (cm)	5.18	0.144	4.85-5.60	280 (28 clutches)
Egg weight (g)	76.97	5.585	64.89-96.91	280 (28 clutches)

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

	Mean	SD	Range	N
Flatback turtles				
Incubation period (oviposition to emergence)				
• census (d)	48.4	1.79	46-53	14 clutches
• entire season (d)	48.2	1.77	46-53	34 clutches
Success of undisturbed clutches				
• Hatching success, census (%)	86.72	14.893	38.4-100	31 clutches
• Hatching success, entire season (%)	81.68	20.193	17.07-100	65 clutches
• Emergence success, census (%)	81.75	20.201	10.14-100	1 clutches
• Emergence success, entire season (%)	77.99	22.769	10.14-100	65 clutches
Green turtles				
Incubation success (%)	69.63	40.092	41.3-98.0	2 clutches
Emergence success (%)	65.00	45.212	33.0-97.0	2 clutches

Peak Island Tables

Table 4.1. Tagging history of flatback turtles, *Natator depressus*, recorded nesting at Peak Island during the two-week census period, 24 November to 7 December 2018.

Tagging history of turtles	# turtles
First time tagged females (Primary tagged turtles)	13
Recaptures from past nesting seasons at Peak Island	
• Recaptured with tags previously recorded at Peak Island	106
• Recaptured with tag scars only, previously applied tags lost	2
• Recaptured with tags from a different colony between breeding seasons	0
TOTAL	121

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

Date	# tracks	# turtles	# clutches laid	# emerged clutches
24 Nov 2018	36		7	0
25 Nov 2018	25		12	0
26 Nov 2018	12		9	0
27 Nov 2018	12		7	0
28 Nov 2018	17		6	0
29 Nov 2018	11		5	0
30 Nov 2018	1		0	0
1 Dec 2018	18		5	0
2 Dec 2018	30		17	0
3 Dec 2018	23		14	0
4 Dec 2018	13		4	0
5 Dec 2018	24		13	0
6 Dec 2018	5		3	0
7 Dec 2018	18		10	0
Total	**236**	**122**	**114**	**0**
Mean (S.D)	**17.58 ± 9.525**	**8.71**	**4.250**	**0**
8 Dec 2018	9		3	0
9 Dec 2018	9		7	0
10 Dec 2018	5		4	0

Table 4.3. Summary of CCL measurements and remigration intervals of nesting flatback turtles, *Natator depressus*, at Peak Island during the 24 November to 7 December 2018 census period.

	Mean	SD	Min	Max	N
	Curved Carapace Length (cm)				
1st breeding season (primary taggings)	92.61	2.56	89.3	97.4	12
All remigrant turtles	93.56	2.73	84.4	98.9	102
Remigrant, lost tags	100.3	-	-	-	1
All Turtles	93.51	2.77	84.4	100.3	116
	Remigration Interval (yr)				
All remigrant turtles	3.33	1.70	1	10	108
	Renesting interval (d)				
Re-nesting interval (d) following unsuccessful nesting attempt	1.15	0.86	0	3	53
Re-nesting interval (d) following successful nesting attempt	13.25	1.53	12	17	16

Table 4.4. Flatback turtle, *Natator depressus*, clutches, and nest descriptions at Peak Island, 2018-2019 breeding season.

	Mean	Std. Dev.	Range	N
Eggs per clutch	51.6	8.135	35-65	29
Yolkless eggs per clutch	0.10	0.409	0-2	29
Multiyolked eggs per clutch	0.35	0.185	0-1	29
Nest depth, top (cm)	35.3	9.55	15-57	25
Nest depth, bottom (cm)	56.4	9.43	37-72	25
Egg diameter (cm)	5.21	0.113	4.94-5.61	250 (25 clutches)
Egg weight (g)	76.81	7.19	67.9-88.1	210 (21 clutches)
Eggs/clutch dug from an existing clutch by a nesting turtle	-	-	-	not recorded

Table 4.5. Incubation period Incubation and emergence success and for Flatback turtle, *Natator depressus*, clutches at Peak Island during 24 November – 7 December 2018.

	Mean	Std. Dev.	Range	N
Incubation period (oviposition to emergence) (days)	51.18	2.960	48-57	11
Clutches laid during mid-season census period				
• Hatching success (%)	82.78	12.532	54.67-98.04	16 clutches
• Emergence success (%)	73.29	19.805	29.51-98.04	16 clutches
Clutches laid mostly outside the mid-season census period				
• Hatching success (%)	79.97	20.332	19.05-100.0	120 clutches
• Emergence success (%)	73.09	24.686	1.79-100.0	120 clutches
Pooling data for all clutches examined				
• Hatching success (%)	80.30	19.562	19.05-100.0	136 clutches
• Emergence success (%)	73.11	24.099	1.79-100.0	136clutches

Avoid Island Tables

Table 5.1 Nightly census of nesting flatback turtles, *Natator depressus*, at Avoid Island during 24 November – 7 December 2018: nightly track count, observed turtles, observed clutches laid and clutches of hatchlings emerging with mean ± SD calculations.

Date	# tracks	# turtles	# clutches laid	# Emerged clutches
24 Nov	2	2	2	0
25 Nov	5	2	2	0
26 Nov	1	1	1	0
27 Nov	1	1	1	0
28 Nov	3	2	3	0
29 Nov	0	0	0	0
30 Nov	1	1	1	0
01 Dec	4	4	4	0
02 Dec	19	11	11	0
03 Dec	2	1	0	0
04 Dec	1	0	1	0
05 Dec	4	2	2	0
06 Dec	3	2	1	0
07 Dec	3	3	2	0
Total	49	32	31	0
Mean ± SD	3.5 ± 4.5	2.3 ± 2.6	2.2 ± 2.6	0

Table 5.2. Summary of curved carapace length measurements, remigration intervals, renesting intervals, and clutches laid per nesting flatback turtle, *Natator depressus*, at Avoid Island during the 2018-2019 breeding season.

	Mean	Std. Dev.	Range	N
Curved carapace length (cm)				
• 1st breeding season	90.2	1.7	87.8-92.8	6
• known remigrant turtles	94.0	2.1	89.9-99.0	26
All turtles	93.4	2.5	87.8-99.0	32
Remigration interval (yr)				
• entire monitoring period	3.0	1.3	1-6	27
Re-nesting interval (d)				
• following an unsuccessful nesting attempt	0.33	0.47	0-1	3
• following a successful nesting	12.7	0.47	12-13	3

Table 5.3. Summary of clutch and nest data for flatback turtle, *Natator depressus*, at Avoid Island during the 2018-2019 census period.

	Mean	Std. Dev.	Range	N
Eggs per clutch-on laying	n.a	n.a	n.a	0
Egg diameter (cm) – at laying	n.a	n.a	n.a	0
Egg weight (g) – at laying	n.a.	n.a	n.a	n.a
Eggs per clutch-on emergence	51.1	5.9	36-60	15
Yolkless eggs per clutch- on emergence	0.13	0.34	0-1	15
Multiyolk eggs per clutch- on emergence	0	0	0	15
Nest depth, bottom (cm)-on emergence	61.1	12.5	26-80	15

Table 5.4. Summary incubation period to emergence, hatching success and hatchling emergence success for flatback turtle, *Natator depressus*, clutches at Avoid Island during the 2018-2019 census period

	Mean	Std. Dev.	Range	N
Incubation period (period to emergence) (d)				
• Entire monitoring	49.8	3.2	45-60	18
Success from clutches laid during mid-season census				
• Incubation success (%)	64.0	38.0	0-95.4	21
• Emergence success (%)	61.0	36.4	0-95.4	21
Success of clutches across the all monitoring periods				
• Incubation success (%)	63.4	39.1	0-98.3	51
• Emergence success (%)	61.5	38.2	0-98.3	51
Success of clutches submerged by high tide/storm surge				
• Incubation success (%)	3.6	7.5	0-25.5	10
• Emergence success (%)	3.5	87.5	0-25.5	10

FIGURES

Introduction

Figure 1.1. Primary nesting study sites for flatback turtles, *Natator depressus*, within the eAust genetic stock (orange type).

Environmental monitoring

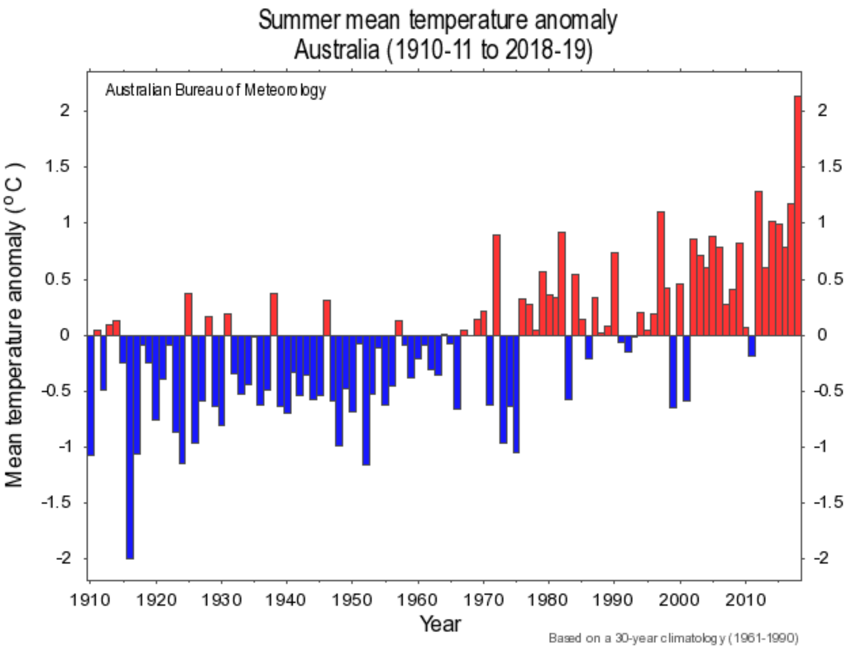


Figure 2.1. Bureau of Meteorology (2019) data documenting the summer of 2018-2019 as the hottest summer for Australia since records commenced in 1910.

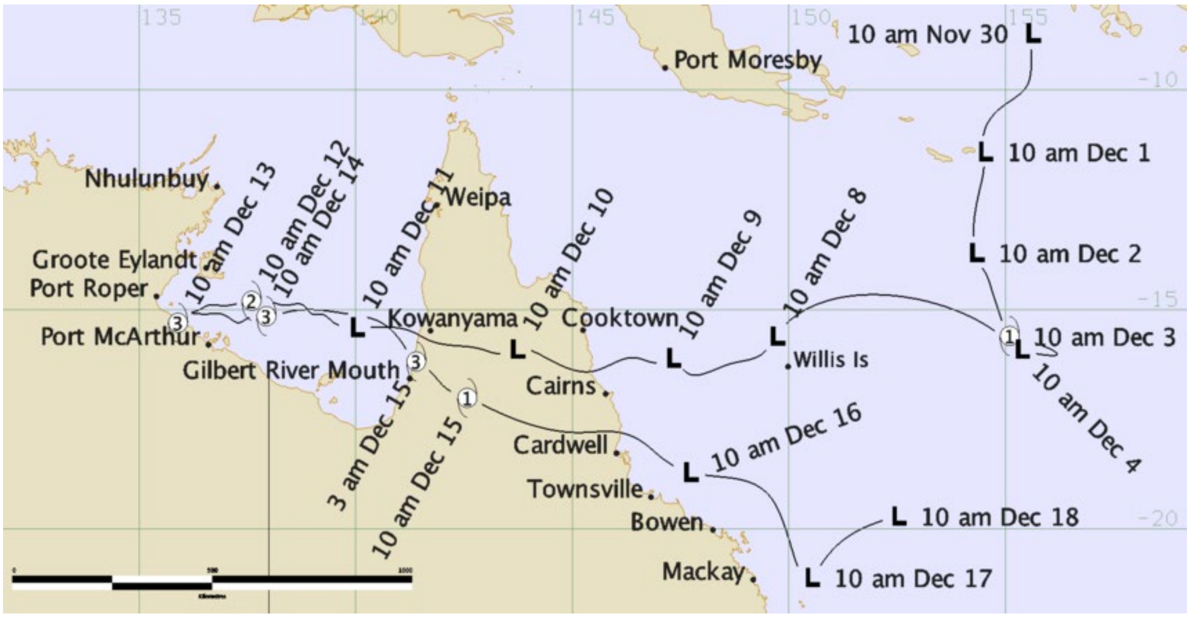


Figure 2.2a. Tropical Cyclone *Owen* travelled within the Coral Sea and Gulf of Carpentaria during December 2018.

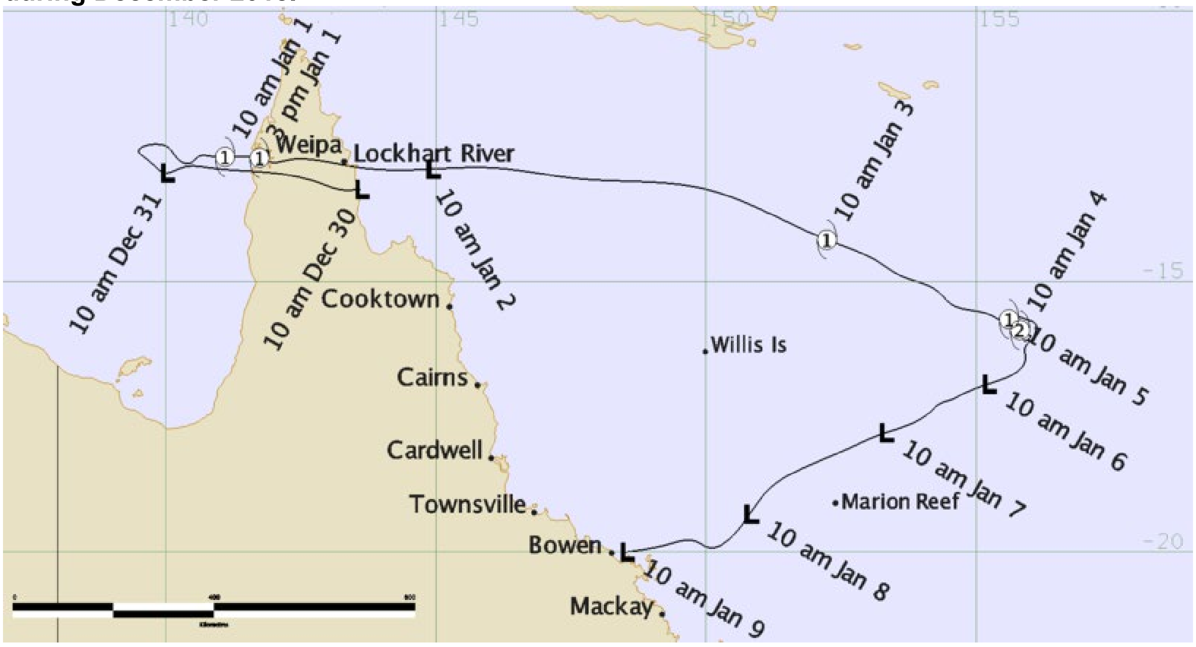


Figure 2.2b. Tropical Cyclone *Penny travelled* within the Coral Sea and Gulf of Carpentaria during late December 2018 – early January 2019.

Figure 2.2. Paths of three tropical cyclones in the Coral Sea – Gulf of Carpentaria region that increased rainfall and wave action on the central Queensland Coast during 2018-2019 marine turtle breeding season, Sourced from the Australian Bureau of Meteorology.

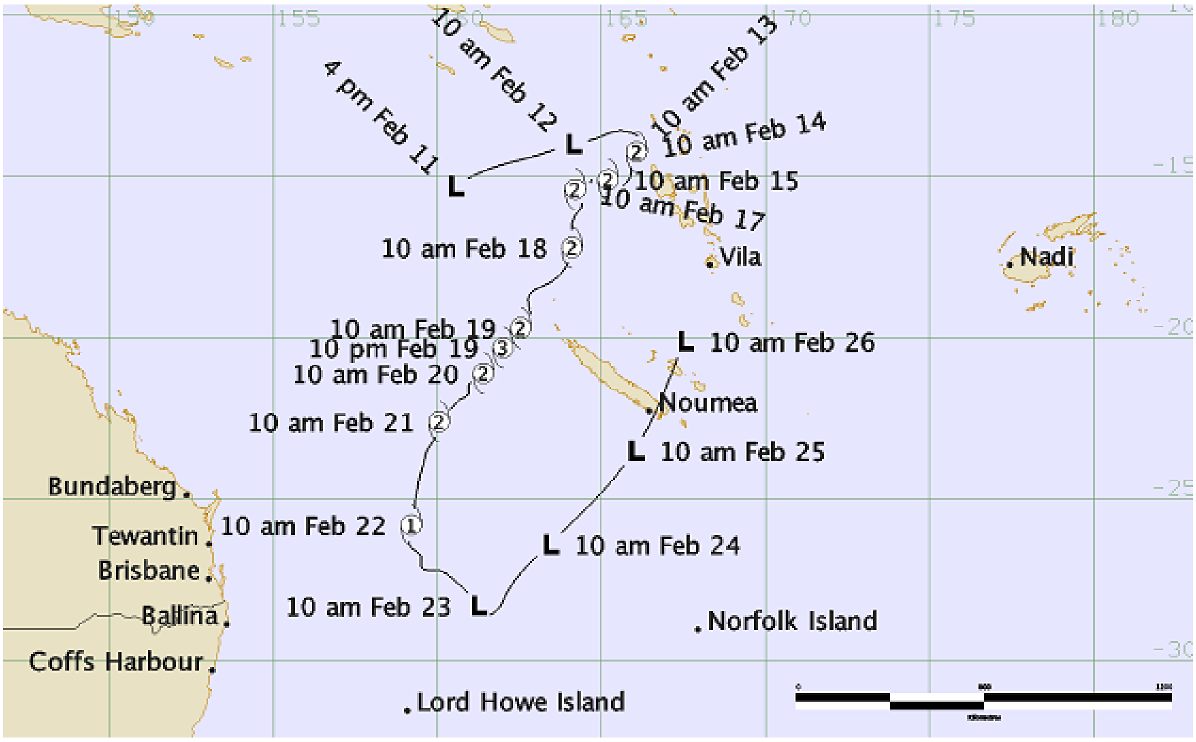


Figure 2.2c. Tropical Cyclone *Oma* travelled within the Coral Sea during February 2019.

Figure 2.2. Continued.

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.

Figure 3.2. A Suzuki Grand Vitara was used for transport of monitoring teams and their equipment on South End Beach, Curtis Island during the 2018-2019 breeding season.

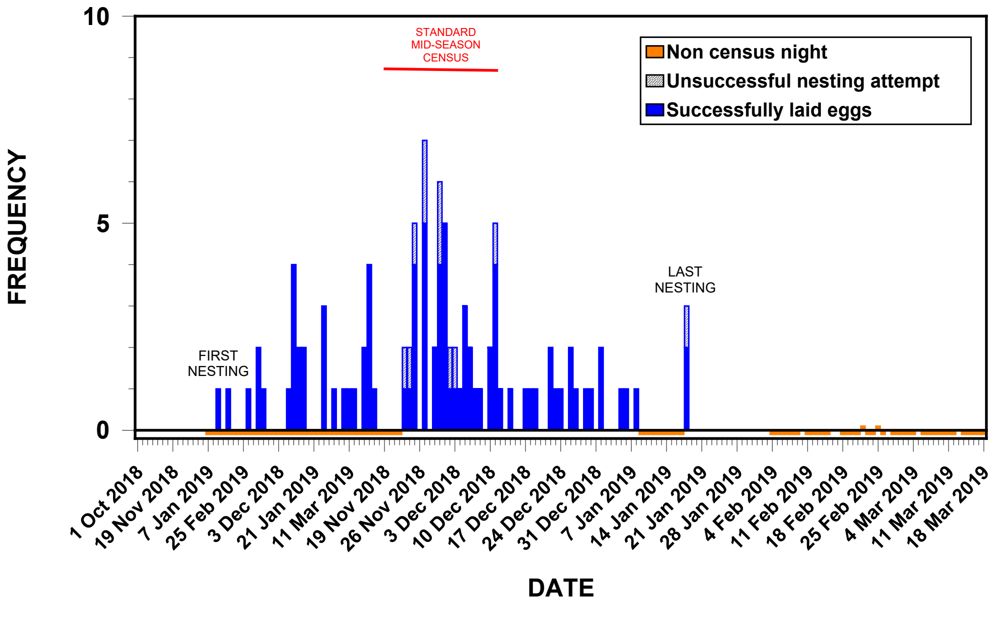
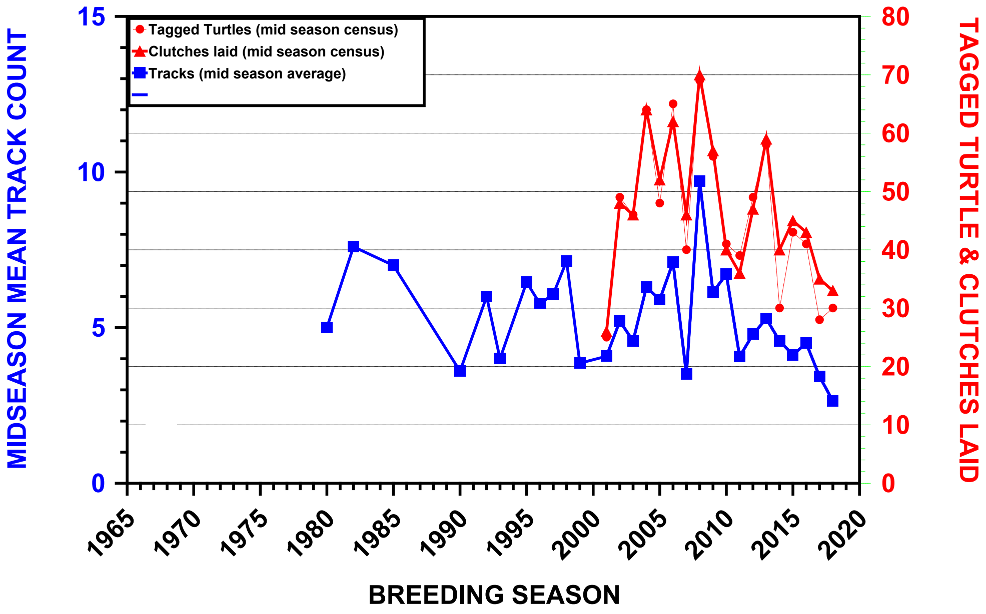
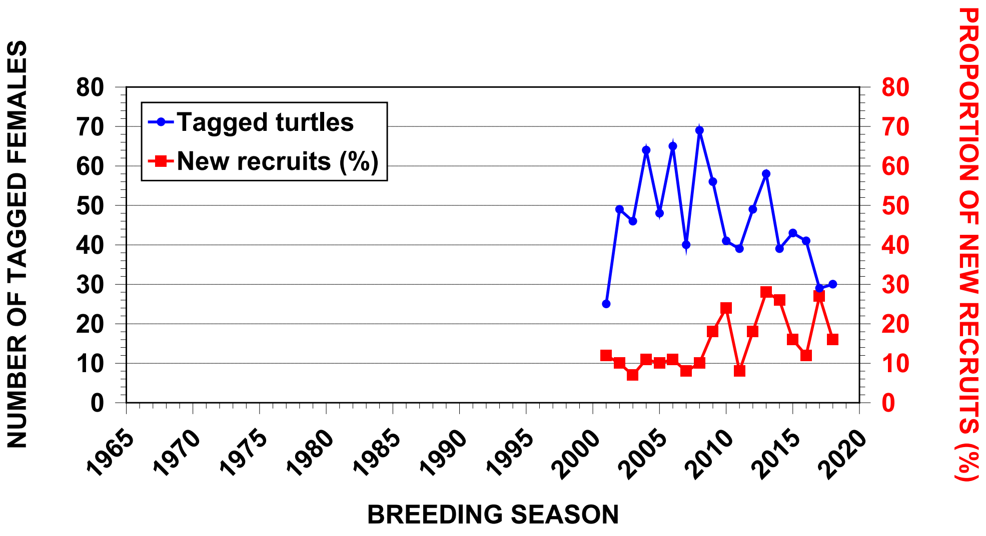


Figure 3.3. Nightly number of flatback turtles, *Natator depressus*, ashore for nesting on South End Beach, Curtis Island during the 2018-2019 nesting season.



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



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

Figure 3.4. Census of flatback turtle, *Natator depressus*, nesting activity at South End Beach, Curtis Island during the mid-season census population from 1980-2018.

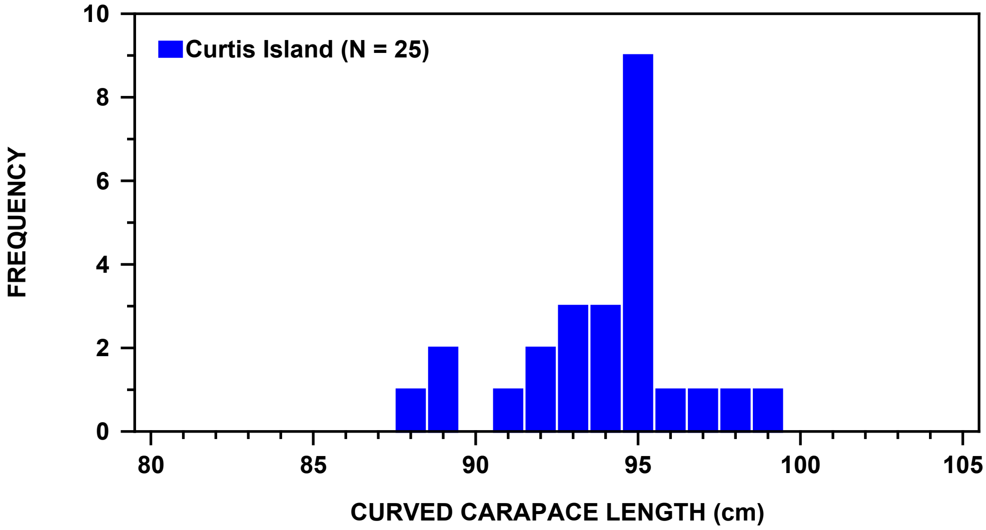


Figure 3.5. Size of nesting flatback turtles, *Natator depressus*, at South End Beach, Curtis Island during the 2018-2019 breeding season.

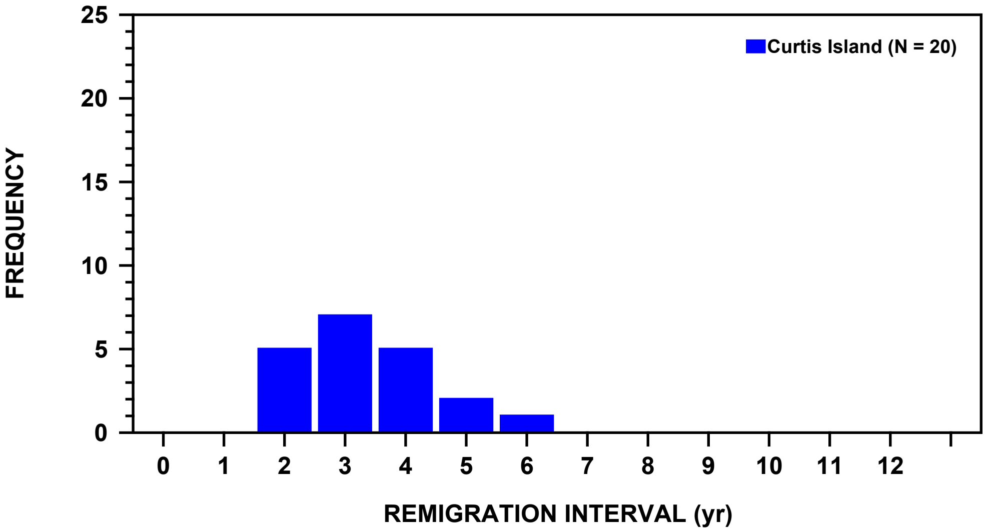


Figure 3.6. Remigration intervals recorded for nesting flatback turtles, *Natator depressus*, at South End Beach, Curtis Island during the 2018-2019 breeding season.

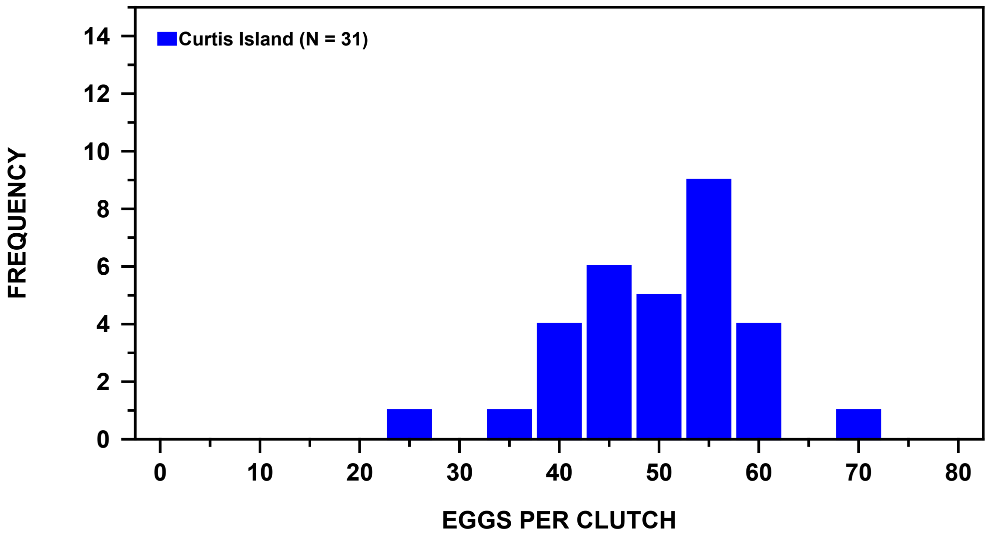


Figure 3.7. Clutch counts recorded for nesting flatback turtles, *Natator depressus*, at South End Beach, Curtis Island during the 2018-2019 breeding season.

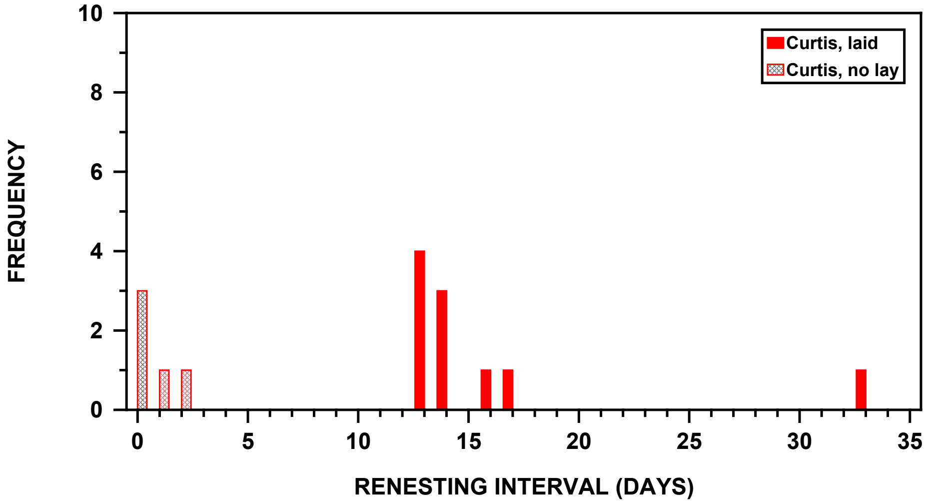
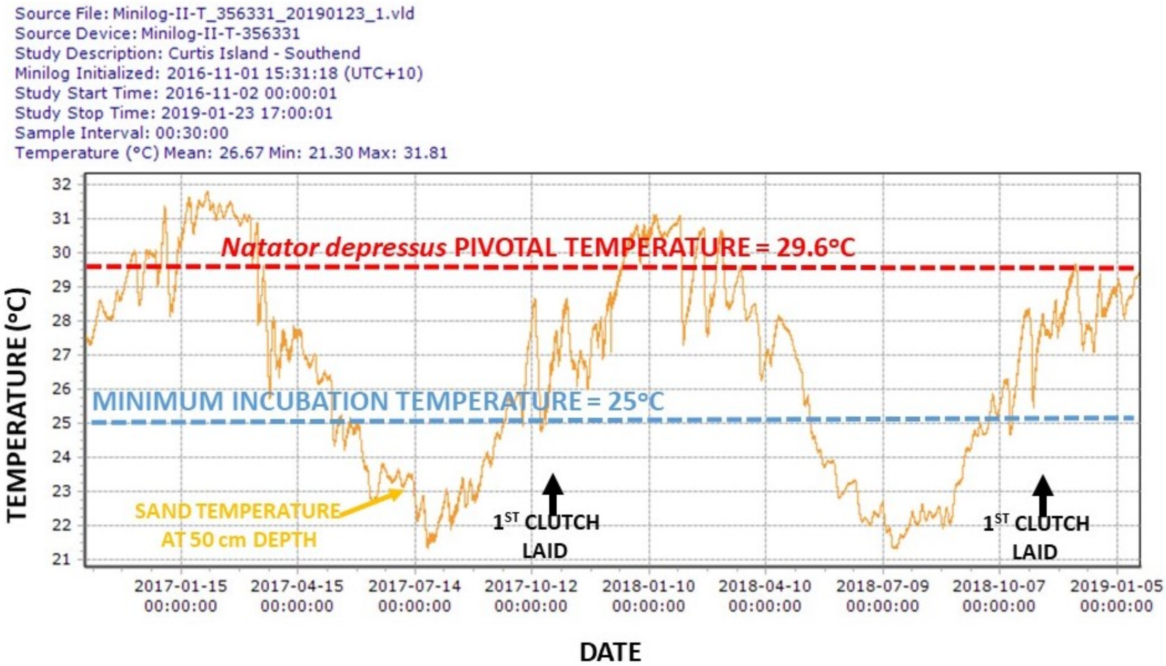
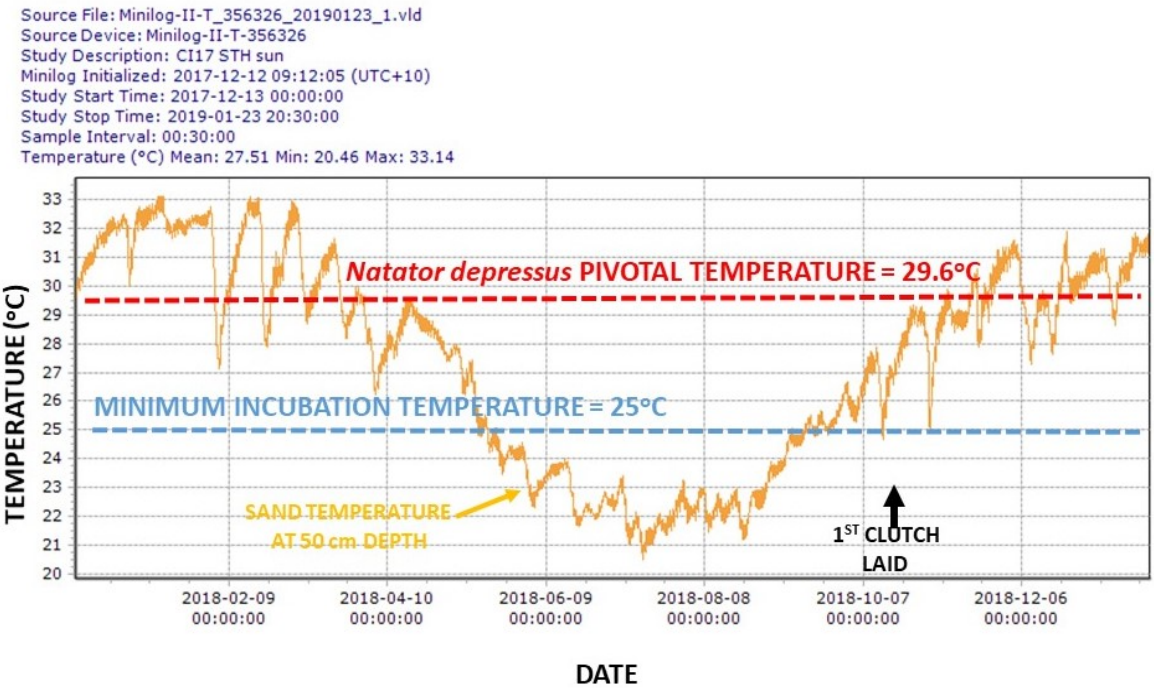


Figure 3.8. Return intervals recorded for nesting flatback turtle, *Natator depressus,* following both successful and unsuccessful nesting attempts at South End Beach, Curtis Island during the 2018-2019 breeding season.



3.9a. Sand temperatures measured at 50 cm depth on the southern end of South End Beach within the turtle nesting habitat in open sun using from 2 November 2016 - 23 January 2019.



3.9b. Sand temperatures measured at 50 cm depth on the northern end of South End Beach within the turtle nesting habitat in open sun from 12 December 2017 - 23 January 2019.

Figure 3.9. Summary of sand temperatures at nest depth at South End Beach, Curtis Island using Vemco Minilog II temperature data loggers.

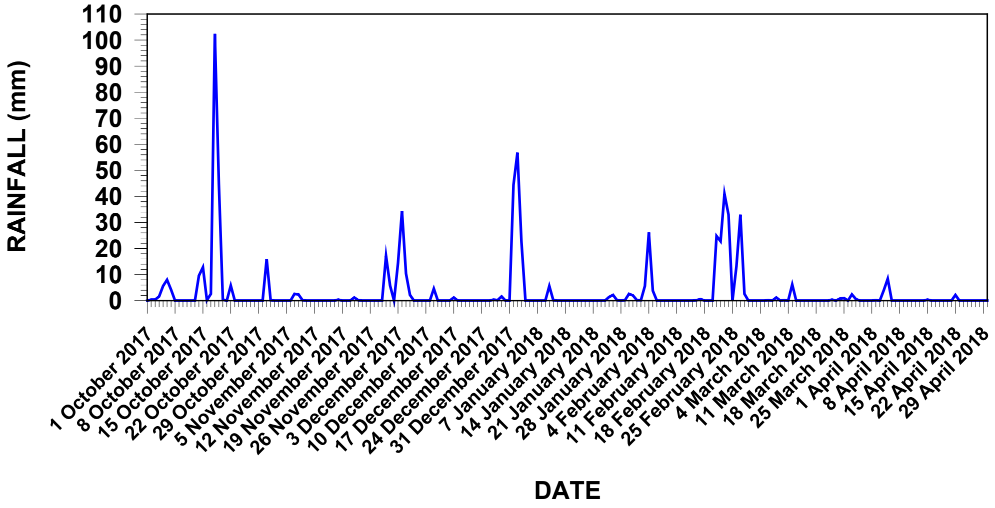


Figure 3.10. Daily rainfall, 1 October 2018 – 30 April 2019, recorded at the Gladstone Airport; Australian Bureau of Meteorology station number 39326, 23.87°S, 151.22°E.

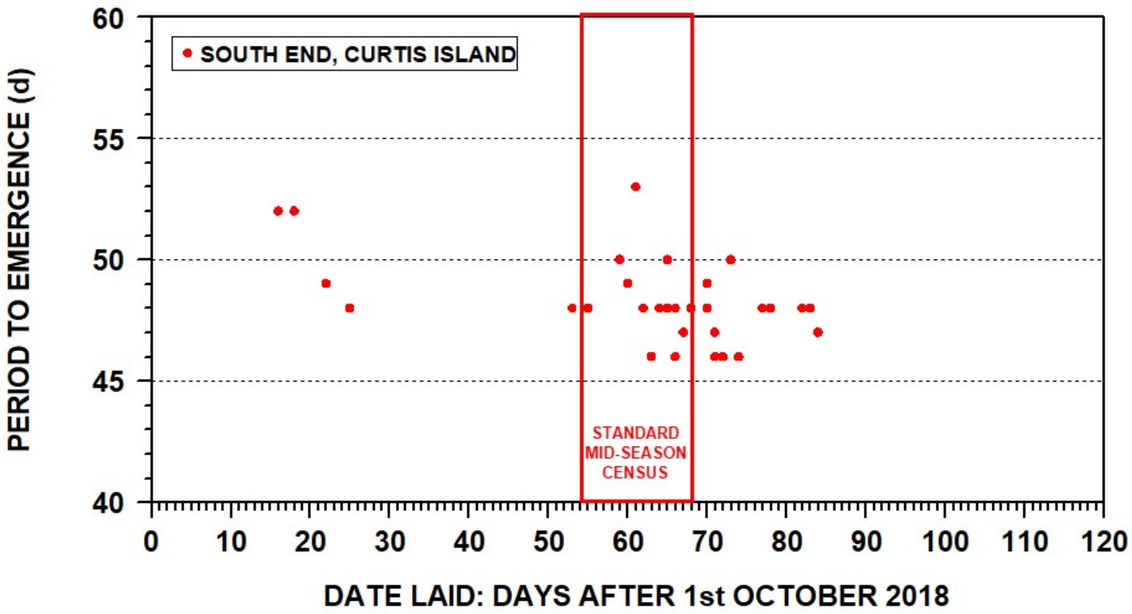


Figure 3.11. Comparison of period to emergence (period from laying to hatchling emergence to the beach surface) for flatback turtles, *Natator depressus,* nesting on South End Beach, Curtis Island, 2018-2019 season.

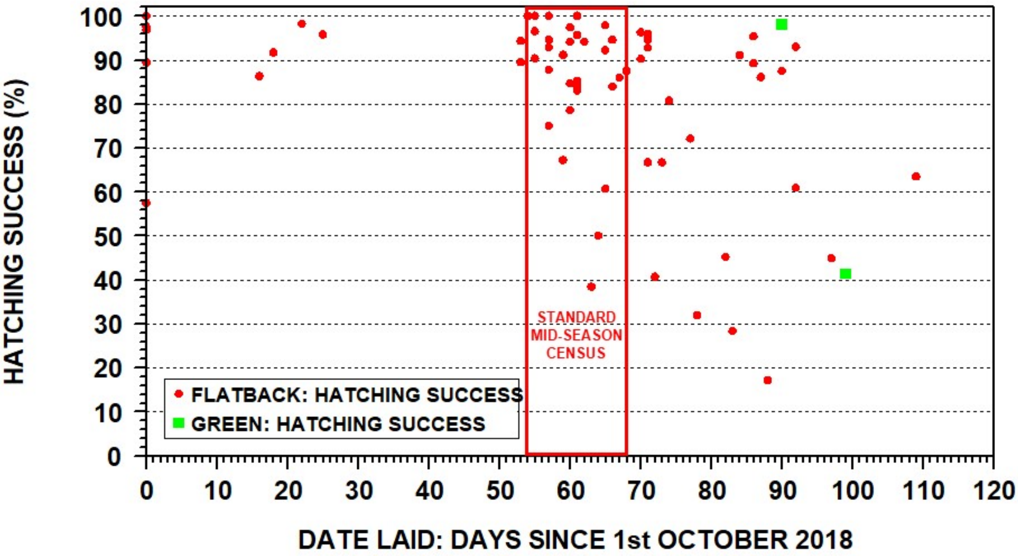


Figure 3.12. Comparison of hatching success (%) for flatback, *Natator depressus,* and green, *Chelonia mydas*, turtles nesting on South End Beach, Curtis Island, 2018 - 2019 season.

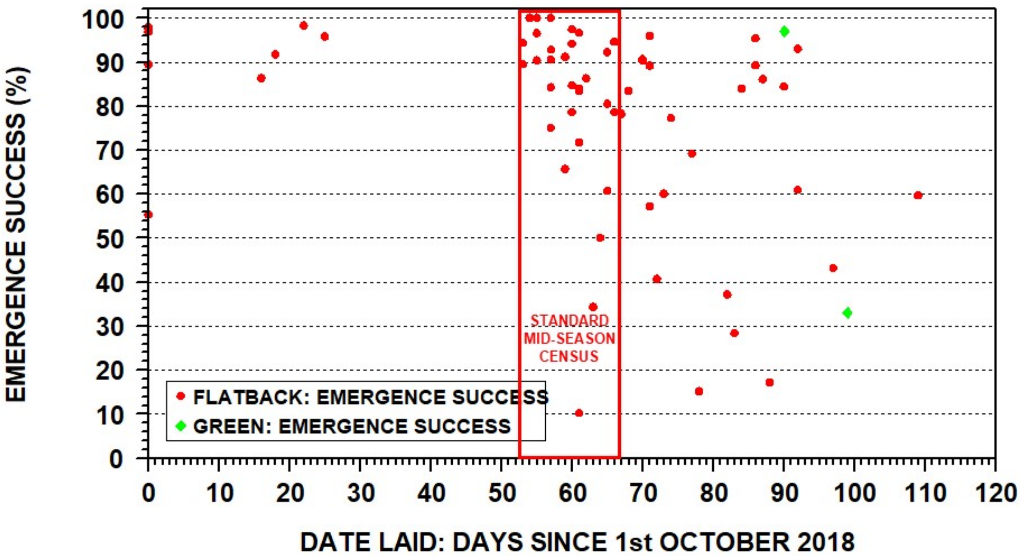


Figure 3.13. Comparison of hatchling emergence success (%) for the 2018-2019 breeding season for flatback, *Natator depressus,* and green, *Chelonia mydas*, turtles nesting on Curtis Island.

Peak Island Figures

a. Peak Island and surrounding areas

b. Peak Island

c. View of the nesting beach from the northern end

d. Track from a nesting flatback turtle.

e. Peak Island National Park sign

f. Camp packed and waiting for extraction from Peak Island by QPWS-Marine Parks

Figure 4.1. Images of Peak Island, 2018-2019 turtle breeding season.

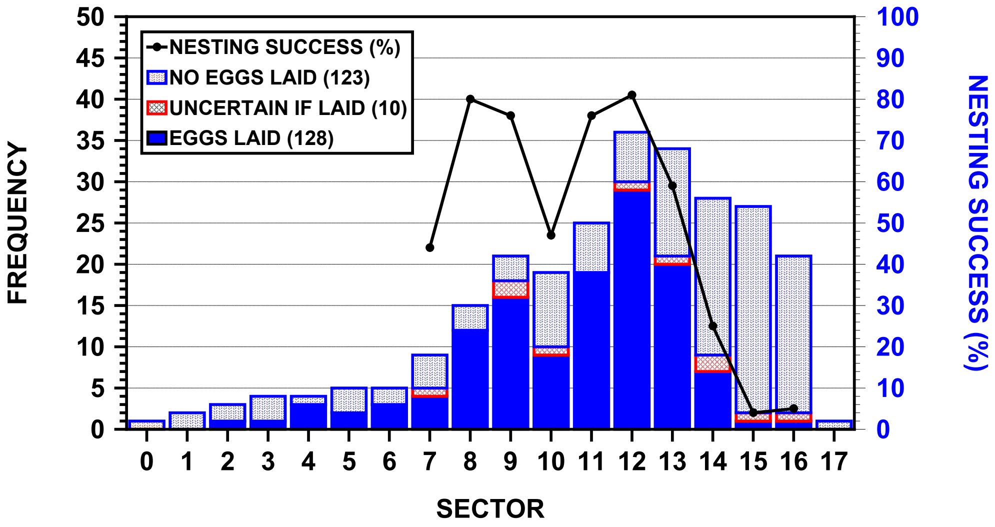


Figure 4.2. Frequency distribution of flatback turtle, *Natator depressus,* nesting crawls (tracks) and nesting success by beach sectors, Peak Island during 24 November – 7 December 2018.

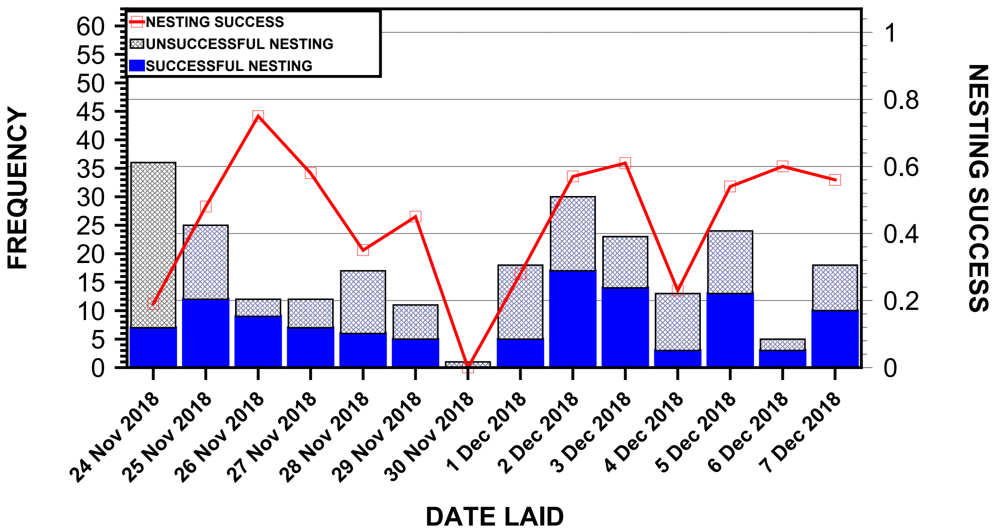


Figure 4.3. Frequency distribution of flatback turtle, *Natator depressus,* nesting crawls (tracks and clutches laid) and nesting success by date, Peak Island during 24 November – 7 December 2018.

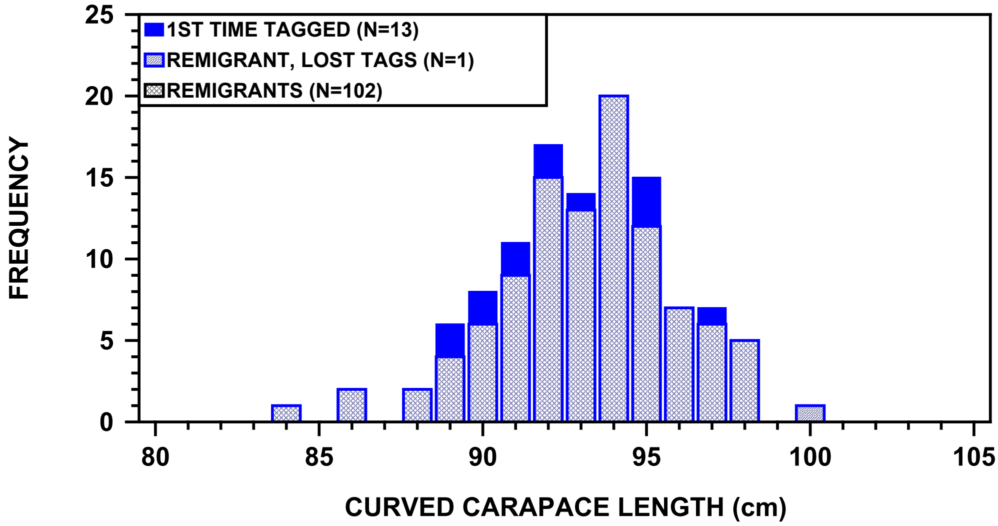
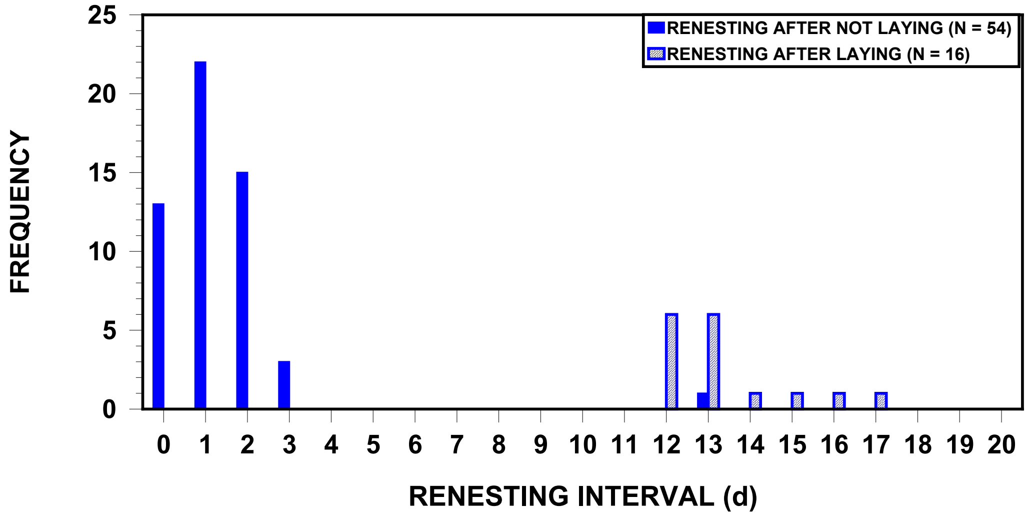
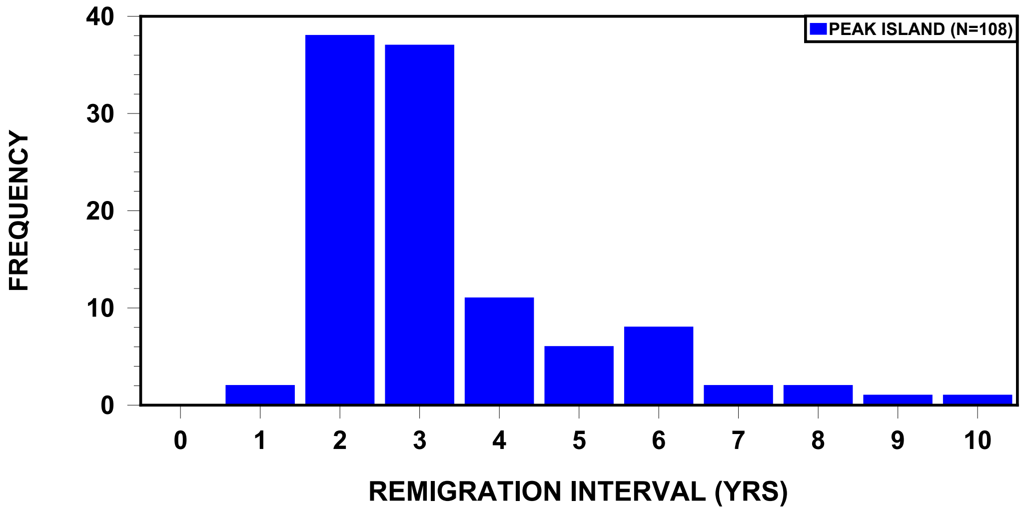


Figure 4.4. Frequency distribution of curved carapace length by breeding experience of flatback turtles, *Natator depressus*, recorded nesting at Peak Island during the 24 November – 7 December 2018.



4.5a. Number of days for return following a beaching be a nesting turtle.



4.5b. Number of years between breeding seasons (remigration interval).

Figure 4.5. Frequency distribution of return intervals of flatback turtles, *Natator depressus*, recorded nesting at Peak Island during the 24 November – 7 December 2018.

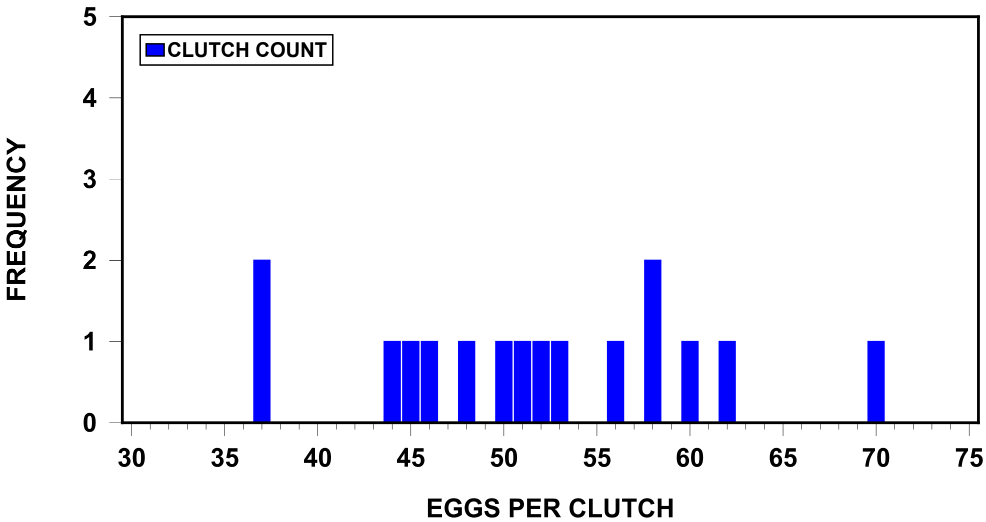


Figure 4.6. Frequency distribution of the number of eggs per clutch of flatback turtles, *Natator depressus*, recorded nesting at Peak Island during the mid-season census period, 24 November – 7 December 2018.

Figure 4.7. Sand temperatures measured at 50 cm depth within the turtle nesting habitat (dune at post 10) in open sun using Vemco Minilog II temperature data logger at Peak Island from 1 February 2017 - 29 January 2019.

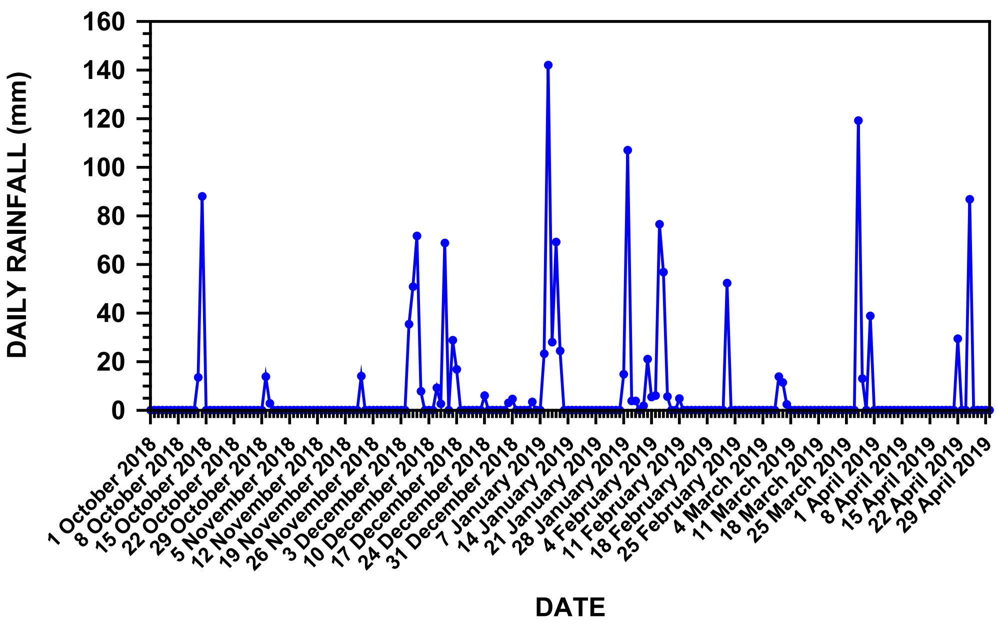


Figure 4.8. Daily rainfall, 1 October 2018 – 30 April 2019, recorded at Yeppoon the Esplanade; Australian Bureau of Meteorology station number 33204, 23.14°S, 150.75°E.

a. Hatchlings that died after leaving a nest following a day light emergence of hatchlings, January 2019.

b. Excessive root invasion of a nest that occurred during incubation of eggs, January 2019.

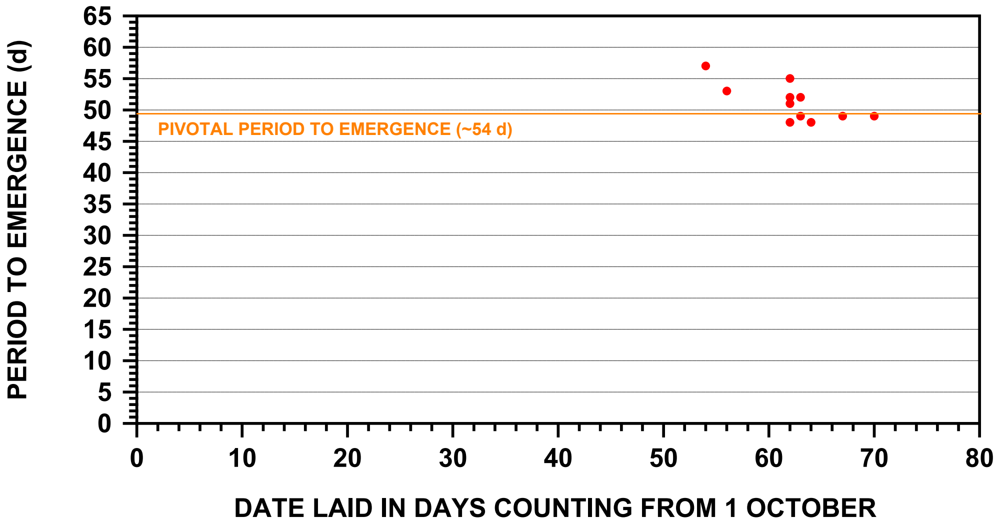
c. Hatchling flatback turtle depredated by Beach Thick-knee during the night of 23 January 2019.

d. Hatchling flatback turtle depredated by White-bellied Sea Eagle morning of 24 January 2019.

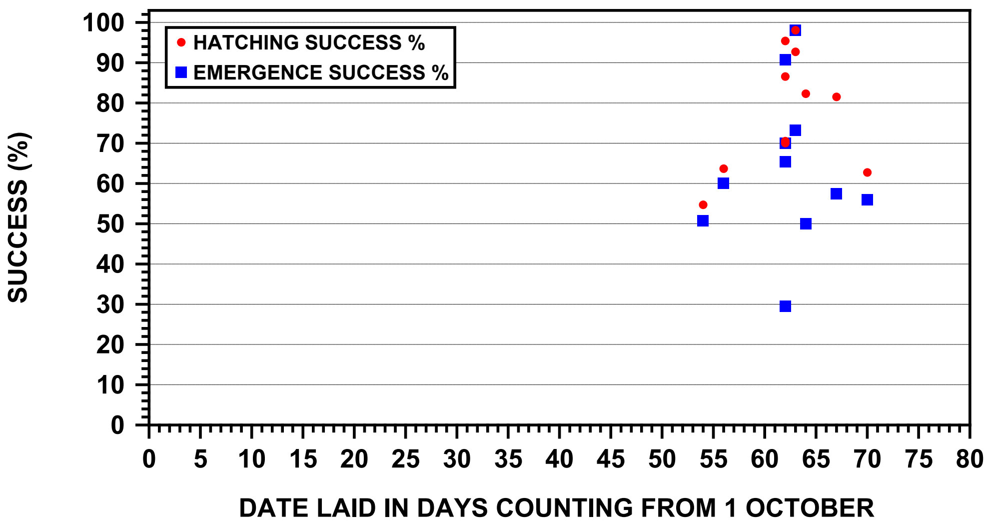
e. Hatchling flatback turtle depredated by ghost crab.

f. Small whaler sharks cruising the shallows adjacent to the beach by day and night were predators of hatchling flatback turtles in he sea.

Figure 4.9. Images illustrating sources of hatchling and egg mortality at Peak Island during January 2019.



a. Incubation period, n = 11



b. Hatching and emergence success, n = 11

Figure 4.10. Incubation period (a) and hatching and emergence success (b) for flatback turtle, *Natator depressus*, clutches recorded when laid on Peak Island during the mid-season census period, 24 November to 7 December 2018.

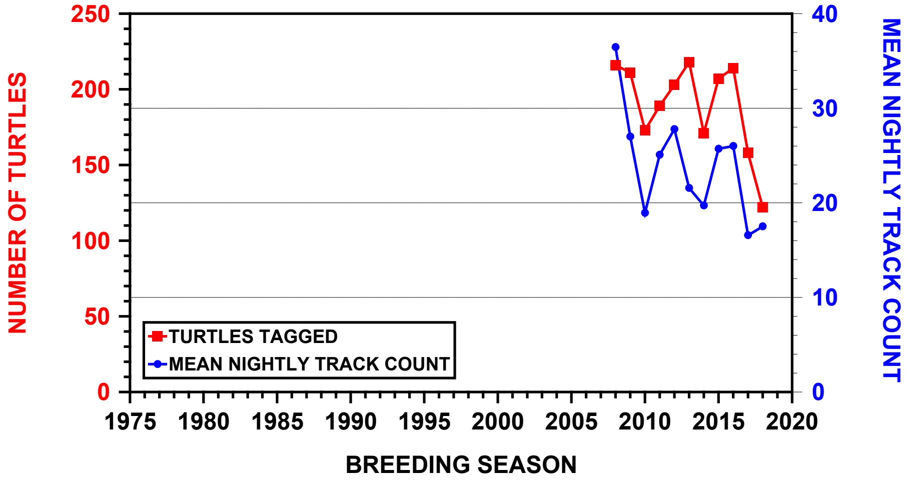
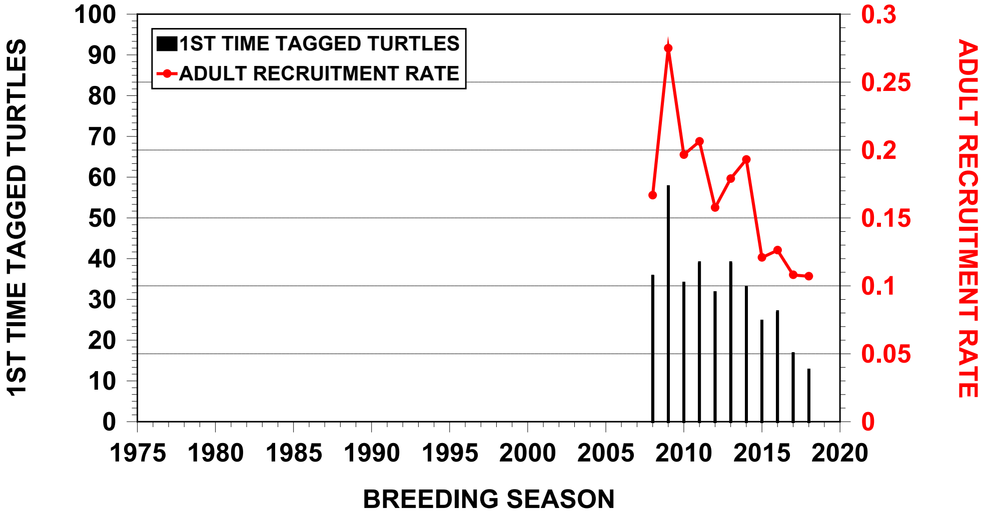


Figure 4.11. Trends in the number of nesting female flatback turtles, *Natator depressus*, tagged during the annual two-week mid-season census (last week of November – first week of December) and the associated mean number of nesting crawls per night during the same period at Peak Island, 2008 to 2018.



MEASURED DURING MID NESTING SEASON

Figure 4.12. Trends in the annual recruitment of new female flatback turtles, *Natator depressus*, to the nesting population at Peak Island, 2008 to 2018 breeding seasons.

Avoid Island Figures

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

a. South Beach, early November

b. Middle Beach

c. Nest site by sticks, showing tidal debris from previous wash over by tide

d. Inundation of nesting habitat early Dec

Figure 5.2. Images illustrating beach habitats at Avoid Island during the 2018-2019 breeding season.

Figure 5.3. Locations of multi-year temperature data loggers in sunny (upper left, sector 41) and shaded (upper right, sector 16) flatback turtle, *Natator depressus* nesting locations on the first dune slope, and on the beach slope in a sunny (lower left, sector 13) and shaded (lower right, sector 27) locations at Avoid Island.

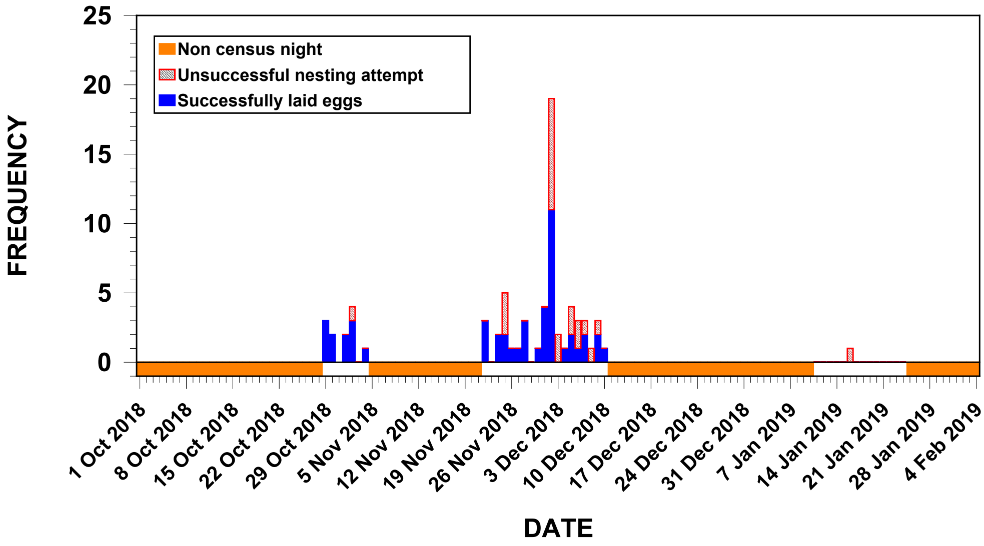


Figure 5.4 Nightly number of track from flatback turtle, *Natator depressus*, nesting on Avoid Island during the 2018-2019 breeding season.

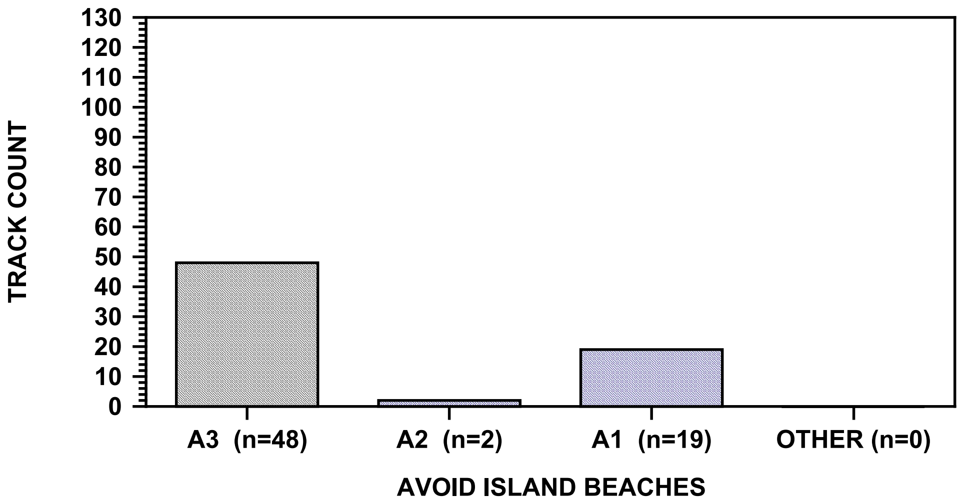


Figure 5.5. Frequency distribution of nesting crawls (tracks) of flatback turtles, *Natator depressus*, by beach at Avoid Island during the 2018-2019 breeding season. A1 = North Beach, A2 = Middle Beach, A3 = South Beach.

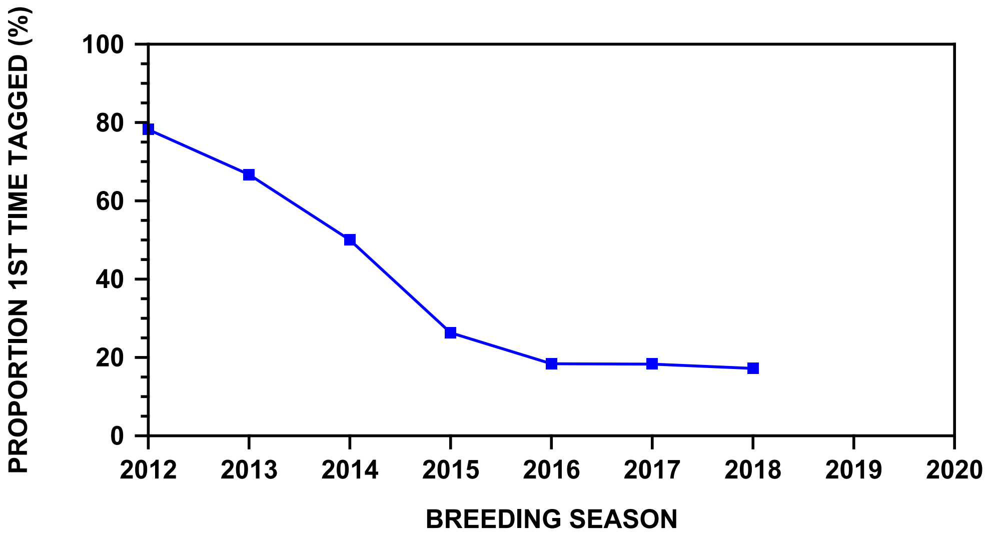


Figure 5.6. Long term trend in the proportion of first time tagged nesting flatback turtles at Avoid Island: 2012-2013 (FitzSimmons, 2013), 2013-2014 (FitzSimmons and Limpus, 2014), 2014-2015 (FitzSimmons and Limpus, 2015), 2015-2016 (FitzSimmons and Limpus, 2016), 2016-2017 (Limpus *et al*. 2017), 2017-2018 (Limpus *et al*. 2018).

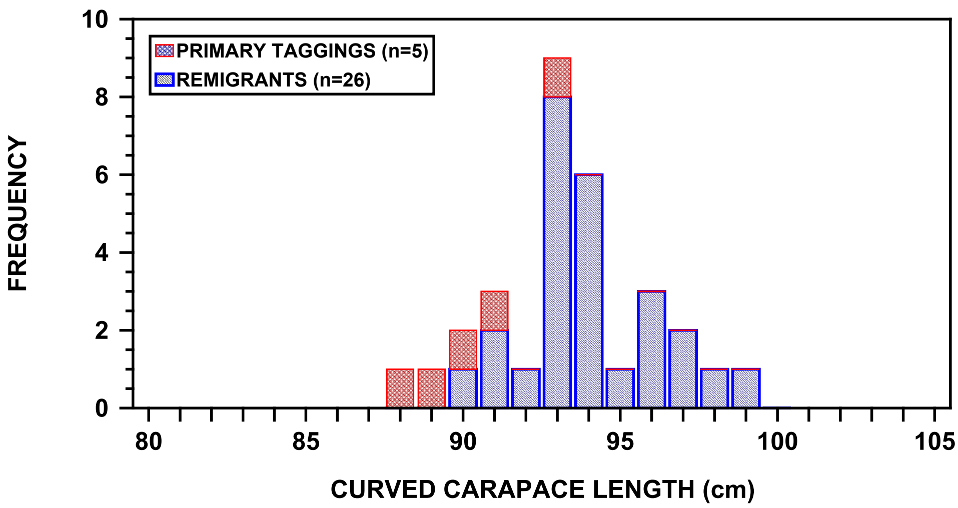


Figure 5.7. Size frequency distribution of nesting flatback turtles, *Natator depressus*, at Avoid Island during the 2018-2019 breeding season.

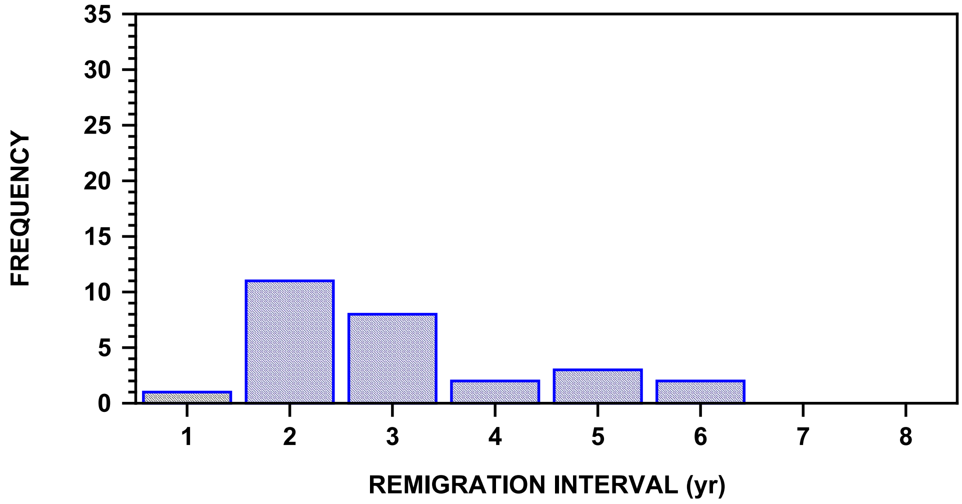


Figure 5.8. Frequency distribution of remigration interval for flatback turtles, *Natator depressus*, at Avoid Island during the entire 2018-2019 breeding season.

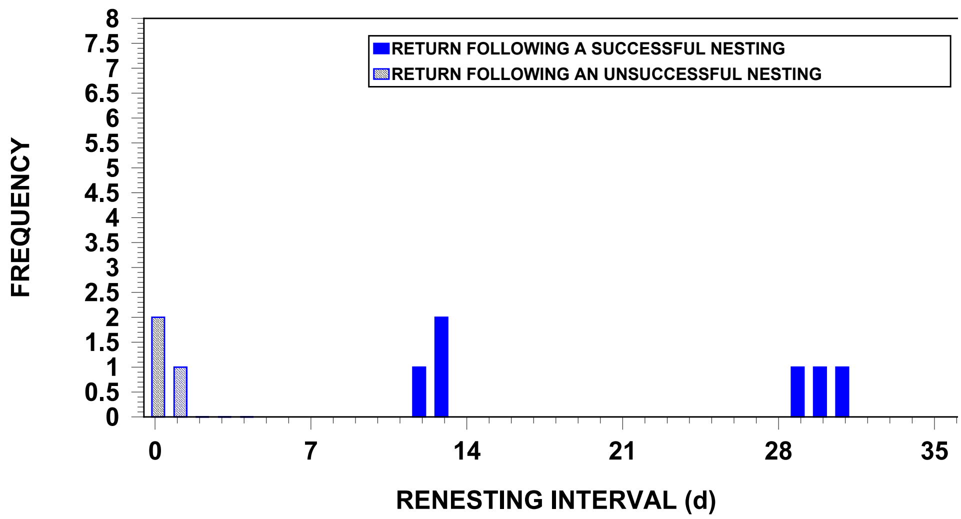


Figure 5.9. Return intervals recorded for nesting flatback turtle, *Natator depressus,* following both successful and unsuccessful nesting attempts at Avoid Island during the 2018-2019 breeding season.

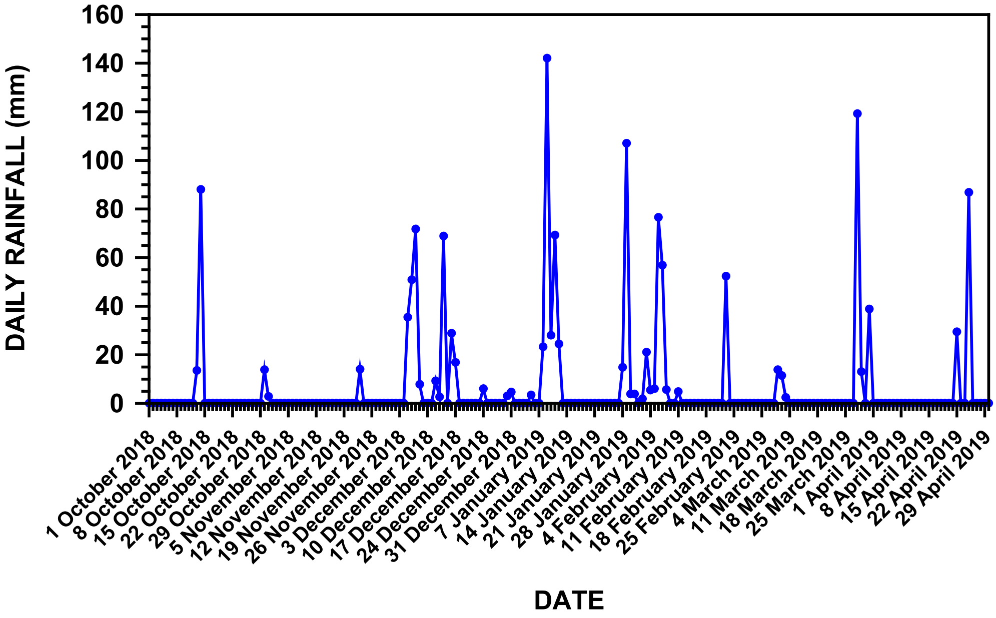


Figure 5.11. Daily rainfall recorded at Carmilla Beach Road (Bureau of Meteorology station number 033186; 21.92ºS, 49.44ºE) during the 2018-2019 flatback turtle, *Natator depressus*, breeding season.

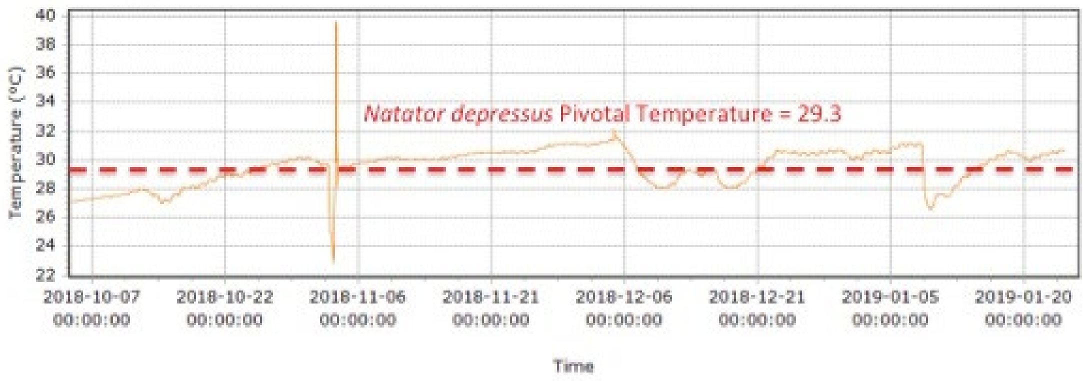


Figure 5.11a. Sand temperature records from an open sunny area on the dune crest, sector 41, Avoid Island, 7 October 2018 – 24 January 2019. Note that the change on temperature on 2 November is when data logger was checked.

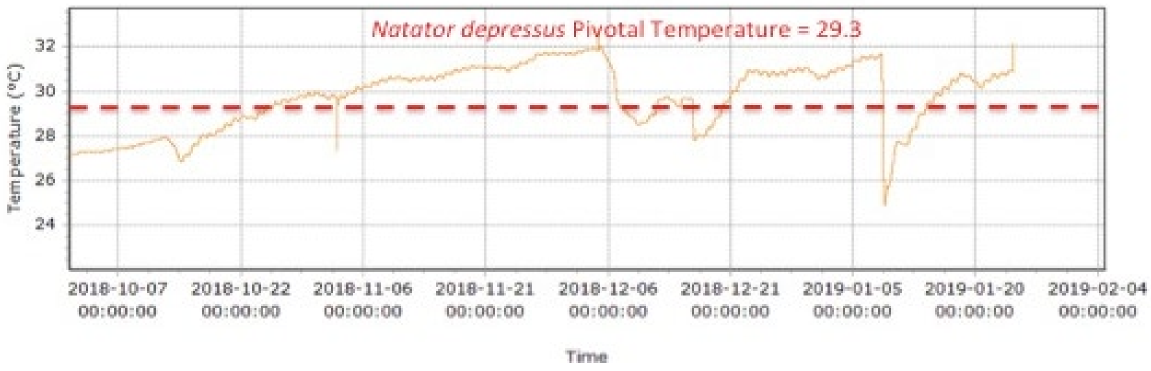


Figure 5.11b. Sand temperature records from an open sunny area on the beach slope, sector 13, Avoid Island, 7 October 2018 – 24 January 2019. Note that the change on temperature on 2 November is when data logger was checked.

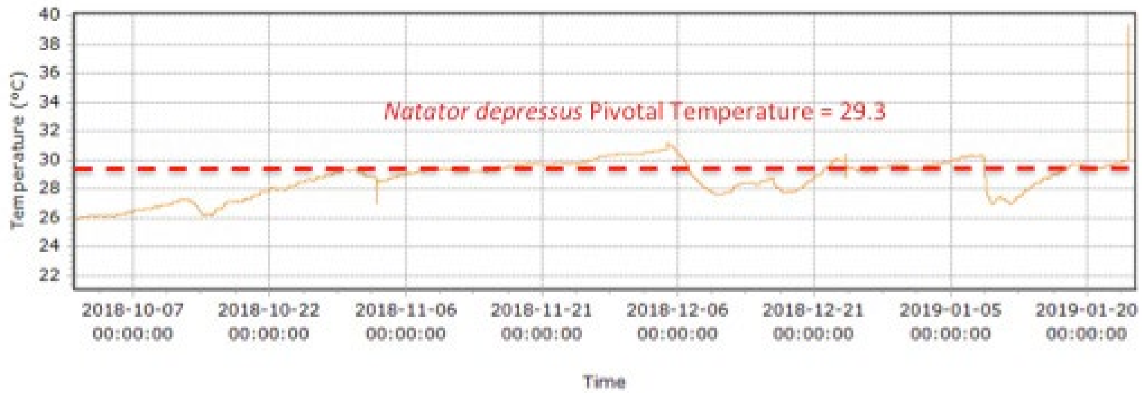


Figure 5.11c. Sand temperature records from a shaded area on the beach slope, sector 27, Avoid Island, 7 October 2018 – 24 January 2018. Note that the change on temperature on 2 November is when data logger was checked.

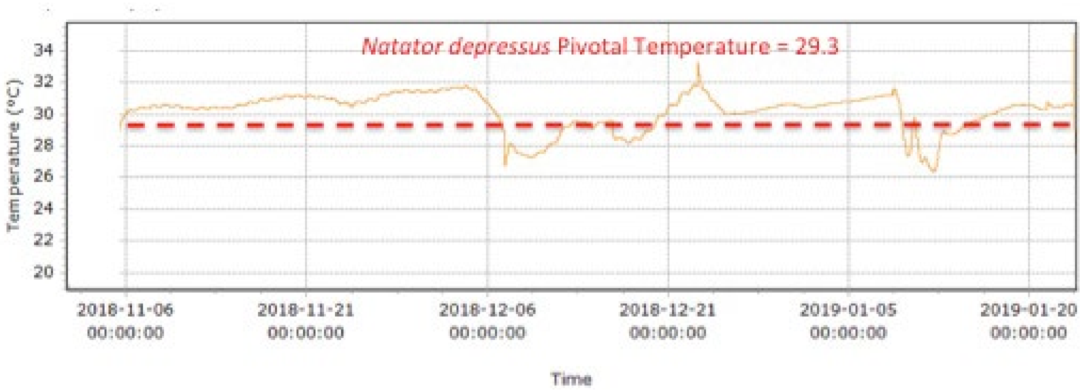


Figure 5.11d. Sand temperature records from an open location below high water, approximately 2 m from a nest that was laid on North beach, Avoid Island, 6 November 2018 – 24 January 2018.

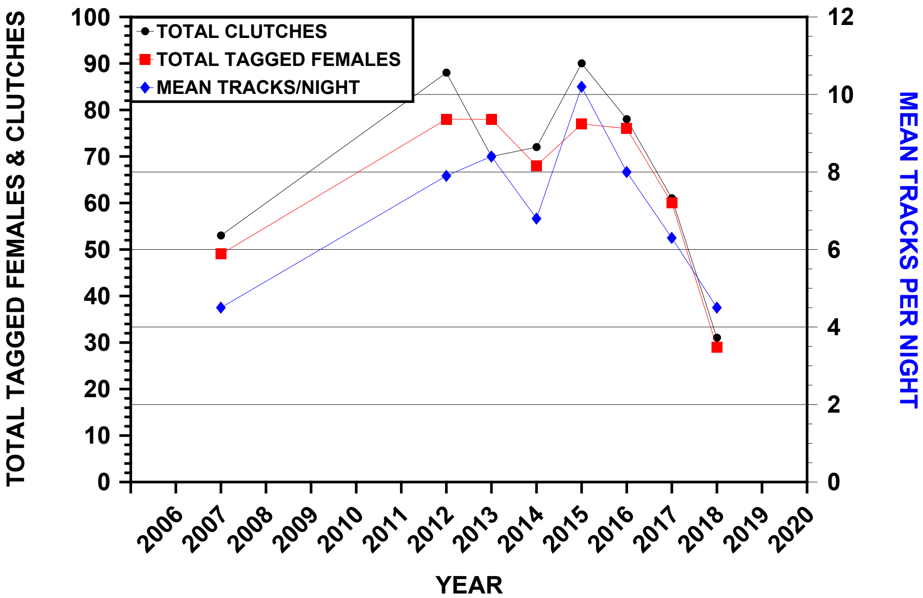


Figure 5.12. Comparison of total number of tagged females, total clutches laid and mean track count per night during the standard mid-season nesting census across breeding seasons for flatback turtle, *Natator depressus*, at Avoid Island.