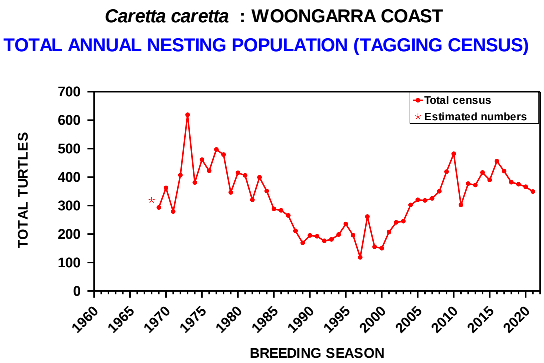
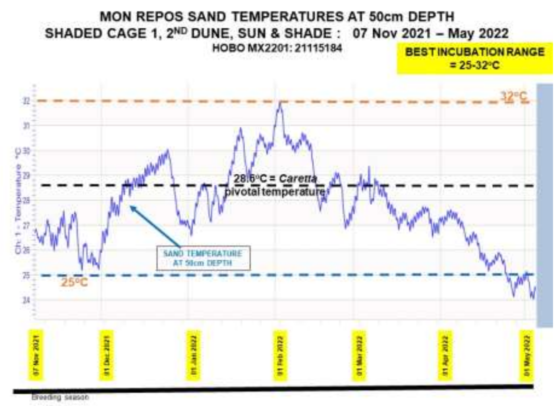
QUEENSLAND TURTLE CONSERVATION PROJECT: DATA REPORT FOR MARINE TURTLE BREEDING ON THE WOONGARRA COAST, 2021-2022 BREEDING SEASON





Colin J. Limpus, Diane Anderson, Kyle Debets, Janine Ferguson, Leisa Fien, Duncan J. Limpus, Maree McLaren and Nicole Murnane

Queensland Government

Department of Environment and Science

Cover photo:
Images of Mon Repos Beach and the monitoring team at work and illustration of some the data collected during the 2021-2022 breeding season.

This report should be cited as: Colin J. Limpus, Diane Anderson, Kyle Debets, Janine Ferguson, Leisa Fien, Duncan J. Limpus, Maree McLaren and Nicole Murnane (2022). Queensland Turtle Conservation Project: data report for marine turtle breeding on the Woongarra Coast, 2021-2022 breeding season. Brisbane: Department of Environment and Science, Queensland Government. (57 pp.)

Editor: Leisa Fien

Reviewer: Dr Megan Ellis, Gladstone Ports Corporation

The study was supported under an agreement between the Queensland Department of Environment and Science and Gladstone Ports Corporation to monitor the turtle nesting population on the Woongarra Coast and the Great Barrier Marine Park Authority to explore options for cooling a marine turtle nesting beach in response to global warming.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

During the 2021-2022 turtle breeding season, 349 Loggerhead turtles, 9 Flatback turtles and 5 Green turtles were recorded ashore for breeding on the Woongarra Coast beaches.

Concern is expressed regarding trends in the Loggerhead nesting population:

- Reduction in the size of the annual nesting population over the past five summers.
- Continuing reduction in annual recruitment of young females into the breeding population.

Abnormal nesting behaviour that could be the result of excessive sky glow impact on the nesting turtles is of concern and warrants investigation:

- Unsatisfactory low nesting success was recorded for Loggerhead turtles at all Woongarra Coast beaches.
- All three species of turtles visiting Mon Repos Beach (naturally dark) displayed a very high fidelity to visiting only that beach throughout the season in contrast with turtles that came ashore for nesting at Oaks, Nielson Park, Kellys and Archies Beaches (beaches illuminated by skyglow), which displayed very low fidelity to nesting at only a single nesting beach.

Beach cooling sand temperatures

The Bundaberg region was exposed to atypical intense rainfall events throughout the 2021-2022 marine turtle breeding season which resulted in beach sand temperatures at nest depth remaining within the 25-32^{o}C temperature range required for good incubation success.

Sand temperature records at nest depth from both long-term Mon Repos: natural open beach monitoring sites show that:

- When there were not heavy rain-induced cooling spikes in the sand temperature at nest depth, sand temperatures were regularly above the Loggerhead pivotal temperature throughout approximately the entire nesting season.
- There were numerous heavy rain-induced cooling events that gave brief periods of temperatures below the pivotal temperature that are expected to have resulted in masculinising of clutches laid approximately 1 month earlier than when the cooling occurred.

These sand temperature data also indicate that the Loggerhead hatchling sex ratio from the natural nesting habitat of the Woongarra Coast beaches should have been strongly female biased during the 2021-2022 breeding season.

Based on sand temperatures within the elevated rainfall conditions of the 2021-2022 summer, the use of 50% shade cloth cover over both hatcheries and the four cages was effective in managing sand temperatures at nest depth necessary for producing hatchlings with an appreciable proportion of both sexes. Cage 4 with the additional shade from the adjacent forest should have produced a strong male biased hatchling sex ratio while cage 2 in the open sun should have produced hatchlings with an extremely female biased sex ratio.

Within both sprinkler plots, the sand temperatures at nest depth at each of the artificial rain sites was cooler than those recorded at the respective control sites with no artificial rain, especially within the 2.0 and 4.0 hr artificial rain sites. Based on sand temperatures within both sprinkler plots, all sites receiving artificial rain (Figure 9G-9L, 9M-9Q) had the potential for producing a male biased sex ratio.

Incubation and emergence success

As a consequence of the atypically elevated rainfall for the summer, incubating clutches from all beaches of the Woongarra Coast showed little impact of heat stress: no clutches were recorded with elevated numbers of dead late-stage embryos and only one clutch was recorded with elevated number of dead but unimpeded hatchlings in the neck of an egg chamber.

- Overall, there was good Loggerhead hatching success and hatchling emergence success in the natural nesting habitat on all beaches, including within the shaded hatcheries and shaded cages and within the sprinkler plots (Table 12) except for the negative impacts on incubation success caused by some localised Tropical Cyclone (TC) *Seth* wave wash into cage 2, hatchery 2 and the south beach sprinkler plot and delays of many hours after laying that occurred when relocating many of the clutches from Nielson Park and Kellys Beach to Archies beach.
- Elevated areas of the frontal dune at Mon Repos in 2021-2022 returned to the high hatchling emergence success (80.6%) that can be expected from a beach that provides a good incubation environment for marine turtle eggs.
- These results reinforce the hypothesis that there is a very high probability that reduced hatchling emergence success of Loggerhead turtle eggs laid on Mon Repos beach in dry summers is linked to a lowered water table under the dunes as a consequence of past draining of the adjacent swampland behind the dunes. Given the continuing probability of increased frequency of heat wave conditions based on BOM modelling of weather data, this issue remains at an elevated level of concern.

Incubation period to hatchling emergence

The natural open sand incubation habitat at Mon Repos gave a longer mean period of incubation from laying until hatchlings emerged at the beach surface (Period to Emergence (PTE)) than similar habitat at Archies and Oaks Beaches, the next most favoured beaches for Loggerhead nesting on the Woongarra Coast. This is indicative of Mon Repos Beach being a cooler beach and more likely to produce a less female biased hatchling sex ratio as a result of shade from the revegetated dune forest.

With an estimated Loggerhead pivotal PTE = 60-61 days, the natural beach incubation habitat and all artificially shaded sites had shorter mean PTE values, indicative of warmer sand and should have produced a female biased hatchling sex ratio, except for the very shaded cage 4 on the top of the second dune.

Population structure and function

The mean size of the nesting females (95.4 cm), the mean number of clutches laid in a season (3.8), the mean number of eggs in a clutch (121.8) and the mean remigration interval (3.97 yr) recorded in 2021-2022 were like those recorded in recent years.

Although two turtles had a breeding lifespan exceeding 40 years, the population as a whole is still biased to relatively young adults. The majority of the nesting turtles commenced breeding after 2001, (the year that compulsory use of turtle exclusion devices (TEDs) was regulated into the northern and eastern Australian prawn trawl fisheries) indicating that the population is still in a recovery mode following the impact of trawling bycatch mortality.

80.4% of Loggerhead turtle nesting attempts on the Woongarra Coast occurred on Mon Repos Beach.

Boat strike injuries to Loggerhead turtles while in their inter-nesting habitat were recorded on one nesting female that survived the propeller cuts.

One nesting female at Mon Repos was rescued from disrupted ocean-finding behaviour caused by excessive sky glow over Bargara and led to the sea by torch light.

One clutch of turtle eggs was lost to foxes at Mon Repos, the first clutch lost to foxes during the six consecutive summers of den fumigation fox control measures. For the first time in decades, no marine turtle eggs laid on the Woongarra Coast were destroyed by dogs, or goannas.

The relocation of 503 clutches of doomed Loggerhead eggs to more elevated incubation sites to minimise clutch loss to erosion, or to dark beaches to minimise the risk of hatchling disorientation towards coastal lighting, resulted in the rescue of 38.9% of the seasonal Loggerhead egg production on the Woongarra Coast.

At least 164 Loggerhead, 2 Flatback and 2 Green turtle clutches were lost to erosion and flooding during the 2021-22 breeding season, with almost all of that loss resulting from TC *Seth* storm surge during 31 December 2021-2January 2022. This was equivalent to a loss of 12.5% of the season's egg production.

As in past summers, nesting turtles digging into existing clutches of eggs caused only minor loss of eggs for the population.

QUEENSLAND TURTLE CONSERVATION PROJECT: DATA REPORT FOR MARINE TURTLE BREEDING ON THE WOONGARRA COAST, 2021-2022 BREEDING SEASON

1. INTRODUCTION

The Woongarra Coast is a primary index site for monitoring and researching the Loggerhead turtle, *Caretta caretta*, within the SW Pacific genetic stock and a secondary index site for nesting Flatback turtles, *Natator depressus* within the eAust genetic stock. Systematic monitoring of these turtles commenced in 1968.

The Loggerhead turtle is listed as *endangered* under both Queensland and Commonwealth conservation legislations while the Flatback turtle is listed as *vulnerable.* IUCN lists the Loggerhead turtle population of the South Pacific as critically endangered and the Flatback turtle as data deficient. While the studies commenced with an emphasis on defining the biology of the Flatback turtle (Bustard and Limpus, 1969), Loggerhead turtles dominate the current conservation considerations for marine turtles on the Woongarra Coast.

Loggerhead turtle breeding within the South Pacific Ocean forms an independent genetic stock that does not interbreed with other Loggerhead turtles elsewhere within the Pacific or Indian Oceans (FitzSimmons and Limpus, 2014. Figure 1). Loggerhead turtle breeding within the South Pacific Ocean is restricted to eastern Australia and New Caledonia, with the majority of the nesting occurring in eastern Australia.

There are five significant concentrations of Loggerhead turtle breeding in eastern Australia (Figure 2; Limpus *et al*. 2013): Woongarra Coast and Wreck Rock Beaches on the mainland and Wreck, Tryon, and Erskine Islands within the Capricornia region of the southern Great Barrier Reef (GBR).

The Woongarra Coast currently supports approximately 50% of annual Loggerhead turtle breeding in eastern Australia (Limpus *et al*. 2013).

The functioning of the Loggerhead turtle nesting in eastern Australia needs to be understood within the context of the complex life history that takes this population into diverse habitats throughout the South Pacific region and the associated diversity of threats to which it is exposed (Figure 3). While breeding success at the nesting beaches contributes to the functioning of the next generation that will return to breed in about 30 years' time, the next generation has to survive well as:

- Small post-hatchlings travelling along the East Australian Current (with exposure to ingestion of floating plastic debris) down the eastern Australian coast and eastward past New Zealand at about six months of age and out into the wider South Pacific Ocean.
- Larger post hatchlings foraging in the plankton rich waters of the eastern Pacific Ocean off Chile and Peru (with exposure to fisheries bycatch in longline and gill net fisheries).
- Large post-hatchlings returning back across the South Pacific (still exposed to longline fisheries bycatch) to recruit into shallow coastal foraging areas of the Coral Sea – Tasman Sea region at about 16 years of age.
- Large immature and adult Loggerhead turtles foraging on benthic invertebrates in shallow coastal waters of the Gulf of Carpentaria, Coral Sea and Tasman Sea (exposed to fisheries bycatch [crabbing, trawling], boat strike, decline in quality of coastal habitats in response to extreme weather events).
- Adults on their migrations of up to 2,600 km from their widely dispersed foraging areas to their traditional breeding sites.

In response to the diverse threats to the Loggerhead turtle, spanning multiple national jurisdictions across the entire South Pacific, the UNEP Convention for Conservation of Migratory Species (CMS) approved in 2014, the ***Single Species Action Plan for the Loggerhead Turtle (Caretta caretta) in the South Pacific Ocean*** (UNEP/CMS/Resolution 11.21; UNEP/CMS/COP11/Doc 23.2.2/Rev.1/Annex 2) (CMS, 2014). As a signatory state to CMS, the Australian Government is expected to implement this Action Plan. This report summarises part of the Queensland Government's contribution to implementation of the Single Species Action Plan for the Loggerhead Turtle in the South Pacific Ocean.

This report also summarises the results of the first year of beach cooling studies funded by the Great Barrier Reef Marine Park Authority (GBRMPA) to explore options for cooling turtle nesting beaches in response to global warming and Gladstone Ports Corporation continued funding of the Research and monitoring project on the Woongarrra Coast.

2. METHODS

The Woongarra Coast supports nine small crescent sand beaches in an otherwise 22 km of rocky coastline between the Burnett and Elliott Rivers in northern Hervey Bay, south Queensland (Figure 4). The inter-tidal areas of these beaches and the majority of the adjacent sub-tidal waters are within the Great Sandy Marine Park. The longest of these beaches is Mon Repos beach (1.6 km) where the nesting habitat occurs mostly within the Mon Repos Conservation Park that is managed by Queensland Parks and Wildlife Service (QPWS) within the Queensland Department of Environment and Science (DES). The remaining beaches are principally within esplanades managed by the Bundaberg Regional Council, except for Kellys Beach where the nesting habitat extends into the seaward margin of privately owned properties.

Standard methodologies of the DES Queensland Turtle Conservation Project (QTCP) within Threatened Species Operations (Limpus *et al*. 1983; Limpus, 1985) were followed for this project, monitoring nesting females and their clutches. Statistical procedures follow Zar (1984). Proportional data were presented as the value ± 95% confidence interval.

Monitoring teams included QPWS staff and QTCP volunteers with training in the methods being implemented. DES is indebted to the tireless efforts of the large team of local volunteers who patrolled the beaches, tagged the turtles, relocated doomed eggs, and recorded data at the Burnett Heads, Bargara and Elliott Heads beaches and are managed by the Burnett Mary Regional Group (BMRG).

Data management

DES maintains the QTCP database which collates data on marine turtle tagging and sightings from nesting beaches, foraging grounds, and stranded turtles. The data are coded into a relational database to facilitate statistical analysis. The data is routinely analysed to investigate:

- distribution and abundance of nesting by beaches.
- trends in size of nesting populations and other demographic parameters.
- description of population characteristics by study year; and
- threatening processes.

Nesting activity

Nesting activity was recorded at all nesting beaches along the Woongarra Coast during the entire breeding season from early October 2021 to May 2022. Monitoring of nesting occurred nightly and additionally during the cooler hours of the day for assessing incubation through late January to May. Procedures included:

- Flipper tagging following the standard methods reported by Limpus (1992). Adult turtles left the beach with a minimum of two titanium tags manufactured by Stockbrands Australia in the front left and right flippers, generally proximal to the flipper scute closest to the body. If scar tissue from previous tagging made this position unsuitable, tags were applied distally to this scute or on hind flippers.
- Flipper tagging using monel tags with this nesting population commenced in 1968 but these tags only lasted a few years before they were lost to corrosion. The introduction of double tagging with titanium tags in 1981 has enabled long term recognition of the individual nesting turtles (Limpus, 1992). Past studies have established that since 1982, any turtle nesting on the Woongarra Coast that is untagged and does not have tag scars from lost previously applied tags, has a 98% probability of being a first time breeding turtle. This has enabled the assigning a year for commencement of breeding to these first-time tagged females with a high level of confidence.
- Passive Integrated Transponder (PIT) tags manufactured by Animal Electronic I.D. Systems were injected into the upper left (or occasionally right) shoulder (just below the carapace) of nesting Flatback and Green turtles and a limited number of high priority Loggerhead turtles.
- 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 *Chelonibia* 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 when logistics permit.
- 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 was 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).
- When clutches were counted, nest depths from the beach surface to the top of the eggs and to the bottom of the nest were measured with fibreglass flexible tape measures (± 1 cm).
- Nest locations were recorded by triangulation measurements from pairs of numbered posts along the crest of the upper dune and extending for the full length of Mon Repos, Oaks, and Archies Beaches.
    - No surface markers were placed on individual nests

Rescuing of doomed eggs

Since the late 1980s, it has been standard management for the majority of clutches of eggs that are laid below or close to the high tide level on the Woongarra Coast to be relocated to more secure incubation sites higher up the dunes. This relocation was completed within 2 hours of the eggs being laid and with the minimum of rotation of the eggs (Limpus *et al*. 1979;

Pfaller *et al.* 2008). The majority of the relocation of clutches was managed by DES staff and trained volunteers.

Because of the high risk of hatchlings heading inland from Nielson Park, Bargara and Kellys Beaches, the majority of clutches of eggs laid on these beaches were relocated to a darker beach, either Mon Repos or Archies Beaches, on the night that they were laid or approximately three weeks later.

Beach cooling: Incubation cages and hatcheries

QPWS maintains four standard shaded, predator- proof cages (Figure 5A) at Mon Repos, and two shaded, open-sided hatcheries (Figure 5B) at Mon Repos, to provide some clutches with a cooler incubation environment. The shading on the cages and hatcheries was provided by 50% shade cloth. The predator-proof cages were enclosed in aluminium mesh with 70 mm diameter mesh size allowing self-release of hatchlings emerging from the enclosed nests.

Additional shaded predator-proof cages have been installed at Archies Beach, Elliott Heads Beach, Moore Park and at Wreck Rock with the assistance of the Bundaberg Regional Council and Gidargil Land and Sea Rangers to provide increased protection of eggs from potential fox, dog and varanid depredations.

Location of incubation cages and hatcheries at Mon Repos, 2021-2022 breeding season:

- Cage 1: sector 1, top of 2nd dune, shaded by *Casuarina* from approximately midday onward.
- Cage 2: Sector 8, 1st dune, shaded by Casuarina from approximately 2pm onward.
- Cage 3: Sector 10, 1st dune, not shaded by the forest until after approximately 5pm.
- Cage 4: Sector 14B, 2nd dune, shaded by casuarina after approximately 12:30pm.
- Hatchery 1: Sector 9C, 1st dune, receives shade from the forest after approximately 4:30pm.
- Hatchery 2: Sector 13C, 1st dune, receives shade from Casuarina after 3:30 pm (Wood *et al*. 2014).

Clutches were relocated and buried at 60 cm spacing and at a depth to the bottom of the artificial nest of 60 cm into the cages and hatcheries from different distances along Mon Repos Beach. Ropes with knots at 60 cm spacing were placed across the ground within each cage and hatchery to guide the positioning of the relocated clutches. A nest tape with tag number and date laid was placed within each clutch of eggs and tied to the knot on the rope above.

The cages at Mon Repos have space for approximately 30 relocated clutches while each hatchery can accommodate up to 100 clutches at a time.

Beach cooling: Artificial rain

Artificial rain was delivered to two 50 m lengths of turtle nesting habitat (Sprinkler plots) on the frontal dune at Mon Repos, one on the northern beach in sectors 9C-10A and the other on the southern beach in sectors 14A-14C. The water was supplied from the QPWS bore behind the frontal dunes that draws freshwater from the aquifer lying below the basalt lava flow beneath the sand dunes.

For each 50 m sprinkler plot, the artificial rain was supplied via irrigation hosing to the top of the dunes and dispensed via 4 separate sprinkler outlets at 150 cm above the beach surface and at 10 m spacings within the sprinkler plot.

A Hobo MX WiFi linked temperature data logger was buried at 50 cm depth to measure sand temperature at nest depth at 30 min intervals and a rain gauge were attached to a post that was located approximately 1 m from each sprinkler. Two control sites with similar temperature data logger and rain gauge were positioned at 10 m spacing from sprinklers along the length of each sprinkler plot (Figure 5C, Figure 5D).

The artificial rain fall (Arain) from each sprinkler was regulated for duration of rainfall and when it occurs during the 24 hr daily cycle using irrigation timed valves (Hunter Node-100-valve-B}. The spread of rainfall was regulated to fall within 5 m of the sprinkler head on low wind days. Previous trials with artificial rain at Mon Repos have shown more effective cooling of sand at nest depth when rain occurs in the heat of the day than in the cool of the night. Therefore, the artificial rain was timed to occur with the duration centred on 1300 hr. Within each sprinkler plot, artificial rain was delivered for durations of 0.5 hr, 1.0 hr, 2 hr and 4 hr as follows:

South Beach sprinkler plot		**North Beach sprinkler plot**	
Sprinkler #	**Arain setting**	**Sprinkler #**	**Arain setting**
1	0.5 hr	7	Control, no Arain
2	1.0 hr	8	0.5 hr
3	Control, no Arain	9	1.0 hr
4	2.0 hr	10	2.0 hr
5	4.0 hr	11	4.0 hr
6	Control, no Arain	12	Control, no Arain

Water supply to sprinkler 11 was discontinued in late December because the prevailing winds for the season were causing a substantial part of the artificial rain from this 4 hr rainfall sprinkler to be windblown into the adjacent Hatchery 1.

Clutches of eggs within the sprinkler plots were mapped via triangulation from exiting beach markers at laying for subsequent finding of the nests at hatchling emergence for assessment of incubation success and period from laying to hatchling emergence.

Incubation and emergence success

Nests were excavated for assessing incubation success and hatchling emergence success after hatchlings had emerged. Previously marked nests were relocated using triangulation measurements from marker posts and confirmed by the presence of nest tags. Nests were excavated no sooner than 24 hours after hatchling emergence or at 9 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 and photographed.
- Observations of heat stress were noted that included:
    - dead hatchlings that had emerged but died in the vicinity of the nest, with no signs of predation.
    - dead hatchlings in the neck of the nest that were not otherwise trapped by roots from emerging.
    - elevated numbers of dead pipped eggs.
- 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.
- Unhatched eggs were opened to determine whether the embryo had developed to an observable phase or whether it appeared to be undeveloped.
- Hatchling 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.

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, 1980, 1982). The pivotal temperature (the theoretical temperature that will result in equal proportions of male and female hatchlings) for the South West Pacific Loggerhead turtle population has been quantified at 28.6^{o}C (Limpus *et al*. 1985), with higher temperatures producing predominantly females and lower temperatures producing predominantly males. If Loggerhead eggs incubate at a constant temperature of 28.6^{o}C:

- Hatching should occur approximately 58 days after the eggs were laid.
- Allowing for 2-3 days for the hatchlings to dig to the beach surface for emergence, the incubation period from laying to hatchling emergence should be approximately 60-61 days.

Thus, incubation duration can be informative regarding the sex of hatchlings. However, heavy rainfall will also influence the sex ratio (Reed, 1980) as cool rain results in a decline in sand temperatures with a corresponding potential to produce more male hatchlings. In contrast, sand temperatures increase in the short term in the absence of rain and as a result of reduced evaporative cooling within the sand. The warmer sand temperatures can be expected to result in an elevated production of female hatchlings.

Extreme weather

The Australian Bureau of Meteorology has identified that there has been a trend for increasing air temperatures in south-eastern Queensland across recent decades (Figure 6. Bureau of Meteorology, 2022). Daily rainfall were accessed via the Australian Bureau of Meteorology from Bundaberg Aero {station 039128} for the year, 1 July 2021 to 30 June 2022 (Figure 7). These data show that during the 2021-2022 breeding season, the Bundaberg district was exposed to atypical successive extreme rainfall scattered throughout the turtle breeding season in coastal south Queensland.

There was only one tropical cyclone in the Coral Sea region that impacted negatively on beach stability on the Woongarra Coast during the 2021-2022 summer turtle breeding season: TC *Seth* caused substantial erosion of nesting habitat during 31 December 2021 – 2 January 2022.

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 minute intervals. The Vemco data loggers were replaced with Hobo MX2201 and MX2203 WiFi linked temperature data loggers on the Woongarra Coast commencing for the 2021-2022 breeding season. These temperature recording instruments can record temperature continuously for up to five years. Temperature data loggers continue to be deployed on Mon Repos Beach year-round within the turtle nesting habitat at the standard temperature monitoring locations:

- Sector 14, on 1st dune grassy habitat in open sun but exposed to afternoon shade from the forest inland of the turtle nesting habitat.
- Sector 9C, on the crest of the 2nd dune in open sun and only exposed to shade from the adjacent forest in the late afternoon.
- Within the centre of each of the two shaded, open sided hatcheries on Mon Repos Beach.
- Within the centre of each of the four shaded predator-proof incubation cages on Mon Repos Beach and at the front wall and at the rear wall of the predator-proof cage at Archies Beach.

As identified above, six temperature data loggers were also deployed similarly within each of the two sprinkler plots (four adjacent to sprinklers and two at control sites within each sprinkler plot).

The recorded sand temperature measurements provide an index of sand temperature at approximately nest depth for Loggerhead and Flatback turtles in the absence of metabolic heating that commences to increase during the temperature sensitive incubation phase when sex of the embryo is determined (Reed, 1980; Yntema and Mrosovsky, 1982).

Graphical summaries of the sand temperatures at 50 cm depth are presented from temperature data loggers at Mon Repos within:

- natural nesting habitat sector 14 (Figure 8A), sector 9C (Figure 8B);
- centre of each of four shaded predator-proof cages: cage 1 (Figure 9A), cage 2 (Figure 9B), cage 3 (Figure 9C) and cage 4 (Figure 9D);
- centre of each of two shaded hatcheries: northern hatchery 1 (Figure 9E) and southern hatchery 2 (Figure 9F).
- South beach sprinkler array: 0.5 hr artificial rain (Figure 9G); 1.0 hr artificial rain (Figure 9H); control, no artificial rain (Figure 9I); 2.0 hr artificial rain (Figure 9J); 4.0 hr artificial rain (Figure 9K); control, no artificial rain (Figure 9L);
- north beach sprinkler array: 0.5 hr artificial rain (Figure 9M); 1.0 hr artificial rain (Figure 9N); control, no artificial rain (Figure 9O); 2.0 hr artificial rain (Figure 9P) and control, no artificial rain (Figure 9Q).

The elevated rainfall scattered throughout the 2021-2022 breeding season resulted in multiple cooling spikes in sand temperature at nest depth that occurred throughout the breeding season as recorded at control temperature monitoring sited (Figures 8A, 8B, 9I, 9L, 9M, 9Q). Even though this summer brought atypically high rainfall, sand temperatures within the natural nesting habitat at Mon Repos Beach were above the pivotal temperature for Loggerhead turtles for the majority of the season. However, the sand temperatures at nest depth remained within the 25-32^{o}C temperature range that is required to support good incubation success.

Sand temperatures at nest depth within the shaded predator proof cages and shaded hatcheries was lower than in the adjacent control sites in open sand natural nesting habitat (Figures 8 and 9A-F)

Sand temperatures at nest depth within the artificial rain sprinkler plots was lowered with respect to sand temperatures at adjacent control sites depending on the duration of the artificial rain (Figures 9G-Q)

3. RESULTS

Marine turtle nesting populations on the Woongarra Coast, 2021-2022.

Turtle nesting on the Woongarra Coast commenced with the first nesting on 09 October 2021 and the last nesting on 07 April 2022 (Table 1).

The marine turtle hatchling emergence from nests on the Woongarra Coast commenced on 20 December 2021 and ceased on 26 April 2022 (Table 1).

Based on the whole of nesting season capture-mark-recapture nightly tagging of all turtles encountered, a total of 363 individual marine turtles of three species were recorded ashore for nesting on the Woongarra Coast beaches during the 2021-2022 breeding season (Table 2).

At least 503 clutches of doomed marine turtle eggs were relocated to more elevated incubation sites to minimise clutch loss to erosion and flooding, or to dark beaches to minimise the risk of hatchlings disoriented towards coastal lighting: 362 clutches on Mon Repos, 68 on Oaks Beach, 20 on Archies Beach, 36 to cage 7 at Archies Beach from other beaches, 9 to cage 8 on Elliott Heads and 7 clutches on other Woongarra Coast beaches. These relocated clutches are equivalent to rescuing 38.9 ± 2.7% of the seasonal marine turtle egg production on the Woongarra Coast for the 2021-2022 breeding season. An additional 239 clutches were relocated into the shaded predator proof cages (n = 96) and shaded hatcheries (n = 143) at Mon Repos in support of the beach colling project. A proportion of these clutches would have included doomed eggs being rescued from flooding and erosion in addition to the above.

3.1. LOGGERHEAD TURTLES, *Caretta caretta*

Breeding population size

A total of 349 Loggerhead turtles were recorded ashore for breeding on the Woongarra Coast beaches this summer. The long term trends in the annual nesting census data (Figure 10) from the 1970s to 2021, illustrates the major decline in annual numbers of nesting Loggerhead turtles attributed primarily to otter trawl by-catch mortality. The compulsory use of TEDs has been regulated via Australian and Queensland fisheries regulation across northern Australia, Torres Strait and eastern Queensland since 2001 (Limpus, 2008). As a consequence, recent Loggerhead turtle nesting numbers on the Woongarra Coast have recovered to a size that is comparable to those of the early 1980s. However, there has been an unexplained decline in the size of the annual Loggerhead turtle nesting population on the Woongarra Coast over the last five breeding seasons.

The annual recruitment rate of Loggerhead turtles (= proportion of turtles recorded breeding for the first time on the Woongarra Coast) was 0.21 ± 0.04 for the 2021-2022 breeding season. This index of recruitment into the adult female breeding population has declined by approximately 50% over the last two decades (Figure 11). This continuing decline in recruitment of new adults into the breeding population is of concern.

The 2021-2022 marine turtle breeding season on the Woongarra Coast (Table 1) commenced at the earliest date recorded in the past 53 years: Flatback turtle, X23103, laid her first clutch for the season on 9 October, followed by the first Loggerhead clutch laid on 26 October.

Reproductive parameters

The size range of the nesting Loggerhead turtles are summarised in Table 3; Figure 12A. The mean CCL of 95.4 cm is typical of the eastern Australian Loggerhead nesting population. Nesting females tended to increase in carapace length with increasing reproductive age (Table 4).

The nesting Loggerhead turtles averaged 3.8 clutches laid per female for the summer (Table 3; Figure 12B). Nesting females tended to increase the number of clutches laid per season with increasing reproductive age across their first four breeding seasons (Table 5).

The nesting Loggerhead turtles averaged 121.8 eggs per clutch (Table 3) which was lower than expected. The occurrence of yolkless and multi-yolked eggs in clutches was uncommon. Nesting females tended to increase the number of eggs per clutch with increasing reproductive age (Table 6).

The nesting Loggerhead turtles averaged approximately 4 yr between seasons (Table 3; Figure 12C) which is longer than expected. Nesting females tended to decrease the number of years between breeding seasons with increasing reproductive age (Table 7).

Nesting behaviour

The proportion of marine turtle nesting crawls and nesting success by Woongarra Coast beaches during the 2021-2022 breeding season are summarised in Table 8.

The vast majority (80.4 ± 1.7%) of the Loggerhead turtle nesting attempts occurred on Mon Repos Beach and the remaining 19.6% of the nesting crawls were spread over the remaining seven beaches (Table 8A). Mon Repos has been the primary beach supporting Loggerhead turtle nesting on the Woongarra Coast in all years since systematic monitoring of turtle nesting began in 1968 (Figure 13).

Unsatisfactory, low nesting success was recorded for Loggerhead turtles across all Woongarra Coast beaches for the 2021-2022 season (Table 8A). It is concerning when numerous turtles turned around at mid-beach and returned to the sea without laying eggs in the absence of observed physical disturbance (e.g. absence of people or dogs; absence of obstructions such as erosion banks or beach debris). The role of sky glow over a nesting beach as a disturbance factor impacting marine turtle breeding success warrants investigation.

Turtles that came ashore to nest on the Woongarra Coast displayed an acceptably high fidelity to an individual nesting beach for all three species with 72.5% of Loggerhead turtles and 88% of Flatback turtles visiting only a single beach throughout the entire nesting season (Table 9A). All three species of turtles visiting Mon Repos Beach displayed a very high fidelity to visiting only the beach at which they first came ashore for the season (Table 9B). In contrast, turtles that came ashore for nesting at Oaks, Nielson Park, Kellys and Archies Beaches displayed very low fidelity to nesting at only a single nesting beach.

Turtles with the longest recorded reproductive life span that bred on the Woongarra Coast were:

- Loggerhead turtle, **X-8400:** 44 yr reproductive life span, commenced breeding in the 1977-1978 breeding season, with 16 recorded breeding seasons.
- Flatback turtle, **X23103**: 47 yr reproductive life span, commenced breeding in the 1974-1975 breeding season, with 18 recorded breeding seasons.

Following the decimation of the eastern Australian Loggerhead turtle nesting population, recovery of the annual nesting numbers commenced following the compulsory regulation of the use of TEDs in the prawn trawl fisheries of northern Australia, Torres Strait, and eastern Queensland in 2001. As a consequence, 316 (92.3%) of the Loggerhead turtles with a known reproductive life span commenced their breeding life since 2001 (Figure 14A). The excessive Loggerhead turtle mortality across decades throughout the majority of the foraging distribution prior to 2001 is interpreted as the underlying reason for there being only 7.9% of older turtles (>20 yr reproductive life) still migrating to this major breeding site.

There was a marked decline in the proportion of turtles returning to breed after more than four breeding seasons (Figure 14B). There was no tight correlation between the reproductive life span of the adult female Loggerhead turtle and the number of recorded breeding seasons. It is presumed that the variability in reproductive life span/number of recorded breeding seasons will be influenced by environmental factors operating across the multiple foraging areas supporting these turtles prior to their breeding migrations.

Boat strike injuries in the inter-nesting habitat

One of the season's nesting Loggerhead turtles survived boat strike injuries that occurred while she was in the adjacent inter-nesting habitat while preparing another clutch of eggs for laying:

- **T22755:** 27 December 2021: adult in her 11th breeding season; recorded with fresh propeller cuts to the rear of the carapace that had occurred between laying her 2nd and 3rd clutches for the season.

Rescued turtle

One nesting Loggerhead turtle, QB2719, was led back to the sea, using torches, at Mon Repos Beach following disorientation by the skyglow over Bargara to the south on the night of 30 January 2022.

Loss of clutches and eggs

One clutch of Loggerhead turtle eggs was lost to depredation by foxes at Mon Repos during the 2021-2022 breeding season. This was the first clutch loss to foxes during the six consecutive summers of successful fox den fumigation and associated soft-jaw trapping project conducted by QPWS, BMRG and Gidargil Land and Sea Rangers on the Woongarra Coast. There were occasional records of fox tracks and of foxes digging into nests after hatchlings had already emerged on Mon Repos Beach throughout the summer and a limited number of sightings of foxes at night in the immediate vicinity of the Conservation Park. It is presumed that the fox control program has reduced the number of foxes in the district that have prior experience of depredation on turtle eggs. Collectively for all beaches on the Woongarra Coast, no marine turtle eggs were destroyed by dogs. The use of predator-proof cages at Archies and Elliott Heads beaches contributed to this result.

A minimum of 164 Loggerhead, 2 Flatback and 2 Green turtle clutches were lost to erosion associated with elevated wind velocities, mostly from TC *Seth* during 31 December – 2 January (Table 10). This is equivalent to the loss of 12.5 ± 1.8% of the season's egg production.

At least 24 incubating Loggerhead clutches were dug into during subsequent nesting activities of Loggerhead turtles (Table 10). In each case only part of the incubating clutch was destroyed by the nesting turtle. As in past seasons, egg destruction by nesting turtles represented the loss of only a small proportion of the total season's Loggerhead egg production on the Woongarra Coast.

Incubation success and hatchling emergence

Of the 1292 recorded Loggerhead clutches laid on the Woongarra Coast during the 2021-2022 breeding season, 1286 clutches were accounted for following hatchling emergence. There were an additional 60 partial clutches that that had been rescued during erosion by TC *Seth* and subsequently reassessed for hatchling emergence. There were apparently six clutches that were not accounted for at hatchling emergence possibly because of faulty triangulation measurements when the eggs were laid or additional clutches lost through erosion by TC *Seth.*

Figure 16 summarises the frequency distribution of incubation period from laying until hatchlings emerged onto the beach surface (PTE) for Loggerhead clutches laid on Mon Repos Beach, from clutches incubating: 16A within the natural beach habitat; 16B within shaded hatcheries and shaded predator proof cages; 16C within artificial rain study plots.

Table 11 summarises the PTE for Loggerhead clutches laid on the Woongarra Coast beaches by species and relocation history of the eggs and their exposure to artificial shade and exposure to artificial rain.

In the absence of directly quantified hatchling sex ratio from sacrificing hatchlings for histological gonad examination, the sex of hatchlings for the season is approximated via two data sources:

1. PTE, period of incubation from laying to hatchling emergence from the nest. Female biased hatchling sex ratio occurs when PTE is shorter than the pivotal PTE (= 60-61 days for Loggerhead turtles), in the absence of a cooling spike in sand temperatures induced by heavy rain.
2. Sand temperatures at nest depth measured with temperature data loggers. Female-biased hatchling sex ratio occurs when nest temperatures during mid-incubation period are above the pivotal temperature (= 28.6ºC for Loggerhead turtles). Nest temperatures at mid incubation within a clutch of eggs can be expected to be slightly above sand temperatures in the absence of eggs because of metabolic heating that commences in about mid incubation.

Based on measured PTE across the open natural beach incubation habitat of beaches on the Woongarra Coast (Table 11), Mon Repos has the highest average PTE and hence should be slightly cooler at nest depth than Archies Beach and even more so than Oaks Beach. However at Mon Repos Beach, only 44 (12.7%) of the 350 Loggerhead clutches within the natural nesting habit with recorded PTE had PTE above the predicted pivotal temperature PTE (Figure 17). Artificially shaded incubation sites that received additional shade from the adjacent forest during a major portion of the afternoon (Hatchery 2 and cages 1 and 4) had longer PTE and hence should have provided cooler incubation environments at nest depth than at the less shaded sites (Hatchery 1 and cages 2 and 3). However, with an estimated Loggerhead pivotal PTE = 60-61 days, the natural beach incubation habitat and all artificially shaded sites had shorter mean PTE values, indicative of warmer sand and should have produced a female biased hatchling sex ratio (Figure 15), except for the very shaded cage 4 on the top of the second dune (Table 11).

Sand temperature records at nest depth from both long-term open beach monitoring sites at Mon Repos at sectors 14A and 9C (Figure 8) show a consistent pattern of sand temperatures:

- When there were not heavy rain-induced cooling spikes in the sand temperature at nest depth, sand temperatures were regularly above the Loggerhead pivotal temperature throughout approximately the entire nesting season.
- There were numerous heavy rain-induced cooling events that gave brief periods of temperatures below the pivotal temperature that are expected to have resulted in masculinising of clutches laid approximately 1 month earlier than when the cooling occurred.

These sand temperature data also indicate that the Loggerhead hatchling sex ratio from the natural nesting habitat of the Woongarra Coast beaches should have been strongly female biased during the 2021-2022 breeding season.

Under the elevated rainfall conditions of the 2021-2022 summer, the use of 50% shade cloth cover over the hatcheries and cages 1, 3 and 4 was effective in managing sand temperatures at nest depth necessary for producing hatchlings with an appreciable proportion of both sexes (Figure 9A-F; Table 11). Cage 4 with the additional shade from the adjacent forest should have produced a strong male biased hatchling sex ratio, based on sand temperatures (Figure 9D). Based on sand temperatures, cage 2 should have produced hatchlings with an extremely female biased sex ratio.

Within both sprinkler plots, the sand temperatures at nest depth at each of the artificial rain sites was cooler than those recorded at the respective control sites with no artificial rain, especially within the 2.0 and 4.0 hr artificial rain sites. Based on sand temperatures within the both sprinkler plots, all sites receiving artificial rain (Figure 9G-9L, 9M-9Q) had the potential for producing a male biased sex ratio.

The PTE from all sprinkler sites within both the north and south beach sprinkler plots and the control sites within the north beach sprinkler plot (Table 11) exceeded the predicted Loggerhead pivotal PTE. Therefore, the clutches incubated with artificial rain beach colling during the 2021-2022 breeding season are expected to have produced a male biased hatchling sex ratio.

Table 12 summarises the hatching success of eggs and hatchling emergence success from nests on the Woongarra Coast by beaches, relocation history of the clutches and beach cooling shading and artificial rain exposure.

As a consequence of the atypically elevated rainfall for the summer and sand temperatures at nest depth below 32^{o}C, incubating clutches from all beaches of the Woongarra Coast showed little impact of heat stress: no clutches were recorded with elevated numbers of dead late-stage embryos and only one clutch was recorded with elevated number of dead but unimpeded hatchlings in the neck of an egg chamber.

Overall, there was good Loggerhead hatching success and hatchling emergence success in the natural nesting habitat on all beaches, in the shaded hatcheries and shaded cages and the sprinkler plots (Table 12) except for the negative impacts on incubation success caused by:

- TC *Seth* wavewash into cage 2 and Hatchery 2.
- TC Seth wavewash over the seaward side of the six sampling sites within the southern sprinkler plot.
- delays of many hours after laying that occurred when relocating some of the clutches laid at Nielson Park and Kellys Beach to Archies beach, especially into cage 7.

TC *Seth* and to a lesser extent high spring tides eroded or severely flooded at least 164 Loggerhead, causing the loss of at least 11.9 ± 1.7%% of the seasons Loggerhead egg production. In addition, clutches that were repeatedly washed over by TC *Seth* wave wash during the high tides on each of three successive days had a reduced incubation success (60.3%) and reduced hatchling emergence success (58.8%) (Table 12).

At least 67 (5.2 ± 1.2%) Loggerhead clutches were negatively impacted by root invasion during incubation of the eggs with resulting death of eggs and some entrapment of hatchlings.

It has been previously identified that hatchling emergence success from clutches laid on Mon Repos Beach have been reduced and fluctuate more widely from year to year since the swampland immediately inland of the dunes was drained by the local farming company, with associated lowering of the water table beneath the frontal dune. Decreases in hatchling emergence success occur in hot or low rainfall years. The Loggerhead hatchling emergence success from natural nests laid in the more elevated areas of the frontal dune at Mon Repos in 2021-2022 returned to the high hatchling emergence success (80.6%) that can be expected from a beach that provides a good incubation environment for marine turtle eggs (Figure 17). The low hatchling emergence success that occurred for Mon Repos Beach during the recent four heatwave years (Figure 17) contrasts with the return to good hatchling emergence success during this last summer with the widespread rainfall with resulting moister and cooler sand at nest depth on the frontal dunes. This reinforces the hypothesis that there is a very high probability that reduced hatchling emergence success of Loggerhead turtle eggs laid on Mon Repos beach in dry summers is linked to a lowered water table under the dunes resulting from the draining of the adjacent swampland behind the dunes. Given the continuing probability of increased frequency of heat wave conditions based on BOM modelling of weather data (2022. Figure 6), this issue remains at an elevated level of concern.

3.2. FLATBACK TURTLES, *Natator depressus*

Nine Flatback turtles were recorded ashore for breeding on the Woongarra Coast beaches this summer (Table 2). The small annual Flatback turtle nesting population on the Woongarra Coast continues to fluctuate but remains within the range recorded over the last half century (Figure 18). Eight of these Flatback turtles nested at Mon Repos Beach while the ninth laid eggs on both Kellys and Archies Beaches. The Flatback turtles continued to display reduced nesting success (68%; Table 8B).

One incubating Flatback clutch was dug into during subsequent nesting activities by Loggerhead turtles (Table 10).

Table 13 summarises the reproductive parameters of this small nesting population at the southern extremity of the breeding range for eAust genetic stock of Flatback turtles for the 2021-2022 breeding season. The reproductive parameters recorded for this season continue to fall within the normal range for these parameters for this stock (Limpus, 2007).

Flatback clutches on the Woongarra Coast during the 2021-2022 breeding season had a mean PTE = 58.4 d (Table 13). The spread of PTE values that were mostly exceeding the estimated pivotal PTE for flatback turtles throughout the season (Figure19) indicates that the 2021-2022 Flatback hatchling sex ratio should have been strongly male biased.

The Flatback clutches had an unsatisfactory hatching success (mean = 61.8%) and hatchling emergence success (mean = 59.6%) (Table 12). The causes of the low emergence success of Flatback clutches on the Woongarra Coast warrant further investigation.

3.3. GREEN TURTLES, *Chelonia mydas*

Five Green turtles were recorded nesting on the Woongarra Coast during the 2021-2022 breeding season. Two of the five Green turtles showed low site fidelity by changing nesting beaches during this summer (Table 8C). These Green turtles also displayed poor nesting success (53%; Table 8B). No incubating Green clutches were dug into during subsequent nesting activities by Loggerhead turtles (Table 10)

Table 14 summarises the reproductive parameters of this small nesting population towards the southern extremity of the breeding range for sGBR genetic stock of Green turtles for the 2021-2022 breeding season. The reproductive parameters recorded for this season continue to fall within the normal range for these parameters for this stock.

Based on PTE and sand temperature records for the season, the Green turtle hatchling sex ratio would have been female biased from this minor Green turtle breeding site (Table 11. Figure 8). The Green turtle clutches had high incubation success (mean = 82.7%) and high hatchling emergence success (mean = 83.5%) (Table 12).

4. REFERENCES

Bustard, H. R and Limpus, C. (1969). Observations on the flatback turtle *Chelonia d*epressa Garman. *Herpetologica* **25**, 29-34.

CMS (2014). Single Species Action Plan for the Loggerhead Turtles (*Caretta caretta*) in the South Pacific Ocean. UNEP/CMS?COP11/Doc 23.2.2/Rev 1/Annex 2.

Fitzsimmons, N. N. and Limpus, C. J. (2014). Marine turtle genetic stocks of the Indo-Pacific: identifying boundaries and knowledge gaps. *Indian Ocean Turtle Newsletter* **20**, 2-18.

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

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

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

Limpus, C. J. (2007). A biological review of Australian marine turtles. 5. Flatback turtle *Natator depressus* (Linneaus). (Queensland Environmental Protection Agency: Brisbane.)

Limpus, C. J. (2008). A biological review of Australian Marine turtles. 1. Loggerhead turtle *Caretta caretta* (linnaeus). (Queensland Environmental Protection Agency: Brisbane.)

Limpus C.J., Parmenter, C.J. and Chaloupka, M. (2013). Monitoring of Coastal Sea Turtles: Gap Analysis 1. Loggerheaad turtles, *Caretta caretta*, in the Port Curtis and Port Alma Region. Department of Environment and Heritage Protection Report produced for the Ecosystem Research and Monitoring Program Advisory Panel as part of Gladstone Ports Corporation's Ecosystem Research and Monitoring Program.

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

Limpus, C. J., Reed, P. C. and Miller, J. D. (1985). Temperature dependent sex determination in Queensland sea turtles: intraspecific variation in *Caretta caretta*. In "Biology of Australian Frogs and Reptiles." (Eds. Grigg, G., Shine, R., and Ehmann, H.) Pp. 343-351. (Surrey Beatty and Sons: Sydney).

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

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

Wood, A., Booth, D. T. and Limpus, C. J. (2014). Sun exposure, nest temperature and loggerhead turtle hatchlings: Implications for beach shading management strategies at sea turtle rookeries. *Journal of Experimental Marine Biology and Ecology* **451**, 105-14.

Yntema, C. and Mrosovsky, N. (1980). Sexual differentiation in hatchling loggerheads (*Caretta caretta*) incubated at different controlled temperatures. *Herpetologica* **36**, 33-36.

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

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

FIGURES

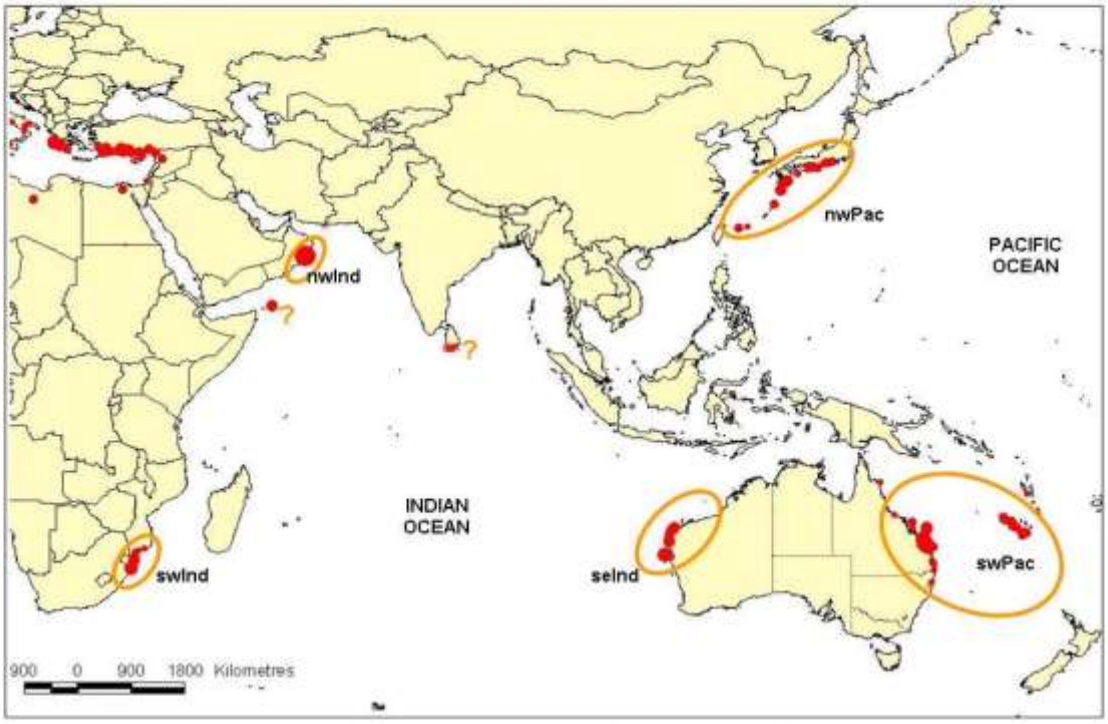


Figure 1: Genetic stocks (management units) of Loggerhead turtles, *Caretta caretta,* within the Pacific and Indian Oceans (FitzSimmons and Limpus, 2014).

Figure 2: Nesting distribution of Loggerhead turtles, *Caretta caretta*, in central-south Queensland with the five principal nesting sites identified with white text (TurtleNet, 8 Oct 2022).

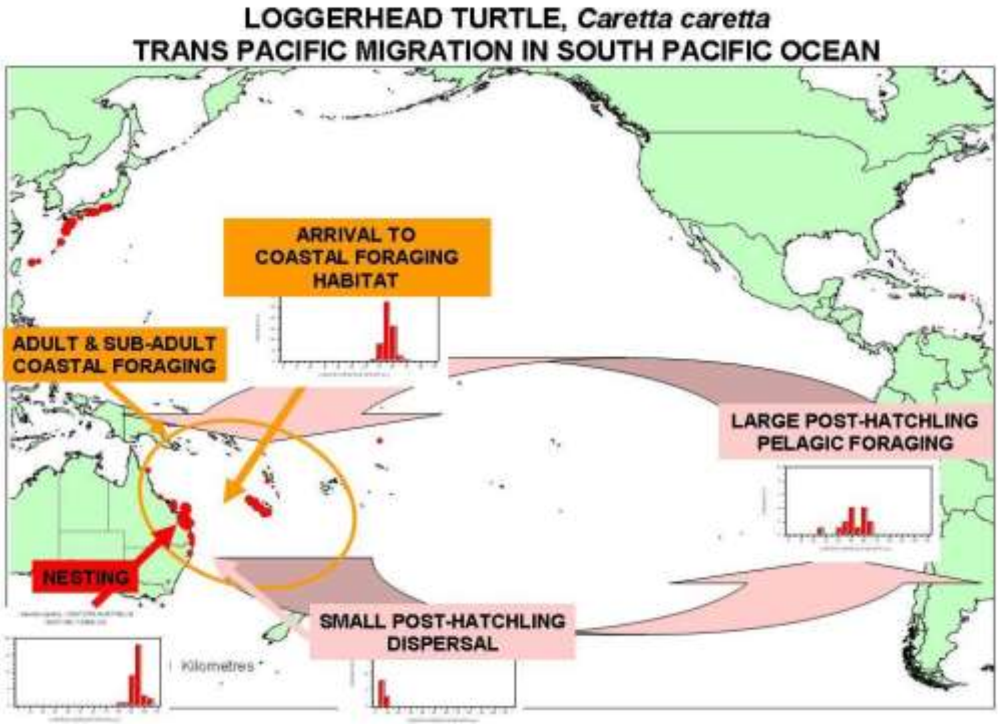


Figure 3: Summary of the life history dispersal of the SW Pacific genetic stock of Loggerhead turtles (CMS, 2014).

Figure 4: Map of the locations of the marine turtle nesting beaches on the Woongarra Coast.

Figure 5A. Hatchery cage (C1), sector 1, dune crest.

Figure 5B. Open hatchery (H1), north Beach, sector 9c.

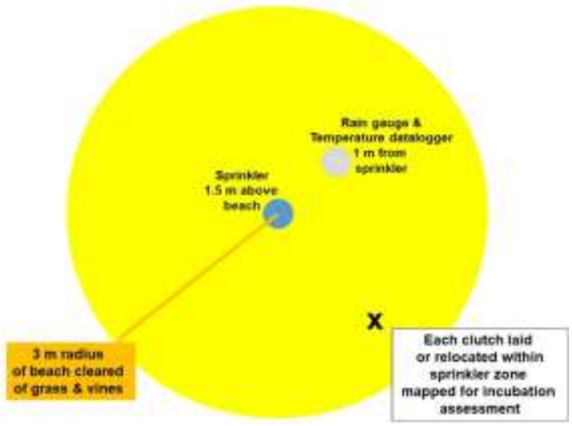


Figure 5C. Schematic design of equipment deployment for each sprinkler in artificial rain experiment.

Figure 5D. Sprinkler array and adjacent rain gauge during artificial rain trials at Mon Repos.

Figure 5: Beach cooling: shaded incubation structures and artificial rain sprinkler plots on Mon Repos Beach.

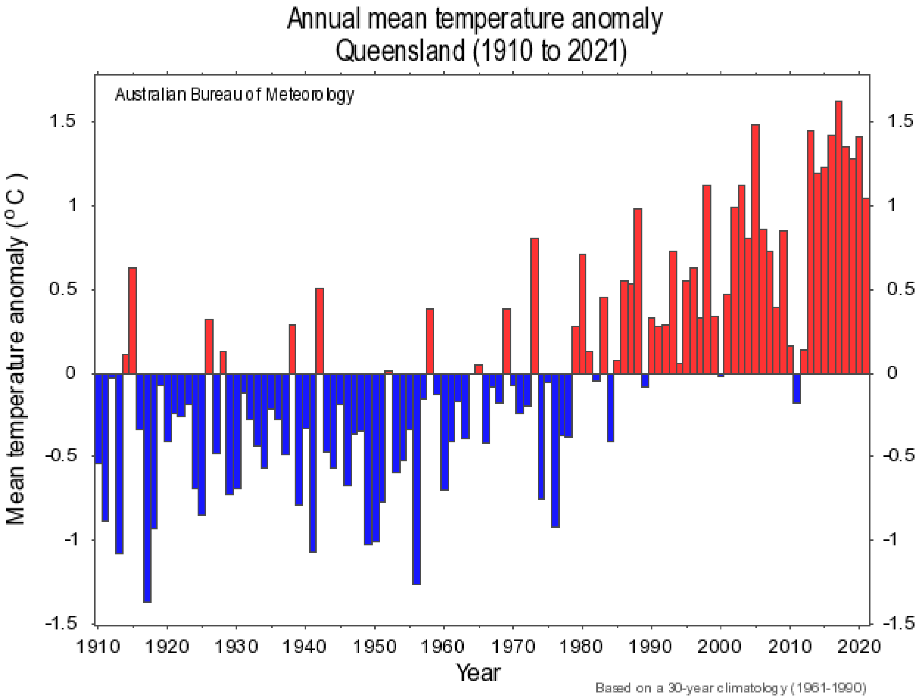


Figure 6A. Australian summer mean temperature anomalies for Queensland derived from the 1981-1990 average temperatures.

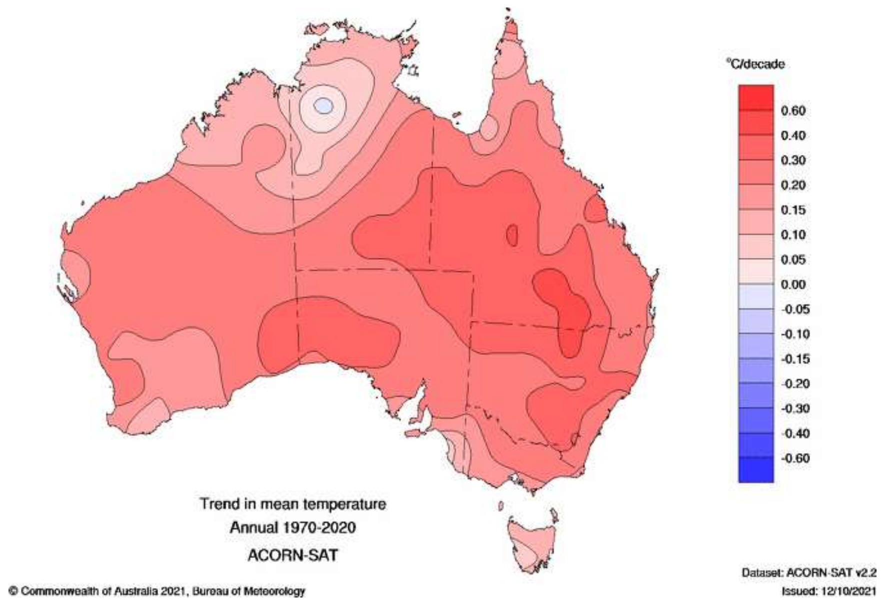


Figure 6B. Decadal trends in annual summer mean air temperatures for Australia derived from 1970-2020 annual temperatures.

Figure 6: Trends in regional climate reported by Australian Bureau of Meteorology, accessed 8 October 2022.

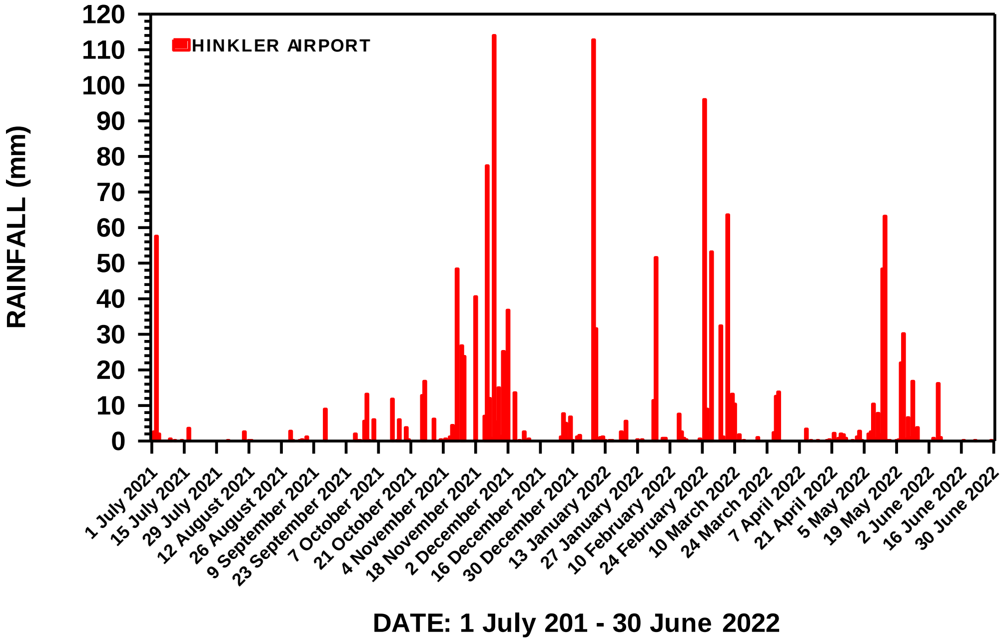
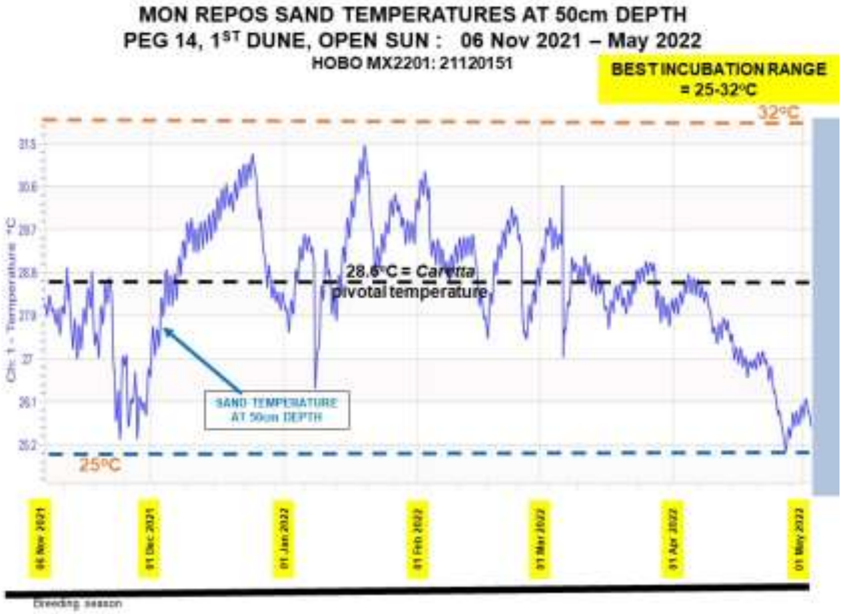
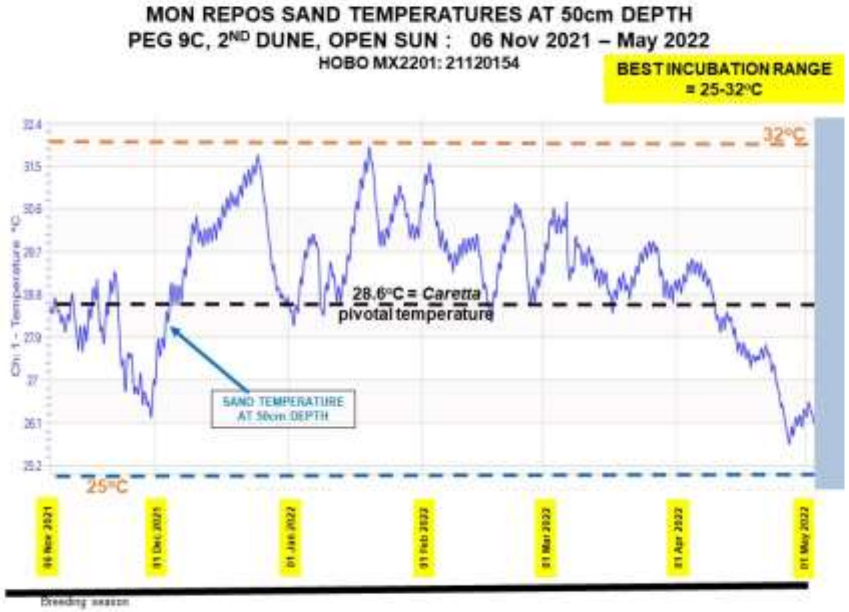


Figure 7: Daily rainfall recorded at Bundaberg Aero (Station 039128) by the Australian Bureau of Meteorology (Australian Bureau of Meteorology sourced 8 October 2022).

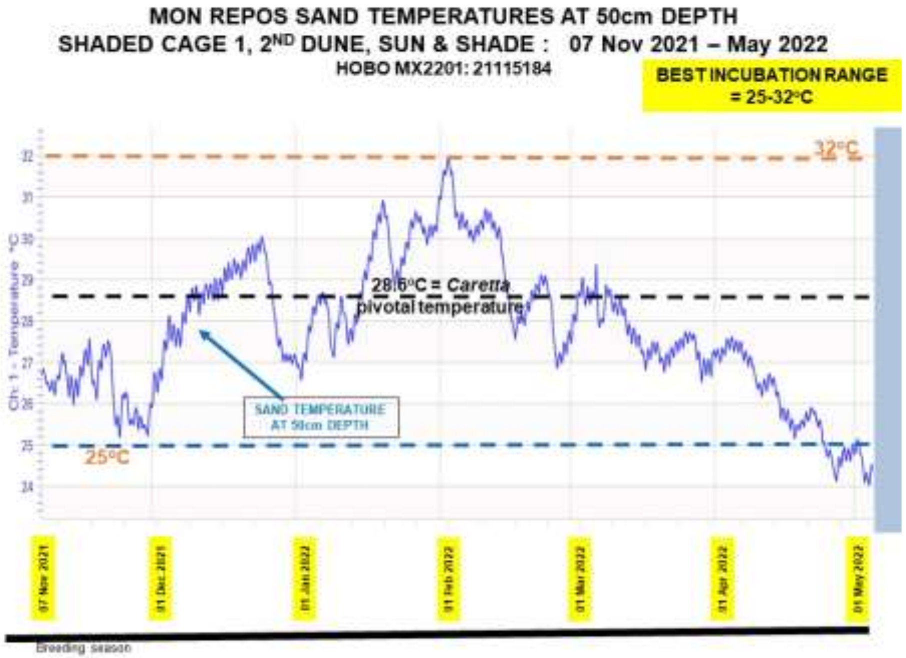


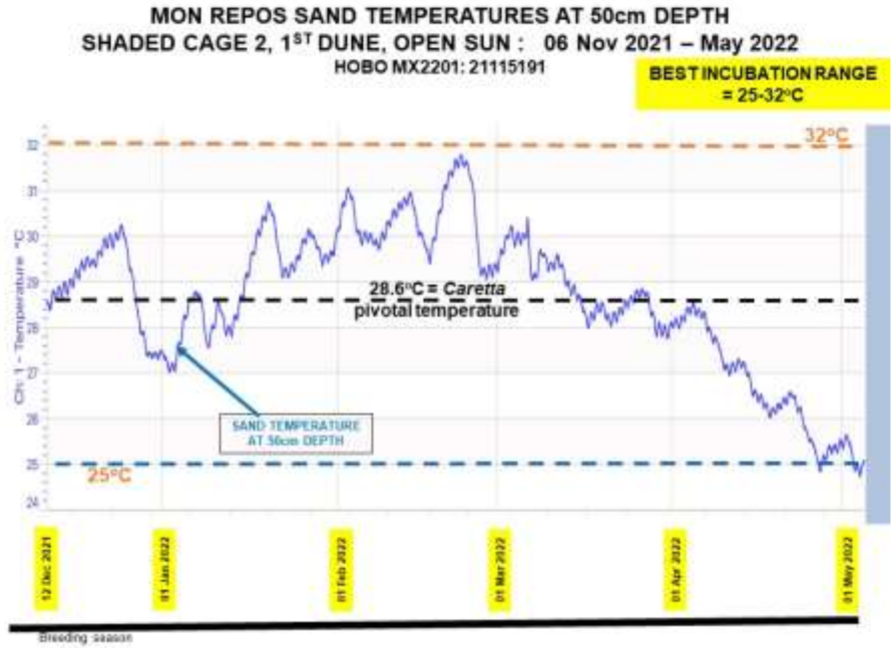


8A. Sector 14 in open sun, receiving forest shade in the late afternoon.

8B. Sector 9C in open sun, receiving forest shade in the late afternoon.

Figure 8: Plot of daily sand temperature data at the two standard recording sites on Mon Repos Beach during the 2021-2022 breeding season.

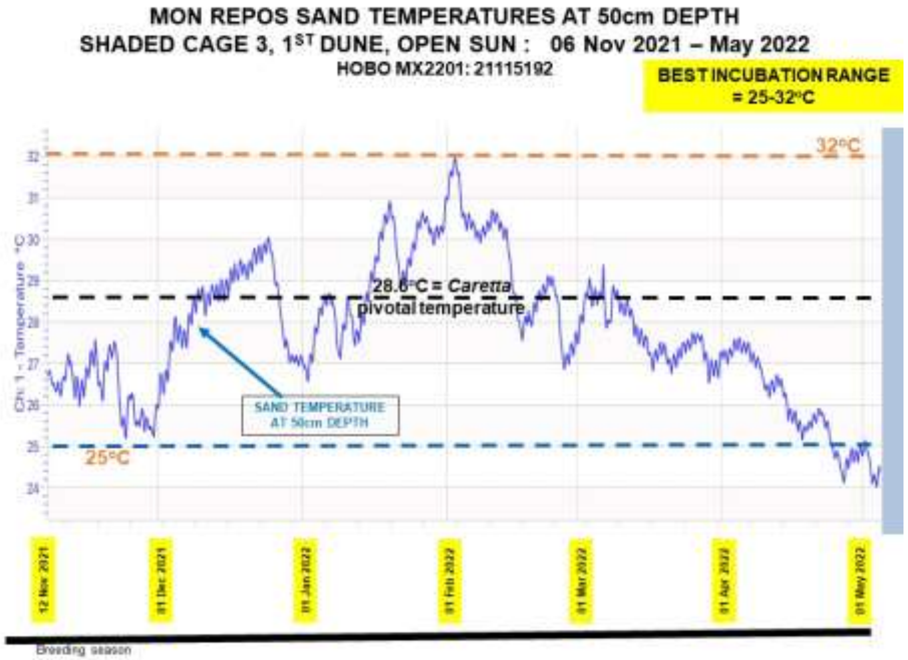




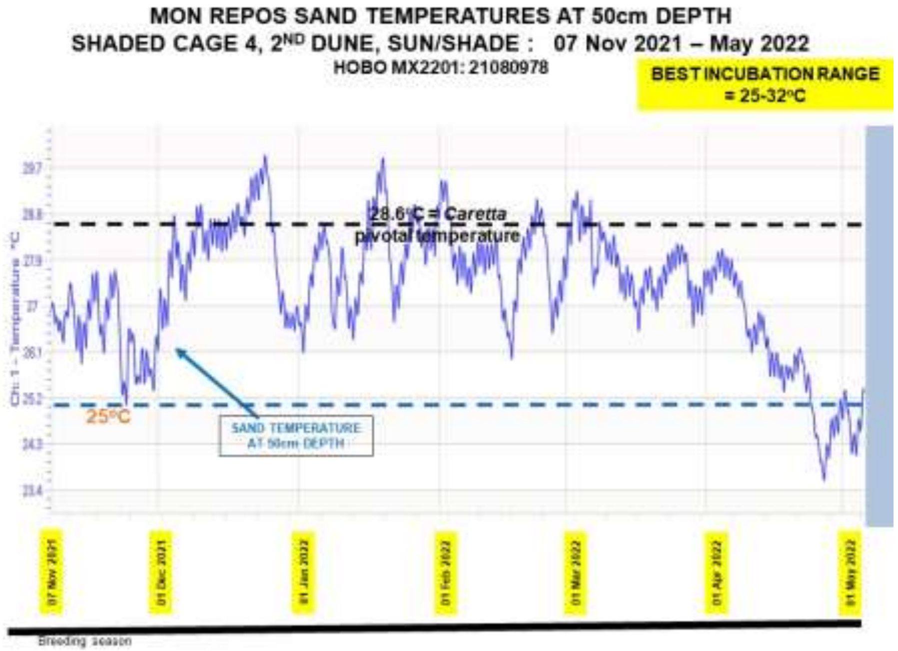
9A. Shaded (50% shade cloth) predator-proof Cage 1, on the 2nd dune, sector 1, Mon Repos Beach (Figure 6A).

9B. Shaded (50% shade cloth) predator-proof Cage 2, on the 1st dune, sector 8, Mon Repos Beach.

Figure 9: Plot of daily sand temperature data within Beach Cooling study areas, Mon Repos Beach, 2021-2022 breeding season.

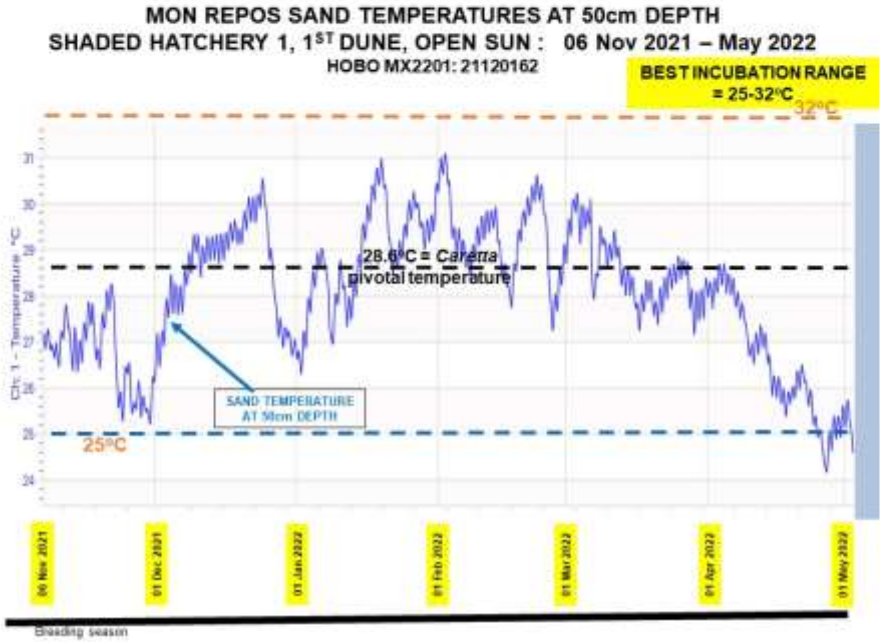


9C. Shaded (50% shade cloth) predator-proof Cage 3, on the 1st dune, sector 10, Mon Repos Beach.

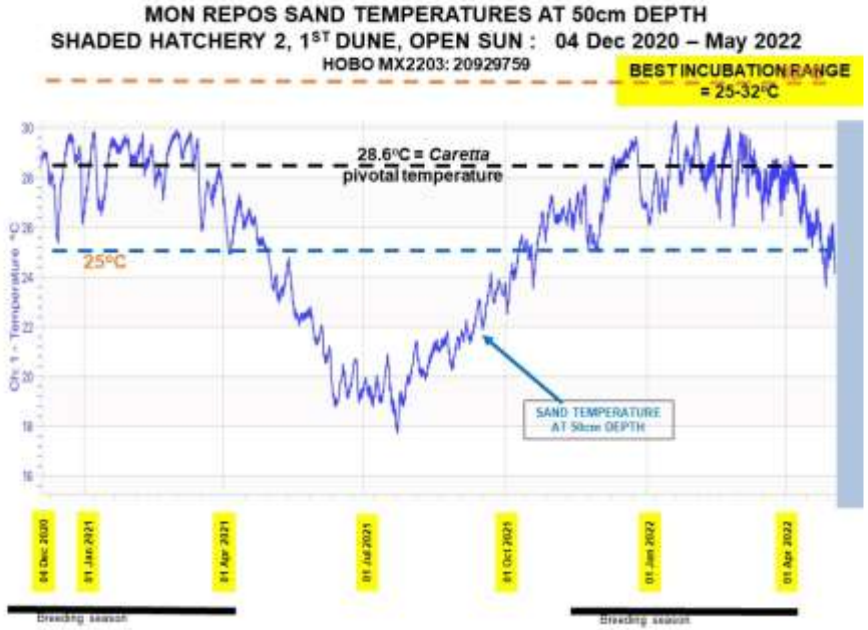


9D. Shaded (50% shade cloth) predator-proof Cage 4, on the 2nd dune, sector 14B, Mon Repos Beach.

Figure 9. Continued.

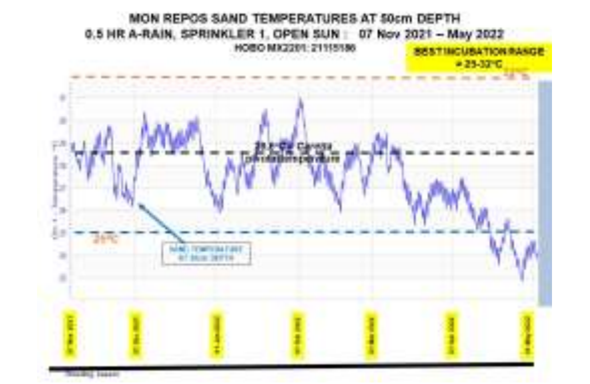


9E. Shaded (50% shade cloth) Hatchery 1, on the 1st dune, sector 9C, Mon Repos Beach (Figure 6B).

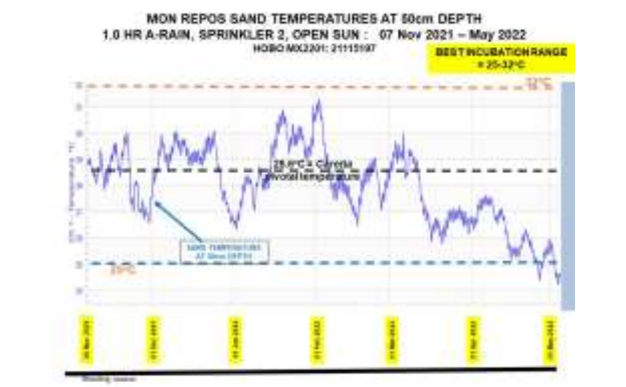


9F. Shaded (50% shade cloth) Hatchery 2, on the 1st dune, sector 13C, Mon Repos Beach. This hatchery has been continuously monitored for two consecutive summers with a HOBO MX2203 temperature data logger.

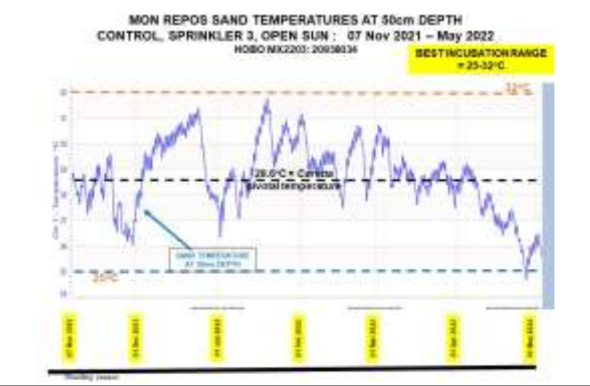
Figure 9. Continued.



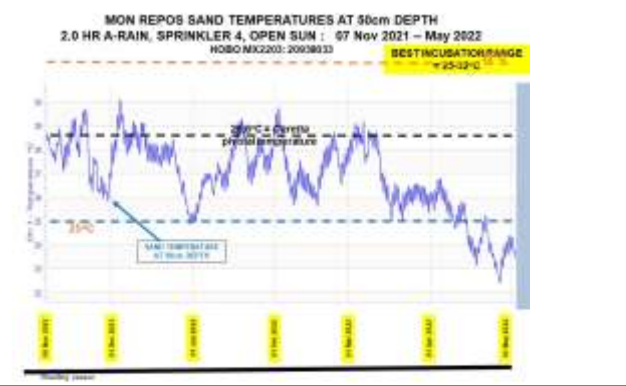
9G. 0.5 hr artificial rain centred at 13:00hr



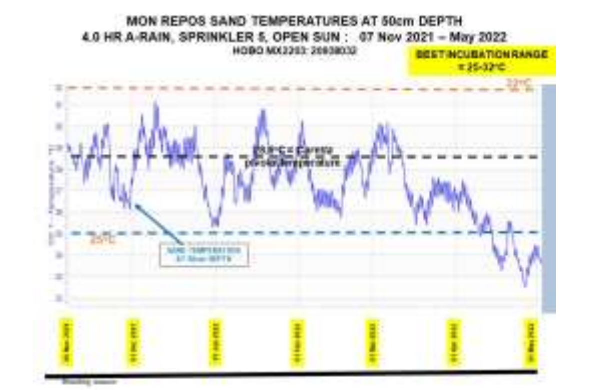
9H. 1.0 hr artificial rain centred at 13:00hr



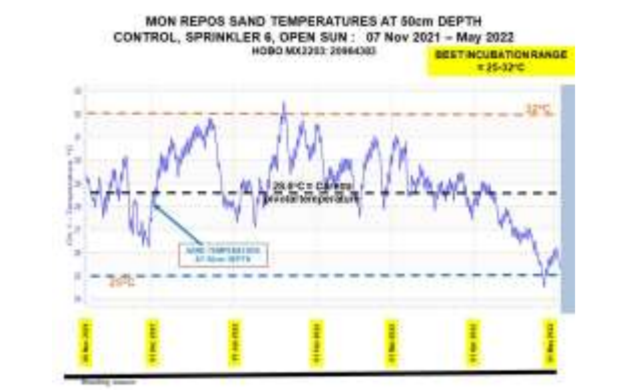
9I. Control, no artificial rain



9J. 2.0 hr artificial rain centred at 13:00hr

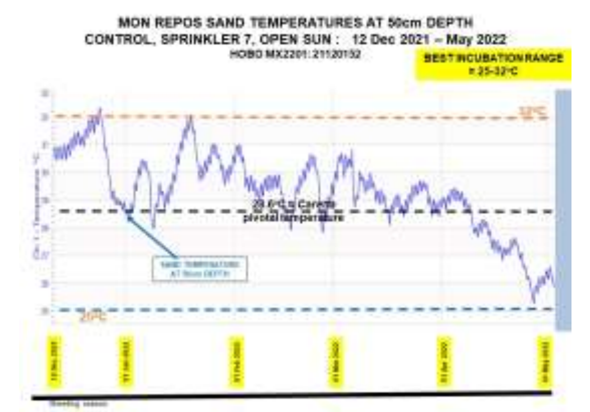


9K. 4.0 hr artificial rain centred at 13:00hr

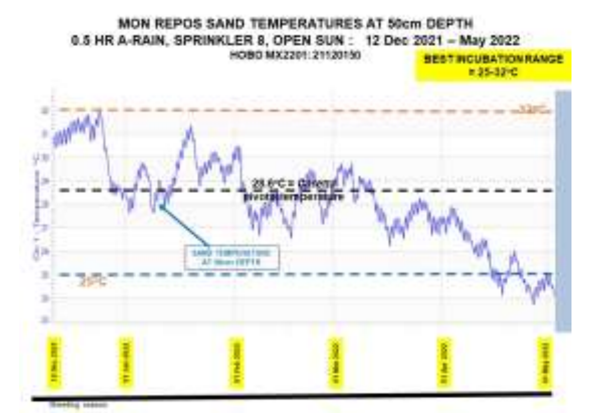


9L. Control, no artificial rain

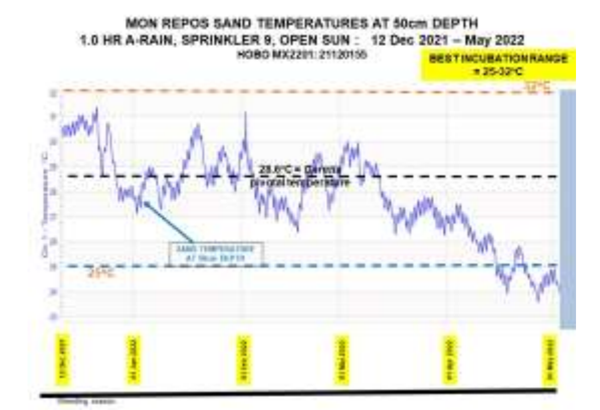
Figure 9. Continued… South Beach sprinkler plots, 1st dune, sector 14A-15, Mon Repos.



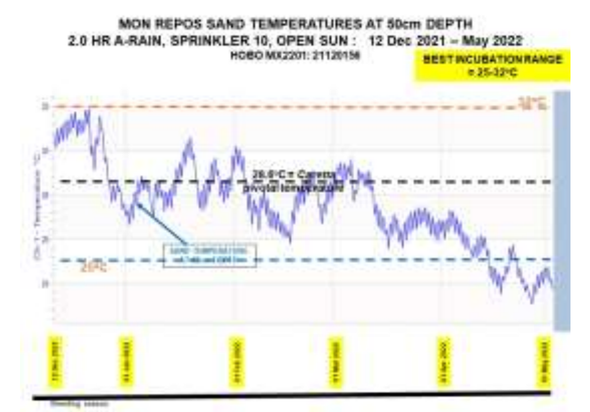
9M. Control, no artificial rain



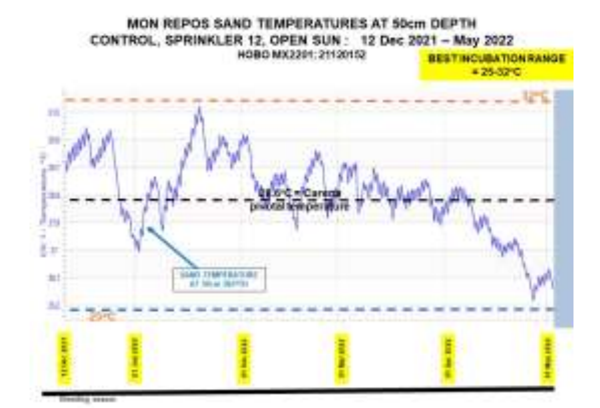
9N. 0.5 hr artificial rain centred at 13:00hr



9O. 1.0 hr artificial rain centred at 13:00hr



9P. 2.0 hr artificial rain centred at 1300:hr



9Q. Control, no artificial rain

Figure 9. Continued… North Beach sprinkler plots, 1st dune, sector 9C-10A, Mon Repos

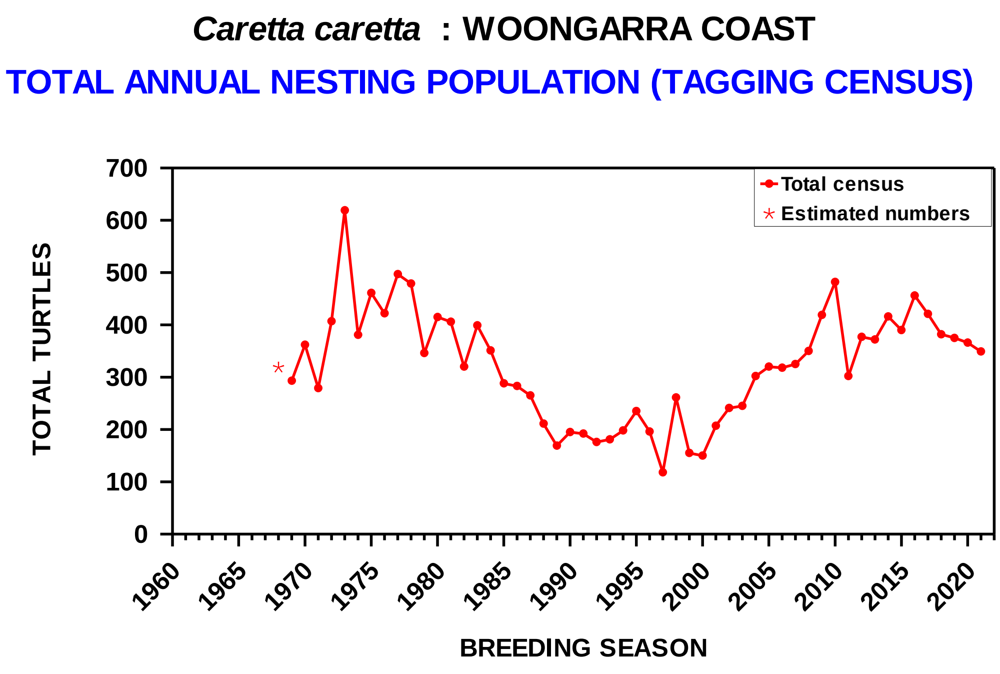


Figure 10: Summary of changing breeding numbers of Loggerhead turtles, *Caretta caretta*, on the Woongarra Coast, 1968 – 2021 breeding seasons.

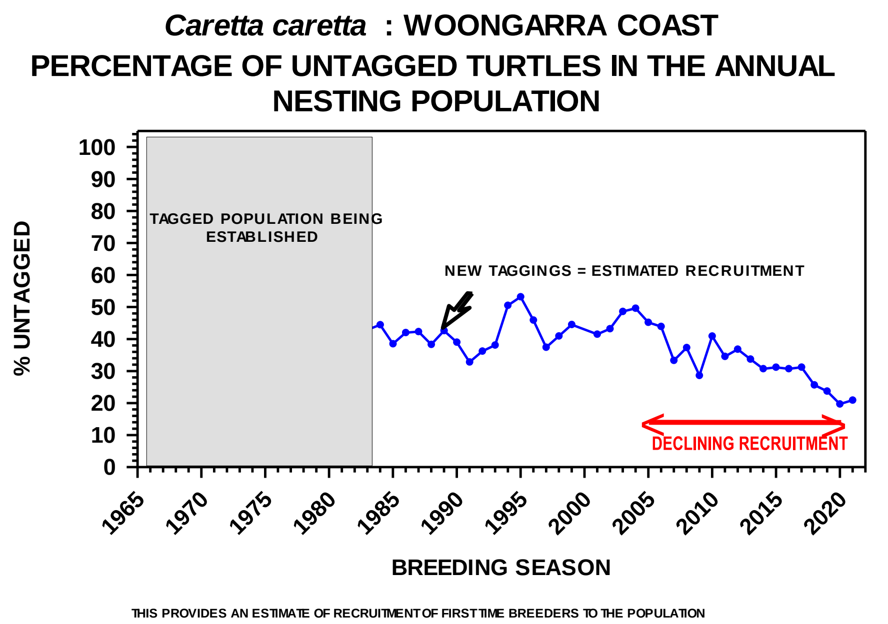
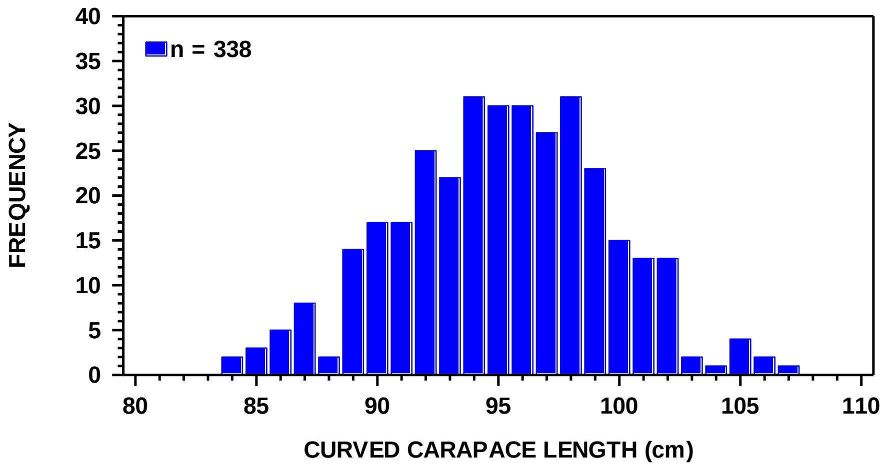
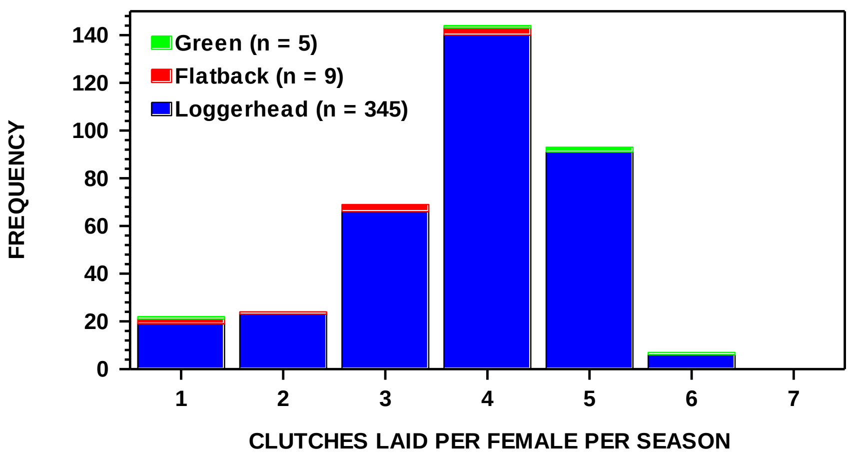


Figure 11: Proportion of first time tagged adult female Loggerhead turtles, *Caretta caretta*, within the annual breeding population on the Woongarra Coast, based on capture-mark-recapture analysis.

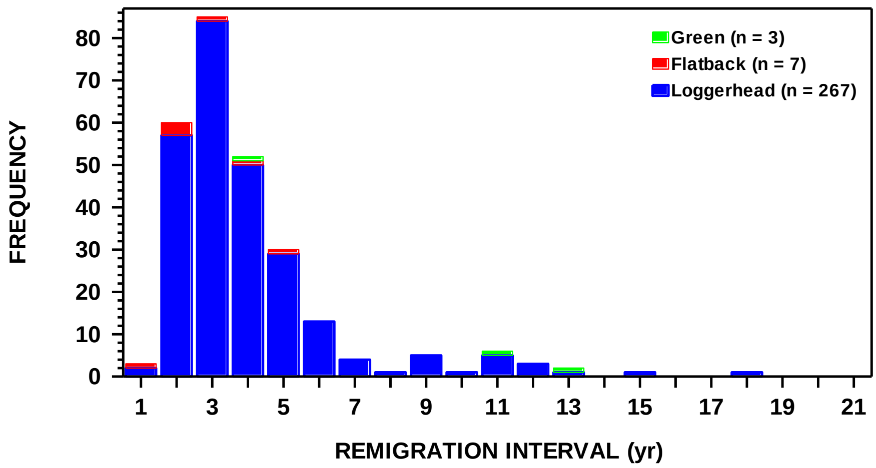


12A. Curved carapace length for the total annual nesting population.



12B. Number of clutches of eggs laid recorded for each female within the breeding season.

Figure 12: Reproductive parameters for marine turtles nesting on the Woongarra Coast, 2021-2022 breeding season.



12C. Remigration interval (years between successive breeding seasons).

Figure 12. Continued…

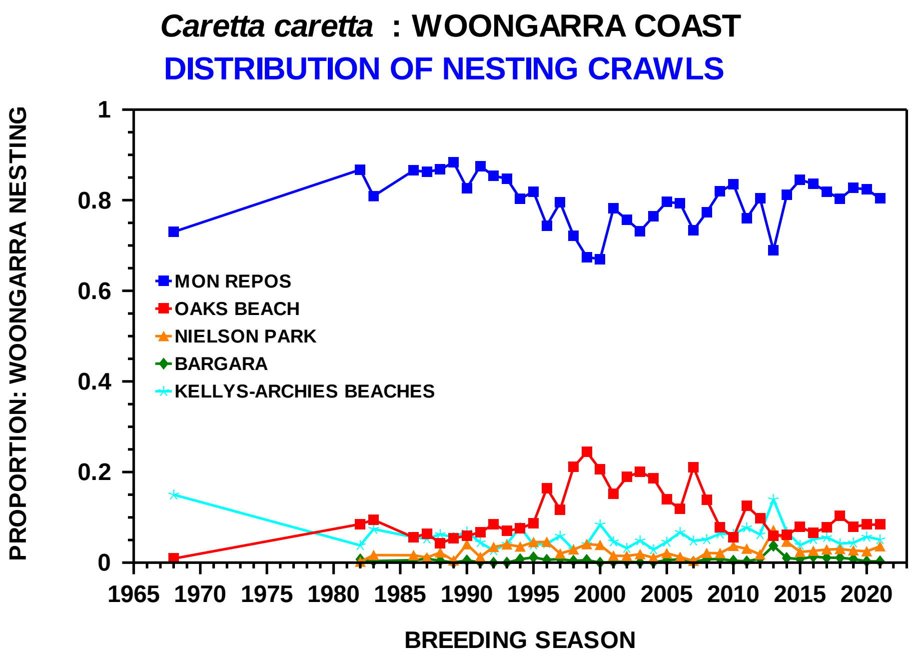
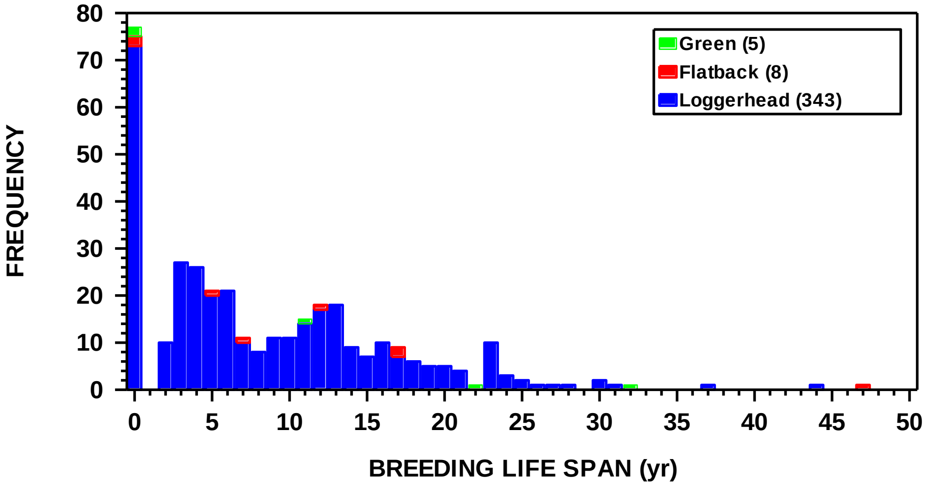
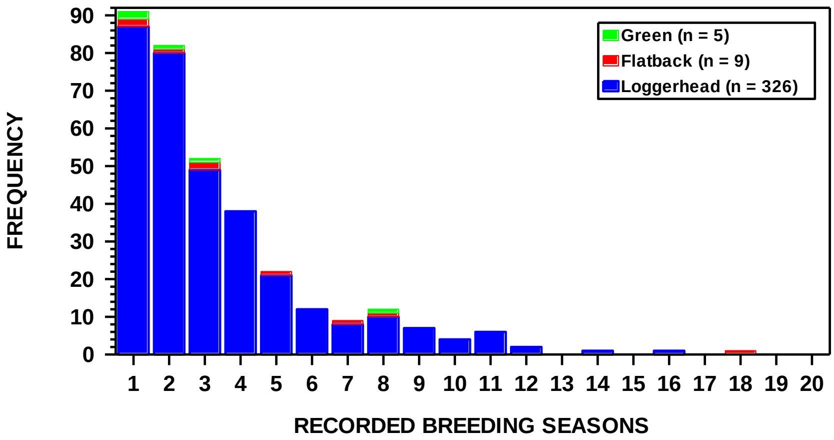


Figure 13: Distribution of Loggerhead turtle, *Caretta caretta*, nesting crawls by principal nesting beaches within the Woongarra Coast, 1968 – 2021 breeding seasons.



14A. Reproductive life span as breeding adults.



14B. Number of breeding seasons per turtle.

Figure 14: Breeding history of Loggerhead turtles, *Caretta caretta*, Flatback turtles, *Natator depressus*, and Green turtles, *Chelonia mydas*, with known commencement of reproductive life that nested on the Woongarra Coast during the 2021-2022 breeding season.

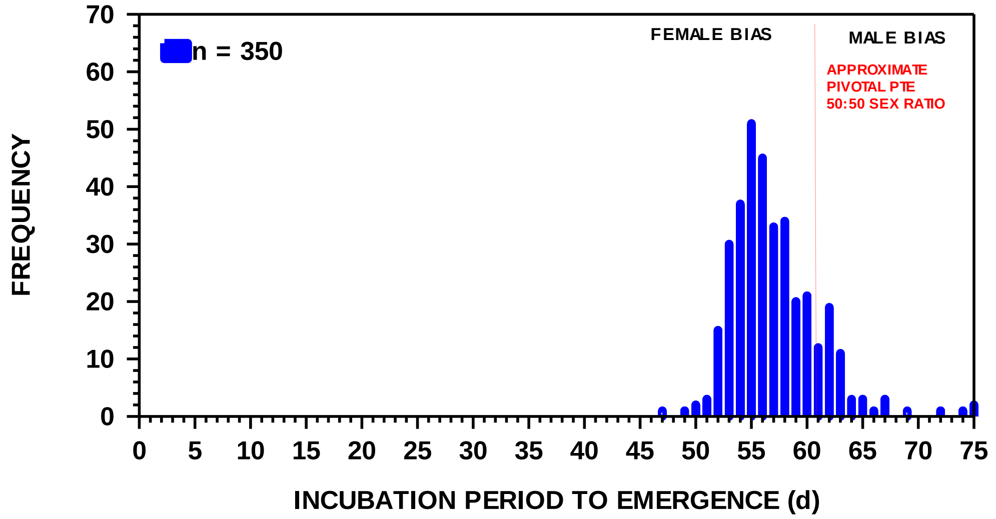
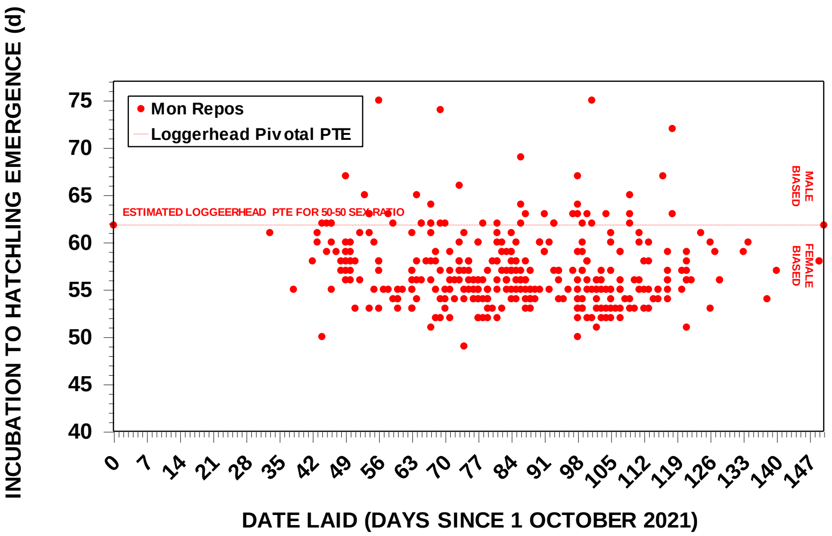
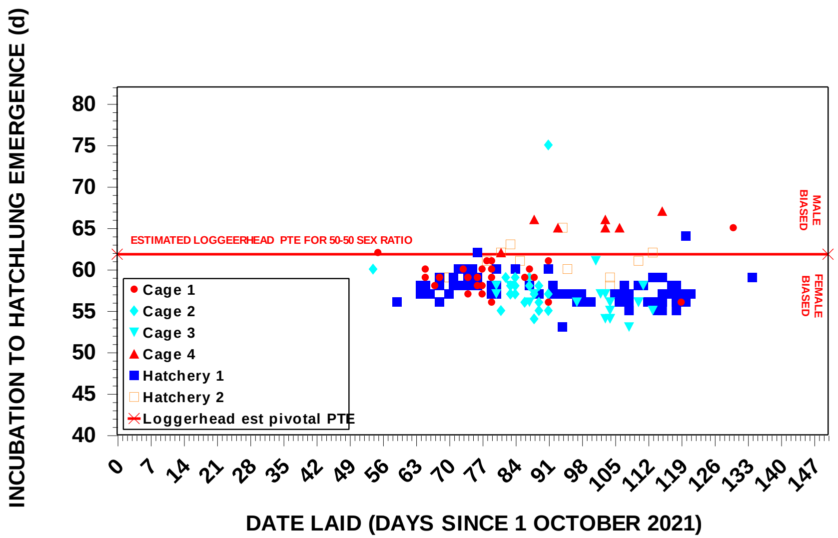


Figure 14: Frequency distribution of incubation period from laying of eggs to hatchlings emerging to the beach surface (PTE) for Loggerhead turtle, *Caretta caretta,* eggs laid on the Woongarra Coast during the 2021-2022 breeding season. The Pivotal Temperature PTE is estimated from Limpus *et al*. (1985).

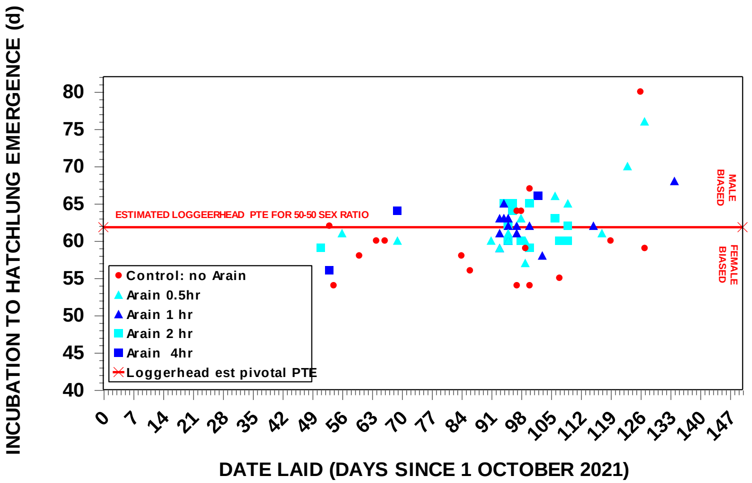




16A. Loggerhead clutches incubated on Mon Repos Beach outside of shaded hatcheries, shaded predator-proof cages and artificial rain sites

16B. Loggerhead clutches incubated on Mon Repos Beach inside shaded hatcheries and shaded predator-proof cages.

Figure 15: Incubation period from laying until hatchlings emerged onto the beach surface for Loggerhead turtle, *Caretta caretta,* clutches laid on all beaches of the Woongarra Coast during 2021-2022 breeding season.



16C. Loggerhead clutches incubated on Mon Repos Beach inside artificial rain experimental plots.

Figure 16. Continued.

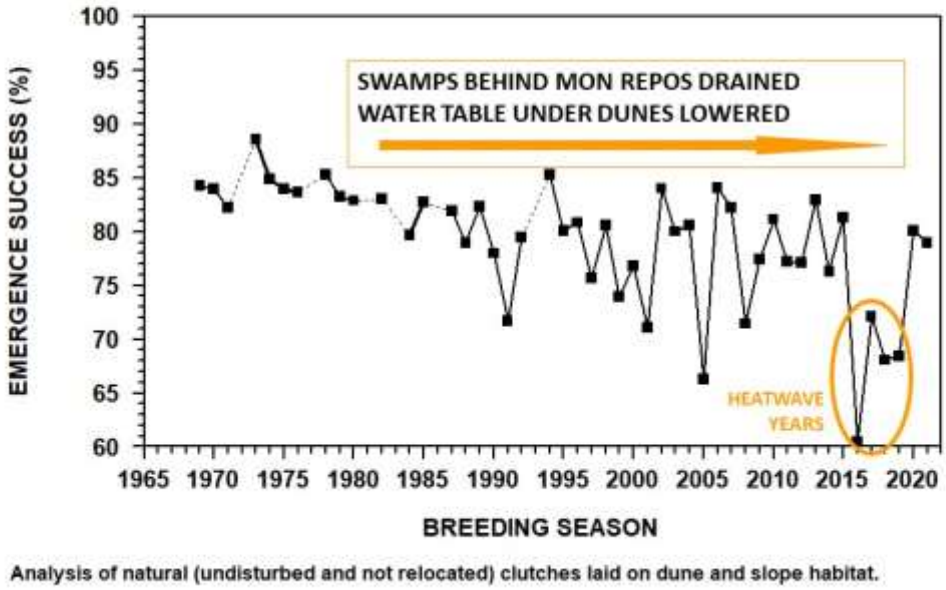


Figure 16: Annual variability of Loggerhead turtle, *Caretta caretta*, hatchling emergence success from naturally incubated clutches laid on the upper slope of the frontal dunes on Mon Repos Beach. Years impacted by lowering of the water table under the dunes resulting from draining of the swamp land immediately inland of the dunes are identified. Data from the recent four heat wave years are circled in orange.

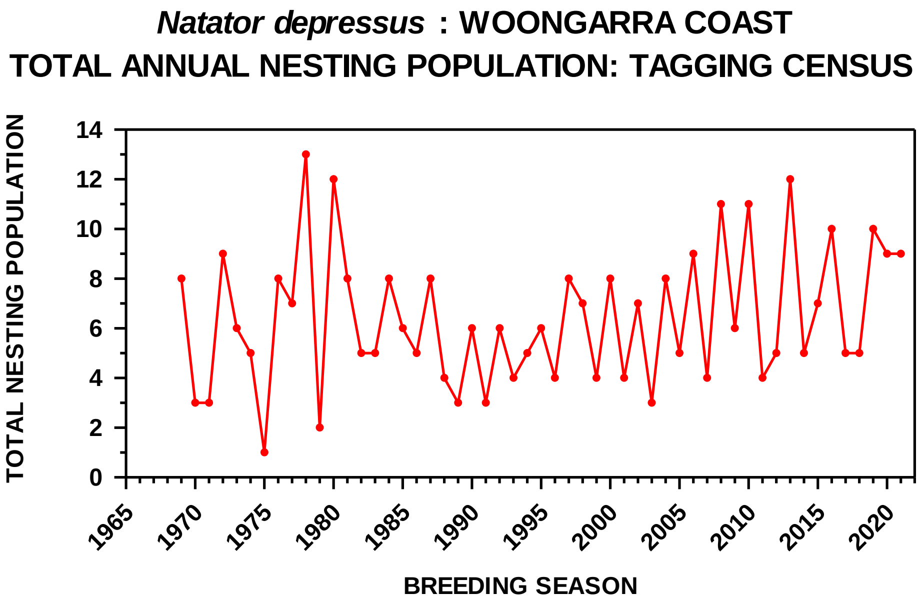


Figure 17: Summary of changing breeding numbers of Flatback turtles, *Natator depressus*, on the Woongarra Coast, 1968-2021.

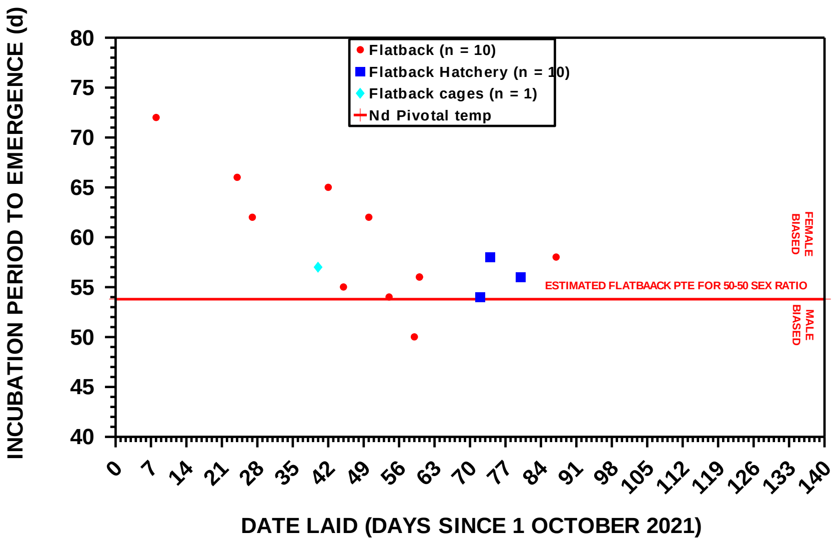


Figure 18: Incubation period from laying until hatchlings emerged onto the beach surface for Flatback turtles, *Natator depressus*, clutches laid on all beaches of the Woongarra Coast during 2021-2022 breeding season.

TABLES

Table 1: Summary of the duration of the 2021-2022 marine turtle nesting and hatchling emergence seasons on the Woongarra Coast

	Caretta caretta **Loggerhead turtle**	***Chelonia mydas*** **Green turtle**	***Natator depressus*** **Flatback turtle**
first nesting crawl	26 October	01 November	09 October
last nesting crawl	07 April	15 February	05 January
first hatchlings	12 January	02 January	20 December
last hatchlings	26 April	10 March	23 February

Table 2: Summary of the breeding history of the three species of marine turtles nesting on the Woongarra Coast, 2021-2022 breeding season.

	Caretta caretta **Loggerhead turtle**	***Chelonia mydas*** **Green turtle**	***Natator depressus*** **Flatback turtle**
1st time tagged turtles (Primary taggings)	73	2	2
Recaptures			
Migration from foraging and 1st time breeding	-	-	-
• Returns from previous season to Woongarra Coast	263	3	7
• Remigrants with lost tags	11	-	-
• Changing nesting colony ○ between seasons	-	-	-
• Changing nesting colony ○ within season	2	-	-
TOTAL	**349**	**5**	**9**

Table 3: Summary of reproductive parameters of Loggerhead turtle, *Caretta caretta,* nesting on the Woongarra Coast, 2021-2022 breeding season, with data pooled across the age classes.

	MEASUREMENT				**Sample size**
	Mean	**SD**	**minimum**	**maximum**	
Curved carapace length (cm)					
1st time tagged	93.8	4.73	84.2	103.5	74
Remigrant turtles	95.9	4.39	85.0	107.2	211
All turtles	95.4	4.45	84.2	107.2	341
Other parameters					
Remigration interval (yr)	3.97	2.34	1	18	266
Eggs & clutches					
Number of clutches laid per season per female	3.8	1.12	1	6	343
Eggs per clutch	121.78	21.93	40	180	574
Mean egg diameter (cm) / clutch	4.03	0.10	3.77	4.22	55 clutches
Mean egg weight (g) / clutch	37.17	2.40	29.68	41.86	56 clutches
Nest depth to top egg	32.1	10.03	4	58	431
Nest depth to bottom	55.9	7.58	38	85	454
Hatchlings					
Mean hatchling length (cm) / clutch	4.29	0.14	3.98	4.59	26 clutches
Mean hatchling weight (g) / clutch	18.84	1.63	14.53	21.5	25 clutches
Incubation period to hatchling emergence (d)	57.29	4.027	47	80	821

Table 4: Curved carapace length by age class of Loggerhead turtle, *Caretta caretta,* nesting on the Woongarra Coast, 2021-2022 breeding season.

Age class Breeding season	CURVED CARAPACE LENGTH (cm)				Sample size
	Mean	SD	minimum	maximum	
1st	94.12	4.514	84.2	103.5	70
2nd	94.90	4.658	85.0	107.2	75
3rd	95.34	4.301	86.2	105.2	44
4th	96.32	3.842	89.2	105.8	37
5th	95.49	4.147	87.6	102.1	19
6th	96.92	4.839	87.0	104.6	11
7th	98.05	1.108	96.5	99.5	8
8th	97.67	4.401	92.1	105.3	10
9th	100.95	2.651	98.3	105.6	6
10th	95.73	4.667	89.1	99.5	4
11th	100.62	2.938	96.5	102.9	6
12th	98.95	3.182	96.7	101.2	2
13th	-				
14th	100.3	-	-	-	1
15th	-				
16TH	99.0	-	-	-	1

Table 5: Number of clutches laid per season by age class of Loggerhead turtle, *Caretta caretta,* nesting on the Woongarra Coast, 2021-2022 breeding season.

Age class Breeding season	CLUTCHES Per SEASON				Sample size
	Mean	SD	minimum	maximum	
1st	3.06	1.288	1	5	72
2nd	4.05	0.908	1	6	76
3rd	3.85	1.135	1	6	46
4th	4.32	0.702	3	6	38
5th	4.20	0.834	3	5	20
6th	4.50	0.674	3	5	12
7th	3.88	0.835	3	5	8
8th	4.10	1.287	2	6	10
9th	4.20	0.837	3	5	5
10th	4.00	0.0	4	4	4
11th	4.17	0.753	3	5	6
12th	4.50	0.753	3	6	2
13th	-				
14th	4.0	-	-	-	1
15th	-				
16TH	4.0	-	-	-	1

Table 6: Number of eggs per clutch by age class of Loggerhead turtle, *Caretta caretta,* nesting on the Woongarra Coast, 2021-2022 breeding season.

Age class Breeding season	EGGS Per CLUTCH				Sample size
	Mean	SD	minimum	maximum	
1st	113.52	21.66	43	167	114
2nd	121.16	20.529	67	172	129
3rd	124.64	23.251	82	180	69
4th	123.44	19.492	83	169	54
5th	120.18	18.896	82	164	40
6th	134.40	21.673	102	177	20
7th	131.67	21.313	106	162	9
8th	127.58	24.121	83	180	19
9th	131.40	19.249	86	159	15
10th	102.43	35.594	66	146	7
11th	138.33	18.042	95	159	12
12th	144.50	10.661	131	154	4
13th	-				
14th	133	-	-	-	1
15th	-				
16th	129.67	0.577	129	130	3

Table 7: Remigration interval by age class of Loggerhead turtle, *Caretta caretta,* nesting on the Woongarra Coast, 2021-2022 breeding season.

Age class Breeding season	REMIGRATION INTERVAL (yr)				Sample size
	Mean	SD	minimum	maximum	
1st	-	-	-	-	-
2nd	5.01	3.006	2	18	77
3rd	3.79	1.817	2	11	47
4th	3.76	2.186	2	12	38
5th	3.65	2.231	2	12	20
6th	2.67	0.888	2	5	12
7th	2.89	0.782	2	4	9
8th	2.70	0.675	2	4	10
9th	2.33	0.817	2	4	6
10th	3.00	1.414	2	5	4
11th	2.33	0.816	2	4	6
12th	2.50	0.707	2	3	2
13th	-				
14th	1	-	-	-	1
15th	-				
16th	2	-	-	-	1

Table 8: Marine turtle nesting on the Woongarra Coast, 2021-2022 breeding season.

8A. Loggerhead turtle, *Caretta caretta*

Beach	NESTING CRAWLS (tracks)				
	Nesting success (%) (± 95% CI)	Laid	did not lay	uncertain nesting success	Total tracks (% by beach ± 95% CI)
Oaks	44.1 ± 7.3%	78	100	1	179 (8.4 ± 1.2%)
Mon Repos	63.2 ± 2.3%	1094	610	10	1714 (80.4 ± 1.7%)
Nielson Park	44 ± 11%	34	42	-	76 (3.6 ± 0.8%)
Bargara	-	1	5	-	6 (0.3 ± 0.2%)
Kellys	57.5 ± 15.3%	123	25	1	49 (2.3 ± 0.6%)
Archies	58.3 ± 12.5%	35	23	2	60 (2.8 ± 0.7%)
Rifle Range	-	1	-	-	1 (0.05%)
Innes Park	40.0 ± 17,5%	12	16	2	30 (1.4 ± 0.5%)
Elliott Heads	-	14	4	-	18 (0.8 ± 0.4%)
TOTAL	60.6 ± 2.1%	**1292**	**825**	**16**	**2133**

8B. Flatback turtle, *Natator depressus*

Beach	NESTING CRAWLS (tracks)				
	Nesting success (%)	Laid	did not lay	uncertain nesting success	Total tracks (% by beach)
Oaks	-	-	-	-	0
Mon Repos	66±16%	23	12	-	35 (92%)
Nielson Park	-	-	-	-	0
Bargara	-	-	-	-	0
Kellys	-	2	-	-	2 (5%)
Archies	-	1	-	-	1 (3%)
Rifle Range	-	-	-	-	0
Innes Park	-				0
Elliott Heads	-				0
TOTAL	**68%**	**26**	**12**	**-**	**38**

8C. Green turtle, ***Chelonia mydas***:

Beach	NESTING CRAWLS (tracks)				
	Nesting success (%)	Laid	did not lay	uncertain nesting success	Total tracks (% by beach)
Oaks	-	1	-	-	1 (2%)
Mon Repos	46%	12	14	-	26 (58%)
Nielson Park	-	-	-	-	0
Bargara	-	-	-	-	0
Kellys	-	3	5	-	8 (18%)
Archies	-	8	2	-	10 (22%)
Rifle Range	-	-	-	-	0
Innes Park	-				0
Elliott Heads	-				0
TOTAL	**53%**	**24**	**21**		**45**

Table 9: Nesting beach fidelity and change of nesting beach by 349 Loggerhead turtles, *Caretta caretta,* and 9 Flatback turtles, *Natator depressus*, and 5 Green turtle, *Chelonia mydas*, identified by tag number when ashore for nesting on the Woongarra Coast, 2021-2022 breeding season.

9A. Number of beaches visited by individual turtles

Number of beaches visited for nesting attempts by each turtle	Loggerhead		Flatback		Green	
	Number of turtles	Proportion of the total Woongarra Coast population (± 95% CI)	Number of turtles	Proportion of the total Woongarra Coast population	Number of turtles	Proportion of the total Woongarra Coast population
1	253	72.5 ± 4.7 %	8	88 ± 20 %	3	60 %
2	78	22.4 ± 4.4 %	1	11 %	2	40 %
3	12	2.9 ± 1.7 %	-	-	-	-
4	3	3.4 ± 1.9 %	-	-	-	-
5	1	0.3 %	-	-	-	-
Total	349		9		5	

9B. Fidelity to individual beaches on the Woongarra Coast.

	Loggerhead			Flatback			Green		
Beach	**Total turtles using this beach at least once**	**Total turtles that only used this beach**	**Fidelity to an individual beach (%)(± 95% CI)**	**Total turtles using this beach at least once**	**Total turtles that only used this beach**	**Fidelity to an individual beach (%)**	**Total turtles using this beach at least once**	**Total turtles that only used this beach**	**Fidelity to an individual beach (%)**
Oaks	29	8	30 %			-	1	1	--
Mon Repos	292	236	88.8 ± 4.5%	8	8	100%	2	2	-
Bargara Beaches	21	5	24 %	1	-	-	2	-	-
Innis Park	3	3	-	-	-	-	-	-	-
Elliott Heads	2	1	-	-	-	-	-	-	-

Table 10: Summary of recorded egg loss during incubation on the Woongarra Coast by beaches during the 2021-2022 breeding season.

Beach	**Predation by canids**	**Erosion of clutches**			**Clutches dug into by nesting turtles**		
	Loggerhead	**Loggerhead**	**Flatback**	**Green**	**Loggerhead**	**Flatback**	**Green**
Oaks Beach							
Mon Repos	1 (fox)	157	**1**	**2**	**24**	**1**	
Nielson Park		1					
Bargara							
Kellys		3					
Archies		2	**1**				
Rifle Range							
Innes Park		1					
Elliott Heads							
Woongarra Coast	**1**	**164**	**2**	**2**	**24**	**1**	**0**

Table 11: Summary of period to emergence (days) from eggs being laid to hatchlings emerging from nests on the Woongarra Coast beaches by species and relocation history of the eggs, 2021-2022 breeding season.

Beach	Subset	Period to Emergence (d)			
		Mean	SD	Range	Sample size
FLATBACK					
Mon Repos	On beach	58.44	5.61	50-72	16
GREEN					
Mon Repos	On beach	59.67	4.93	54-71	18
LOGGERHEAD					
Combined beaches	On beach	57.29	4.027	47-80	821
No beach cooling	**trials**				
Mon Repos	On beach	57.84	3.941	47-80	669
Oaks Beach	On beach	53.10	1.707	48-59	69
Archies Beach	On beach	56.22	2.969	48-64	45
Elliott Heads	Cage 8	61.00	2.06	58-63	9
Beach cooling	**trials**				
	Artificial	**shade**			
Mon Repos	Hatchery 1	57.56	1.65	53-64	87
	Hatchery 2	59.78	2.26	57-65	18
	Cage 1	59.21	1.83	56-65	28
	Cage 2	58.09	4.21	54.75	22
	Cage 3	56.19	1.78	57.61	21
	Cage 4	65.14	1.57	62.67	7
Archies Beach	Cage 7	55.96	3.15	48-64	25
	Artificial	**rain**			
Mon Repos South Beach	S01: 0.5 hr AR	61.38	3.58	56-67	8
	S02: 1hr AR	64.22	5.49	59-76	9
	S04: 2 hr AR	71.33	7.50	67-80	3
	S05: 4 hr AR	64.00	1.41	63-66	4
	S03 & S06 control, zero AR	61.00	7.39	56-72	4
Mon Repos North Beach	S08: 0.5 hr AR	61.07	2.79	57-68	14
	S09: 1 hr AR	61.64	2.40	55-65	22
	S10: 2 hr AR	61.60	2.284	58-65	15
	S07 & S12 control, zero AR	57.12	3.371	52-54	17

Table 12: Summary of hatching success of eggs and hatchling emergence from nests on the Woongarra Coast beaches by species, relocation history of the eggs and exposure to beach cooling trials during the 2021-2022breeding season.

Beach	Subset	Hatching Success (%)				Emergence Success (%)			
		Mean	SD	Range	Sample	Mean	SD	Range	Sample
FLATBACK									
Mon Repos	Combined	61.75	26.38	11.1-98.0	22	59.58	26.54	1.9-96.1	22
GREEN									
Mon Repos	Combined	82.66	24.99	12.5-99.1	21	83.47	20.27	9.6-98.9	21
LOGGERHEAD									
No beach	**cooling trials**								
Mon Repos	Natural nests	81.54	20.32	0.9-100	346	80.63	19.91	1.0-100	346
	Relocated to dune	79.98	20.14	1.27-100	259	77.21	20.18	1.27-100	259
Oaks	Natural nests	92.02	9.42	75.9-100	5	88.21	11.34	69.0-99.0	5
	Relocated to dune	79.98	15.19	29.1-100	61	75.51	15.60	28.2-97.1	61
Archies	Natural nests	84.85	18.30	40.4-99.1	18	83.64	9.11	37.1-99.1	18
	Relocated to dune +Delayed relocation	70.13	23.21	34.2-88.4	6	67.00	22.91	31.6-88.4	6
Elliott Heads	Cage 8	87.33	7.75	71.5-97.5	9	86.91	7.80	73.5-97.5	9
TC Seth	**Recorded**	**impact**							
Mon Repos	Wave washed nests	60.25	27.54	12.3-93.6	25	58.75	28.12	12.3-93.6	25
	Eroded but rescued & relocated eggs	54.32	29.35	0.7-99.1	54	53.61	28.37	0.8-97.9	53

Table 12. Continued

Beach	Subset	Hatching Success (%)				Emergence Success (%)			
		Mean	SD	Range	Sample	Mean	SD	Range	Sample
Beach	**cooling trials**								
	Artificial shade								
Mon Repos	Hatchery 1	79.16	20.65	2.0-100	96	75.62	23.01	2.0-100	96
	Hatchery 2 +TC *Seth* wavewash	76.93	23.77	9.9-100.0	25	75.83	23.43	9.9-100	25
	Cage 1	84.13	14.25	39.4-97.8	29	81.88	14.22	38.0-96.2	29
	Cage 2 +TC *Seth* wavewash	75.97	19.60	25.5-96.9	30	73.24	18.64	24.8-95.3	30
	Cage 3	81.05	17.86	33.3-97.7	30	77.56	18.63	33.3-96.5	30
	Cage 4	76.91	31.38	1.3-97.7	8	76.24	31.13	1.2-97.7	8
Archies Bch	Cage 7 +Delayed relocation	75.35	18.67	14.2-96.5	30	71.74	18.85	12.8-94.4	30

Table 12 continued

Beach	Subset	Hatching Success (%)				Emergence Success (%)			
		Mean	SD	Range	Sample	Mean	SD	Range	Sample
Beach	**cooling trials**								
	Sprinkler plots								
Mon Repos	S1: 0.5 hr AR	78.39	15.75	53.2-93.4	10	77.02	15.32	50.7-95.3	10
South beach	S2: 1 hr AR	78.80	19.72	22.8-95.0	11	75.70	20.83	22.8-95.0	11
	S4: 2 hr AR	77.07	21.80	33.9-97.1	7	76.36	22.00	33.9-97.1	7
(AR = artificial rain) TC *Seth* wavewash	S5: 4 hr AR	64.24	20.38	28.6-91.9	8	63.14	20.65	27.7-94.9	8
	S3 & S6: controls Zero AR	70.67	25.36	34.9-93.2	5	69.57	25.68	33.7-95.2	5
Mon Repos	S8: 0.5 hr AR	83.50	11.33	57.0-96.7	18	79.77	13.46	52.6-96.7	18
North beach	S9: 1 hr AR	81.6	20.81	2.4-97.6	29	79.94	20.96	2.4-97.0	29
(AR = artificial rain)	S10: 2 hr AR	79.06	15.61	44.9-97.3	17	75.37	15.10	44.9-97.1	17
	S11: 4 hr AR	Cancelled	trial						
	S7 & S12: controls Zero AR	84.31	18.35	10.9-98.4	24	82.19	18.03	10.9-98.4	24

Table 13: Summary of reproductive parameters of Flatback turtle, *Natator depressus,* nesting on the Woongarra Coast, 2021-2022 breeding season, with data pooled across the age classes.

	MEASUREMENT				Sample size
	Mean	SD	Minimum	Maximum	
Curved carapace length (cm)					
All turtles	93.8	3.41	89.5	97.6	8
Remigration interval (yr)	2.71	1.38	1	5	7
Eggs & clutches					
Number of clutches laid per season per female	2.78	1.20	1	4	9
Number of eggs per clutch	57.9	8.34	40	73	20
Mean egg diameter (cm) / clutch	5.13	0.09	5.00	5.28	13 clutches
Mean egg weight (g) / clutch	75.21	3.44	69.71	81.00	13 clutches
Nest depth to top egg	30.8	6.73	16	42	16
Nest depth to bottom	51.75	5.37	40.5	60	17
Hatchlings					
Mean hatchling length (cm) / clutch	6.03	0.16	5.77	6.37	15 clutches
Mean hatchling weight (g) / clutch	40.58	2.62	35.83	45.08	15 clutches
Incubation period to hatchling emergence (d)	58.44	5.61	50	72	16

Table 14: Summary of reproductive parameters of Green turtle, *Chelonia mydas,* nesting on the Woongarra Coast, 2021-2022 breeding season, with data pooled across the age classes.

	MEASUREMENT				Sample size
	Mean	**SD**	**minimum**	**maximum**	
Curved carapace length (cm)					
All turtles	104.8	6.04	98.0	110.4	5
Remigration interval (yr)	9.3	4.73	4	13	3
Eggs & clutches					
Number of clutches laid per season per female	4.2	1.92	1	6	5
Number of eggs per clutch	105.3	21.66	70	144	18
Mean egg diameter (cm) / clutch	4.34	0.11	4.21	4.50	12 clutches
Mean egg weight (g) / clutch	45.13	3.56	39.26	50.57	12 clutches
Nest depth to top egg	40.1	12.59	13	57	16
Nest depth to bottom	62.8	10.51	48	76	14
Hatchlings					
Mean hatchling length (cm) / clutch	4.83	0.12	4.66	4.99	11 clutches
Mean hatchling weight (g) / clutch	22.59	0.92	20.99	24.00	11 clutches
Incubation period to hatchling emergence (d)	59.67	4.93	47	71	18