Gnaraloo Turtle Conservation Program

Gnaraloo Bay Rookery
Gnaraloo Cape Farquhar Rookery

Report 2008 - 2018

www.gnaraloo.org

Gnaraloo Wilderness Foundation & Gnaraloo Turtle Conservation Program

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1 EXECUTIVE SUMMARY

The Gnaraloo Turtle Conservation Program (**GTCP**) is a scientific research and public outreach program aimed at identifying, monitoring and protecting sea turtle rookeries located along a 65 km stretch of beach at the southern end of the Ningaloo Reef at Gnaraloo, Western Australia (**WA**; **Appendix A1**). The sea turtle nesting habitat at Gnaraloo Bay, including a 20 km radius internesting habitat buffer, was identified as a habitat which is critical to the survival of loggerhead turtles of the southeast Indian Ocean regional management unit (**RMU**; Recovery Plan for Marine Turtles in Australia, 2017 – 2027). Since 2008, the GTCP has conducted daily beach track surveys, along with a variety of complementary research and monitoring activities (e.g. Night Surveys, flipper tagging, satellite tagging, Nest excavations), in the Gnaraloo Bay Rookery (**GBR**) between 1 November and 28 February. Additional beach track surveys commenced in season 2011/12 in the Gnaraloo Cape Farquhar Rookery (**GCFR**), which is located approximately 22 km north of the Gnaraloo Homestead and unreported prior to 2011. The primary species nesting in both the GBR and GCFR Survey Areas is the endangered loggerhead turtle (*Caretta caretta*), with green turtles (*Chelonia mydas*) nesting infrequently (**Figure 2**). Hawksbill turtles (*Eretmochelys imbricata*) have been observed foraging in the waters off the Survey Areas, but no evidence of their nesting has been confirmed. In this document, we report on the activities of the GTCP during the sea turtle nesting season 2017/18 and summarise findings of the 10-year monitoring program.

Current indications are that the valuable turtle and feral animal Monitoring, Evaluation, Reporting and Improving (**MERI**) research work at Gnaraloo by the GTCP, in the form undertaken during 2008/09 – 2017/18 with full season nesting surveys from November to February, will end on 30 June 2018. There is because, at the time of this report, there is no funding from private or public sources (including from the Gnaraloo Station Trust or co-investment grants from Government) for continuation of this work. Some of the implications of the GTCP ending on 30 June 2018 in its current format (i.e. daily surveys during consecutive annual full nesting periods for 10 years) are that the 30-year consecutive baseline data set of nesting by loggerhead sea turtles in the GBR Survey Area will be broken and lost. The GTCP research field teams will also no longer be present to notice and rescue stranded female sea turtles in real time during the nesting period nor to monitor and record the impact of feral animals on turtle Nests, including the possible return of European red foxes (*Vulpes vulpes*) in future. The level of Predation of turtle Nests by foxes may return to the high levels reported for the GBR Survey Area prior to 2008/09, but will go unnoticed as the research undertaken to date by the GTCP will no longer be conducted in the GBR Survey Area. We will all be the poorer for this.

Given the important findings by the private sector driven scientific sea turtle survey program at Gnaraloo over the past decade, there is a high likelihood that there are other important turtle nesting hotspots on beaches of the southern Ningaloo Coast from Quobba Station to Coral Bay. To the authors' knowledge, these beaches along the southern Ningaloo Coast have never been systematically surveyed via scientific on-ground long-term surveys. As such, potential unknown critical sea turtle nesting habitat on beaches of the southern Ningaloo Coast are not currently specifically protected from potential threats, such as driving on beaches, camping activities and/or inappropriate future coastal development.

As a reading aid for the report, capitalised words are defined in the Glossary.

Gnaraloo Bay Rookery – Day Surveys

GBR Day Surveys were conducted during 1 November 2017 – 28 February 2018 with no missed days. A total of 516 Nesting Activities were recorded, including 284 Nests, all laid by loggerhead turtles. The first Nest was laid on 10 November 2017 and the last Nest was laid on 21 February 2018. The temporal distribution of Nesting Activities throughout the season was similar to previous seasons, showing an increase in Nesting Activities and Nests between mid-December and late January. However, in previous seasons, the GBR Survey Area received an average of 69 Nesting Activities and 38 Nests per week between 13 December and 23 January, while during season 2017/18, only 53 Nesting Activities and 30 Nests per week were recorded for the same period. As in previous seasons, GBR Sub-section BP8 – BP9 recorded the majority of Nesting Activities (70.7 %), followed by Sub-sections GBN – BP7 (21.5 %) and BP7 – BP8 (7.8 %).

In total, season 2017/18 recorded the second lowest number of total Nesting Activities (the lowest season being 2015/16) and lowest number of Nests since monitoring began in 2008 (**Table 1, Figure 1**). No evidence of green turtle nesting was observed, but there was a single green turtle U-Track. The seasonal numbers of Nesting Activities in the GBR Survey Area from 1 November – 28 February show a decreasing trend since 2009/10[1], while the total number of Nests per season do not show a clear trend since 2008/09. Nesting success (i.e. the proportion of emergences resulting in a Nest) in the GBR is generally relatively low and has been variable since 2008/09, depending on how favourable local beach conditions are. Nesting Activities in season 2017/18 were less likely to occur during high spring tides associated with a full moon, likely because they often created powerful shore-break and high escarpments on the beach. It is important to keep in mind that 10 years are a relatively short time in terms of loggerhead turtle life cycles, and inferences on nesting abundance trends and population dynamics should be made with caution. However, due to the likely long-standing impact of fox Predation on turtle Nests in the GBR prior to the initiation of the Gnaraloo Feral Animal Control Program (**GFACP**)

[1] Nesting Activity total for 2008/09 excluded because the dates and locations of unsuccessful activities were not recorded during this season.

in 2008, a general decline in Nest numbers or a stabilisation at low levels may have to be expected for another two decades.

Coarse analysis of sea surface temperatures (**SST**) in the eastern Indian Ocean reveals a potential inverse correlation with Nest numbers in the GBR Survey Area. Warmer SST associated with Indian Ocean Dipole (**IOD**) events might have negatively impacted the number of females getting ready to breed at Gnaraloo in season 2017/18. Comparing the 10-year trend in nesting numbers in the GBR Survey Area supports this hypothesis, as it could explain the trend for 80 % of the data (**Chapter 5**). More detailed analyses with larger data sets are necessary to get a better understanding of SST in foraging habitats and associated nesting abundance on nesting beaches. Further research is particularly warranted in light of potential consequences which an increase in SST, due to climate change, might have on sea turtle nesting.

Based on the number of Nests laid in the GBR during each season, it is estimated that between 60 and 120 female loggerhead turtles nest in the GBR during any nesting season. As remigration intervals for these females are currently not known and likely highly variable, estimates for the total population of nesting turtles in the GBR range from 200 – 450.

Gnaraloo Bay Rookery – Night Surveys

Night Surveys were conducted in the GBR Survey Area during 16 November – 21 December 2017. The primary goal of Night Surveys was to verify track interpretations made during Day Surveys in terms of Species Identification (**SI**) and Nesting Activity Determination (**NAD**), as well as to estimate a Nest detection bias (i.e. the likelihood of correctly identifying Nests during Day Surveys). For the first time this season, all turtles encountered during Night Surveys were also fitted with titanium flipper tags.

Day Survey track monitoring had an accuracy of 100.0 % for SI (consistent with previous years, which have all been > 95 %), and 75.4 % for NAD. While this was below the desired 80.0 % accuracy level for NAD, it was not necessarily indicative of the quality of work of this year’s field research team, as newly implemented procedures such as flipper tagging and clutch counts made it increasingly difficult to leave turtle activities unblemished for identification the following day during Day Survey. Nest detection bias was -10.5 %, indicating that there was a negative systematic bias in terms of Nest identification, resulting in an overall tendency to underestimate Nest abundance). Nest detection bias during 2010/11 – 2017/18 averaged -10.7 %, but also decreased during that period, suggesting an overall tendency to underestimate Nest abundance, but improvement in Nest detection at the program level over time. Thus, Nest totals given in **Table 1** are likely conservative. These results highlight the importance of implementing Night Survey verification in nesting beach programs where track surveys provide indices of Nest abundance.

Gnaraloo Bay Rookery – Flipper tagging

Flipper tagging allows identifying and tracking of individual turtles over time and was a successful and valuable addition to the GTCP this season, which revealed interesting information about the size and internesting intervals of the females nesting in the GBR. 52 loggerhead turtles were flipper tagged during season 2017/18 with a mean CCL of 93.1 cm, ranging from 82.6 to 102.5 cm. During the Night Survey period, 11 turtles were observed laying more than one Nest, with an average internesting interval of 16.1 days. As long-term flipper tagging can reveal information about population dynamics, remigration intervals and recruitment rates, it is essential to continue this work for many more consecutive years.

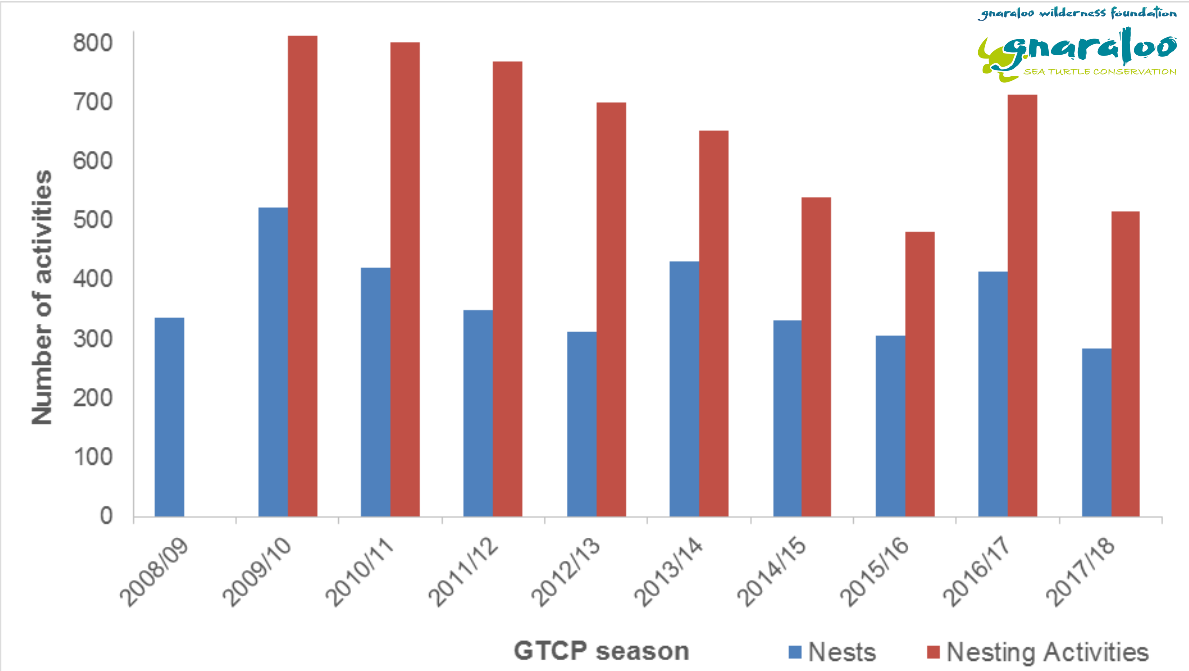

Figure 1: Sea turtle Nesting Activities in GBR Survey Area, 2008/09 – 2017/18 (all species)

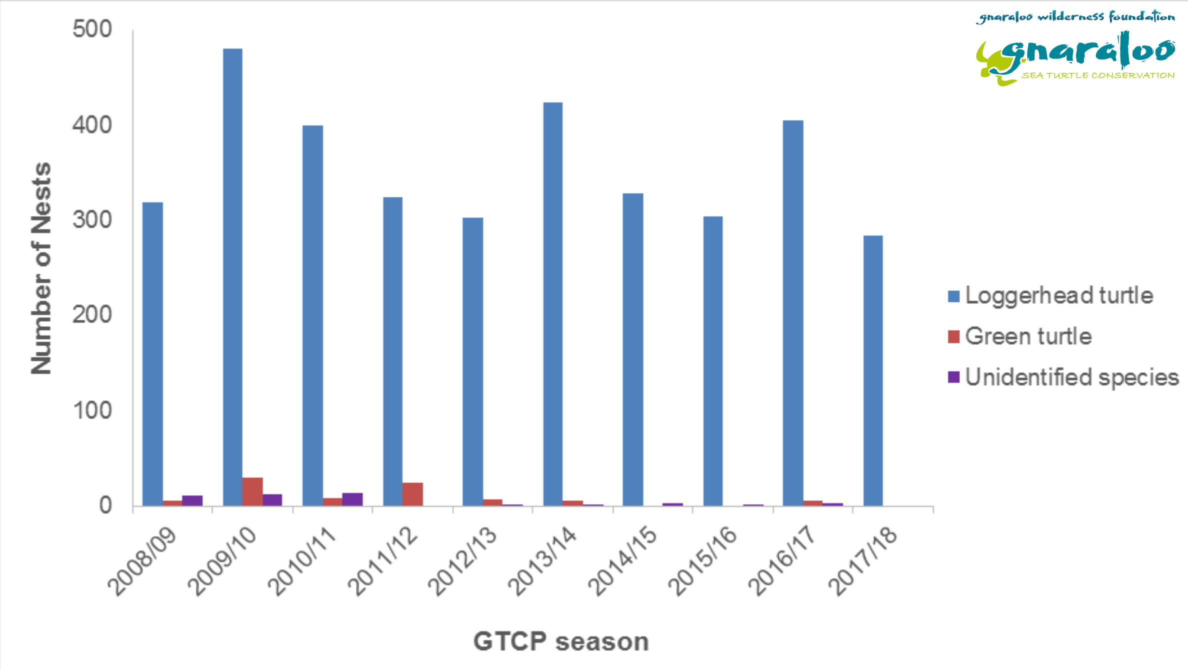

Figure 2: Nests of all sea turtle species in GBR Survey Area, 2008/09 – 2017/18

Gnaraloo Bay Rookery – Satellite tagging

Two loggerhead turtles nesting in the GBR were fitted with satellite trackers in early December 2017. Both turtles, now named Gnargoo and Baiyungu, laid three more Nests after the initial tagging event. Their internesting intervals shortened from 15 and 16 days to 14 days in correlation with increasing water temperatures during the internesting period, which shortens the time needed to produce a new clutch of eggs. Both turtles nested exclusively in the GBR Survey Area, but spent all internesting intervals in the waters off the beach in the GCFR Survey Area. Immediately after laying her last Nest, Gnargoo started her homeward migration, which lasted approximately 3 months. She swam approximately 4,100 km before reaching her foraging habitat in the eastern Gulf of Carpentaria, approximately 35 km offshore of the remote community of Aurukun in far north western Queensland (**Qld**). Baiyungu returned to her internesting habitat in the GCFR Survey Area after her last Nest, and started her post-nesting migration one week later. She swam slower and less direct than Gnargoo, migrating approximately 4,700 km and taking 4.5 months to join Gnargoo in her foraging habitat.

These findings offer valuable new knowledge of the foraging habitats used by some of the loggerhead turtles that nest at Gnaraloo. Previous satellite tracking undertaken by the GTCP in 2015 - 2017 revealed foraging grounds ranging from Shark Bay, approximately 250 km south of Gnaraloo, in WA all along the western coast of Australia, to Darwin, Northern Territory (**NT**; Strydom et al., 2017). The wide dispersion of foraging habitats along 4,700 km of Australia's western and northern coastline, including 3 States and Territories, highlights the importance and necessity of comprehensive and collaborative approaches to sea turtle conservation. As sea turtles spend most of their lives in foraging grounds, protection of these habitats is crucial and directly affects the number, health and ability to migrate and breed of resident sea turtles. For effective sea turtle conservation, it is therefore not enough to focus all protection and management actions on nesting habitats.

The movements of both turtles can be monitored by the public on the free Turtle Tracker App of the Gnaraloo Wilderness Foundation (**GWF**), which was launched in December 2015, and on www.seaturtle.org (Western Australian Loggerheads – Gnaraloo Bay and Gnaraloo Cape Farquhar 2015 – 2018).

Gnaraloo Bay Rookery – Sampled Nest Surveys

Within the GBR Survey Area, a subset of Nests (n = 52) were designated as Sampled Nests. These were monitored daily for evidence of Predation or Disturbance by feral or native animals, Inundation, sand movement and evidence of hatchling emergence on the surface. No signs of Disturbance or Predation by feral animals were observed. In contrast, 90.4 % of all Sampled Nests were either disturbed or predated by ghost crabs (*Ocypode convexa* or *O. ceratophthalma*), which was the second highest number of Sampled Nests affected by Disturbance or Predation since 2011/12. However, the precise impact of crab Disturbance and Predation on turtle Hatching success and Emergence success remains unknown and should be investigated further.

Despite the absence of major storms during season 2017/18, 40.4 % of all Sampled Nests were inundated by high tides and/or storm surges at least once. Only two seasons since 2011 (2011/12 and 2012/13) had more Sampled Nests inundated, whereas season 2012/13 was affected by tropical cyclone Nerelle. No instances of Erosion (i.e. exposure of the egg chamber by environmental factors) were observed, despite 9.6 % of all Sampled Nests experiencing a loss of sand of 20 cm or more on top of the suspected egg chamber. The same number of Sampled Nests had 20 cm or more sand accumulating on top of the suspected egg chamber throughout the season, with a maximum of 129 cm on one Sampled Nest (**Section 9.4.6.2**). It is recommended that the issue of large accumulations of sand on top of egg chambers during the Incubation period in the GBR Survey Area, which can lead to suffocation of eggs and hatchlings, be considered in future for management intervention.

The Incubation period for the 31 Sampled Nests that showed evidence of hatchling emergence on the surface (i.e. hatchlings or hatchling tracks emerging from the egg chamber) ranged from 58 to 76 days, with an average of 67.5 days.

A total of 41 Sampled Nests and 1 non-Sampled Nest were excavated at the end of their monitoring period. No egg chambers were found for 6 Sampled Nests, indicating that they may not have been Nests as identified during Day Survey. Of all excavations, 26.2 % exposed only few small egg shell fragments, but no intact egg chamber, indicating crab Predation before, during or after hatching (i.e. coming out of the shell, rather than emerging on the surface). Excavations of the remaining Sampled Nests revealed that all clutches hatched to some extent. Overall Hatching success in the GBR Survey Area was 80.5 ± 20.7 % and Emergence success was 79.3 ± 20.6 %. Estimated clutch size in the GBR Survey Area was 115.4 ± 25.8 eggs. These values are similar to those reported from other loggerhead turtle rookeries and emphasise the importance of Nest excavations, as they give a more accurate and biologically meaningful indication of the reproductive success of a rookery than just superficial observations.

Gnaraloo Cape Farquhar Rookery – Day Surveys

In addition to monitoring turtle nesting in the GBR Survey Area, the GTCP again conducted Day Surveys in the Gnaraloo Cape Farquhar Rookery (**GCFR**) for three consecutive weeks during the assumed peak nesting period (27 December 2017 – 16 January 2018). A total of 181 Nesting Activities, including 71 Nests, were recorded during these surveys (**Table 3**). All activities were attributed to loggerhead turtles. While it is not yet possible to make full-season comparisons with Nesting Activity in the GBR, the GCFR generally records slightly fewer Nests than the GBR during overlapping monitoring periods (**Table 2**). This may be attributed to local beach conditions, as Nesting success in the GCFR over the past four seasons has on average been approximately 15 % lower than in the GBR during the same monitoring period. As there are no human disturbances present in the GCFR Survey Area, further investigation may be warranted to investigate reasons for the low Nesting success. Continued work in the GCFR is recommended for future seasons.

Education and community engagement

Community engagement has been a central focus of the GTCP since the season 2010/11 and continued to expand during the season 2017/18. The GTCP directly engaged with 4,665 persons in total (1 June 2017 – 31 May 2018). This was done partially onsite, but also through offsite presentations at schools, post-secondary institutions and community groups. Offsite presentations also included 24 *Skype in the Classroom* (Microsoft Education) lectures to students in the USA, Sweden, Sri Lanka, New Zealand, Malaysia, Brazil, Egypt, India, Indonesia and Australia. Additionally, 38 Field Diaries were published during the season 2017/18, allowing a glimpse into the life and work of the GTCP field research team as well as explaining scientific findings associated with the sea turtle research at Gnaraloo. The free Turtle Tracker App developed by the GWF was used to share the travels of the two satellite-tracked loggerhead turtles with the public. The GTCP was also featured in media articles, radio and television interviews during the season 2017/18. The GTCP Facebook page has over 3,892 followers as of 31 May 2018.

The GTCP also shares its data and program information with the scientific and conservation community (local, national and international) via several online repositories and websites.

Remarkably the GTCP's outreach activities during 2010/11 – 2016/17 were provided free of charge to all participants. Given the end of grant support as well as the previous significant financial support by the Gnaraloo Station Trust for the season 2018/19 (from 1 July 2018), small fees were asked during 2017/18 for onsite visitor participation with the program as an investment in its future. From 1 July 2018, the GTCP will also no longer be able to provide the offsite school and public presentations free of charge as was given during 2010/11 – 2017/18. Education, engagement of and outreach to the community are important pillars of successful conservation strategies. The accessibility by the public to onsite activities related to sea turtle science and conservation at Gnaraloo, including participation in surveys, as well as the educational presentations and *Skype in the Classroom* lessons should be carried on in future to continue to build and raise community awareness of sea turtle biology and conservation.

Table 1: 10-year summary of sea turtle Nesting Activities in GBR Survey Area, 2008/09 – 2017/18

GTCP SEASON		2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18
Loggerhead turtle *Caretta caretta*	**Nesting Activities (N, UNA, UT, Ua) recorded by Day Survey**	N/A	731	758	700	672	635	528	479	695	512
	Nests recoded by Day Survey	319	480	399	324	303	424	328	304	405	284
	Nest detection bias	N/A	*N/A*	-17.8 %	-21.4 %	-15.8 %	-11.9 %	-11.4 %	0.0 %	+2.8 %	-10.5 %
	Estimated number of females (range)	62 – 76	97 – 119	78 – 96	65 – 79	58 – 71	80 – 98	61 – 75	56 – 69	77 – 94	53 – 65
	Percentage of species composition (excludes Unidentified species)	98.2 %	94.1 %	98.0 %	92.8 %	97.7 %	98.6 %	100.0 %	100.0 %	98.5 %	99.8 %
Green turtle *Chelonia mydas*	**Nesting Activities recorded by Day Survey**	N/A	60	15	53	10	10	0	0	9	1
	Nests recorded by Day Survey	6	30	8	25	7	6	0	0	6	0
	Estimated number of females	1	5	1	4	1	1	0	0	1	1
	Percentage of species composition (excludes Unidentified species)	1.8 %	5.9 %	2.0 %	7.2 %	2.3 %	1.4 %	0.0 %	0.0 %	1.5 %	0.2 %
Unidentified species	**Nesting Activities recorded by Day Survey**	N/A	22	28	16	17	7	11	1	9	3
	Nests recorded by Day Survey	11	12	14	0	2	2	3	1	3	0
Total Nesting Activities recorded by Day Survey (all species)		N/A	813	801	769	699	652	539	480	713	516
Total Nests recorded by Day Survey (all species)		336	522	421	349	312	432	331	305	414	284

Notes:

1. This table supersedes all previously issued GTCP nesting summary tables. The numbers recorded for the GBR Survey Area are conservative as we do not monitor the entire rookery nor the entire nesting period, but only parts thereof due to logistical and resource constraints. This table only reflects data collected during the now standard GTCP monitoring period (1 November – 28 February) in the now standard GBR Survey Area (GBN – BP9).
2. If errors were identified in Day Survey track assessments based on comparison with direct Night Survey observations, they were corrected prior to data summary for this table.
3. Some minor deviations in timing occurred from the now standard GTCP monitoring period. Notably, the portion of GTCP season 2008/09 that is relevant to Table 1 ran from 1 December 2008 – 28 February 2009, while GTCP season 2010/11 ran from 13 November 2010 – 4 February 2011 (with one day missed due to a cyclone). Thus, numbers for these seasons are conservative. During season 2011/12, 4 survey days were missed and during season 2012/13, 1 survey day was missed. Overall, the mean number of days surveyed during GTCP seasons 2008/09 – 2017/18 was 112.8 (SD = 14.0)
4. Only Nest numbers were recorded during the GTCP season 2008/09, other Nesting Activity (i.e. UNA, U-Track and Ua) numbers were not recorded during the first year of the program. All necessary data were recorded for all Nesting Activity types in the remaining seasons 2009/10 – 2017/18. The Nest total for 2008/09 was included because dates and locations for all Nests were recorded.
5. Nests for which the species could not be identified were excluded from species composition calculations.
6. Particularly during the early years of the GTCP (2008/09 – 2009/10), a significant number of tracks in the GBR was considered to be from hawksbill turtles despite this species being reported to rarely nest as far south as Gnaraloo (*pers. comm*., R.I.T. Prince, DBCA). Because hawksbill turtle tracks can be extremely difficult to distinguish from small loggerhead turtle tracks, particularly on wind prone beaches such as those at Gnaraloo, these track interpretations had a potential for error. Since 2010/11, we have directly observed 604 turtles during Night Surveys in the GBR Survey Area (as of 28/02/2018; this includes multiple sightings of individual turtles since most were not flipper tagged and therefore individuals could not be identified). No hawksbill turtles have been seen. In contrast, the low proportion of green turtles seen during Night Surveys in the GBR has aligned closely with the proportion of tracks attributed to this species during Day Surveys. Furthermore, the proportion of tracks ascribed to loggerhead turtles during Day Surveys was initially lower than the proportion seen during Night Surveys but was equivalent if the putative hawksbill tracks were re-classified as loggerhead turtle tracks. Based on this evidence, we changed all suspected hawksbill turtle tracks in the Day Survey data set 2008/09 – 2015/16 to loggerhead turtles to minimise species identification errors. The number of hawksbill turtle Nests changed to loggerhead turtle Nests during GTCP seasons 2008/09 – 2015/16 was respectively: 14, 78, 2, 0, 1, 5, 0 and 2.
7. Nest detection bias for loggerhead turtles was determined by comparing Day Survey track interpretations with independent, direct observations of turtle nesting activities during Night Surveys, which were conducted during a subset of seasons 2010/11 – 2017/18. To be considered 'verified' during Night Surveys, the turtle had to be observed during a nesting phase that would ensure 100 % certainty of the nesting activity (i.e. Nest, UNA or U-Track). For Nests, the turtle had to be seen at the laying phase at the latest and witnessed depositing eggs into the egg chamber. For UNAs, the turtle had to be seen at the egg chamber phase at the latest and observed returning to the ocean without laying eggs. For U-Tracks, the turtle had to be seen at the emergence phase at the latest and witnessed returning to the ocean without attempting to dig a Nest. For each season, we extracted all verified Night Survey observations and their corresponding Day Survey track interpretations. This included cases in which a verified activity was missed entirely the following morning or incorrectly assigned to a green turtle. We then tallied the number of Nests recorded in each data set. The Night Survey Nest count was taken to represent the true value and the Day Survey Nest count represented the observed value. We calculated the percent error between the two using the formula: *% error = (observed - true) / true * 100*. This analysis

was not conducted for green turtles due to the paucity of Night Survey observations for this species.

8. Only the Nest numbers recorded by Day Surveys per season are shown in the table (i.e. not the adjusted Nest numbers per season in line with the Nest detection bias percentage for that particular season), due to the sample sizes for some of the seasons being too small.

9. To estimate the number of female loggerhead turtles likely nesting in the GBR during each season, we consulted the literature for clutch frequency estimates for this species derived from satellite telemetry. Telemetry-based estimates more accurately reflect true clutch frequency than survey-based estimates since nesting events may be missed during beach surveys if they are outside a prescribed survey area or period, or are simply not detected (Tucker, 2010). We calculated the mean and standard deviation (**SD**) of the estimated clutch frequency (**ECF**, 4.9 ± 0.5) based on values from currently available studies (Scott, 2006; Rees et al., 2008; Rees et al., 2010; Tucker, 2010). We then divided the number of Nests recorded during Day Surveys within each season by the mean ECF ± 1 SD to provide an estimate.

10. The number of female green turtles was estimated using a clutch frequency of 6 (Limpus et al., 2001).

Table 2: 4-year summary of sea turtle Nesting Activities in GCFR Survey Area (27 Dec – 9 Jan), 2014/15 – 2017/18

GTCP SEASON		2014/15	2015/16	2016/17	2017/18
Loggerhead turtle *Caretta caretta*	**Nesting Activities (N, UNA, UT, Ua) recorded by Day Survey**	64	134	114	131
	Nests recoded by Day Survey	33	59	55	45
	Percentage of species composition (excludes Unidentified species)	100 %	100 %	100 %	100 %
Unidentified species	**Nesting Activities recorded by Day Survey**	1	0	0	0
	Nests recorded by Day Survey	0	0	0	0

Total Nesting Activities recorded by Day Survey (all species)	65	134	114	131
Total Nests recorded by Day Survey (all species)	33	59	55	45

Table 3: 2-year summary of sea turtle Nesting Activities in GCFR Survey Area (27 Dec – 16 Jan), 2016/17 – 2017/18

GTCP SEASON		2016/17	2017/18
Loggerhead turtle *Caretta caretta*	**Nesting Activities (N, UNA, UT, Ua) recorded by Day Survey**	172	181
	Nests recoded by Day Survey	86	71
	Percentage of species composition	100 %	100 %

2 BACKGROUND

2.1 Program overview

The Gnaraloo Turtle Conservation Program (**GTCP**) is a scientific research and community engagement program aimed at identifying, monitoring, and protecting marine turtle rookeries located along a 65 km stretch of coast at the southern end of the Ningaloo Reef at Gnaraloo, WA (**Appendix A**). The GTCP commenced on-ground in 2008 at Gnaraloo Station, a pastoral station and wilderness tourism business located adjacent to the Ningaloo Marine Park (**NMP**), Ningaloo Coast World Heritage Area, and Ningaloo Coast National Heritage Listed Area. It is jointly administered by the GWF, a nature-based not-for-profit charity and by the private Gnaraloo Station Trust. While turtle nesting occurs on most sandy beaches along the Gnaraloo coast line, the focus of the GTCP for the past 10 years has been on two high density turtle rookeries: the Gnaraloo Bay Rookery (**GBR**, 6.7 km) and Gnaraloo Cape Farquhar Rookery (**GCFR**, 7.1 km). Loggerhead turtles (*Caretta caretta*) are the primary nesting species in both rookeries, with green turtles (*Chelonia mydas*) nesting infrequently and hawksbill turtles (*Eretmochelys imbricata*) sighted in the waters. Since 2008, GTCP research teams have conducted early-morning beach track surveys and nest monitoring activities, using protocols adapted from the Ningaloo Turtle Program (**NTP**)[2] in Exmouth. Other research activities added in later years include verification of Day Survey track interpretations via direct observation during Night Surveys, Nest excavations, flipper tagging and satellite tagging. The Gnaraloo Station Trust also administered the Gnaraloo Feral Animal Control Program (**GFACP**) until 30 June 2015 (**Section 2.7**), which simultaneously conducted the control of invasive feral animals such as European red foxes (*Vulpes vulpes*), cats (*Felis catus*) and wild dogs (*Canis lupus familiaris*) in order to reduce the impact of feral animal Predation on sea turtle Nests and hatchlings.

A peer review paper with the GTCP turtle nesting data from 2008/09 – 2015/16 was -published in the scientific journal, Chelonian Conservation and Biology, during 2016/17[3]. A satellite tagging project for loggerhead turtles was initiated and completed in both the GBR and GCFR Survey Areas for the first time in 2015/16 (Hattingh et al., 2017) and continued in 2017/18.

In addition to monitoring and research, the GTCP conducts a wide range of educational and

[2] http://www.ningalooturtles.org.au

[3] http://www.bioone.org/doi/10.2744/CCB-1219.1

community engagement activities, including onsite participant programs at Gnaraloo, school presentations, Skype lessons with international school groups and media appearances. The GTCP has also partnered with external scientists at several Australian universities to facilitate Honours and Masters-level research projects and has developed a substantial public profile including a Facebook page with more than 3,892 followers as at 31 May 2018.

Gnaraloo's terrestrial and marine landscape is also habitat to many flora and fauna other than endangered sea turtles. The area is a unique and rare remaining remnant of Australian wilderness. Gnaraloo's management team established the GWF on 12 January 2016. Its aim is to protect the native terrestrial and marine flora and fauna in, on and under the landscape at Gnaraloo for present and future generations. The Foundation is a separate legal entity to the Gnaraloo Station Trust and its charter can be viewed on its website (www.gnaraloo.org).

2.2 Sea turtle conservation: global to regional perspectives

Globally, six of seven sea turtle species are listed as Vulnerable, Endangered or Critically Endangered on the International Union for the Conservation of Nature (**IUCN**) Red List of Threatened Species[4], while the seventh, the flatback turtle (*Natator depressus*), is considered Data Deficient. Australia is home to six of seven sea turtle species (i.e. all but the Kemp's ridley turtle, *Lepidochelys kempii*). Sea turtles are highly migratory and often have home ranges displacing them hundreds to thousands of kilometres (Briscoe et al., 2016). For this reason, conservation efforts must be made at appropriate scales. Geopolitical boundaries arbitrarily delineate sub-populations and hinder effective management of migratory species (Nevins et al. 2009). Because Australia's sea turtles are often part of a larger population, it is not just important to protect foraging or nesting regions close to shore, but the entire ecosystems associated with these dynamic creatures. To achieve this kind of conservation, management plans must be created to expand the bureaucratic framework to seek assistance from international, national and local organizations and individuals of all kinds. Australia has signed several international agreements seeking to protect sea turtles, whose migratory movements often cross international boundaries. Since 1991, Australia has been a signatory to the Convention on the Conservation of Migratory Species of Wild Animals (**CMS**), also known as the Bonn Convention. The CMS provides a global platform for conservation of animals that pass through multiple countries within their migratory range. Australia ratified the Convention on International Trade in Endangered Species of Wild Fauna and Flora

[4] http://www.iucnredlist.org

(**CITES**) in 1976 and all marine turtles occurring in Australian waters are listed on CITES Appendix I (Species threatened with extinction). Australia is also a signatory to the Indian Ocean and South-East Asian *(***IOSEA***)* Marine Turtle Memorandum of Understanding, a multi-lateral agreement supported by the United Nations Environment Programme and the CMS, which seeks to reduce threats to marine turtles, conserve critical habitat, promote exchange of scientific data, increase public awareness and enhance regional co-operation on sea turtle conservation.

At the national level, Australian sea turtles are protected under the Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth, **EPBC Act**). The EPBC Act protects and manages nationally and internationally significant flora, fauna, ecological communities and heritage places. It aims to provide broad environmental protection, especially for Matters of National Environmental Significance (**MNES**), which include World Heritage and National Heritage properties, nationally threatened species and ecological communities, migratory species and commonwealth marine areas. Under the EPBC Act, loggerhead, leatherback (*Dermochelys coriacea*) and olive ridley (*Lepidochelys olivacea*) turtles are currently listed as Endangered while green, hawksbill, and flatback turtles are considered Vulnerable[5]. Conservation efforts for sea turtle population recovery in Australia are guided by the Recovery Plan for Marine Turtles in Australia 2017 - 2027 and broader strategic plans such as Australia's Biodiversity Conservation Strategy 2010 - 2030.

At the regional level, sea turtle conservation is mandated and implemented under region-specific legislation and strategic plans. In WA, the green, hawksbill, leatherback and flatback turtles are listed as Vulnerable while the loggerhead and olive ridley turtles are listed as Threatened under the Wildlife Conservation Act 1950[6]. All sea turtle species are protected as native fauna, although provision is made for take by indigenous people. Management of sea turtle populations and habitats in WA also fall under the purview of the Marine Bioregional Plan for the North-west Marine Region (2012) of the Department of the Environment and Energy (Australian Government), which supports the implementation of the EPBC Act at the regional level.

Primary threats to Australian sea turtles include bycatch in commercial fisheries, mortality related to entanglement in or ingestion of marine debris, Predation of turtle eggs by native and introduced predators, direct harvest of adult turtles and eggs, and coastal human activities, such as light pollution, that endanger critical nesting, foraging or migratory habitats (Recovery Plan for Marine

[5] http://www.environment.gov.au/marine/marine-species/marine-turtles

[6] Wildlife Conservation (Specially Protected Fauna) Notice 2017

Turtles in Australia, 2017 – 2027). Climate change is also an important conservation issue for sea turtles (Hawkes et al., 2009) for several reasons, including that increasing sand temperatures at Nest depths can skew hatchling sex ratios and increase mortality in embryos and hatchlings (Fuentes et al., 2010). Increasing sea surface temperatures (**SST**) associated with climate change in foraging and breeding habitats influence the timing and abundance of sea turtle nesting (Chaloupka et al., 2008, Weishampel et al. 2004; Mazaris et al. 2008, 2009; Weishampel et al. 2010). Warmer water is associated with lower ocean productivity and thus lower prey abundance, impacting the breeding capacity of sea turtles (Chaloupka et al., 2008). In order to reliably assess sea turtle population trends and develop effective management strategies to protect against these and other threats, it is critical to gain an understanding of the biology and status of nesting aggregations. Nesting beach programs in WA began relatively recently (e.g. the NTP was established in 2002), limiting our understanding of WA nesting aggregations. Thus, it is vital to undertake and expand nesting beach programs in WA to provide longitudinal datasets and enact conservation measures, as necessary, to facilitate population recovery and protection.

2.3 GTCP and GFACP in context

The activities of the GTCP and GCFAP align with sea turtle conservation goals set at the international, national, and regional levels through the aforementioned legislation and strategic plans. Specifically, the GTCP and GFACP contribute to sea turtle conservation by:

- supporting the recovery of sea turtle populations and threat abatement for species listed in the EPBC Act as MNES;
- identifying significant coastal nesting rookeries and critical nesting habitat for loggerhead sea turtles on the Gnaraloo coastline, which were largely unknown or unsurveyed prior to 2008;
- developing and managing an annual on-ground monitoring program of seasonal sea turtle nesting and feral animal activities in the rookeries on the Gnaraloo coastline;
- annually identifying and undertaking management activities to protect Gnaraloo rookeries from threats that may impact reproductive success;
- implementing an extensive annual training and employment program of graduate scientific professionals as future leaders and decision-makers, including a comprehensive scientific internship program (up to 6 months, full time);

- collaborating with external researchers (e.g. university faculty and students) to undertake targeted research projects to address questions of ecological and conservation importance;

- carrying out an extensive annual educational and community engagement program that includes primary and high schools, post-secondary institutions, community and indigenous groups, non-government organisations and the general public (in all categories: local, national and international);

- freely sharing information about the Gnaraloo sea turtles with government departments, universities, and sea turtle experts (in all categories: local, national and international).

2.4 Focal species: loggerhead turtle

2.4.1 Distribution and population

The loggerhead turtle is distributed throughout the world's tropical and warm temperate oceans (Bolten & Witherington, 2003). For management purposes, this species has been divided into ten RMUs based on available nesting, genetic and movement data (Wallace et al., 2010). However, these RMUs do not necessarily represent genetically distinct stocks, but overlap in the case of the Western Australian genetic stock and the southeast Indian Ocean RMU (Fitzsimmons & Limpus, 2014). According to the most recent IUCN assessment (Casale & Tucker, 2017), the northwest Atlantic Ocean and northern Indian Ocean RMUs comprise the majority of annual nesting abundance for the species (83,717 and 70,000 Nests per year, respectively), while the southeast Indian Ocean constitutes a relatively small proportion (2,955 Nests per year; **Table 4, Figure 3**; Casale & Tucker, 2017). Critically, however, the southeast Indian Ocean RMU is among the least well-studied RMUs. Therefore, vital information on loggerhead turtle reproductive biology in this region are lacking, including nesting census data from key rookeries (Hamann et al., 2013).

Table 4: Estimated sizes of the 10 loggerhead turtle RMUs (Casale & Tucker, 2017)

REGIONAL MANAGEMENT UNIT (RMU)	NESTS PER YEAR
Northwest Atlantic Ocean	83,717
North Indian Ocean	70,000
Northeast Atlantic Ocean	15,000
North Pacific Ocean	9,053
Southwest Atlantic Ocean	7,696
Mediterranean Ocean	7,200
Southwest Indian Ocean	4,600
Southeast Indian Ocean	**2,955**
Northeast Indian Ocean	25
South Pacific Ocean	Data not available

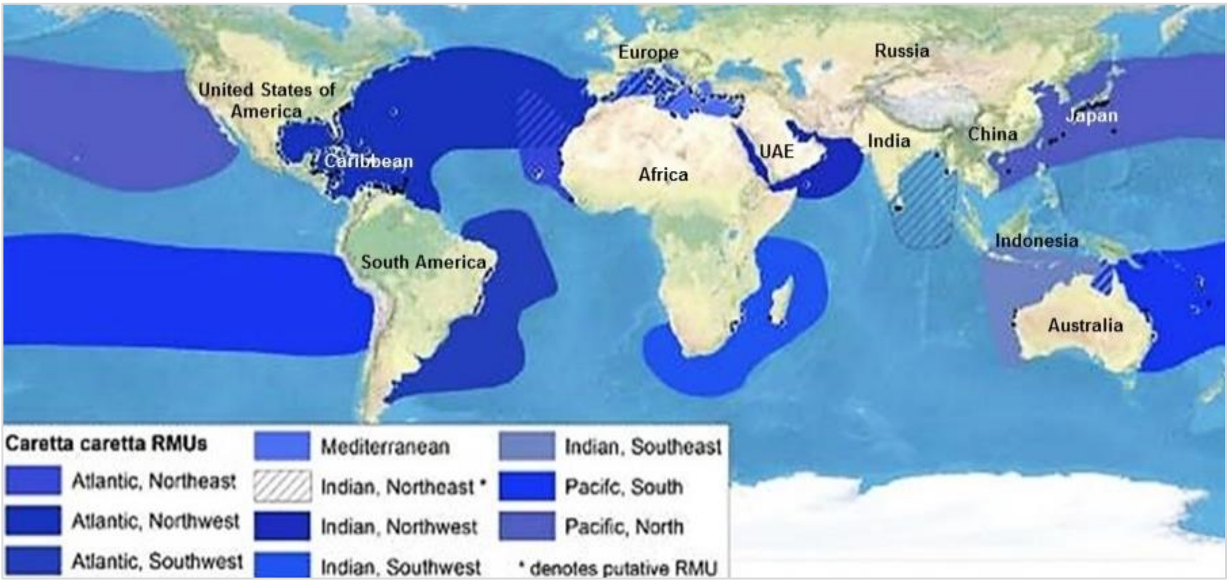

Figure 3: Distribution of the 10 loggerhead turtle RMUs (Wallace et al., 2010)

2.4.2 Nesting in WA

All known nesting by loggerhead turtles in the southeast Indian Ocean occurs in WA (Dodd

1988; Baldwin et al., 2003; Wallace et al., 2010). Primary nesting sites are located at Dirk Hartog Island, the Muiron Islands offshore of Exmouth and on mainland beaches along the Ningaloo coast from Carnarvon to Exmouth. Dirk Hartog Island hosts approximately 70 % of all loggerhead turtle nesting in WA, with an estimated 1000 – 3000 females nesting at this site annually (Baldwin et al., 2003; Limpus, 2008; Reinhold & Whiting, 2014). In terms of mainland rookeries, together the GBR and GCFR at Gnaraloo represent one of the largest known nesting aggregations on the Ningaloo coast. A comparable amount of nesting by loggerhead turtles may occur on beaches monitored by the NTP in Exmouth (Markovina & Prophet 2014), although methodological differences (e.g. length and timing of surveys) make direct comparisons difficult. The nesting habitats of Gnaraloo Bay, Dirk Hartog Island, Muiron Islands and Ningaloo coast, including a 20 km radius internesting habitat buffer for each nesting habitat, were identified as habitats critical to the survival of loggerhead turtles of the southeast Indian Ocean RMU (Recovery Plan for Marine Turtles in Australia 2017 – 2027.

Mainland rookeries in WA tend to be much smaller than the island rookeries and this is likely due, at least in part, to historical Predation by introduced foxes, which are not present on Dirk Hartog Island or the Muiron Islands, but have been active on the mainland coast since at least the 1960s (Limpus, 2008). Quantitative data on fox Predation rates on sea turtles Nests in WA is lacking. However, anecdotal evidence suggests that a large proportion of turtle Nests – perhaps as much as 70 % – can be destroyed by foxes in the absence of control measures (Baldwin et al., 2003; Limpus, 2009). This figure is consistent with data from some locations in Qld, where foxes were reported to destroy up to 90 % of turtle Nests in the late 1970s and early 1980s (Limpus, 2008). In addition to fox Predation, human activity on some mainland nesting beaches (i.e. vehicle traffic) has likely also contributed to the difference in rookery sizes between mainland and island sites. Thus, it is likely that mainland rookeries in WA remain depleted relative to historic levels. Long-term monitoring and protection of these beaches is therefore critical.

2.4.3 Conservation status

The IUCN Marine Turtle Specialist Group conducted an assessment of the conservation status of loggerhead turtles at the global and sub-population levels in 2015. Globally, the species was downgraded from Endangered to Vulnerable (Casale & Tucker, 2017), while the southeast Indian Ocean sub-population was assessed as Near Threatened (Casale et al., 2015). However, the authors of these assessments emphasized well-known limitations associated with applying IUCN Red List criteria to marine turtles and other long-lived, globally-distributed species (Seminoff & Shanker, 2008). Furthermore, they also note that loggerhead turtles are now largely dependent on conservation intervention (e.g. nesting beach protection) and that critical data gaps exist that preclude the assessment of the southeast Indian Ocean loggerhead turtle sub-population under most Red List criteria. Therefore, it would be a mistake to interpret the global downgrade as an indication of a reduced need for conservation of loggerhead turtles or to conclude that adequate information is available to understand and mitigate threats to this species in the southeast Indian Ocean. Rather, regional-scale programs aimed at loggerhead turtle monitoring and conservation in WA are urgently needed to facilitate rigorous status assessments, inform management planning and undertake effective on-ground protective action.

2.5 Recruitment and team composition

The GTCP managed recruitment for the seasonal GTCP field research team 2017/18. The recruitment campaign focused on attracting and appointing capable candidates from Australia and overseas. The available five positions were advertised in over 20 countries. More than 60 applications were received from Australia and overseas (22 applications for the position of Program Assistant were received from 9 countries and 39 applications for the four internship positions were received from 13 countries).

The GTCP research team 2017/18 comprised the following persons:

- GTCP Lead Scientific Officer and Project Manager: Ms. Karen Hattingh (MPhil in Environmental Science, BA LLB, South Africa; GradCert of Law, WA), with over 20 years commercial experience in Australia and overseas, co-founder and lead scientist of the GTCP and GFACP since inception;
- GTCP Program Assistant: Dr Simone Bosshard (PhD in Neuroscience Switzerland, GradDip in Environmental Management and Conservation, Australia), with previous sea turtle monitoring experience, including in WA;
- GTCP Scientific Intern: Ms. Heather Shipp (BSc in Wildlife Science, USA), with previous sea turtle monitoring experience;
- GTCP Scientific Intern: Ms. Tess DeSerisy (BSc in Marine Science, USA), with previous sea turtle monitoring experience;
- GTCP Scientific Intern: Ms. Tessa Concannon (GradDip in Conservation Biology, BSc in

Animal Science, Australia), with previous sea turtle monitoring experience;

- GTCP Scientific Intern: Ms. Megan Soulsby (BSc in Zoology, UK), with previous sea turtle monitoring experience.

During 2008/09 – 20017/18, the GTCP engaged 64 scientists in total: 38 (59 %) from Australia, 12 (21 %) from the United States of America and Canada, 12 (21 %) from Europe and 2 (3%) from other countries (Israel and Brazil). These figures do not include all the communications, social media, graphic design, logistical support and accounting professionals who supported the GTCP during the same period.

2.6 Training

Since season 2014/15, the GTCP has managed and provided training to the seasonal GTCP field teams through GTCP personnel and appointed specialist contractors. Pre-season training in October 2017 was provided by Mr. Alistair Green with follow-up support to mid December 2017.

The GTCP training components included, but were not limited to, the following elements:

- turtle track interpretations;
- turtle flipper tagging;
- turtle satellite tagging;
- feral animal track interpretation;
- 4WD operating and recovery techniques;
- office practices, including GTCP methodologies, practices and protocols.

Importantly, the training of the GTCP field research teams was again supported and enhanced by the Day and Night Surveys (from November to February), during which the learning, knowledge and experience of the field research teams expanded and developed significantly pertaining to the specific local conditions at Gnaraloo.

2.7 Funding and resourcing

Funding for the GTCP and GFACP was provided by various parties (**Table 5** and **Table 6**).

The GFACP was jointly managed by the Gnaraloo Station Trust and Animal Pest Management Services (**APMS**) during 2008/09 to 2014/15. Due to changes to the Gnaraloo pastoral lease area by the State Government which came into effect on 1 July 2015, the Gnaraloo Station Trust relinquished the management of the feral control program for the Gnaraloo coastline (which became public lands) to the Department of Biodiversity, Conservation and Attractions (**DBCA**, WA), Rangelands NRM WA and APMS.

2.8 Approvals

Research by the GTCP during season 2017/18 was conducted under three Regulation 17 licences issued by DBCA under the Wildlife Conservation Act 1950 (WA). The licences covered beach monitoring, Nest excavations, flipper tagging, satellite tagging and collection of biometric data.

Table 5: Funding and resourcing of GTCP 2008/09 – 2017/18

NUMBER	FINANCIAL YEAR	TOTAL PROGRAM COST (NOTE 2) GST EXCL	GNARALOO STATION TRUST	PARTNERS INTRODUCED BY THE GNARALOO STATION TRUST		SUPPORT SECURED BY THE GNARALOO STATION TRUST		
				BRAINS	AUBREY STRYDOM	AUS. GOV.	RANGELANDS NRM WA	DBCA WA (NOTE 1)
1	GTCP 2008/09	$80,063.64	$55,900 Financial + In-kind	-	-	$21,663.64 Financial	-	$2,500 In-kind
2	GTCP 2009/10	$250,000	$250,000 Financial + In-kind Solely Funded	-	-	-	-	-
3	GTCP 2010/11	$220,249	$192,249 Financial + In-kind	-	-	$25,000 Financial	-	$3,000 (Note 4) In-kind
4	GTCP 2011/12	$220,249	$192,249 Financial + In-kind	-	-	$25,000 Financial	-	$3,000 (Note 4) In-kind
5	GTCP 2012/13	$243,000	$240,000 Financial + In-kind	-	-	-	-	$3,000 (Note 4) In-kind
6	GTCP 2013/14	$496,419.60	$306,042 Financial + In-kind	-	-	$169,877.60 Financial	$18,000 Financial	$2,500 (Note 5) In-kind
7	GTCP 2014/15	$517,544.40	$269,710 Financial + In-kind	-	-	$229,834.40 Financial	$18,000 Financial	-

Table 5 Cntd: Funding and resourcing of GTCP 2008/09 – 2017/18

NUMBER	FINANCIAL YEAR	TOTAL PROGRAM COST (NOTE 2) GST EXCL	GNARALOO STATION TRUST	PARTNERS INTRODUCED BY THE GNARALOO STATION TRUST		SUPPORT SECURED BY THE GNARALOO STATION TRUST		
				BRAINS	AUBREY STRYDOM	AUS. GOV.	RANGELANDS NRM WA	DBCA WA (NOTE 1)
8	GTCP 2015/16	$435,260.71	$104,922.69 Financial + In-kind	$125,000 Financial + In-kind	$4,376.42 Financial	$199,856 Financial	-	$1,105.60 (Note 6) Financial + In-kind
9	GTCP 2016/17	$358,748.17	$28,292.17 In-kind	$125,000 Financial + In-kind	$3,300 In-kind	$199,856 Financial	-	$2,300 (Note 7) Financial
10	GTCP 2017/18	$260,645.03	$38,360 In-kind	$12,500 Financial + In-kind	$9,929.03 Financial + In-kind	$199,856 Financial	-	Note 8 In-kind
TOTAL INVESTMENT VALUE		**$3,082,179.55**	**$1,677,724.86**	**$262,500**	**$17,605.45**	**$1,070,943.64**	**$36,000**	**$17,405.60**

Notes:

1. Department of Biodiversity, Conservation and Attractions (WA).
2. The contributions by all the partnerships introduced to the project by the Gnaraloo Station Trust are not included in this table. This includes financial and in-kind donations of money, time, resources and equipment, including but not limited to: esri Australia, Microsoft, Ricoh, Soundwave Nomad Production, Animal Pest Management Services, Chilli Finance, Department of Environment and Natural Resources (NT), Claire Guillaume, the seasonal GTCP field teams (significant labour component) and others. See http://gnaraloo.org/current-past-supporters/
3. The in-kind contributions by the Gnaraloo Station Trust for 2015/16 – 2017/18 are for accommodation only. It also gave in-kind support of time, resources and equipment.
4. NTP training and accommodation in Exmouth (GTCP season 2010/11 – 2012/13).
5. NTP training in Exmouth (GTCP season 2013/14).
6. Support to satellite tagging work.
7. Helicopter fee to retrieve carcass of satellite tagged Gnaraloo loggerhead turtle called Marloo.
8. Loan of tagging equipment.

Table 6: Funding and resourcing of Gnaraloo Feral Animal Control Program 2008/09 – 2014/15

NUMBER	FINANCIAL YEAR	TOTAL PROGRAM COST GST EXCL	GNARALOO STATION TRUST & ITS PARTNER APMS	SUPPORT SECURED BY THE GNARALOO STATION TRUST		
				AUS. GOV.	RANGELANDS NRM WA	DBCA WA
1	GFACP 2008/09	$77,408.72	$36,169.69 Financial + In-kind	$39,184.85 Financial	-	$2,054.18 In-kind
2	GFACP 2009/10	$77,408.72	$36,169.69 Financial + In-kind	$39,184.85 Financial	-	$2,054.18 In-kind
3	GFACP 2010/11	$77,408.72	$36,169.69 Financial + In-kind	$39,184.85 Financial	-	$2,054.18 In-kind
4	GFACP 2011/12	$70,246	$70,246 Financial + In-kind Solely Funded	-	-	-
5	GFACP 2012/13	$95,683.50	$70,283.50 Financial + In-kind	-	-	$25,400 Financial
6	GFACP 2013/14	$101,546	$34,690 Financial + In-kind	$14,856 Financial	$44,572 Financial	$7,428 Financial
7	GFACP 2014/15	$100,561	$34,690 Financial + In-kind	$14,856 Financial	$51,015 Financial	-
TOTAL INVESTMENT VALUE		**$600,262.66**	**$318,418.57**	**$147,266.55**	**$95,587**	**$38,990.54**

3 GNARALOO WEATHER

3.1 Introduction

Gnaraloo is located in the central Gascoyne region of WA, which is characterised by a semi-arid and sub-tropical climate (Gascoyne Development Commission, 2015). The mean annual maximum temperature in the region is 27.2 °C, while the annual minimum is 16.6 °C. During the survey period of 1 November to 28 February, the mean maximum temperature is 29.9 °C and the minimum is 20.6 °C (Bureau of Meteorology, 2018). The average wind speed for the Gascoyne area is between 18.8 - 25 km/h from a predominantly southerly to south-westerly direction (Bureau of Meteorology, 2018).

3.2 GBR Survey Area

The GTCP field research team recorded daily climatic data from 1 November 2017 – 28 February 2018 in the GBR Survey Area, using a Davis Vantage Pro 2 Weather Station. This data has been collected since the season 2009/10. The GBR Weather Station was located just south of the Sub-section marker at Beach Point (**BP**) 7, immediately adjacent to the GBR Survey Area (**Appendix A2**). Measurements of atmospheric conditions including temperature, wind speed and direction, and rainfall were recorded hourly and downloaded on a weekly basis.

Season 2017/18 was characterised by moderate day-time and mild night-time temperatures (**Figure 4**). The maximum temperature (42.6 °C) was recorded on 4 January 2018, but similar temperatures were recorded on 23 November 2017 (40.4°C), 25 December 2017 (41.1 °C), 13 January 2018 (41.0 °C) and 15 February 2018 (40.6 °C). Temperatures fell to as low as 15.4 °C on 19 November 2017. Daily mean temperatures were within a range of 21.4 - 31.2 °C for the GTCP season 2017/18. Gnaraloo features a prevailing southerly wind, which remained relatively constant during November 2017 – February 2018. Wind speeds reached a maximum of 57.9 km/h (27 February 2018), with an average of 17.5 km/h for the entire season (**Figure 5**). Rainfall is not common in the Gnaraloo region and was only recorded on seven occasions during 2017/18, totalling 7.8 mm.

Since 2010/11, the weather in the GBR Survey Area has remained fairly consistent with average weekly temperature ranging from 22.4 °C early in the season to 27.1 °C towards the end of the season. While the start and end of the season 2017/18 were slightly cooler than the 8-year average, temperatures for December 2017 and January 2018 were mostly around the 8-year average. No exceptionally high peaks in weekly mean temperatures were seen during the season 2017/18 as observed during the second half of seasons 2010/11, 2011/12 and 2013/14 (29.8 °C, 30.3 °C, 32.2 °C, respectively; **Figure 4**). Average weekly wind speeds varied greatly over time during the season 2017/18, ranging from 17.6 km/h mid-season to 13.0 km/h near the end of the season. Wind speeds in the first half of season 2017/18 were similar to the 8-year average, but were consistently higher than the 8-year average throughout the second half of the season (**Figure 5**). Rainfall was low in season 2017/18 as it had been for most of the last eight seasons, with the only considerable spike being with a cyclone in season 2010/11 (337 mm). Additionally, season 2016/17 had an uncharacteristically rainy season beginning in mid-January (138.4 mm; **Figure 6**).

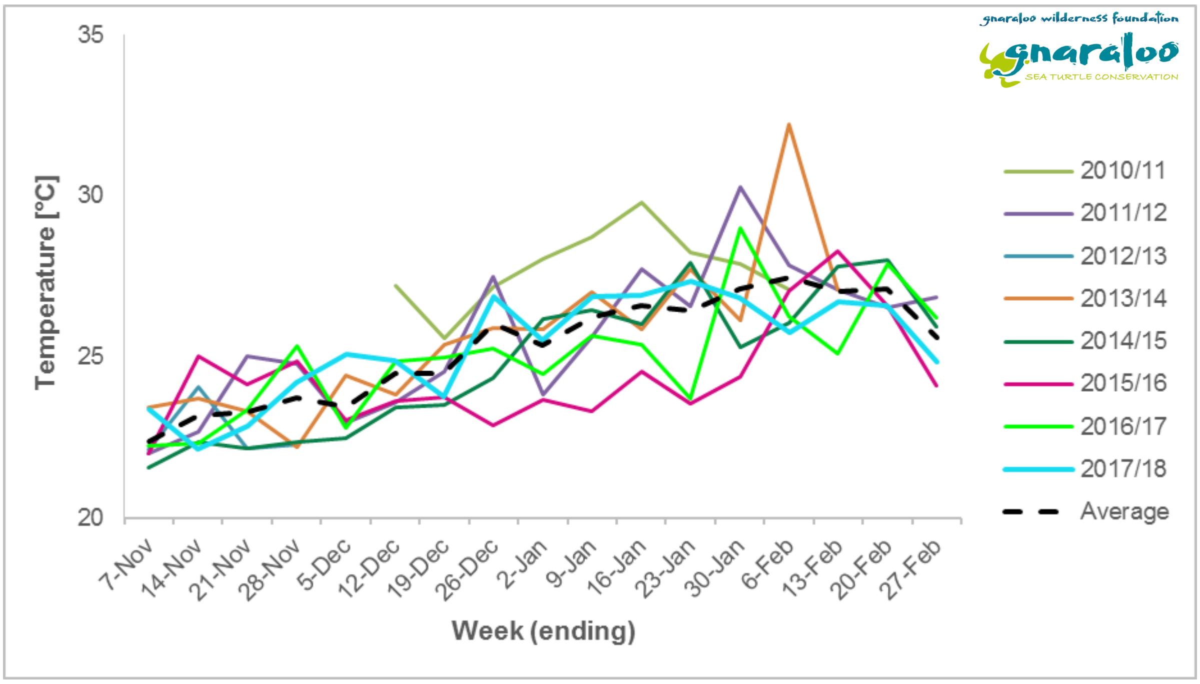

Figure 4: Weekly mean temperatures in GBR Survey Area (1 Nov – 28 Feb), 2010/11 – 2017/18

Note: Weather data collection in the GBR Survey Area started in season 2009/10, but only 2 weeks of overlapping weather data were obtained (15 – 28 February 2010) at the end of the now standard monitoring period (1 November – 28 February), so this season was excluded.

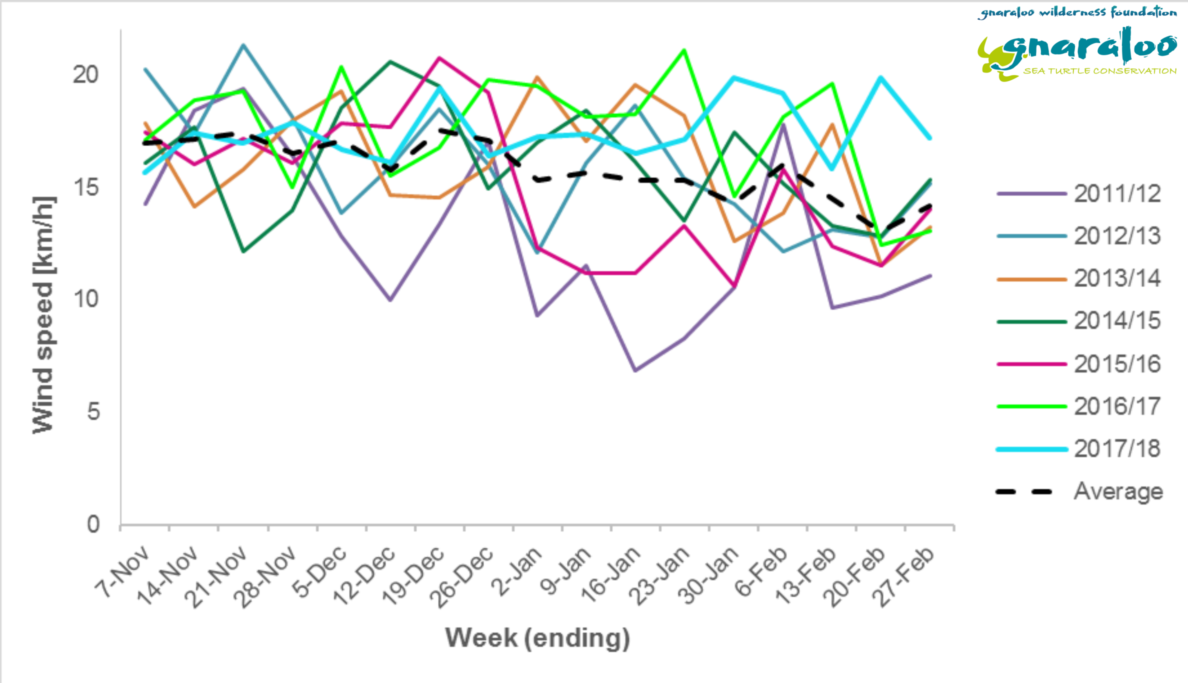

Figure 5: Weekly mean wind speeds in GBR Survey Area (1 Nov – 28 Feb), 2011/12 – 2017/18

Note: Wind speed data was not collected during season 2010/11.

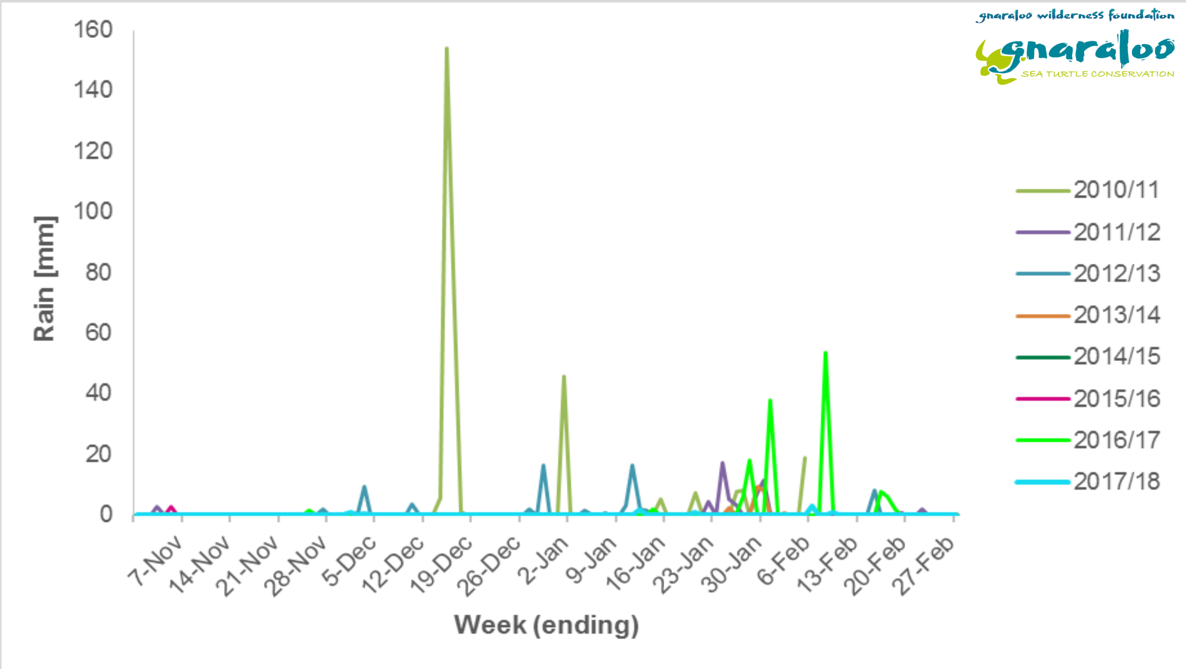

Figure 6: Daily rainfall recorded in GBR Survey Area (1 Nov – 28 Feb), 2010/11 – 2017/18

3.3 GCFR Survey Area

During the Gnaraloo Cape Farquhar Rookery (**GCFR**) survey period between 27 December 2017 and 16 January 2018 (21 days), the GTCP installed a second Davis Vantage Pro 2 Weather Station in the GCFR Survey Area at the marker for Sub-section Gnaraloo Farquhar Runway (**GFR**), immediately adjacent to the Survey Area. Atmospheric conditions were recorded in the same manner as with the GBR Survey Area Weather Station. Weather data have been collected from the GCFR Survey Area since the season 2015/16. While seasons 2016/17 and 2017/18 had identical survey periods, the survey period in the season 2015/16 was one week shorter at 14 days, running from 27 December 2015 to 9 January 2016.

The maximum recorded temperature for the season 2017/18 at GCFR was 42.9 °C on 4 January 2018, compared with 42.6 °C in the GBR Survey Area. On average over the 21-day period, there was no discernible difference in temperature between the GFCR Survey Area (26.6 ± 0.8 °C) and the GBR Survey Area (26.4 ± 0.8 °C). This is consistent with the season 2015/16, however the season 2016/17 showed a slightly greater temperature difference between the GBR Survey Area (25.1 ± 0.6 °C) and the GCFR Survey Area (28.3 ± 0.4 °C). The average temperature in the GCFR Survey Area during the season 2017/18 was lower than the previous season 2016/17 (28.3 ± 0.4

°C, 21 days), but higher than season 2015/16 (23.7 ± 0.2 °C, 14 days; **Figure 7**).

Over the 21-day survey period, average wind speeds were slightly higher in the GBR (17.0 ± 0.4 km/h) than in the GCFR (13.7 ± 0.9 km/h). Over the past three seasons, the highest average weekly wind speed in the GCFR was recorded in 2016/17 at 16.6 km/h, while season 2017/18 recorded the lowest average weekly wind speed at 12.6 km/h (**Figure 8**). Additionally, the past three seasons recorded no more than a total of 3.2 mm of rainfall.

Further research over longer periods of time would be needed to make any conjectures regarding the effect of weather, climate and beach profile in the GCFR Survey Area on turtle nesting.

Daily weather records from both Survey Areas are provided in **Appendix B**.

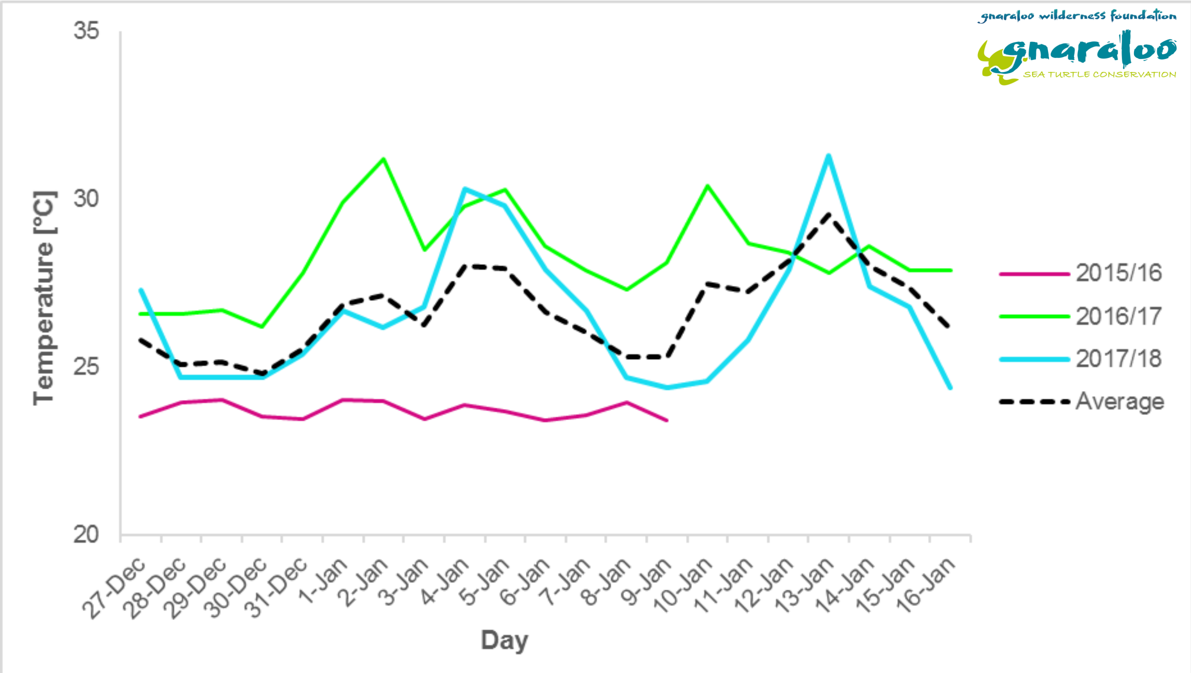

Figure 7: Weekly mean temperatures in GCFR Survey Area (27 Dec – 16 Jan), 2015/16 – 2017/18

Note: Weather data for the season 2015/16 is available for 2 weeks. The 3-week weather surveys commenced in 2016/17.

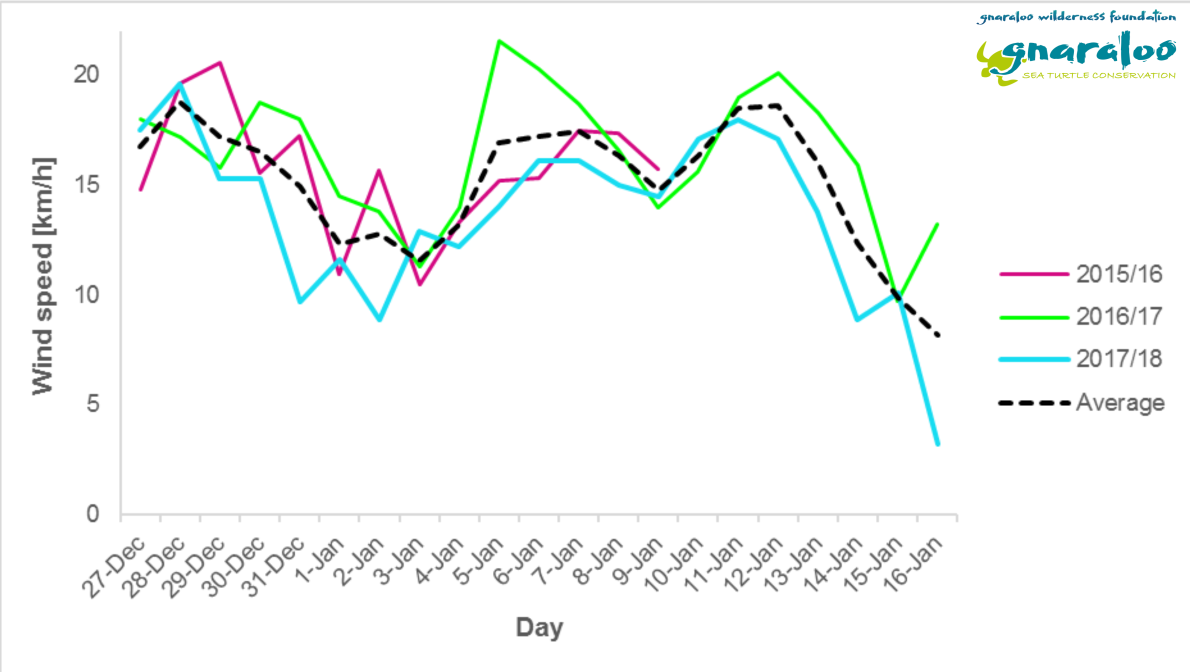

Figure 8: Weekly mean wind speeds in GCFR Survey Area (27 Dec – 16 Jan), 2015/16 – 2017/18

4 FERAL ANIMAL MERI MONITORING

4.1 Introduction

The Gnaraloo Feral Animal Control Program (**GFACP**) was initially started in 2008 by the Gnaraloo Station Trust to protect the Gnaraloo sea turtle rookeries from feral animals such as introduced European red foxes, feral cats and wild dogs. Prior to the commencement of the GFACP, a large proportion of sea turtle Nests in parts of the GBR Survey Area were affected by fox Predation (Butcher & Hattingh, 2013). It was considered that minimising the impact of feral Predation on sea turtle Nests through effective control strategies was critical to the reproductive success of the Gnaraloo sea turtles. From 2008/09 to the end of 2014/15, the GFACP was jointly managed by the Gnaraloo Station Trust and APMS, a specialised pest control company. Due to changes to the Gnaraloo pastoral lease area by the State Government which came into effect on 1 July 2015, the Gnaraloo Station Trust relinquished the management of the feral control program for the Gnaraloo coastline (which became public lands) to DBCA (WA), Rangelands NRM WA and APMS. However during 2015/16 to 2017/18, the Gnaraloo Station Trust and the GWF have continued work on feral animal MERI in the turtle Survey Areas.

Under the MERI work, the GTCP monitors and reports on the effectiveness in the GBR and GCFR Survey Areas of the feral animal control program for the Gnaraloo coastline (i.e. the extent of positive on-ground outcomes and quantifiable protection provided to sea turtles). The GTCP field research team records and reports any evidence of feral animal presence, Disturbance of turtle Nests, and/or Predation of turtle eggs during the early-morning beach surveys from 1 November to 28 February each year.

During the season 2017/18, the GTCP again recorded and shared the results of these feral animal MERI surveys, including Global Positioning System (**GPS**) details and photographic evidence of activity, with APMS in real time. Subsequent feral animal control activities by APMS focussed on specifically observed species and/or locations of feral animal activity in or around the rookeries. APMS acted on the GTCP's feedback to undertake targeted action during their ongoing feral animal control activities at Gnaraloo and adjusted, where required, the following: targeted species and areas, bait type used, bait placement strategy and other control methods used.

The GTCP has developed specific training, procedures and protocols since 2008 to ensure accurate daily identification of feral animal activities to monitor the success of the feral control program in the turtle Survey Areas. During the season 2017/18, APMS provided specialist training in feral animal track identification to the GTCP field research team at the start of the season. The training included office-based education, written assessments and field demonstrations. It provided the GTCP team members with the knowledge and skills necessary to confidently identify and accurately distinguish between fox, feral cat and wild dog tracks, which can be challenging in windblown locations such as the Gnaraloo coastline.

For further details and findings of the GFACP to 30 June 2015, see the annual reports. Below we present the results of the feral animal MERI surveys in the GBR and GCFR Survey Areas during 2008/09 - 2017/18.

4.2 Objectives

The objectives of feral animal MERI monitoring in the GBR and GCFR Survey Areas during the season 2017/18 were to:

- record evidence of feral animal activity (i.e. tracks, scats, Nest Disturbance or Nest Predation) during Day Surveys;
- integrate feral animal control by APMS with the GTCP for the most effective and efficient on-ground protection of the Nests in the turtle rookeries;
- facilitate informed adaptive feral animal control by APMS;
- allow real-time, on-ground responses by APMS to control specific feral animal presence in the turtle rookeries;
- conduct independent monitoring and reporting of the effectiveness in the turtle rookeries of the feral control program for the Gnaraloo coastline.

4.3 Material and methods

MERI monitoring in 2017/18 was conducted by the GTCP field research team during GBR and GCFR Day Surveys for four consecutive months and three weeks, respectively (**Chapters 5, 10**). The GTCP Procedure 2017/18 (2018) and prior GFACP annual reports (e.g. Butcher & Hattingh, 2015) contain detailed methods. Briefly, while surveying for turtle Nesting Activities during Day Surveys, GTCP researchers also recorded the presence of fox, feral cat or wild dog tracks and scats between the water and the start of the dune system. Any evidence of Disturbance (e.g. digging into Nest) or Predation (e.g. turtle eggshell fragments, whole turtle eggs or yolky turtle eggshells present at the surface, or an exposed egg chamber) of sea turtle Nests was also recorded. The start and end points of each track were recorded using a handheld GPS unit. If tracks could not be clearly identified and attributed to a species, photographs were taken for later consultation with APMS. To avoid duplication on subsequent days, tracks were wiped out after data collection.

4.3.1 Data analysis

A presence / absence approach was used for data analysis, meaning a day that recorded one or more tracks of a particular feral animal species was considered a single 'Track Day' for that species. This was necessary due to the inability to determine how many individuals were responsible for multiple tracks or track segments in the same day. As tracks from different species observed on the same day were counted as individual Track Days, it is possible to reach up to three Track Days for one survey day.

To compare feral animal activity in the GCFR and GBR, only identical survey periods were considered. GCFR monitoring occurred for 14 days (27 December – 9 January) in seasons 2014/15 and 2015/16. In seasons 2016/17 and 2017/18, the GCFR was monitored for 21 days (27 December – 16 January). The time period of 27 December – 9 January was used for a four – year comparison between the GBR and GCFR, while the time period of 27 December – 16 January was used for a two – year comparison between the two rookeries.

4.4 Results

4.4.1 Feral animal activity in GBR Survey Area

During the 120 survey days of the season 2017/18, a total of 44 feral animal tracks were observed by the field team across 32 survey days. 36 tracks were attributed to feral cats or wild dogs within the GBR Survey Area on 27 survey days. During 5 survey days, 3 feral cat tracks were located just outside of the Survey Area on route to the Sub-Section markers, and a further 5 wild dog tracks were determined to be domestic dogs due to their association with human footprints.

The majority of Track Days within the GBR Survey Area occurred within Sub-section GBN – BP7 (26), while Sub-sections BP7 – BP8 and BP8 – BP9 recorded a much lower number (2 and 1, respectively). The 29 Track Days were spread over 27 survey days, due to multiple tracks occurring on the same date.

No signs or evidence of fox presence was observed within the GBR Survey Area during the survey period (**Figure 9**).

Feral cat presence was observed on 23 survey days (19.2 %), with cat Track Days accounting for 85.2 % of all feral animal Track Days recorded within the GBR Survey Area (**Figure 10**). Within Sub-section GBN – BP7, cat tracks were observed on 22 survey days (18.3 %), frequently being seen in the dunes and along the edge of vegetation. On four different occasions, tracks were observed leading across three of the Sampled Nests, although no evidence of Disturbance or Predation was recorded. Feral cat tracks were only observed once within Sub-sections BP7 – BP8 and BP8 – BP9, with no signs of tracks, Disturbance or Predation on any monitored Sampled Nests.

Presence of wild dogs was recorded on 4 non-consecutive survey days (3.3 %) within Sub-sections GBN – BP7 and BP7 – BP8 (**Figure 10**). The majority of wild dog tracks was observed within Sub-section GBN – BP7, with tracks only being observed once within Sub-section BP7 – BP8. The wild dog tracks were often observed running along the water's edge and digging large pits, although no Disturbance or Predation was observed to any sea turtle Nests. On the first occasion (24 November 2017), the wild dog track was observed moving along Sub-section GBN – BP7, before moving into the dunes of Sub-section BP8 – BP9.

Further to that, no evidence of turtle Nest Disturbance or Predation was recorded from feral animals.

A detailed GBR Feral MERI Monitoring Log 2017/18 is available separately.

4.4.2 10-year trends of feral animal activity in GBR Survey Area

Total survey days varied from 83 to 120 days over the past 10 years (data labels in **Figure 9**). Fox presence in the GBR Survey Area has declined dramatically since the commencement of the GFACP in 2008 (**Figure 9**). During seasons 2008/09 and 2009/10, fox tracks were observed on 82.0 % (73 / 89) and 86.7 % (104 / 120) of total survey days, respectively. Since then, a total of 9 survey days with fox tracks have been recorded, split between seasons 2011/12 (3.4 %, 4 / 116), 2012/13 (3.4 %, 4 / 119) and 2016/17 (0.8 %, 1 / 120). There was no evidence of fox presence on the beach in seasons 2013/14 to 2015/16 or during season 2017/18 and no evidence of sea turtle Nest Disturbance or Predation by foxes.

The number of days when feral cat tracks were observed within the GBR Survey Area has varied widely, without obvious trends between seasons 2008/09 – 2017/18 (**Figure 9**). During a peak in season 2011/12, feral cat tracks were observed on 47.7 % (55 / 116) of total survey days, increasing significantly from observations on 2.4 % (2 / 83) of all survey days the previous season. Observations of feral cat tracks decreased constantly after season 2011/12 until season 2015/16, when feral cat tracks were observed on 39.2 % (47 / 120) of total survey days. Despite a slight decrease since, feral cat track observations have remained on a relatively high level with tracks observed on 32.5% (39 / 120) of all survey days in 2016/17, and on 19.2 % (23 / 120) of total survey days in 2017/18.

The presence of wild dog tracks in the GBR Survey Area increased gradually between seasons 2008/09 – 2014/15, peaking at 13.3 % (16 / 120) of total survey days observed with wild dog tracks in 2014/15 (**Figure 9**). Observations of wild dog tracks have since slowly decreased until season 2017/18, when dog tracks were seen on 3.3 % (4 / 120) of all survey days, compared to 1.7 % (2 /120) of survey days in season 2016/17.

During each of the past 10 monitoring seasons, the majority of feral animal tracks was observed in Sub-section GBN – BP7. Sub-sections BP7 – BP8 and BP8 – BP9 generally recorded substantially less survey days with tracks present, with Sub-section BP7 – BP8 mostly receiving more tracks than Sub-section BP8 – BP9 (**Figure 10**).

Although observations of feral cat and wild dog tracks have been very dynamic throughout seasons, little evidence of Disturbance or Predation of sea turtle Nests has been observed in the GBR Survey Area due to activity from these feral animals. The GTCP recorded one instance of Disturbance (not Predation) of a Nest in the GBR Survey Area during the season 2012/13, being digging by a feral cat on 17 December 2012 (Sub-section BP8 – BP9). During the season 2014/15, the GTCP recorded fresh tracks of 2 wild dogs on and around a turtle's tracks and her Nesting Activity (2 December 2014, Sub-section GBN – BP7, not Predation). This demonstrates that feral cats and wild dogs, along with foxes, are interested in the turtle Nests as possible food sources.

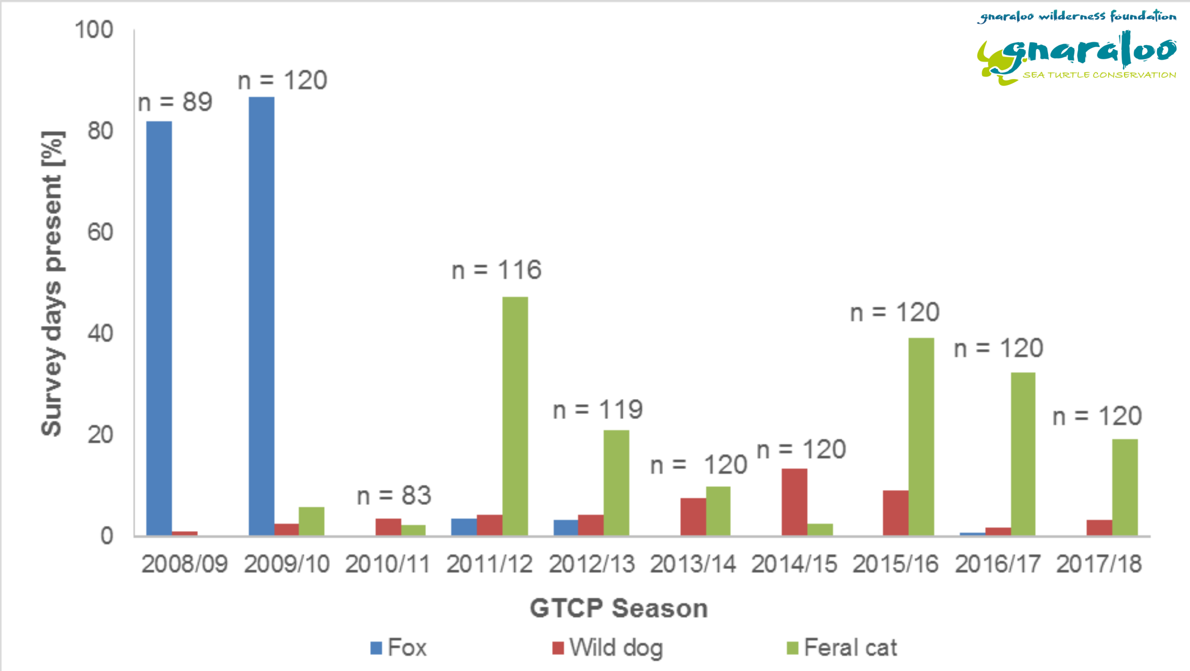

Figure 9: Feral animal presence in GBR Survey Area, 2008/09 – 2017/18

Note: Numbers indicate total number of survey days per season.

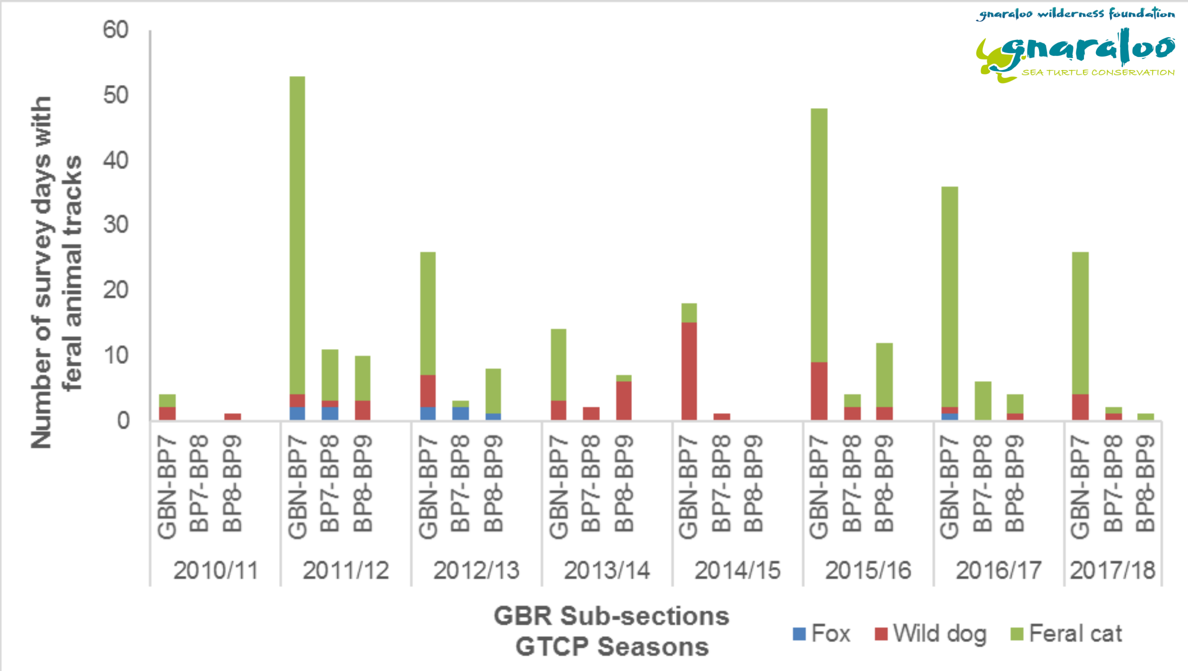

Figure 10: Feral animal presence per GBR Sub-section, 2010/11 – 2017/18

Note: Seasons 2008/09 and 2009/10 not included here as Sub-section delineation differed within the GBR Survey Area.

4.4.3 Feral animal activity in GCFR Survey Area

A total of 35 feral animal tracks on 16 survey days were observed during the 21-day monitoring period of the GCFR during the season 2017/18. All tracks were attributed to feral cats or wild dogs, with 32 tracks located within the GCFR Survey Area. 1 feral cat track was found in one of the parking areas outside the Survey Area and 2 wild dog tracks were observed on the road driving to the GCFR.

The majority of Track Days within the GCFR Survey Area occurred within Sub-section GFR - GLN (16), while Sub-section GRS – GFR recorded 6 Track Days. The 22 Track Days were spread over 18 survey days due to multiple tracks occurring on the same date.

No evidence of fox presence or activity was apparent during the three weeks of monitoring in the GCFR Survey Area.

Feral cats comprised the majority of the feral animal presence recorded in the GCFR Survey Area, with cat tracks recorded on 15 survey days (71.4 %, **Figure 11**). Feral cat tracks were observed on 14 survey days (66.7 %) in Sub-section Gnaraloo Farquhar Runway (**GFR**) to Gnaraloo Lagoon North (**GLN**), but only on 4 survey days (19.0 %) in Sub-section Gnaraloo Runway South (**GRS**) to Gnaraloo Farquhar Runway (**GFR, Figure 12**).

The presence of wild dogs was recorded on 3 survey days (14.3 %), with visual confirmation of the animal by the Day Survey team on one day (**Figure 11**). Dog tracks were observed on 2 survey days (9.5 %) in each Sub-section.

Although the presence of feral animals was recorded regularly in the GCFR, no signs of Disturbance or Predation of the sea turtle Nests or other interference with sea turtles and their Nesting Activities were observed.

A detailed GCFR Feral MERI Monitoring Log 2017/18 is available separately.

4.4.4 7-year trends of feral animal activity in GCFR Survey Area

Total survey days in the GCFR Survey Area varied from 9 to 21 days per season over the past seven years (data labels in **Figure 11**). Since feral animal monitoring began in the GCFR Survey Area in 2011/12, fox tracks have only been recorded once in season 2012/13 (**Figure 11**). No evidence of foxes has been observed since.

The presence of feral cats has varied over the past seven years, with no feral cat tracks recoded in seasons 2011/12, 2013/14, and 2015/16 (**Figure 11**). Seasons 2012/13, 2014/15 and 2016/17 had feral cat tracks occurring on 18.8% (3 / 16), 7.1 % (1 / 14), and 9.5 % (2 / 21) of survey days, respectively. Feral cat tracks peaked in season 2017/18, when tracks were observed on 71.4 % (15 / 21) of all survey days.

Wild dog tracks were regularly observed throughout the years, with the exception of seasons 2011/12 and 2015/16 (**Figure 11**). The highest occurrence of wild dog tracks on 14.3 % of all survey days was observed in seasons 2014/15 and 2017/18.

Feral animal track distribution was not confined to one particular Sub-section, but rather varied substantially over the seasons. In the past two seasons, Sub-section 3 (GFR – GLN) recorded more feral animal tracks than Sub-section 2 (GRS – GFR), but this pattern was not observed in any of the other seasons (**Figure 12**).

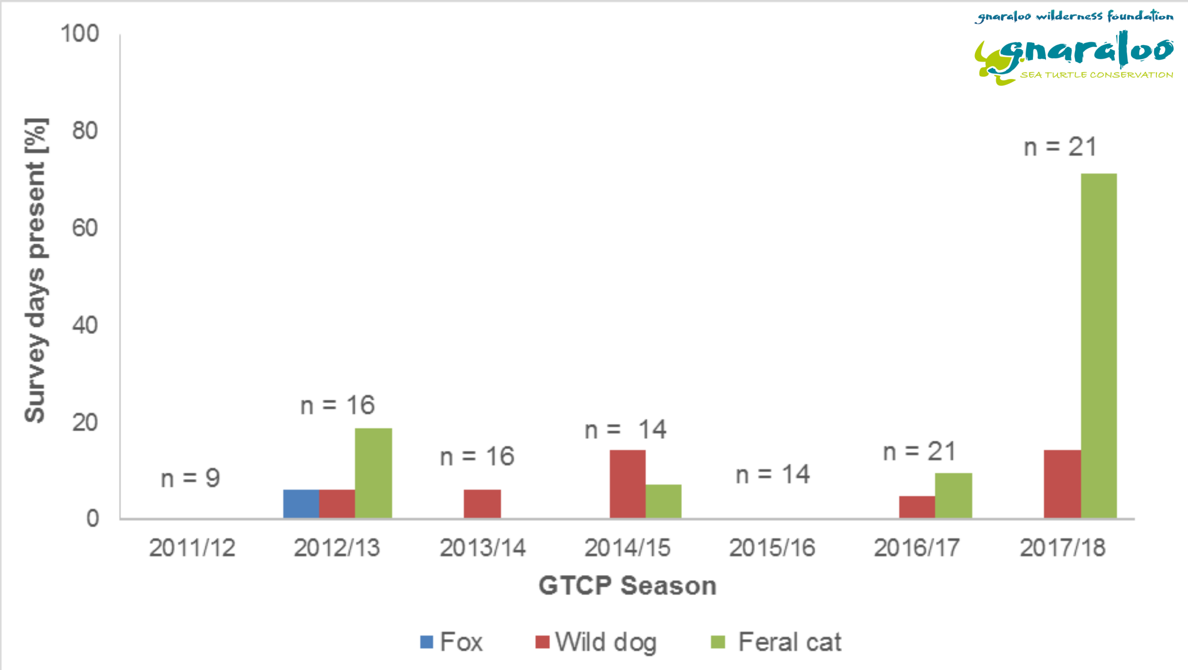

Figure 11: Feral animal presence in GCFR Survey Area, 2011/12 – 2017/18

Note: Numbers indicate total number of survey days per season. Seasons 2011/12 – 2013/14 covered 4 Sub-sections and seasons 2014/15 – 2017/18 surveyed 2 Sub-sections (being the areas with the highest turtle Nesting Activities since these surveys started in 2011/12).

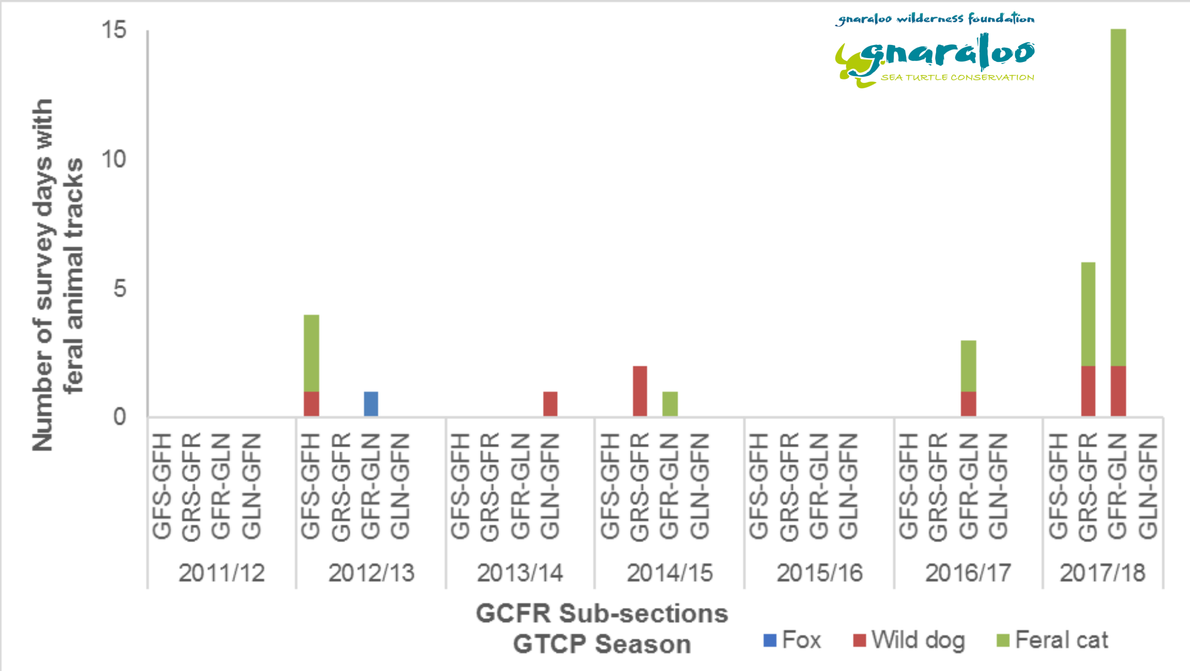

Figure 12: Feral animal presence per GCFR Sub-section, 2010/11 – 2017/18

Note: Seasons 2011/12 – 2013/14 covered 4 Sub-sections and seasons 2014/15 – 2017/18 surveyed 2 Sub-sections. Sub-sections GFS – GFH and GLN – GFN were not monitored after 2013/14.

4.4.5 Comparison of GBR and GCFR Survey Areas

4.4.5.1 4-year comparison for 14 days

Comparison of the 14-day identical monitoring periods (27 December to 9 January) over four years (2014/15 – 2017/18) reveals a varying presence of feral animals in the GBR and GCFR Survey Areas. No fox tracks were detected during this time in any of the four seasons in neither rookery.

Feral cat tracks during this time were observed in each of the four GTCP seasons in the GBR Survey Area (**Figure 13**). However, no feral cat tracks were found in the GCFR Survey Area in season 2015/16, which was the season with the highest occurrence of feral cat tracks in the GBR Survey Area. Feral cat track observations were identical or similar between the two rookeries during seasons 2014/15 and 2016/17, but were significantly more frequent in the GCFR Survey Area (57.1 %) in season 2017/18 compared to the GBR Survey Area (28.6 %).

No wild dog tracks were present during this time in either rookery during the seasons 2015/16 and 2016/17. For the remaining two seasons, wild dog tracks were present on more survey days in the GCFR Survey Area than in the GBR Survey Area (**Figure 13**).

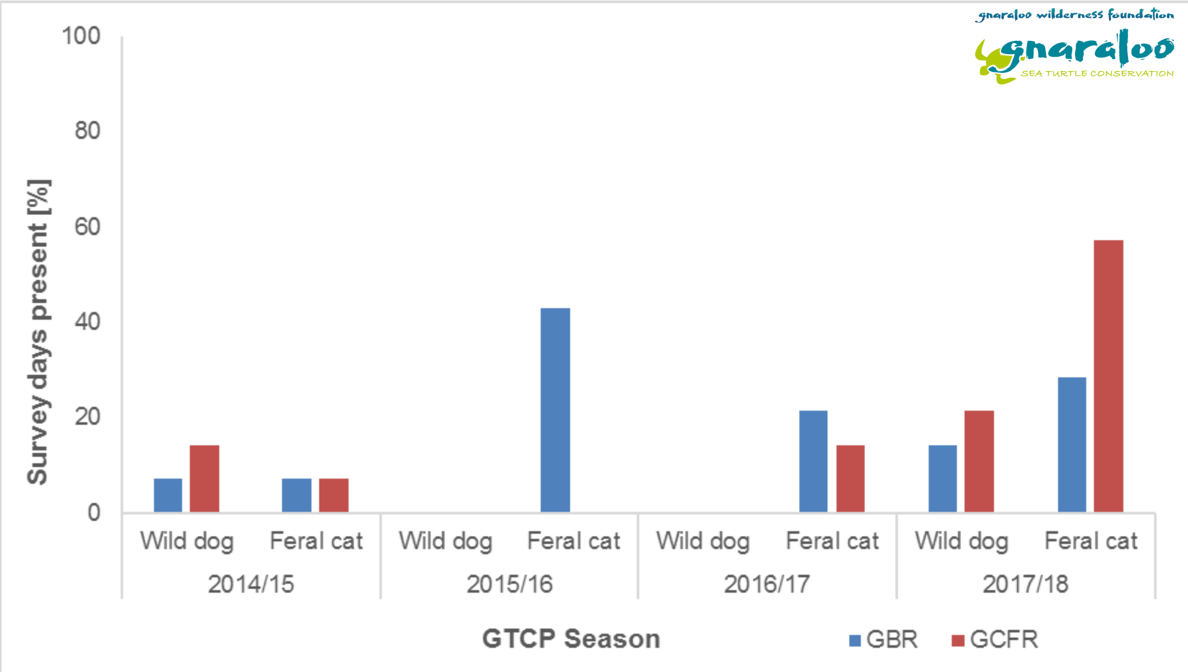

Figure 13: Comparison of feral animal presence in GBR and GCFR Survey Areas (27 Dec – 9 Jan), 2014/15 – 2017/18

4.4.5.2 2-year comparison for 21 days

Comparison of the 21-day identical monitoring period (being 27 December to 16 January) over two years (2016/17 – 2017/18) indicates no foxes were present in either rookery during this time (**Figure 14**).

Feral cat tracks during this time were more frequent in the GBR Survey Area than in the GCFR Survey Area during the season 2016/17 (**Figure 14**). However, there was a spike in survey days affected by feral cat tracks in season 2017/18 for the GCFR Survey Area (71.4 %), compared to 9.5 % in season 2016/17 and 23.8 % for the GBR Survey Area in 2017/18.

While no wild dog tracks during this time were recorded in the GBR Survey Area in season 2016/17, they were present on 19.1 % of the survey days in season 2017/18 (**Figure 14**). Wild dog track observation also increased in the GCFR Survey Area from 4.8 % of survey days in 2016/17 to 14.3 % in 2017/18.

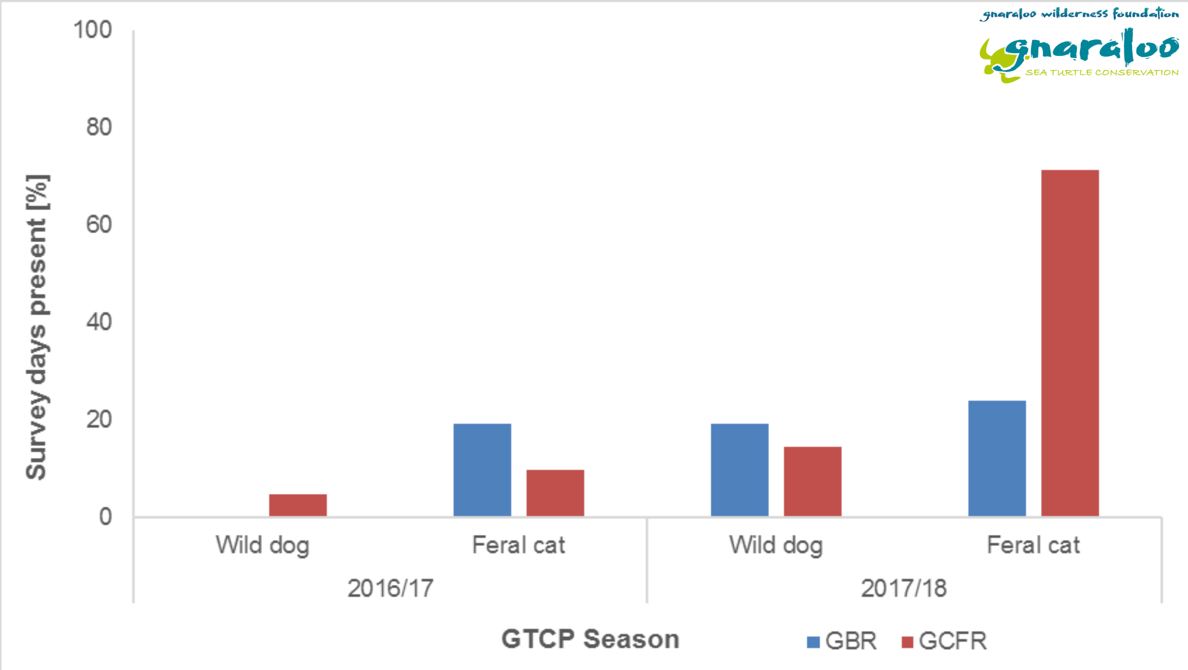

Figure 14: Comparison of feral animal presence in GBR and GCFR Survey Areas (27 Dec - 16 Jan), 2016/17 – 2017/18

4.5 Discussion

The results of the GTCP's feral animal MERI monitoring in the GBR and GCFR Survey Areas affirm the success of the ongoing feral control program on the Gnaraloo coastline. The season 2017/18 was the eighth consecutive season since season 2010/11, in which no sea turtle Nests were predated or disturbed by feral animal activities. This enormous effort contributes to an estimated 310,000 loggerhead turtle eggs[7] being protected from feral animal Predation during the past eight years in the GBR Survey Area. The number of eggs protected from feral animal Disturbance and

[7] Seasons 2010/11 – 2017/18 recorded a total of 2,771 loggerhead turtle Nests in the GBR Survey Area. With an average clutch size of 112 eggs (**Section 6.4**, Van Buskirk & Cowder, 1994), there were approximately 310,352 loggerhead turtle eggs laid in the GBR Survey Area during this time period. The influence of factors other than feral animals, such as native predators (e.g. crabs) and environmental impacts (shifting sand dunes, inundation, cyclones) on those Nests are not quantified here.

Predation in the GCFR Survey Area has not been quantified as full season surveys are not undertaken.

Days with no records of feral animal tracks did not necessarily indicate the absence of feral animals in the Survey Areas. Factors such as wind and researcher expertise could influence the accuracy of track detection and identification. Therefore, the feral animal presence reported here is conservative.

4.5.1 GBR Survey Area

Feral cat and wild dog tracks were observed throughout the entire GBR Survey Area, but occurred most frequently in Sub-section GBN – BP7. Interestingly, this Sub-section only gets a fraction of sea turtle Nests compared to Sub-section BP8 – BP9 (**Section 5.4**). Feral animal activity does not seem to be driven by the number of sea turtle Nests on a specific section of the beach. This is corroborated by the observations that even though some feral animal tracks went directly across Nests, no signs of digging or Predation were detected.

The 10 - year results display how successful the GFCP is in protecting sea turtle Nests from their main feral predator, the European red fox. It took two years of intense baiting after the program's commencement in 2008/09 to effectively control foxes (Butcher & Hatting, 2012, 2013). However, since season 2010/11, no more turtle Nests have been disturbed or predated by foxes, despite occasional track sightings throughout the years. This illustrates the importance of ongoing feral animal control, as cessation of the program would eventually lead to an influx of foxes from the surrounding properties to the detriment of the turtle Nests.

The 10 – year results also illustrate how feral cats benefit from the absence of foxes. The number of days when feral cat tracks were observed increased greatly two years after most of the foxes were eliminated. There is a high degree of dietary overlap between feral cats and foxes, leading to a competition for prey between the two mesopredators (Catling, 1988; Risbey. et al., 1999). By removing foxes through a control program, feral cat numbers have been shown to rise, mainly in response to increased prey availability (Risbey et al., 1999; Marlow et al., 2015). However, the removal of foxes may also allow feral cats to move around more freely and potentially expand their home ranges (Butcher, M., *personal communication*). As the current method does not allow the distinction of individual animals, it is not possible to determine whether the increase in observed feral cat tracks results from an increase in feral cat numbers, or from the same individuals moving around more. It is likely that both effects play a role in the numbers of cat tracks observed in the GBR Survey

Area, however, other factors are probable to contribute to the fluctuating number of cat tracks observed.

4.5.2 GCFR Survey Area

Feral animal tracks were recorded in both GCFR Sub-sections on the same survey day on multiple occasions, three times for feral cat and once for wild dog tracks. Since feral animal presence is recorded on a daily presence / absence basis, those days were recorded as one Track Day per species, as the same animal may have traversed both Sub-sections.

However, it is highly likely that more than one cat was present on the beach, as multiple cat tracks were recorded within the same area on several survey days. On 14 January 2018, clear cat prints of a mother and kitten were found alongside each other in Sub-section GFR – GLN. Nevertheless, this still counted as a single Track Day only so to not affect data analyses.

Multiple wild dog tracks and one wild dog were seen and recorded along the roads heading towards the GCFR Survey Area. This information was relayed to APMS; however, none of these were included in the Track Day analysis as they were outside the GCFR Survey Area.

Due to differences in survey periods and frequencies over the seven years of monitoring in the GCFR since 2011/12, feral track results are difficult to compare across the full monitoring period. A relative comparison of the percentage of survey days affected by a feral animal track reveals relatively low occurrences of feral animal tracks throughout the seasons. Importantly, fox tracks were only observed in season 2012/13, and no turtle Nests were disturbed or predated by feral animals in any of the seasons.

When compared to previous seasons, a significantly larger number of feral animal tracks was encountered in season 2017/18. While there are currently no means of quantifying feral animal track numbers more objectively, the observed differences may be attributed to differences in observation rather than differences in the actual abundance of feral animals. With an emphasis on recording feral animal presence along the Gnaraloo rookeries in season 2017/18, the monitored area often included the first part of the dunes behind the vegetation, where most of the tracks were found. Conversely, it seems that in some previous seasons, feral animal tracks were observed or recorded when they crossed with a sea turtle track on the beach.

4.6 Conclusion

Feral animal control along the Gnaraloo coastline remains a critical component of the sea turtle conservation strategy at Gnaraloo, as it has effectively eliminated Disturbance and Predation impact on sea turtle Nests by feral animals, predominantly foxes. This success has protected more than 310,000 loggerhead turtle eggs from feral animals in the past eight years in the GBR Survey Area alone. While the eradication of foxes may have contributed to an increase in feral cats, as indicated by a higher number of observed feral cat tracks, no evidence of Nest Predation by cats has been observed at Gnaraloo so far.

5 GBR DAY SURVEYS

5.1 Introduction

Annually since 2008/09, the GTCP has conducted early morning track surveys in the GBR Survey Area to monitor sea turtle Nesting Activity. These surveys are conducted for 120 consecutive days during 1 November – 28 February[8], with the aim of building a long-term data set that will be useful for elucidating Nesting Activity trends over a meaningful period. Temporal variation in the number of Nesting Activities or Nests per year in key rookeries can provide important insights into population trends (Limpus 2008; Witherington et al., 2009). Thus, daily nesting beach surveys during the breeding season can provide critical information on population health, contribute to conservation status assessments, identify populations for which management intervention is required, and allow for evaluation of the efficacy of management actions (e.g. Balazs & Chaloupka, 2004). Analysis of spatial trends in sea turtle Nesting Activity can help identify factors that influence Nest site selection (e.g. Wood & Bjorndal, 2000) and evaluate anthropogenic factors that may negatively impact nesting and/or Emergence success.

Beach surveys at Gnaraloo are particularly valuable due to the location of the rookeries. They are situated between Dirk Hartog Island (Reinhold & Whiting, 2014) to the south and the rookeries located further north along the Ningaloo coast, which are surveyed by the NTP in Exmouth (e.g. Markovina & Prophet, 2014). While the rookeries at Dirk Hartog Island and the north of the Ningaloo coast have been monitored for some time (Dirk Hartog Island monitoring began in 1993/94, while the NTP was established in 2002/03), formal monitoring at Gnaraloo only began in 2008/09. Since then, monitoring at Gnaraloo has been bridging an important data gap between the rookeries on Dirk Hartog Island and further north along the WA mainland coast.

5.2 Objectives

The objectives of Day Survey monitoring in the GBR Survey Area during 2017/18 were to:

- complete the daily nesting beach monitoring dataset which began in 2008/09;
- identify the species of nesting sea turtles;

[8] Minor deviations from this timing have occurred (Notes to **Table 1**).

- evaluate trends in the number of nesting loggerhead and green turtles over ten seasons from 2008/09 – 2017/18;
- assess spatial and temporal trends in the distribution of loggerhead turtle Nesting Activities to gain insight into factors influencing Nest site selection and Nesting success.

5.3 Material and methods

5.3.1 Study area

Gnaraloo Bay is located adjacent to the NMP, Ningaloo Coast World Heritage Area and Ningaloo Coast National Heritage Listed Area.

Daily beach track monitoring during 2017/18 was conducted in the GBR Survey Area (-23.76708° S; 113.54584° E to -23.72195° S, 113.57750° E), a 6.7 km long, sandy beach, starting at the northern end of the Gnaraloo Bay Marine Sanctuary Zone of the NMP (**Appendix A2**). The GBR Survey Area stretches from the Gnaraloo Bay North (**GBN**) marker in the south to BP9 in the north and is divided into three Sub-sections: GBN – BP7 (3.35 km), BP7 – BP8 (1.63 km) and BP8 – BP9 (1.72 km).

The topography of the Gnaraloo Bay shoreline ranges from wide, flat, low-energy beaches at the southern and northern ends to steep, high-energy beaches backed by large dynamic dune systems throughout the midsection (north of BP7). Throughout season 2017/18, the beach profile in the GBR Survey Area was characterised by large, rapidly shifting sand dunes and ocean swells that resulted in large escarpments and bedrock exposed intermittently on long stretches along the beach. High tides create powerful waves and escarpments of up to one metre between beach and steep dunes. Vegetation is sparse, primarily comprising low-lying shrubs on or behind the dunes. The benthic habitat supports a coral reef system intermixed with sand-bottomed channels (Thomson et al., 2016).

5.3.2 GBR Day Survey protocol

The GTCP Procedure 2017/18 sets out the complete Day Survey protocol. Briefly, each morning from 1 November 2017 to 28 February 2018, the GBR Survey Area was walked by two researchers. Sea turtle Nesting Activities were recorded and their location noted using a hand-held GPS unit. Recorded Nesting activities included: Nest (**N**), Unsuccessful Nesting Attempt (**UNA**), U-Track (**UT**) or Unidentified Activity (**Ua**). The species creating each activity was assessed based on track characteristics, and track width was measured and recorded. Track widths of turtles which had part or all of a flipper missing were excluded from analysis.

5.3.3 Estimating the number of nesting female loggerhead turtles

Determining the number of females comprised in the breeding population at Gnaraloo is challenging as conversion parameters such as remigration intervals and number of clutches per female per season are not known for the population. These parameters are known to differ greatly between populations and have not been determined for the WA loggerhead turtle population. A rough estimate of the number of female loggerhead turtles nesting in the GBR Survey each season was derived by dividing the total number of Nests for each season by the mean of the estimated clutch frequency per year derived from satellite telemetry (Scott, 2006; Rees et al., 2010; Tucker, 2010). Published clutch frequencies of different loggerhead turtle populations range from 2 to 8, with a mean of 4.9 ± 0.5 clutches per season per female. To make an estimate of the entire nesting population, remigration intervals of 3 – 5 years were assumed (Casale & Tucker, 2017).

5.3.4 Correlating Nesting Activities with spring and neap tides

Spring tides around full and new moons are characterised by tidal amplitudes higher than average. During the survey period, spring tides at Gnaraloo had particularly high amplitudes around the full moon, with slightly smaller amplitudes around the new moon. The more moderate tidal amplitudes of neap tides occur between the spring tides during quarter moons (Carnarvon, WA tidal chart, Australian Bureau of Meteorology). As the tides are influenced by the moon, lunar phases from November to February were used to quantify loggerhead turtle emergence timings with the tidal cycles. For ease of analysis, 'moon weeks' were created which included the day of one of the main lunar phases (i.e. full, last quarter, new, first quarter) plus the three days before and after. However, due to the lunar cycle lasting 29.5 days (Lunar and Planetary Institute, 2018), 'moon weeks' around quarter moons lasted either 7 or 8 days. All Nesting Activities from season 2017/18 were then added up during each 'moon week'.

5.3.5 Wind effects on track interpretation

Weather Data was collected according to the GTCP Procedure 2017/18 and **Chapter 3** of this report**.** Any days where comments on Day Survey data sheets indicated Nesting Activities as being windblown were used for analysis. The maximum recorded wind speed and the predominant wind direction between 23:00 and 6:00 of the night immediately preceding Day Surveys were used for analysis.

5.3.6 Data analysis

Nesting success rate was calculated as the ratio of Nests and total Nesting Activities. Uas were excluded from this analysis.

Statistical analysis of all data was performed using the Data Analysis add-on package for Excel (Microsoft Office 2016). Long-term trends were analysed using linear regression. Direct comparisons of mean values were analysed using a t-test (two-sample assuming unequal variances, $\alpha = 0.05$). All data are given as mean ± SD.

5.3.7 GBR Maps

A detailed description can be found in the GTCP GIS Manual 2017/18 (2018). Briefly, GBR maps (**Appendix A**) were created using ArcGIS Desktop 10.2.2 and the Spatial Analyst extension. The maps were created by projecting GPS co-ordinates recorded during Day Surveys onto the Geocentric Datum of Australia (**GDA**) 1994 (Map Grid of Australia Zone 49) co-ordinate system. To represent all the data collected throughout the season, the GBR maps include a variety of point distribution maps and density hotspots. Point distribution maps were created by designating a single point per activity and allocating various colours in order to represent different categories of data. Density hotspots along the Survey Area were calculated using the kernel density model of the ArcGIS Spatial Analyst toolset. Using a selected radius of 100 m, the kernel density model calculated the number of point features within the specified radius of each cell generating a smooth raster showing areas of high density versus low density along the Survey Area.

5.4 Results

5.4.1 Nesting Activities

A total of 516 Nesting Activities were observed in the GBR Survey Area during 2017/18, including 284 Nests, 162 UNAs, 67 UTs and 3 Uas. This represents the second lowest number of total Nesting Activities (the lowest season being 2015/16) and lowest number of Nests recorded since monitoring began in 2008/09. All activities for which the species could be identified were attributed to loggerhead turtles, except for a single green turtle U-Track. The species could not be determined for 3 Unsuccessful Nesting Attempts (**Figure 15**).

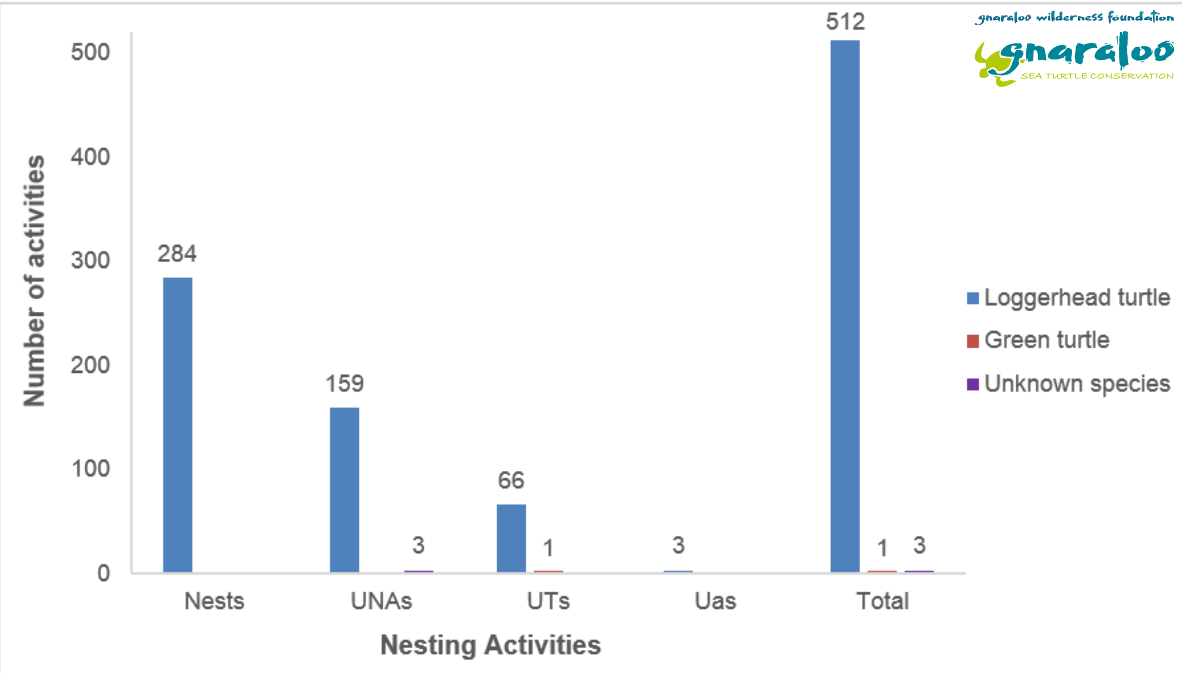

Figure 15: Sea turtle Nesting Activities in GBR Survey Area (1 Nov – 28 Feb), 2017/18

The average loggerhead turtle track width was 65.4 ± 6.8 cm, while the green turtle track width was significantly wider at 102 cm. The majority of tracks were between 55 - 70 cm wide (**Figure 16**).

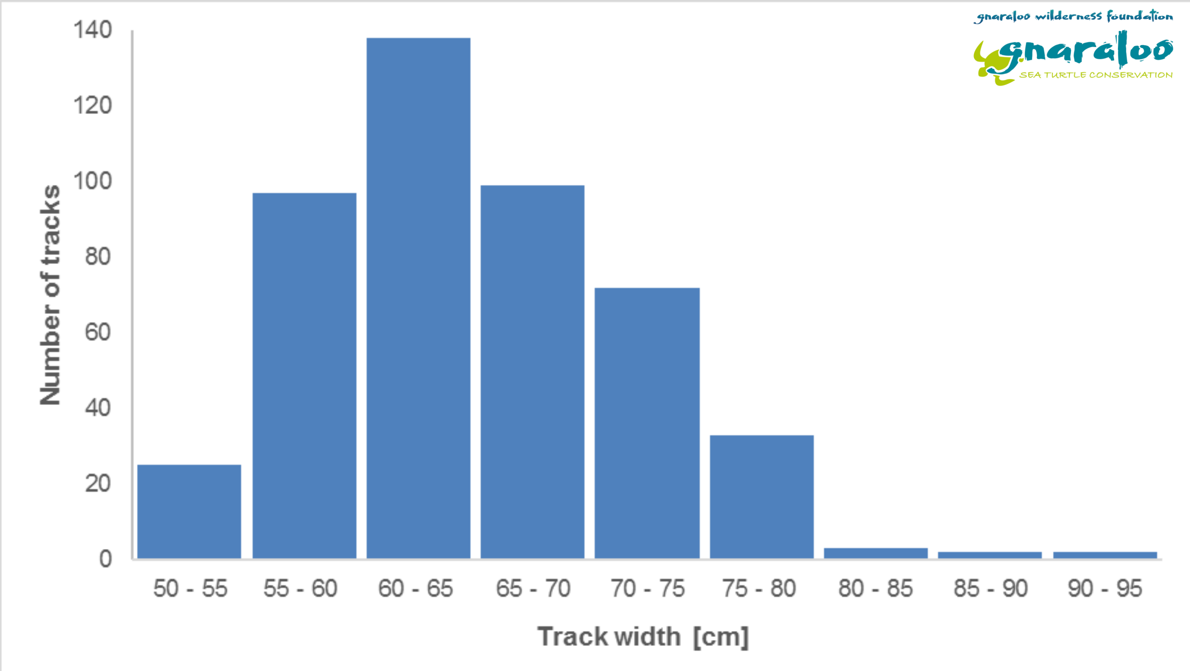

Figure 16: Loggerhead turtle track widths in GBR Survey Area (1 Nov - 28 Feb), 2017/18

5.4.2 Spatial distribution of Nesting Activities

Nesting Activities (including Uas) during 2017/18 were concentrated in Sub-section BP8 – BP9 (365 / 516 total activities, 70.7 %), followed by Sub-sections GBN – BP7 (111, 21.5 %) and BP7 – BP8 (40, 7.8 %). Nests followed the same pattern, with the majority (218 / 284, 76.8 %) occurring in Sub-section BP8 – BP9, followed by Sub-sections GBN – BP7 (50, 17.6 %) and BP7 – BP8 (16, 6.0 %; **Figure 17**).

Nesting success followed the same trend, with the highest success rate in Sub-section BP8 – BP9 (60.2 %) and lower success rates in Sub-sections GBN – BP7 (45.0 %) and BP7 – BP8 (40.0 %). The overall Nesting success rate for season 2017/18 was 55.4 %, which is slightly below the 10-year average (57.6 ± 7.8 %; **Figure 17**). The distribution of Nesting Activities, Nests, and Nesting success are consistent with all previous seasons. Similar to previous seasons, mapping of Nest densities within each Sub-section revealed low density and patchy nesting throughout Sub-sections GBN – BP7 and BP7 – BP8 and higher density nesting with some hotspots throughout Sub-section BP8 – BP9 (**Appendices A4, A5**).

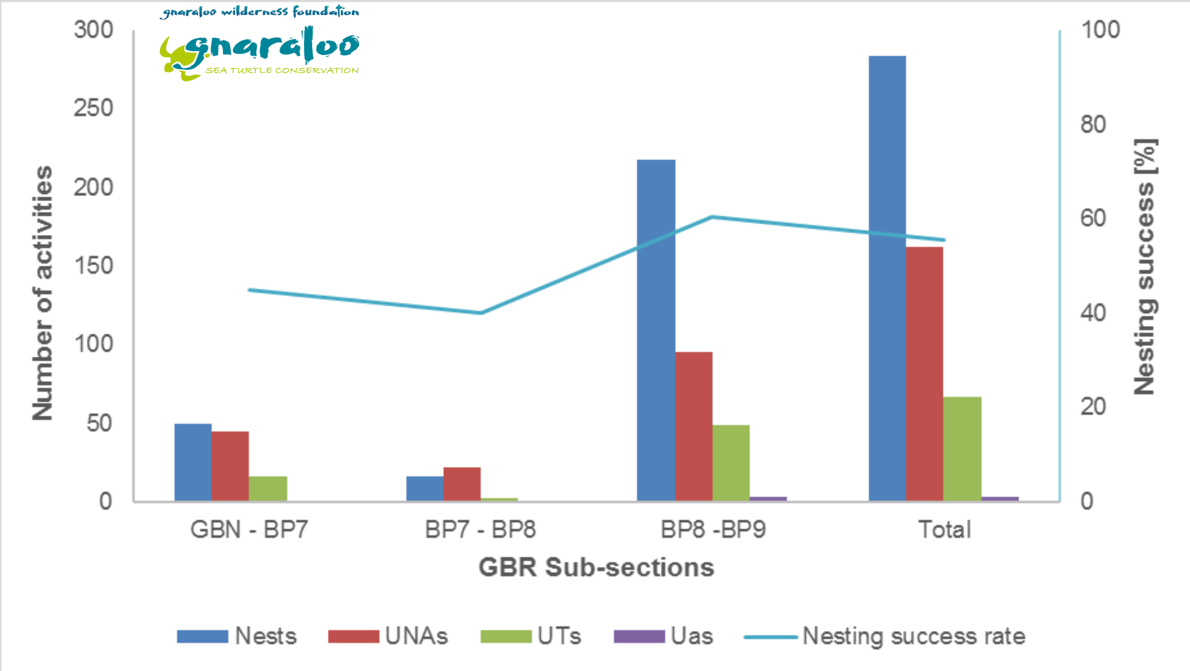

Figure 17: Nesting Activities (bars) and Nesting success (blue line) in GBR Sub-sections (1 Nov – 28 Feb), 2017/18

Note: Number of Nesting Activities are listed on left Y-axis, Nesting success rate is listed on right Y-axis

5.4.3 Temporal distribution of Nesting Activities

No old Nesting Activities were observed in the GBR Survey Area one day prior to the commencement of the field season on 1 November 2017. The first Nesting Activity (Nest) was recorded on 10 November 2017 and additional activities progressed gradually through late November and early December 2017. An increase in Nesting Activities and Nests was recorded between mid-December 2017 and late January 2018 (**Figure 18**). Following the peak nesting season, Nesting Activities during 2017/18 dropped considerably to a total of only 33 Nesting Activities between 31 January and 28 February 2018 as compared to the 10 – year average of 69 Nesting Activities for the same time period (**Figures 19, 21**). The last Nesting Activity (Nest) for Season 2017/18 occurred on 21 February 2018.

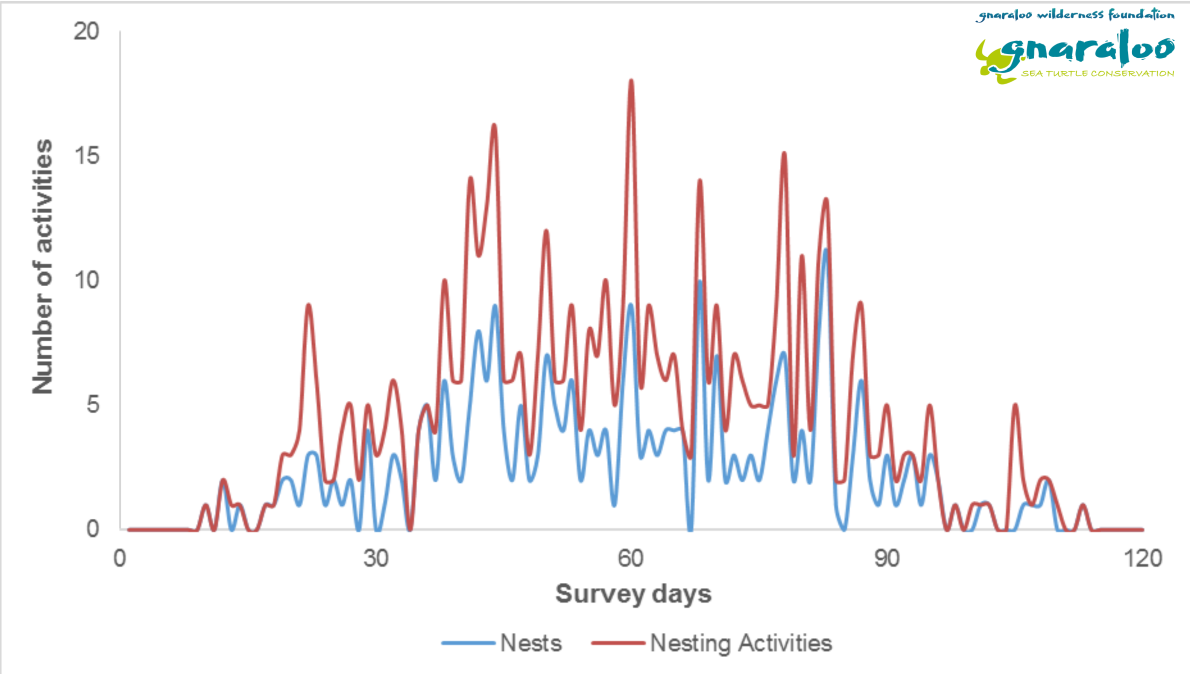

Figure 18: Daily Nesting Activities and Nests in GBR Survey Area (1 Nov – 28 Feb), 2017/18

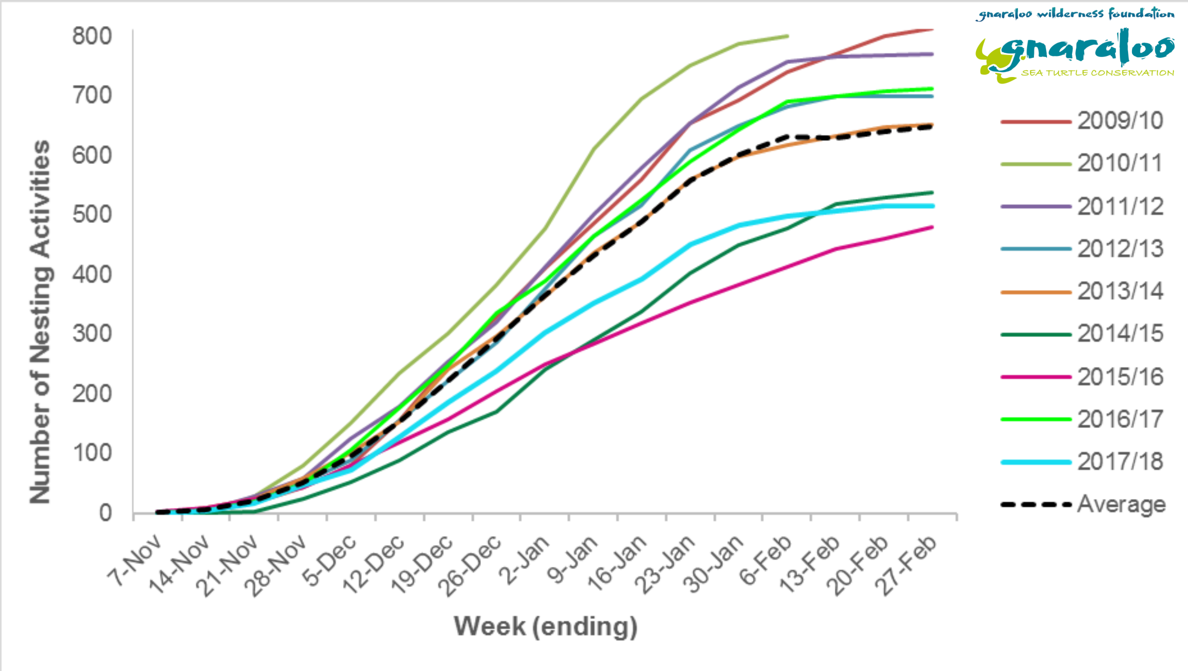

Figure 19: Cumulative weekly Nesting Activities in GBR Survey Area (1 Nov – 28 Feb), 2009/10 – 2017/18

5.4.4 Multi-year trends in GBR

5.4.4.1 Species composition since 2008/09

Loggerhead turtles are the predominant species in the Gnaraloo Survey Areas, accounting for 95.4 % of all Nesting Activities. 2.6 % of all Nesting Activities are attributed to green turtles, while the species of the remaining activities could not be identified (1.9 %; **Figure 2**).

5.4.4.2 Nesting Activities and Nests since 2008/09

The total number of Nesting Activities (including Uas) per season during 2009/10 – 2017/18[9] ranged from 480 (2015/16) to 813 (2009/10), with an average of 664.7

[9] Only Nest numbers were recorded during 2008/09, other Nesting Activity (i.e. UNA, UT and Ua) numbers were not recorded during the first year of the program. All necessary data were recorded for all Nesting Activity types in the remaining seasons 2009/10 – 2017/18. The Nest total for 2008/09 is included because dates and locations for all Nests were recorded.

± 126.1 Nesting Activities. With exception of season 2016/17, Nesting Activities show a decreasing trend ($r^2 = 0.63$; **Figure 20**).

The total number of Nests per season during 2008/09 – 2017/18 ranged from 284 (2017/18) to 522 (2009/10), with an average of 370.6 ± 74.2 Nests. A periodicity of peaks every 3 – 4 seasons is apparent, with no significant trend in nesting numbers obvious ($r^2 = 0.18$; **Figure 20**).

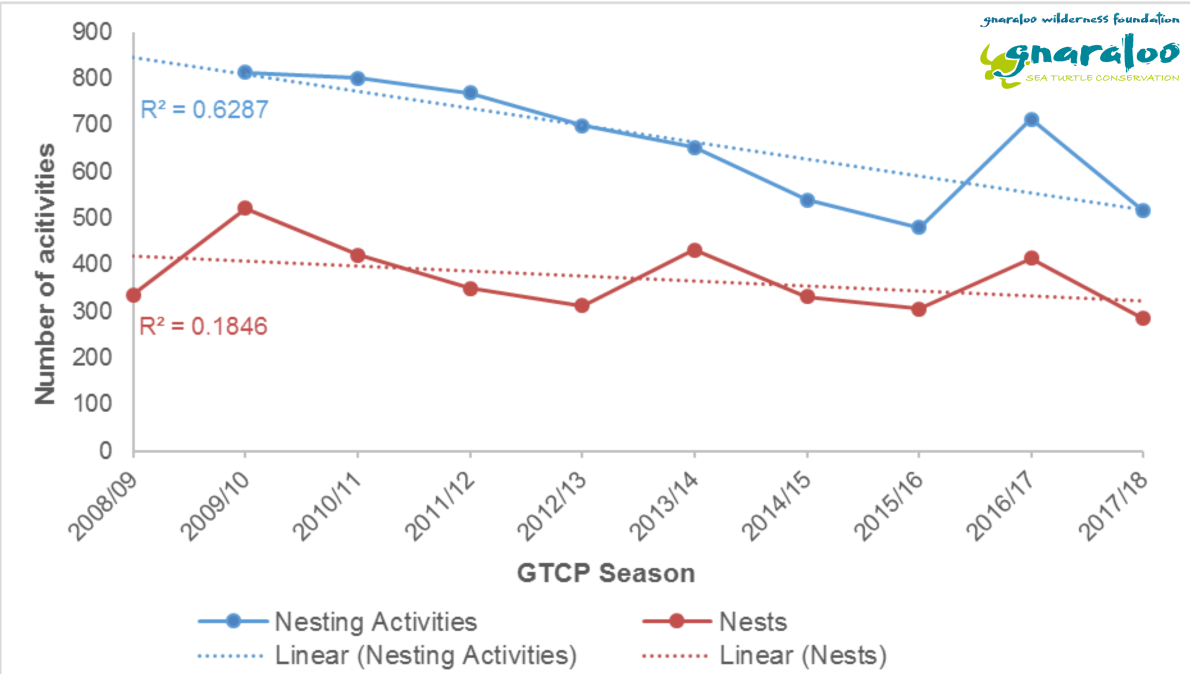

Figure 20: Nesting Activities and Nests in GBR Survey Area, 2008/09 – 2017/18

Note: Season 2008/09 Nesting Activity data are not included as researchers did not record the details of emergences that did not result in Nests (i.e. UNAs, UTs).

The peak in Nesting Activities and Nests during season 2017/18 was less pronounced than in most previous seasons (**Figure 21**). On average over the past 10 seasons, the GBR received 405 Nesting Activities and 224 Nests from 13 December – 23 January. However, during season 2017/18, only 323 Nesting Activities and 180 Nests occurred during this 6 – week period.

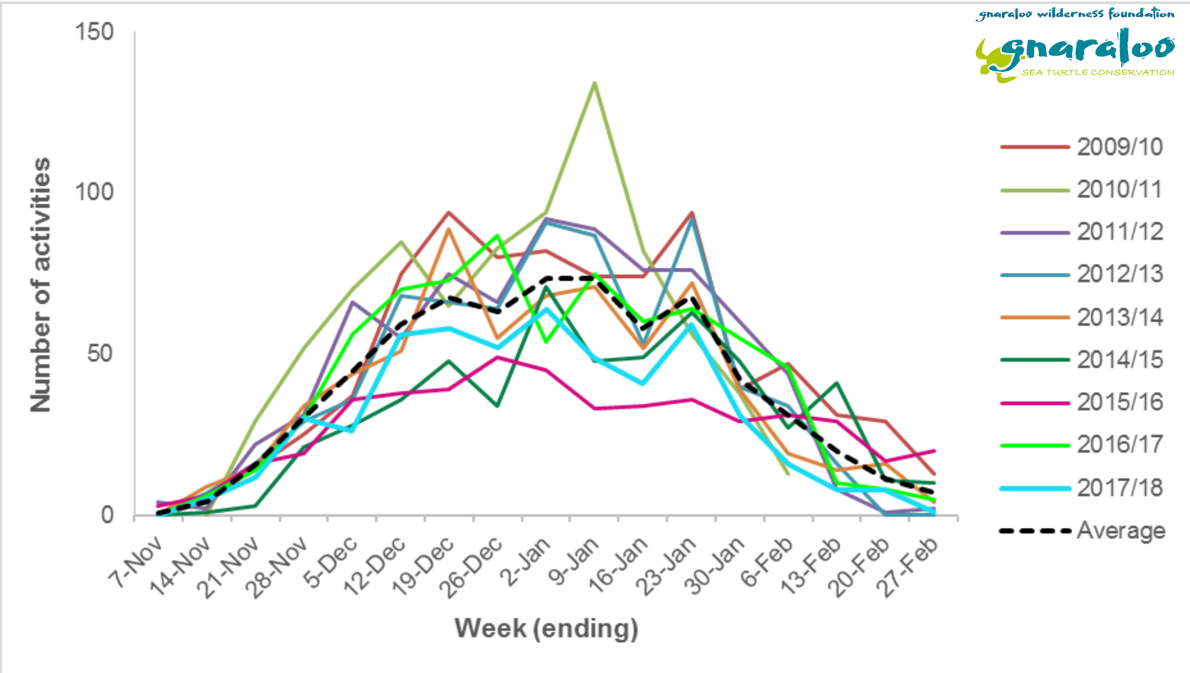

Figure 21: Weekly Nesting Activities in GBR Survey Area (1 Nov - 28 Feb), 2009/10 – 2017/18

Note: Season 2008/09 Nesting Activity data are not included as researchers did not record the details (date, location) of emergences that did not result in Nests (i.e. UNAs, UTs).

5.4.4.3 Nesting Activities and Nests by Sub-section since 2008/09

The number of Nesting Activities per Sub-section recorded each season fluctuated substantially between 2010/11 – 2017/18. Nesting Activities in Sub-section GBN – BP7 had the greatest range of activities from 83 (2014/15) to 251 (2011/12), while the range was smallest in Sub-section BP7 – BP8, from 34 (2015/16) to 94 (2010/11). Nesting Activities ranged from 365 (2017/18) to 511 (2013/14) in Sub-section BP8 – BP9, which on average also had the highest number of Nesting Activities per season (436.5 ± 50.3). Average numbers of Nesting Activities per season were significantly lower in Sub-sections GBN – BP7 (148.4 ± 62.0, $p < 0.001$) and BP7 – BP8 (61.3 ± 20.6, $p < 0.001$; **Figure 22**) compared to Sub-section BP8 – BP9.

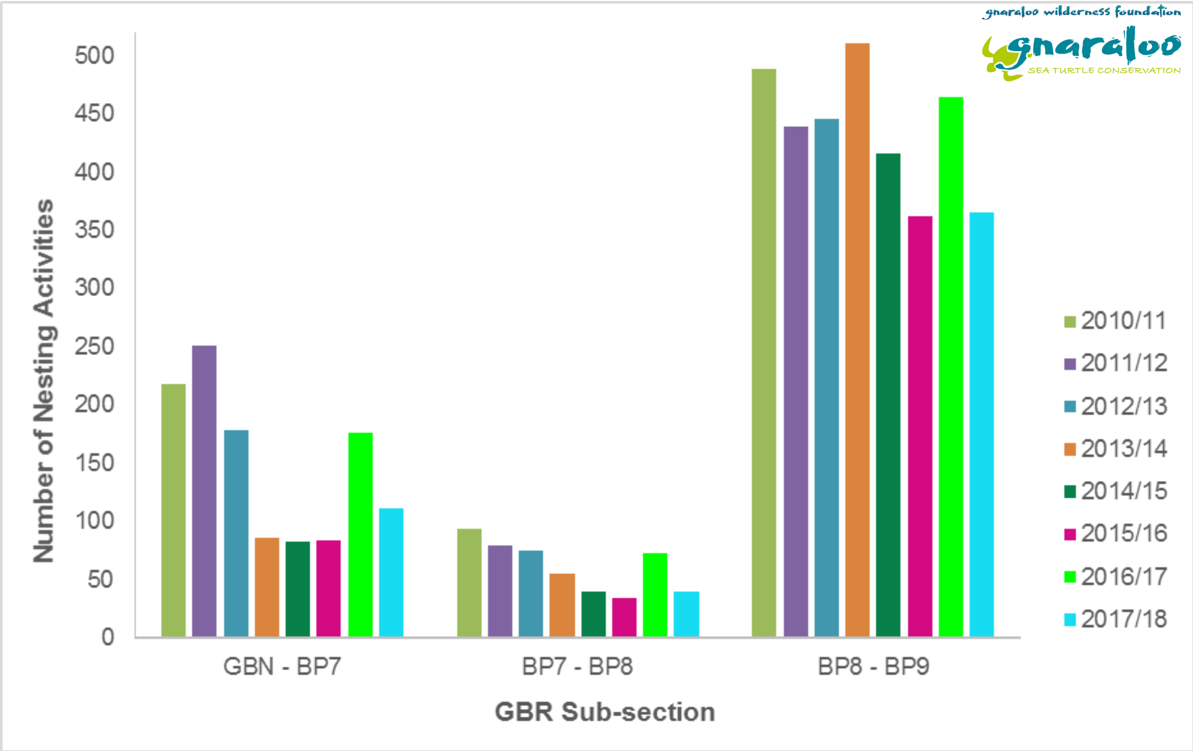

Figure 22: Nesting Activities in GBR Sub-sections (1 Nov – 28 Feb), 2010/11 – 2017/18

Note: Different Sub-section breaks were used during 2009/10 (i.e. GBN – BP6, BP6 – BP7 and BP7 – BP9) and the locations of some UNA and UT were not recorded, so it was not possible to allocate these activities to particular Sub-sections. Therefore, this season is excluded.

The number of Nests per season during 2008/09 – 2017/18 was consistently highest in Sub-section BP8 – BP9 (248.10 ± 48.3), while significantly fewer Nests per season were laid in Sub-sections GBN – BP7 (91.0 ± 37.5, $p < 0.001$) and BP7 – BP8 (31.6 ± 15.9, $p < 0.001$; **Figure 23**). The trend in Nest numbers in Sub-sections GBN – BP7 and BP7 – BP8 is slightly decreasing ($r^2 = 0.62$ and $r^2 = 0.42$, respectively), while no trend was obvious in Sub-section BP8 – BP9 ($r^2 = 0.04$).

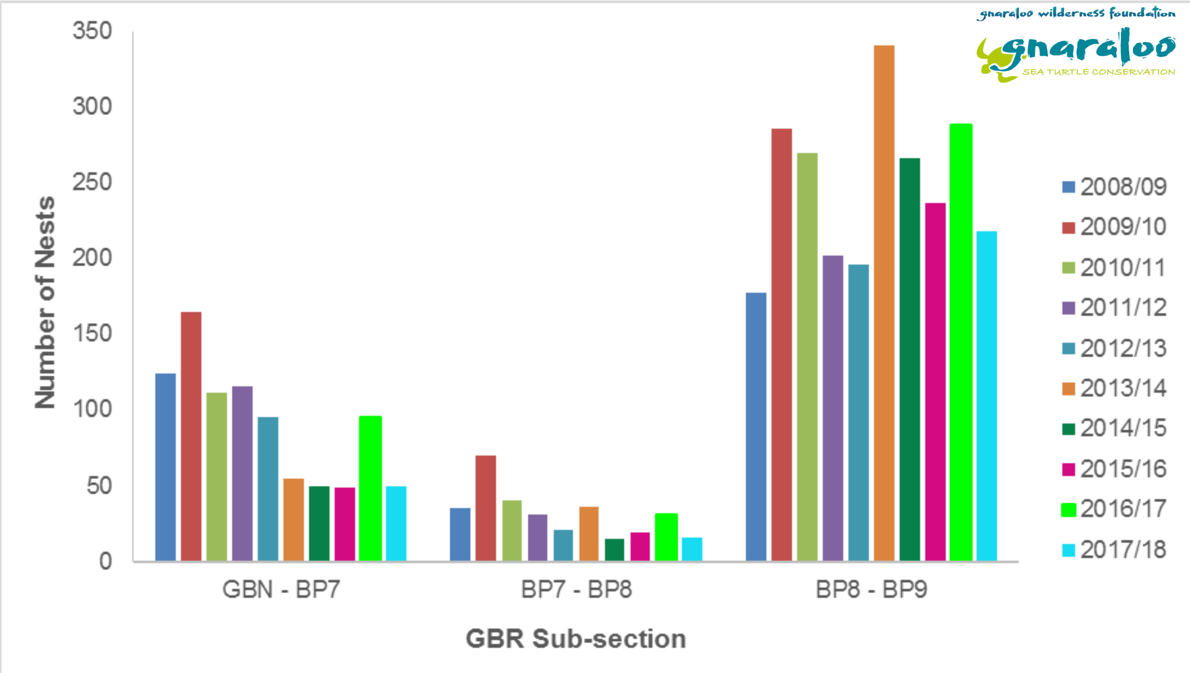

Figure 23: Nests in GBR Sub-sections, 2008-09 – 2017/18

5.4.4.4 Nesting Success since 2009/10

Overall Nesting success in the GBR Survey Area, as determined from Day Survey data, varied greatly over the nine seasons, ranging from 46.0 % (2011/12) to 67.3 % (2009/10), with an average Nesting success rate of 57.5 ± 7.8 % (**Figure 24**). No significant trend in Nesting success rate is apparent since 2009/10 (r^2 = 0.04).

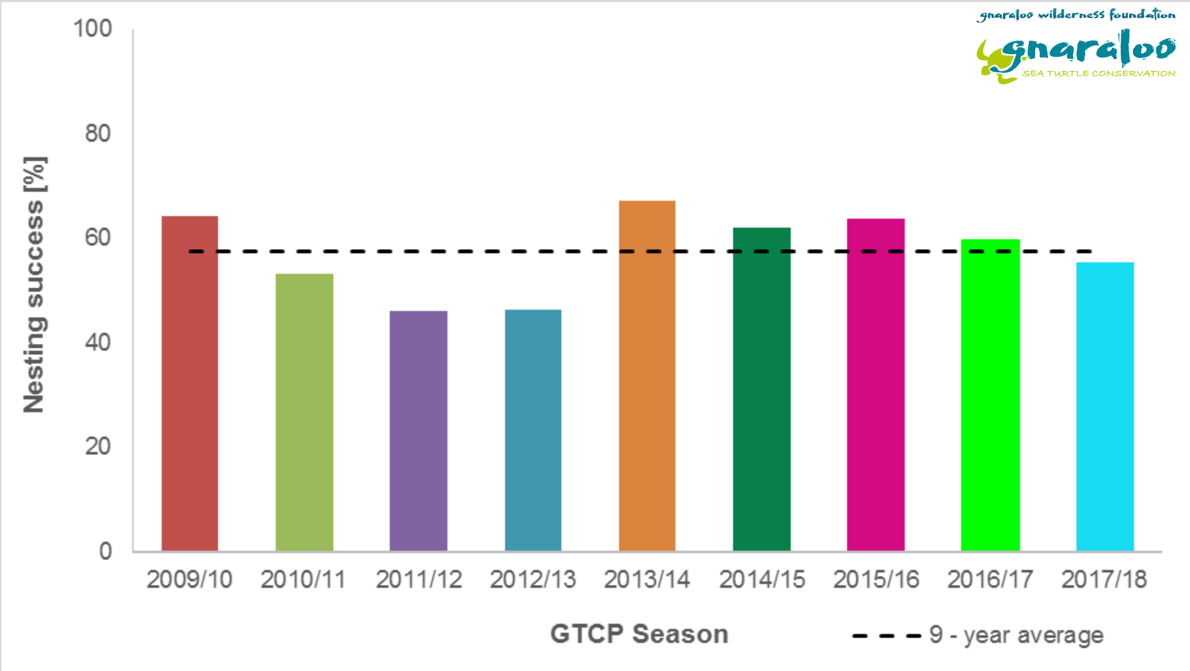

Figure 24: Nesting success rate in GBR Survey Area (1 Nov – 28 Feb), 2009/10 – 2017/18

While Nesting success rates for each of the Sub-sections fluctuated substantially over the years, Sub-section BP8 – BP9 consistently had a Nesting success rate of 60 % or higher since season 2013/14. On average over the nine seasons, Sub-section BP8 – BP9 had the highest Nesting success rate (58.8 ± 0.1 %), while Sub-sections GBN – BP7 and BP7 – BP8 had lower Nesting success rates (54.7 ± 0.1% and 44.9 ± 0.1 %, respectively; **Figure 25**).

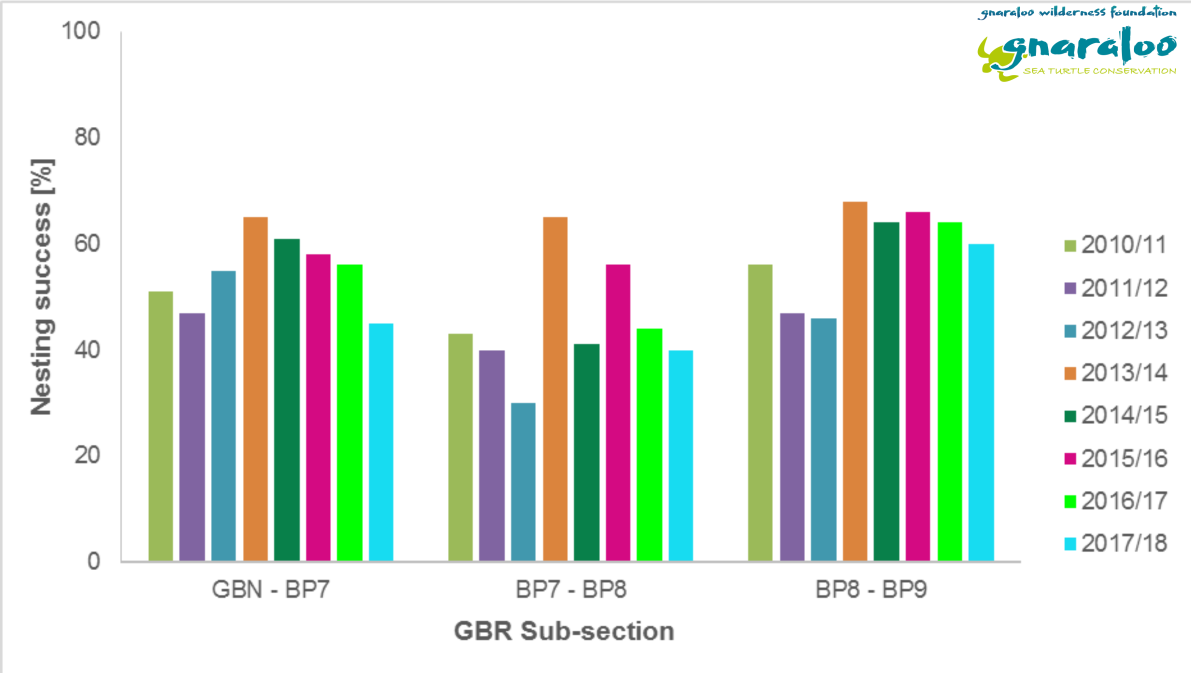

Figure 25: Nesting success rates in GBR Sub-sections (1 Nov – 28 Feb), 2010/11 – 2017/18

5.4.5 Number of nesting female loggerhead turtles

A total of 284 loggerhead turtle Nests were laid in the GBR Survey Area during Day Surveys in 2017/18. Hence, it is estimated that between 53 - 65 female loggerhead turtles nested in the GBR Survey Area during the season 2017/18.

Based on the number of Nests laid in the GBR Survey Area during each season, it is estimated that between 60 and 120 female loggerhead turtles nest in the GBR Survey Area during any nesting season. As remigration intervals for these females are currently not known and likely highly variable, estimates for the total population of nesting turtles in the GBR range from 200 – 450.

5.4.6 Nesting Activities correlation with lunar and tidal cycles

Loggerhead turtles during the season 2017/18 were 16 % more likely to emerge during moderate neap tides (277 / 516 Nesting Activities) than during spring tides (239; **Figure 26**). While Nesting Activities around new moons (133) were only slightly lower than during waning (139) and waxing (138) quarter moons, there were significantly less emergences around full moons (106).

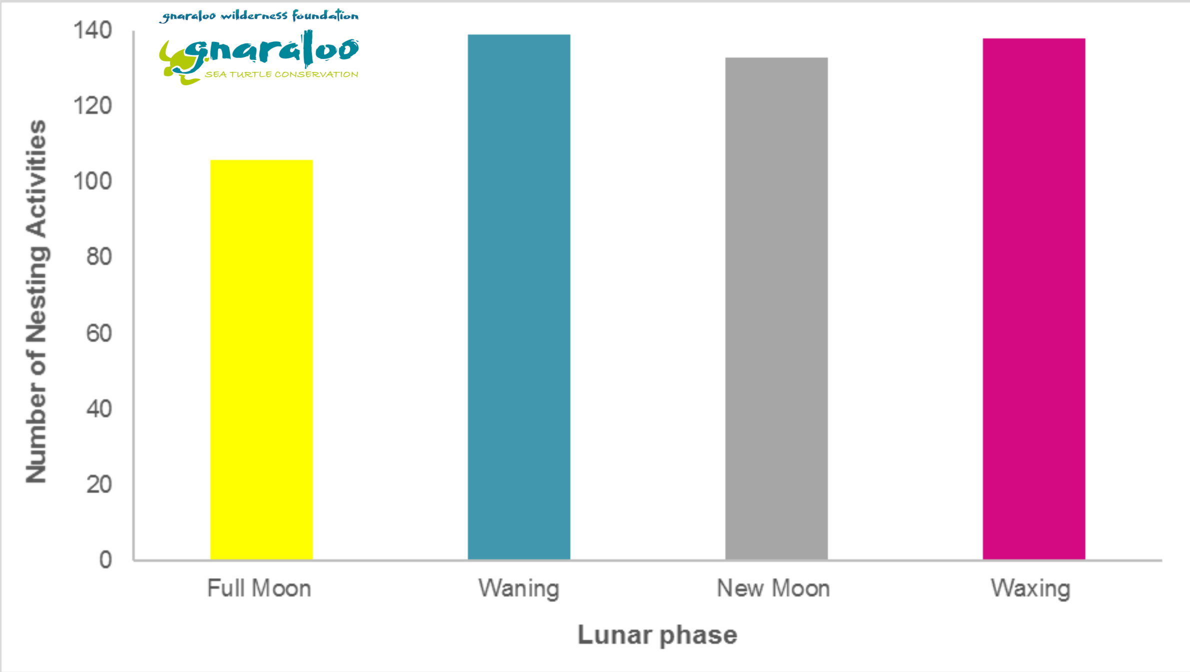

Figure 26: Nesting Activities in GBR Survey Area during different lunar phases (1 Nov – 28 Feb), 2017/18

5.4.7 Wind effects on track interpretation

During the monitoring period from 1 November 2017 – 28 February 2018, the interpretation of at least 24 out of 516 Nesting Activities was affected by wind in the GBR Survey Area. The maximum wind speeds during the affected nights (15 out of 120 nights) ranged from 17.7 – 45.1 km/h (**Figure 27**). Winds during all affected nights came from a southerly (**S**) to south-easterly (**SE**) direction (**Figure 28**).

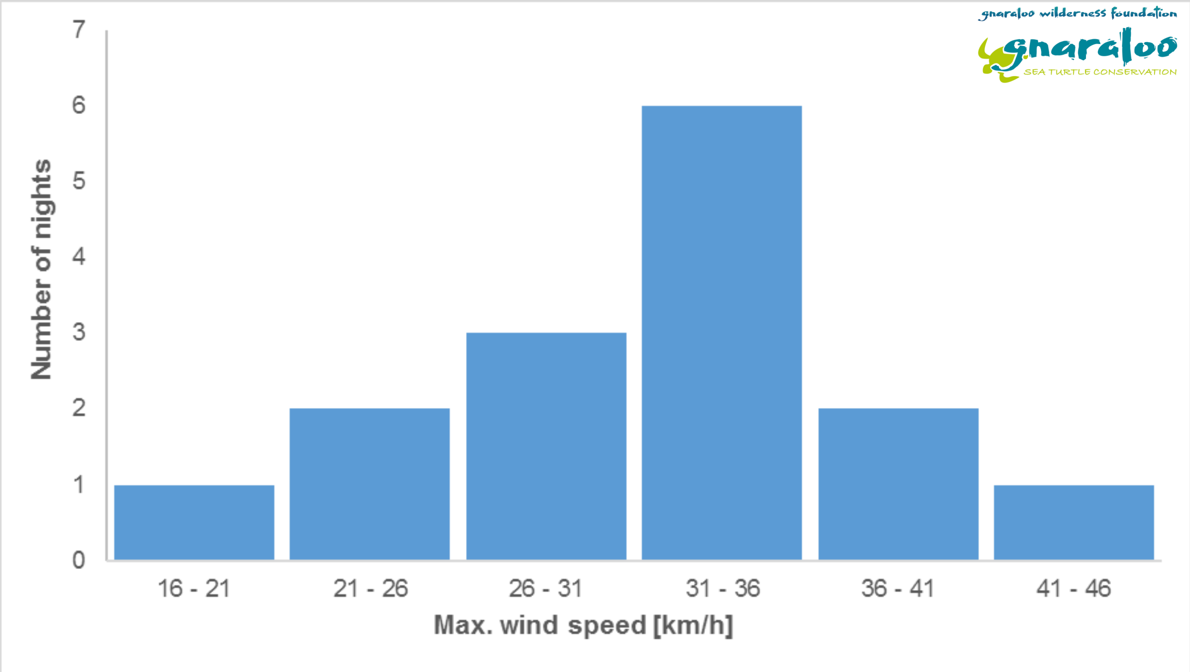

Figure 27: Maximum nightly wind speeds affecting turtle track identification in GBR Survey Area (1 Nov – 28 Feb), 2017/18

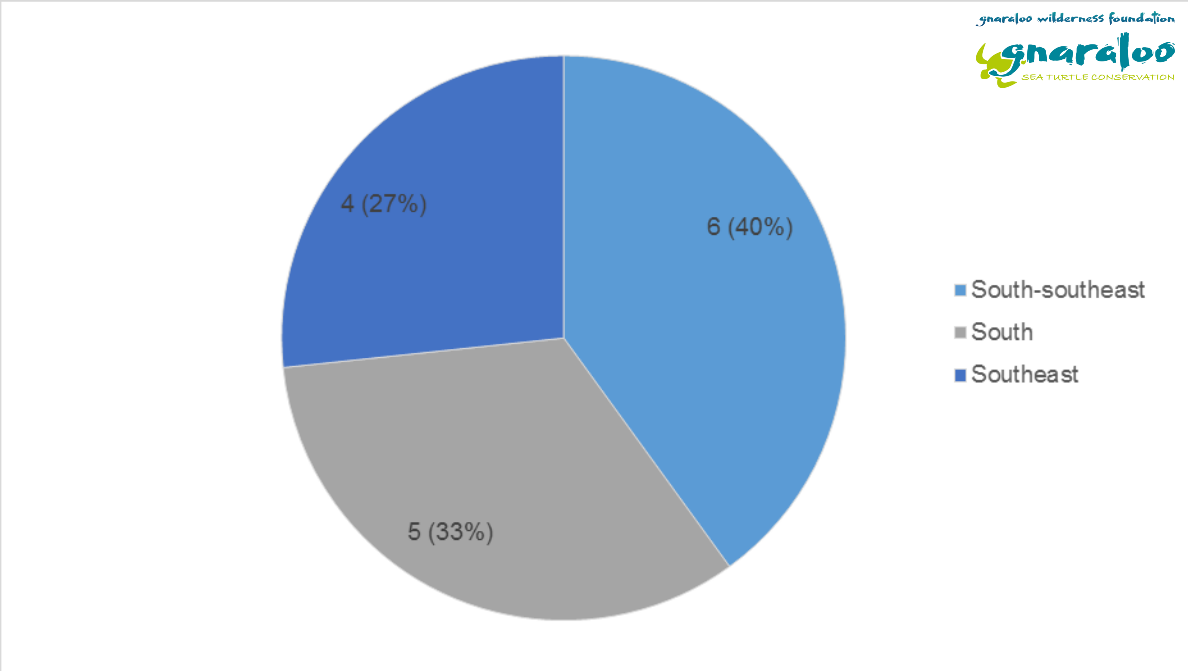

Figure 28: Prevailing nightly wind directions during nights with windblown turtle tracks in GBR Survey Area (1 Nov – 28 Feb), 2017/18

5.4.8 Mortalities and strandings

During the season 2017/18, 5 sea turtle mortalities were recorded in the GBR Survey Area (3 in Sub-section BP8 – BP9, 1 in GBN – BP7 and 1 in BP7 – BP8). All mortalities were juvenile green turtles. Three carcasses were fresh and looked severely emaciated. One showed injuries on the left side of the head and neck, but it was not possible to determine whether they were the cause of death. The other two carcasses showed no signs of injuries. Of the other two mortalities, one was mummified and one consisted of only disarticulated bones when found. The mortalities were recorded on 31 October 2017, 10 November 2017, 21 November 2017, 29 November 2017 and 26 January 2018.

One stranding of a disoriented female adult loggerhead turtle was recorded on 26 November 2017. The turtle, which was observed and flipper tagged during Night Survey, was stranded behind a very steep dune during a nesting attempt. She was rescued and returned to the water in the early morning by the GTCP researchers.

5.5 Discussion

5.5.1 Seasonal and long-term Nesting Activities and Nests

Spatial and temporal patterns of Nesting Activities in the GBR Survey Area during 2017/18 were broadly similar to previous seasons. Patterns exhibited across the years were evident in season 2017/18, but often seen at a lesser magnitude. Season 2017/18 had the second lowest number of Nesting Activities since monitoring began in 2008/09, reaching only marginally more than season 2015/16. Additionally, the lowest number of Nests was laid this season in the GBR Survey Area. While there was an increase in Nesting Activities between mid-December and late January, the peak was less pronounced and of smaller magnitude than most previous seasons, with the exception of season 2015/16. The number of Nests laid per week stagnated around 31 Nests for 5 weeks in December 2017 and early January 2018, contrary to most previous seasons which generally still saw an increase in weekly Nests during that time period. Nesting Activities did not start until 10 November 2017 and ended on 21 February 2018.

The low total number of Nests in 2017/18 suggest a lower number of female loggerhead turtles nested in the GBR Survey Area this season, and/or the females laid less clutches compared to an average season. Large variations in Nesting Activities between seasons are thought to be driven by varying remigration intervals as result of environmental variability both at foraging and nesting habitats (Hays, 2000; Solow et al., 2002; Mazaris et al., 2009). Sea-surface temperature (**SST**) in foraging and breeding habitats has been shown to influence the timing and abundance of sea turtle nesting (Chaloupka et al., 2008; Weishampel et al. 2004; Mazaris et al. 2008, 2009; Weishampel et al. 2010), likely by influencing the breeding capacity of sea turtles through ocean productivity and thus prey abundance (Chaloupka et al., 2008). Satellite tracking of loggerhead turtles nesting at Gnaraloo (Strydom et al., 2017; **Chapter 8** this report) reveals their foraging habitats spread out along the coast of Western and Northern Australia, from Shark Bay (WA) to the Gulf of Carpentaria (NT/Qld). Warmer than normal temperatures throughout the eastern Indian Ocean for all of 2016 were observed due to a strong negative IOD event in 2016 (Lu et al., 2017). Warmer SST are associated with lower ocean productivity and therefore lower prey abundance for sea turtles (Chaloupka et al., 2008). As female sea turtles require at least one year to acquire sufficient body fat deposits to induce vitellogenesis (yolk deposition in egg follicles) and to meet the energy requirements needed for long migrations (Miller, 1997), the elevated SST might have negatively impacted the number of females getting ready to breed at Gnaraloo in season 2017/18. Comparing the 10-year trend in nesting numbers with IOD events supports this hypothesis, as it could explain the trend for 80 % of the data. The three peaks in nesting numbers observed during seasons 2009/10, 2013/14 and 2016/17 were each preceded by a positive IOD event, leading to cooler than normal SST throughout the eastern Indian Ocean in the years prior to the nesting season (i.e. 2008, 2012, 2015; NOAA, 2017). Conversely, all negative IOD events (i.e. 2010, 2013, 2014, 2016) were followed by low nesting numbers at the GBR after a one-year lag (i.e. 2011/12, 2014/15, 2015/16, 2017/18). However, seasons 2008/9 and 2012/13 cannot be explained by this theory, as both followed a positive IOD event, but nesting numbers in the GBR Survey Area remained relatively low. In the Pacific Ocean, inverse correlations of SST and nesting abundance have been shown for loggerhead (Chaloupka et al., 2008), green (Limpus and Nicholls, 2000; Chaloupka, 2001) and leatherback turtles (Saba et al., 2007). It is therefore plausible to assume similar associations between SST and nesting abundance in the Indian Ocean sea turtle populations. Nevertheless, more detailed analyses with larger data sets are necessary to get a better understanding of SST in foraging habitats and associated nesting abundance on nesting beaches. Further research is particularly warranted in light of potential consequences that an increase in SST, due to climate change, might have on sea turtle nesting.

While the total number of Nesting Activities in the GBR Survey Area generally show a decreasing trend, with the exception of season 2016/17, the number of Nests has varied greatly without showing a significant decline over the 10 years of monitoring. Numbers of Nests for the 10 seasons did not correlate with the total number of Nesting Activities, resulting in a highly variable Nesting success rate for the GBR Survey Area. High Nesting success likely relates to more favourable local beach conditions during those seasons. This is corroborated by observations of the beach made during the season 2017/18, which had a below average Nesting success rate. Steep dunes, large escarpments and exposed bedrock were observed along the beach in the GBR Survey Area, particularly in Sub-section BP7 – BP8, which had the lowest Nesting success rate of all Sub-sections. Spatial accounts of Nesting Activities and Nests over the 10 seasons show a decrease of Nests in Sub-section GBN – BP7, but no strong trend in Sub-sections BP7 – BP8 and BP8 – BP9. As the Sub-section with highest Nest abundance and Nesting success over the 10 years, Sub-section BP8 – BP9 likely provides the most favourable beach conditions for sea turtle nesting. Importantly, despite fluctuations, the Nesting success rate for the GBR Survey Area as a whole has not declined since 2009/10, notwithstanding a general downward trend in Nesting Activities.

It is important to keep in mind that in terms of loggerhead turtle life cycles, a 10-year time series is still relatively short, and inferences on nesting abundance trends and population dynamics should only be made with caution. However, based on the history of introduced foxes, which have been active in WA since the 1960 (Limpus, 2008), and the high fox Predation rate reported for the GBR Survey Area prior to the establishment of the GFACP in 2008/09 (Butcher & Hattingh, 2012), a general decline in Nest numbers, or a stabilisation at low levels, may have to be expected as several decades of fox Predation impacts are likely still affecting the current loggerhead turtle breeding populations at Gnaraloo. Furthermore, although not quantified, ghost crabs appear to exert a high level of Predation pressure on turtle Nests and hatchlings at Gnaraloo, particularly toward the northern end of the GBR Survey Area which has the highest density of Nests (**Section 9.4.2;** Hattingh et al. 2011). This may exacerbate the impacts of historical fox Predation and suppress the reproductive success of a rookery that is already likely depleted relative to historic levels. In the future, it would be valuable to conduct experimental assessments to quantify the actual impact of crab Predation on the Nests and hatchlings in the GBR Survey Area, and compare the findings with other loggerhead turtle rookeries in Australia. A better understanding of the magnitude of the impact of crab Predation on the reproductive success in the GBR Survey Area is necessary to determine whether further management interventions are required at Gnaraloo in order to support a highly fecund loggerhead turtle population.

5.5.2 Nesting Activities correlated with lunar and tidal cycles

For aquatic species, such as sea turtles, travelling in terrestrial environments can be physically difficult and energy consuming (Pike, 2008). Therefore, nesting female turtles may time their emergence to minimise their exposure on land by assessing environmental conditions before emerging. Lunar and tidal cycles have been found to influence turtle nesting numbers on some beaches (Pike, 2008; Law et al., 2010), but not on others (Ekanayake et al. 2002). By emerging on a high tide, the nesting female may reduce the distance and duration of her crawl, saving energy and limiting exposure to potential threats.

However, loggerhead turtles at the GBR Survey Area showed an inverse correlation to tide amplitudes, with the least emergences occurring around full moons, when tides were highest. Rather, they were most likely to emerge during nights of waning and waxing quarter moons, when tidal ranges were more moderate. Emergences around new moons were only slightly lower than during waxing and waning periods, which is likely due to the high tides around new moons being much more moderate at the GBR Survey Area than around full moons. Personal observations during Night Survey indicate that the combination of the often steep beach profile and exceptionally high tides, as seen around full moons, made it challenging for turtles to emerge. Three turtles on separate occasions were observed as aborting their emergence attempt during spring high tides due to high wave action on the beach, which resulted in the turtle being washed back and forth, making it difficult and energy consuming to emerge. Wave action was generally gentler during neap tides and even during new moon high tides, allowing easier access to the beach for emerging females.

5.5.3 Wind effects on track interpretation

Strong winds during the season 2017/18 complicated track interpretation on many occasions during Day Surveys, making it difficult or impossible to determine the type of activity, track width and species. During the Night Survey period in the GBR Survey Area, winds from a southerly to south-easterly direction were prevalent in all nights where tracks were affected. As the nesting beach at Gnaraloo Bay is bordered by an extensive dune system, strong winds from this direction tend to blow large amounts of dry sand from the dunes onto the beach and potential turtle tracks.

5.6 Conclusion

During the season 2017/18, the GBR Survey Area received a lower than average number of sea turtle Nesting Activities and the lowest number of Nests since 2008/09. The timing of nesting in season 2017/18 was broadly similar to previous seasons. Females in season 2017/18 preferentially emerged during nights of moderate high tides, which likely relates to the beach profile and condition present during the season 2017/18. Strong winds blowing sand from the dunes onto the tracks made track and species interpretation challenging at times. Coarse analysis of SST in the eastern Indian Ocean reveals a potential inverse correlation with Nest numbers in the GBR Survey Area. Despite a general decline in Nesting Activities, with the notable exception of season 2016/17, the number of Nests does not show a clear decreasing trend, revealing a highly variable Nesting success rate in the GBR Survey Area, which is likely due to constantly changing beach conditions. Despite the continuous 10-year data set, the time series is relatively short when compared to loggerhead turtle life cycles, and ongoing monitoring and further research is warranted to uncover biologically meaningful trends in Nest numbers.

6 GBR NIGHT SURVEYS

6.1 Introduction

Relying on daytime beach surveys only to monitor sea turtle Nesting Activity involves considerable potential for error, as it relies on the researcher's ability to correctly interpret subtle track characteristics to infer the type of Nesting Activity (e.g. Nest or UNA) and species responsible (Schroeder & Murphy, 1999). Furthermore, environmental conditions such as strong winds, tidal wash or vegetation can obscure essential track characteristics, making reliable interpretation even more challenging (Whiting, 2008). While well-developed guidelines exist to help researchers with track interpretation (Schroeder & Murphy, 1999), the subjective nature of this method and the potential for track degradation or masking means that 100 % accuracy in Nesting Activity Determination (**NAD**) and Species Identification (**SI**) is challenging to achieve during Day Surveys. Verifying Day Survey track assessments by comparing with direct and independent observations of turtle Nesting Activities at night is therefore critical for programs such as the GTCP, which relies primarily on daytime beach track survey as an index of turtle nesting abundance (Schroeder & Murphy, 1999). In addition to critical data verification, Night Surveys also allow researchers to gain an improved understanding of turtle nesting behaviour and the physical characteristics of tracks produced by different Nesting Activities. For these reasons, the GTCP introduced the Night Survey component to its research from the season 2010/11. Furthermore, Night Surveys enable the application of flipper tags (**Chapter 7**) and the collection of important additional data for individual turtles, such as morphological measurements, clutch counts and internesting intervals.

6.2 Objectives

The objectives of Night Surveys in the GBR Survey Area during 2017/18 were to:

- determine the accuracy of SI and NAD assessments during Day Surveys;
- allow for the correction of SI and NAD errors in the Day Survey spreadsheets;
- estimate the Nest detection bias for Day Surveys;
- improve the interpretive skills of the GTCP field team;
- flipper tag as many turtles as possible;
- calculate the average clutch size for loggerhead turtles nesting at GBR.

6.3 Material and methods

6.3.1 Night Survey protocol

The GTCP Procedure 2017/18 sets out the detailed Night Survey protocol. Briefly, on any given Night Survey, researchers search the beach in the GBR Survey Area after sunset for a minimum of 6 hours. Night Surveys were conducted primarily in GBR Sub-section BP8 – BP9, where most of the Nesting Activities occur (**Section 5.4**). However, opportunistic observations were also made in Sub-section BP7 – BP8 on the way to and from Sub-section BP8 – BP9.

Night Surveys were conducted each night from 16 November 2017 to 21 December 2017 by two GTCP team members. Opportunistic Night Surveys were also completed from 22 January 2018 to 27 January 2018, and on 6 February 2018, to accommodate visitor interest in the program and to increase the number of flipper tagged turtles. Those Night Surveys were often shorter than the standard 6-hour surveys, but otherwise followed the same protocol. They were also used in SI and NAD accuracy determination, to confirm or correct Day Survey track interpretations and to calculate the Nest detection bias.

When a turtle was sighted, the species was identified and behavioural observations were made until the Nesting Activity could be verified (i.e. Nest, UNA, UT). For an activity to be considered verified, the turtle had to be observed during a nesting phase that would ensure 100 % certainty of the activity. For Nests, the turtle had to be seen at the laying phase at the latest and be witnessed depositing eggs into the egg chamber. For UNAs, the turtle had to be seen at the egg-chambering phase at the latest and observed returning to the ocean without laying eggs. For UTs, the turtle had to be seen at the emergence phase at the latest and witnessed returning to the ocean without attempting to dig a Nest.

For turtles that were laying eggs, the number of eggs were counted during oviposition using a hand-held counter. Only full clutches were recorded, i.e. if a turtle had already started egg-laying before being encountered, the remaining eggs were not counted.

The curved carapace length (**CCL**) was measured from the skin/carapace junction at the anterior edge of the nuchal scute to the posterior notch at midline between the supracaudal scutes (Bolten, A. B., 1999). The curved carapace width (**CCW**) was measured at the widest point of the carapace, independent of anatomical reference points. All measurements were taken and flipper tags applied (**Chapter 7**) once the turtle had either finished laying eggs or was clearly returning to the ocean after a UNA or UT.

6.3.2 Target sample sizes

The GTCP Procedure 2017/18 contains the target sample size calculations for SI and NAD. For SI verification, a target sample size of 10 turtle observations was calculated (0.95 confidence interval, 0.1 margin of error, average accuracy from previous seasons of > 95 %), with a desired accuracy of 98 %. For NAD verification, a target sample size of 52 verified Nesting Activities was calculated (0.95 confidence interval, 0.1 margin of error, and an average accuracy from previous seasons of > 80 %), with a desired accuracy of 80 %. Upon reaching these sample sizes, the seasonal accuracy for SI and NAD was determined. If the desired accuracy (98 % for SI and 80 % for NAD) was not reached, the target sample size would be recalculated using the current season's level of accuracy and additional observations were made until the revised target sample size was achieved.

6.3.3 Nest detection bias

A Nest detection bias for loggerhead turtle Nesting Activities was determined by comparing Day Survey track interpretations with independent, direct observations of turtle Nesting Activities during Night Surveys. For each season, all verified Night Survey observations and their corresponding Day Survey track interpretations were extracted, including cases in which verified activities were missed entirely the following morning. The number of Nests recorded during Night Surveys was taken to represent the true value, while the number of Nests counted during Day Surveys represented the observed value. The discrepancy between true and observed numbers of Nests was calculated (*% error = (observed – true) / true * 100*) for each season to determine any over - or - underestimation of Nest numbers.

6.4 Results

6.4.1 Summary of Night Surveys

Night Surveys for the season 2017/18 commenced on 16 November 2017 and concluded on 21 December 2017, running for a total of 36 consecutive nights. This time period was sufficient to reach the target sample size and accuracy for SI, but not for NAD, for reasons discussed below (**Section 6.5.3**). A further 3 Night Surveys were conducted opportunistically, at the request of visitors, between 22 January 2018 and 27 January 2018. One loggerhead turtle was observed nesting by the field team in the evening on 6 February

2018 and included in the Night Survey dataset.

A total of 88 turtle observations were made during the combined 40 Night Surveys. The number of turtles seen per Night Survey ranged from 0 to 10, with an average of 2.2 ± 2.2 turtles per night.

6.4.2 Clutch sizes

A total of 26 complete clutch counts were recorded during Night Surveys. All counts were from loggerhead turtles and the researchers did not account for the variation of egg sizes, indicative of normal, double-yolked and unfertilised eggs. Clutch sizes ranged from 49 – 147 eggs (106.6 ± 22.8). Clutch sizes and CCLs were slightly positively correlated (r^2=0.23; **Figure 29**).

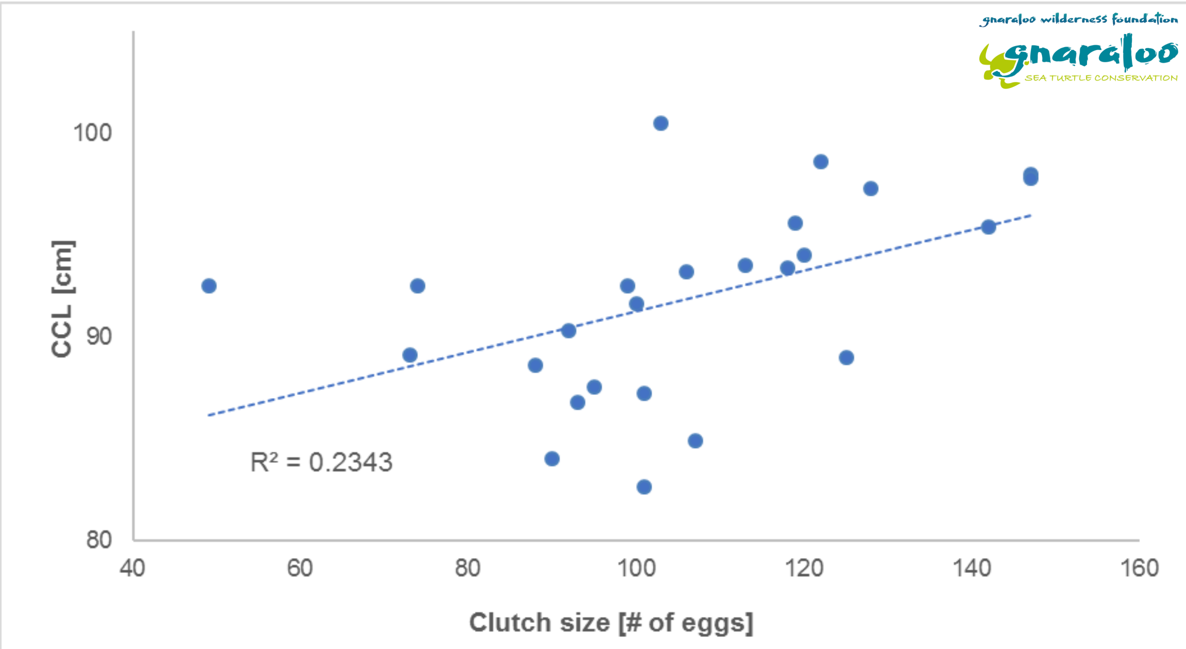

Figure 29: Correlation of loggerhead CCL and clutch size in GBR Survey Area during Night Surveys, 2017/18

6.4.3 SI accuracy

The species of the first 10 turtles observed during Night Surveys was correctly identified during Day Survey track interpretations. Although the target sample size for SI verifications (10) was reached on 26 November 2017, SI verifications continued throughout the duration of Night Surveys. In total, 80 turtles (100 %) verified to species during Night Surveys were correctly identified as loggerhead turtles during Day Surveys. 8 additional verified loggerhead turtles were excluded from the SI accuracy determination because they were either observed by the entire field team during satellite tagging nights (4) or in the evening (1), the track was missed by the Day Survey team (1), the track was too windblown to be interpreted in the morning (1), or the turtle was still on the beach in the morning (1).

6.4.4 NAD accuracy

The target sample size for NAD (52) was reached in December 2017, but NAD calculations were continued because the desired accuracy of 80 % was not yet achieved. The final NAD sample size consisted of 65 Nesting Activities: 37 Nests, 24 UNAs and 4 UTs. The GTCP field research team 2017/18 achieved a NAD success rate of 75.4 %. Day Survey researchers had an overall accuracy of 78.4 % (29 / 37) when identifying Nests, 66.7 % (16 / 24) when identifying UNAs and 100 % (4 / 4) when identifying UTs. NAD accuracy calculations do not include verified activities from satellite tagging nights (2), missed by the morning team (1), from the turtle that was still on the beach in the morning (1), or from the turtle that was observed by the entire field team in the evening (1).

6.4.5 Nest detection bias

A total of 66 verified Nesting Activities, including one that was verified during Night Survey but whose track was missed during Day Survey, were used to estimate Nest detection bias. The error between the Night Survey verified Nest count (38) and the corresponding Day Survey Nest count (34) was -10.5 %. Thus, there was a systematic negative bias in terms of Nest identification (i.e. researchers were conservative in Nest identification).

6.4.6 Observed nesting activities and phases

Of the 88 turtle observations during Night Surveys in the season 2017/18, a total of 70 Nesting Activities were verified[10]. The majority of verified activities were Nests (61.5 %), while UNAs and UTs were recorded more rarely (Figure 30). Considering all 88 turtle observations, turtles were most frequently observed during the emergence, body pitting or

[10] This includes 5 activities which were excluded for NAD or Nest detection bias calculations because the activities were either witnessed by the entire team (3), the activity was missed during Day Survey (1), or the turtle was still on the beach in the morning during Day Survey (1).

egg chambering phases, with initial observations of turtles during laying, covering, camouflaging or returning phases occurring less frequently (Figure 31).

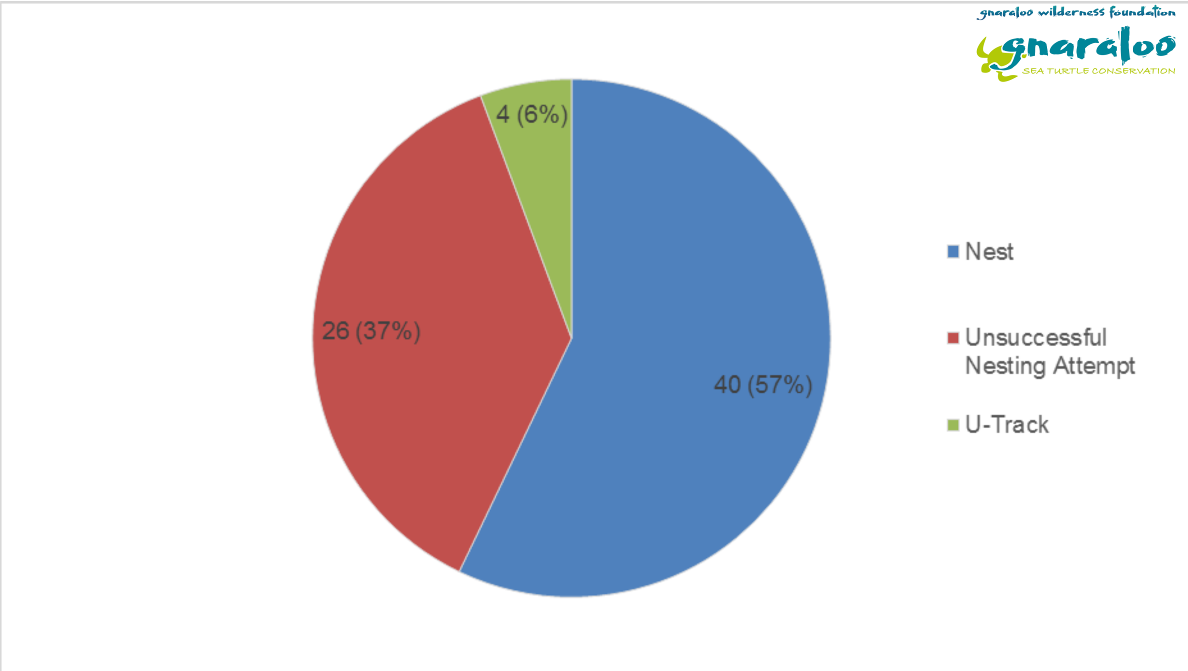

Figure 30: Verified Nesting Activities observed in GBR Survey Area during Night Surveys, 2017/18

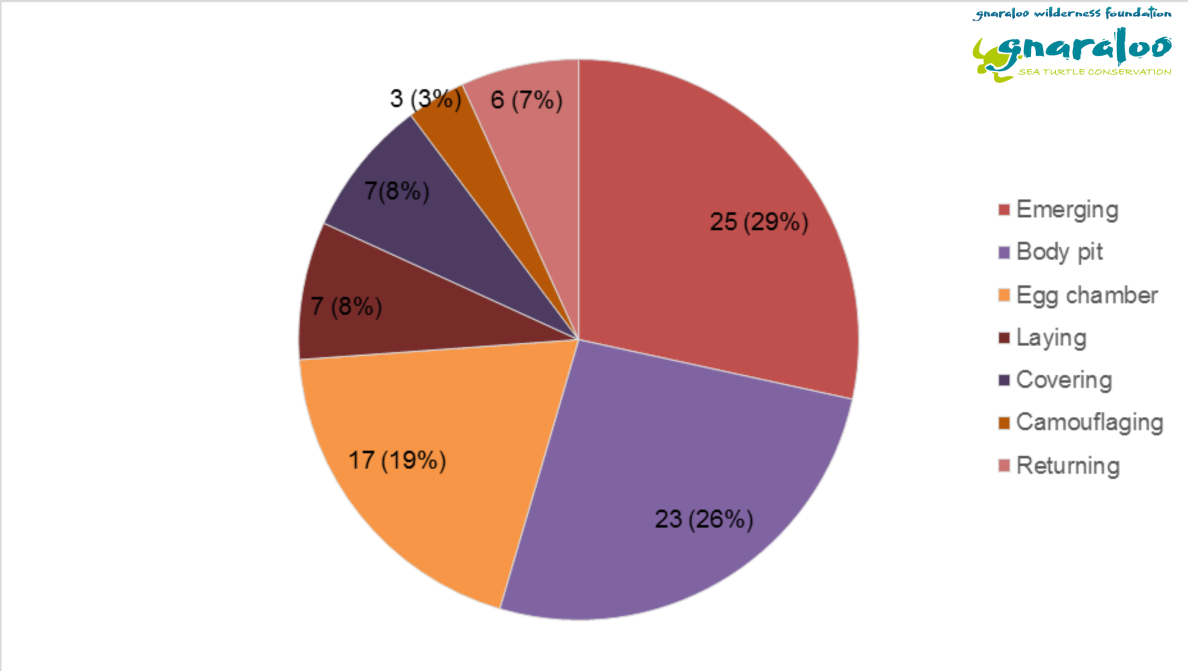

Figure 31: Nesting phases of loggerhead turtles when first observed in GBR Survey Area during Night Surveys, 2017/18

6.5 Discussion

6.5.1 Clutch size

Every nesting season demands an extremely high energy investment of sea turtles to create many offspring which have a low chance of survival. Laying several clutches over the course of a nesting season reduces any potential negative environmental impacts, such as by cyclones or heavy rains, on the reproductive output (Miller et al., 2003). As sea turtles do not show any parental care to their offspring, reproductive success cannot be increased by learned behaviour (Broderick et al., 2003) and each clutch from one female is therefore independent of the previous one. In order to preserve energy, it is advantageous for a female turtle to lay larger but fewer clutches to minimise the time spent on the beach for each egg laid (Hays & Speakerman, 1991). However, ultimately, clutch size is dictated by the space available in the coelomic cavity of the female turtle, therefore a larger turtle would be able to carry more eggs, thus increasing the overall clutch size (Broderick et. al., 2003).

The findings during the season 2017/18 suggest a positive relationship between clutch size and CCL, but the two were not highly correlated. Small sample size (n = 26) could have affected the overall correlation and it is suggested in further studies to increase the number of clutch counts during the Night Survey period. The mean clutch size in the GBR is similar to the global average of 112 eggs per clutch (Van Buskirk and Crowder, 1994).

6.5.2 SI accuracy

The GTCP field research team 2017/18 achieved an SI success rate of 100 %. These results are consistent with the previous seven monitoring seasons (i.e. 2010/11 – 2016/17[11]), which all had SI accuracies exceeding the desired 95.0 %. Thus, current levels of training by the GTCP and previous turtle monitoring experience of the seasonal GTCP field research teams appear adequate for reliable SI during Day Surveys.

6.5.3 NAD accuracy

The GTCP field research team 2017/18 did not achieve a NAD success rate of 80 %, despite prolonged Night Surveys with additional verified activities. The implementation of new procedures during 2017/18, such as flipper tagging and clutch counts, made it increasingly difficult to leave Night Survey turtle activities unblemished for identification by Day Survey observers the following day. On many occasions, tracks and activities were walked over or disturbed as a result of these activities, ultimately causing the Day Survey team to misinterpret activities verified by Night Surveys. In some instances, flipper tagging disrupted the turtle’s behaviour (covering or camouflaging the egg chamber), leaving an unfinished Nest which was difficult to interpret. Therefore, it was determined that the NAD success rate of 75.4 % for the season 2017/18 was sufficient and not necessarily indicative of the level of experience and training of this season’s field research team. Nevertheless, it is important to continue Night Surveys in future to ensure accurate interpretation skills and evaluate variation in error rates at the program level.

6.5.4 Nest detection bias

The comparison of Nest counts from Night and Day Surveys allow for the derivation of a correction factor to better estimate the number of Nests in the GBR Survey Area. Correction

[11] Night surveys for data verification purposes commenced in 2010/11.

factors are important to detect potential systematic errors in morning track interpretation. The combination of frequent strong winds and steep dune systems in the GBR Survey Area causes Nesting Activities to deviate from what traditional textbook Nesting Activities look like. Determining a Nest detection bias accounts for these challenging circumstances and improves the accuracy of the estimation of the total number of Nests in the GBR Survey Area each season.

GTCP researchers in season 2017/18 underestimated the number of Nests during Day Surveys, resulting in a negative Nest detection bias for the season. The Nest detection bias of this season is slightly lower than seasons 2010/11 – 2015/16, which also produced an underestimation of Nests (Hattingh et al., 2016), indicating an adequate level of training and expertise of this year's field research team.

6.6 Conclusion

During the season 2017/18, SI accuracy was above, while NAD accuracy was below, the set target levels (98.0 % and 80.0 %, respectively). It was determined that NAD accuracy and Nest detection bias should not be as heavily weighted as in previous seasons due to the addition of flipper tagging and clutch counting, which disturbed the tracks and caused misinterpretation of tracks by Day Survey observers. However, current levels of training by the GTCP and the previous turtle monitoring experience of the GTCP field research teams appear adequate for reliable track interpretation, taking into consideration that track interpretation may always involve some level of error. Continuation of Night Surveys, with flipper tagging and clutch counting, will allow a greater understanding of the population nesting in the GBR Survey Area and should therefore be continued in future seasons.

7 FLIPPER TAGGING

7.1 Introduction

The ability to recognise individual sea turtles is essential for many studies. Over successive seasons, flipper tags can create a unique mark-recapture history of individuals which can be used to estimate remigration intervals, reproductive biology, recruitment and population dynamics (Balazs, 1999). Different types of flipper tags are used by different sea turtle programs around the world. Titanium tags are commonly used for long-term studies as they have a long lifespan and are resistant to corrosion, which is essential for mark-recapture studies. The tags carry a unique number on one side used to individually mark and identify sea turtles (Balazs, 1999), and are most commonly applied to the front flippers of female turtles on nesting beaches. While the lifespan of titanium tags can outlast a decade, it is important to note that they are not permanent. To increase the chances of getting tag recapture information, more than one flipper tag is often placed onto one individual turtle (i.e. one on each front flipper). The recapture of tagged turtles, recoveries of tags from deceased turtles, or sightings of tags by scuba divers and snorkelers all provide important information about the whereabouts of the tagged turtles throughout their migrations. Flipper tagging can also provide information about the connectivity of the Gnaraloo rookeries with adjacent nesting sites along the Ningaloo Coast, at Shark Bay and Dirk Hartog Island (WA).

The GTCP continued flipper tagging during the season 2017/18[12]. Limited flipper tagging was first done during the season 2015/16 of 16 loggerhead turtles in the GBR and GCFR Survey Areas (Strydom et al., 2017). The flipper tagging data collected throughout the season 2017/18 should mark the start of a long-term mark-recapture program which will give valuable information about the population dynamics of the sea turtles nesting in the GBR Survey Area.

7.2 Objectives

The objectives of the flipper tagging in the GBR Survey Area during 2017/18 were to:

- mark as many nesting turtles as possible;
- estimate internesting intervals and clutch frequencies.

[12] DBCA loaned the flipper tagging equipment, including flipper tags.

7.3 Material and methods

The flipper tagging methods and protocols follow the Standard Operating Procedure (**SOP**) No: 12.5 of the Department of Environment and Conservation (WA, 2009).

Flipper tagging commenced on 21 November 2017 and was conducted during all Night Surveys. The titanium flipper tags (Stockbrands Co. Pty. Ltd., Mt Hawthorn, Australia) were stamped with a number on the top (WB prefix, in accordance with the DBCA number sequence) and a return address at the back.

Upon sighting a turtle, the stage of nesting was determined and the time recorded (detailed methods in **Section 6.3.1**). If the turtle nested, tags were applied after she finished oviposition and started covering her egg chamber. If the turtle did not nest, tags were applied on her return to the ocean, as to limit interference with her attempts of nesting.

Flipper tags were attached to the trailing edge of each front flipper proximal and directly adjacent to the first scale. This position was shown to have the smallest rate of tag loss over time (Limpus, 1992). Where possible, consecutive numbers were used, with the lower number applied to the left flipper. In the rare instances where tags were misaligned and did not clinch properly, they were carefully removed using long-nose pliers, and a new tag was inserted. Each time a tagged turtle was observed again on the beach, tags were checked and barnacles removed where necessary.

All tag numbers were recorded in addition to location, CCL and CCW of the turtle and the information was passed on to DBCA as part of the research licence return during June 2018.

Skin biopsies for DBCA were taken from the hind flippers of 20 loggerhead turtles for genetic and stable isotope analyses. The results of this work will be available from DBCA.

Internesting intervals were determined from observations during Night Surveys. The number of days between a successful Nest and the next nesting attempt (successful or not; Limpus, 1985) was calculated for each turtle that were observed nesting more than once (n = 11). Importantly, for this parameter, the Nest did not have to be verified as described in **Section 6.3.1**. Activities where turtles were covering or camouflaging and showed all parameters of a Nest were included in the calculation of internesting intervals.

For all turtles but the two satellite tagged turtles, only one internesting interval was determined. For the two satellite tagged turtles, three internesting intervals were determined based on their movement patterns and data transmitted by the trackers.

7.4 Results

7.4.1 Turtles tagged

New flipper tags were applied to 52 individual sea turtles during the season 2017/18 (for details see **Appendix C**). In all cases, the female turtles were identified as loggerhead turtles, with no other species encountered, and titanium flipper tags were applied to each front flipper. One turtle was encountered with tags applied during the season 2015/16 (WB1527, WB1528; for the turtle named Nerine) for the first satellite tagging project of the GTCP. This turtle was encountered three times during Night Surveys during the season 2017/18, and successfully nested two of these times. No turtles with flipper tags from different entities or organisations were encountered.

For the initial application of flipper tags, 29 females (55.8 %) were tagged after successfully nesting. The other 23 females (44.2 %) did not nest and were consequently tagged as they returned to the water.

7.4.2 Biometric measurements

CCL measurements were taken for most of the tagged turtles (51 / 53), while CCW measurements were taken for 48 turtles. As the application of flipper tags was prioritised over biometric measurements, some of the tagged turtles re-entered the water before accurate carapace measurements were obtained. CCL measurements ranged from 82.6 - 102.5 cm, with a mean of 93.1 ± 4.8 cm. Most turtles of this season's nesting population measured between 90 – 94 cm (19) and 94 – 98 cm (14) CCL. Only two females were larger than 100 cm CCL, and four were smaller than 86 cm (**Figure 32**). CCW measurements ranged from 76.8 - 96.0 cm, with a mean of 84.7 ± 5.0 cm. CCW was positively correlated with CCL ($r^2 = 0.69$; **Figure 33**).

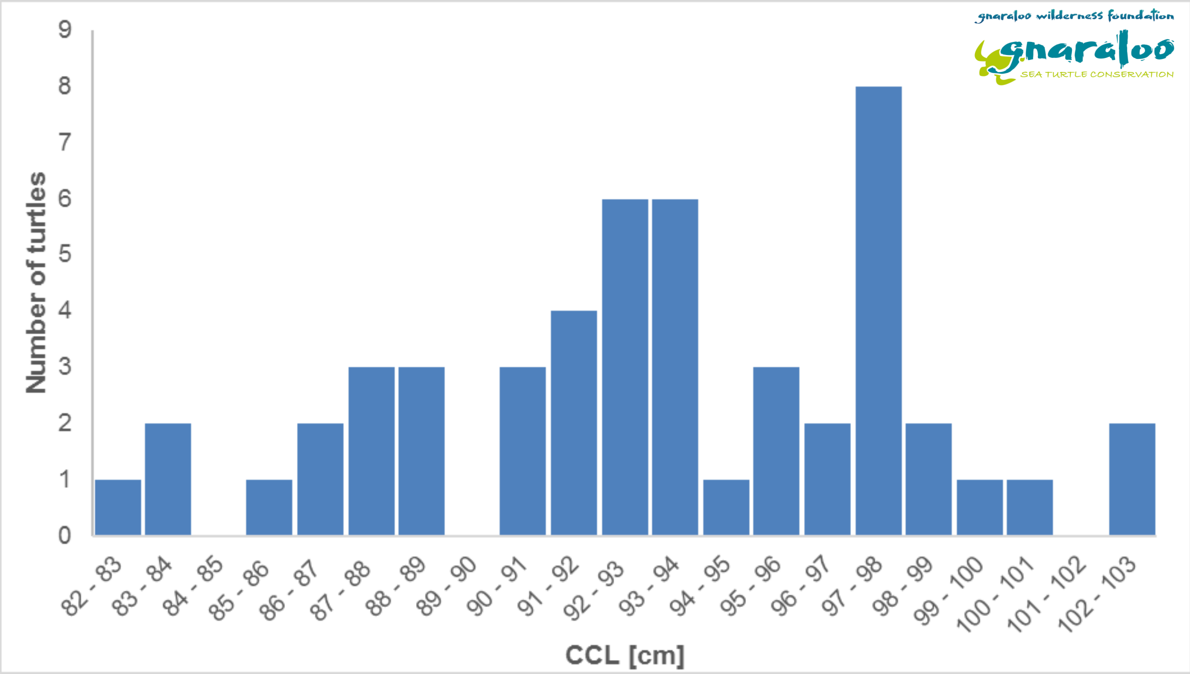

Figure 32: Distribution of loggerhead CCL in GBR Survey Area during Night Surveys, 2017/18

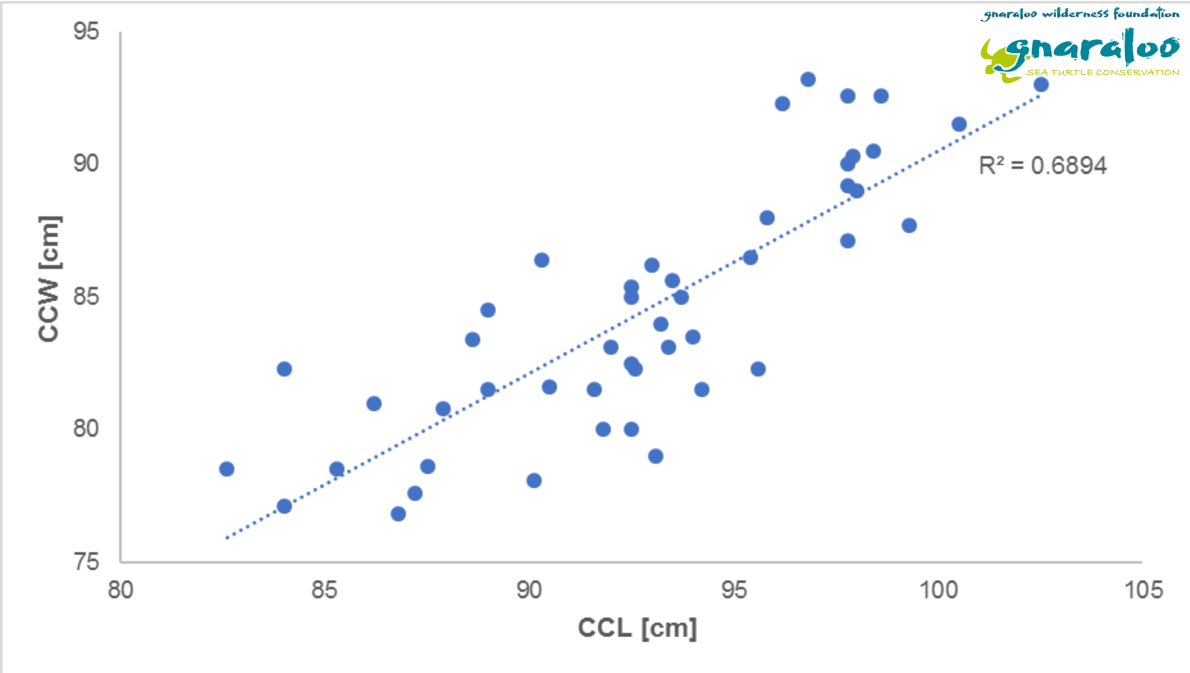

Figure 33: Correlation of CCW and CCL of loggerheads in GBR Survey Area during Night Surveys, 2017/18

7.4.3 Internesting intervals

11 turtles were re-encountered at least once more after laying a successful Nest, providing data for 15 internesting intervals, including 6 of which were from this season's two satellite tagged turtles (Gnargoo and Baiyungu, **Section 8.4.2**). The average internesting interval was 16.1 ± 2.0 days, ranging between 14 and 20 days (**Figure 34**).

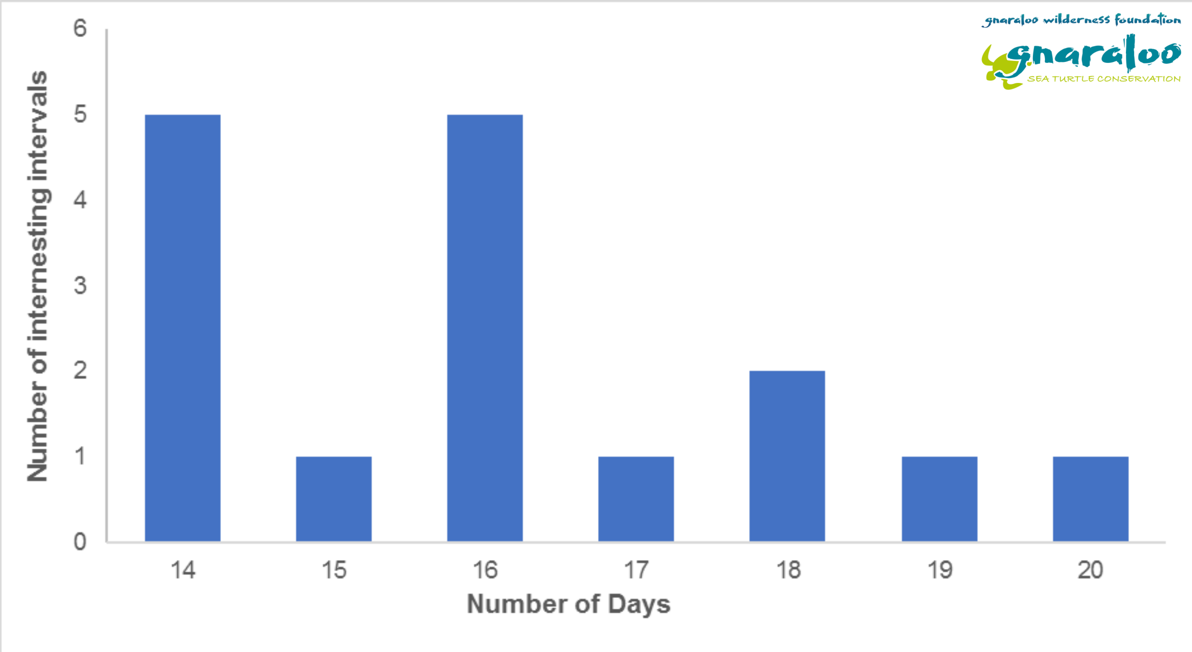

Figure 34: Duration of loggerhead internesting intervals in GBR Survey Area during Night Surveys, 2017/18

7.5 Discussion

7.5.1 Turtles tagged

The season 2017/18 was the first to introduce systematic flipper tagging of the turtles nesting in the GBR Survey Area. By tagging 52 of the estimated 53 – 65 loggerhead turtles nesting in the GBR Survey Area during the season 2017/18, the flipper tagging program should be a highly successful start to a long-term mark-recapture program at Gnaraloo, which will enable the GTCP to better understand the nesting population of the GBR Survey Area, and, in the future, obtain a more accurate population estimate.

7.5.2 Biometric information

The size (CCL) of the female loggerhead turtles nesting in the GBR Survey Area during 2017/18 was slightly smaller than the ones nesting in eastern Australia (95.8 ± 4.4 cm and 95.7 ± 4.7 cm for Mon Repos and Heron Island, respectively; Limpus, 2008). While the majority of turtles had a CCL of 90 – 100 cm, only 3 turtles were larger than 100 cm, and none approached the maximum CCL reported from eastern Australia (Limpus, 2008).

However, the females nesting in the GBR Survey Area were larger than the populations in Japan (73.8 – 91.9 cm; Ishihara & Kamezaki, 2011) and in the Mediterranean Sea (66.5 – 84.7 cm; Casale et al., 2009). Size differences have been linked to differences in foraging strategies and habitats between populations (Ishihara & Kamezaki, 2011). Larger sizes of nesting females may have different reasons: the females may be of larger size at the time of maturation and first nesting, or the nesting population may consist of mainly older females. As the latter case would present a serious concern for this turtle population, further research based on a long-term flipper tagging program is warranted.

7.5.3 Internesting intervals

As ectotherms, the metabolic rate of sea turtles is affected by the ambient water temperature, which in turn can alter the rate with which eggs develop within a female, leading to faster development in warmer water (Hays et al., 2002). As the female lays her eggs once the embryos have developed to a specific stage (Miller, 1997), the interval between two Nests will become shorter at warmer water temperatures. A strong relationship between water temperature and interesting intervals has been demonstrated by two studies on loggerhead and green turtles in Japan and Europe (Hays et al., 2002; Sato et al., 1998). Due to the Night Surveys mainly taking place during 5 weeks in November/December 2017, internesting data could not be collected for more than two consecutive Nests, except for the two satellite tagged turtles (Gnargoo and Baiyungu, **Chapter 8**). Further, it is important to keep in mind that is was not possible to observe each emergence and Nesting Activity along the beach in the GBR Survey Area during Night Surveys. The researchers work predominantly in BP8 – BP9, for 6 hours per Night Survey, for 5 weeks only at the start of the nesting period. Actual internesting intervals may therefore be shorter than reported here, as it was not possible to determine if and when a turtle had emerged before being observed during Night Surveys. To learn more about interesting intervals for turtles nesting in the GBR, prolonged work is suggested over the entire Survey Area for longer periods.

7.6 Conclusion

Flipper tagging allows identification and tracking of individual turtles over time and was a successful and valuable addition to the GTCP this season. This season revealed interesting information about the size of the turtles nesting in the GBR Survey Area and about some of their internesting intervals. However, in order to unlock the full potential of flipper tagging and collect information on population dynamics, remigration intervals and recruitment rates, it is essential to continue for many more consecutive years.

8 SATELLITE TAGGING

8.1 Introduction

Sea turtles are highly migratory species that undertake complex migrations throughout their life cycle (Wallace, 2000), posing considerable challenges for studying their behaviour and habitat use. Most conservation efforts focus on the protection of sea turtle nesting beaches, their Nests, and the nearby coastal waters (Troëng et al., 2005). However, considering that sea turtles spend most or all of their live away from nesting beaches, this approach only offers limited protection to populations as a whole. The development of satellite telemetry in recent decades has provided important insights into sea turtle migration patterns, highlighting key migration corridors, and unlocking information on their use of breeding and foraging habitats (Broderick et al., 2007). This information is essential for effective conservation and management as one animal can traverse multiple jurisdictions, where variations in protection, environmental conditions and anthropogenic threats (e.g. bycatch, pollution, harvesting) impact the sea turtle's longevity and survival (Godley et al., 2002). For loggerhead turtles, foraging habitats can be located close to coastal nesting beaches or thousands of kilometres away. Foraging habitats within the Southeast Indian Ocean RMU remain largely unstudied, except for the Eastern Gulf of Shark Bay in WA (Heithaus et al., 2005; Thomson et al., 2012). The use of satellite telemetry allows a better understanding of migratory routes and habitat use by these loggerhead turtles, which include the turtles nesting in the GBR and GCFR Survey Areas, and provides insight into critical aggregation areas (Godley et al., 2008), enabling targeted conservation management.

A satellite tracking project was first initiated at Gnaraloo during the season 2015/16 (Strydom et al., 2017), when 16 nesting loggerhead turtles were satellite tagged in the GBR and GCFR Survey Areas. However, due to tracker hardware malfunction, only 10 turtles were able to be tracked to their foraging habitats. Of those, 5 went south to the Shark Bay (WA) region, while the other 5 migrated north into tropical waters along the WA and NT coast (Strydom et al., 2017).

The GTCP was able to continue the satellite tagging project with 2 additional trackers during the season 2017/18[13], to gain further insight into the behaviour and migration routes of the turtles nesting in the GBR Survey Area.

[13] The satellite tags, Regulation 17 licence approval and ongoing support were provided by Mr. Aubrey Strydom. This aspect of research was undertaken as a joint project with Mr. Strydom.

8.2 Objectives

The objectives of satellite tracking project of nesting loggerhead turtles in the GBR Survey Area during 2017/18 were to:

- assess within season site fidelity of re-nesting female turtles;
- record internesting intervals, habitat and behaviour of re-nesting female turtles;
- determine where female loggerhead turtles from the GBR Survey Area migrate to after completion of their nesting activities;
- identify the female turtle's foraging habitat.

8.3 Material and methods

On 8 and 9 December 2017, two female loggerhead turtles were randomly selected to be satellite tagged in the GBR Survey Area. Nesting phase was determined as described in **Section 6.3.1**. Once the turtle finished camouflaging and began moving towards the ocean, a wooden restraining box was placed around her and her eyes covered with a moist towel. The turtles were flipper tagged, CCL and CCW measurements were taken, and two skin biopsy samples were collected before preparing her carapace for the attachment of the satellite tracker.

A mounting area of approximately 250 x 300 mm on the first two vertebrate scutes was cleaned and sanded by hand, using scrapers and sandpaper to remove algae growth and barnacles. The carapace was then washed with fresh water and acetone, and dried with cloths. A cool-curing two-component epoxy glue (Powers Pure 150, Powers Fasteners Europe, Germany) was evenly applied to the cleaned area and the satellite tracker (SPOT, Wildlife Computers, USA) was pressed firmly into the glue. The cool-curing epoxy glue takes approximately 4 hours to cure as it prevents temperature-related injuries to the animal. Once the epoxy glue stopped feeling tacky, a coat of antifouling (Micron 66, Interlux, USA) was applied to reduce epibiont encrustation. Once the epoxy glue fully cured and the antifouling was dry, the turtles were released and returned to the ocean in the early hours of the morning.

The satellite tags were programmed to transmit when on the surface. Subsequent telemetry data was generated utilising the ARGOS satellite Doppler GPS position calculations. Information (approximate GPS locations and times) on the turtles' movements were relayed to the field team by Mr Aubrey Strydom. For Nesting Activities by the 2 satellite tagged turtles that were not witnessed during Night Surveys, the Nesting Activities recorded during Day Surveys were matched with locations obtained from the satellite tags and tentatively attributed to each turtle.

8.3.1 Data analysis

Internesting intervals were determined based on the number of days between a successful Nest and the next nesting attempt (successful or not; Limpus, 1985). Nesting attempts were determined based on a high proportion of dry time recorded by the satellite tracker combined with high quality fixes locating the turtle on the beach, or by the satellite tracker indicating the occurrence of a 'haul out' event. Average temperatures for each internesting interval were derived from SSTs transmitted by the satellite tracker. Direct comparisons of mean values were analysed using a t-test (two-sample assuming unequal variances, $\alpha = 0.05$). All data are given as mean ± SD.

8.4 Results

8.4.1 Functionality of tags / details on turtles tagged

The loggerhead turtle tagged on 8 December 2017 was given the name Gnargoo, after the Gnargoo Range, a suspected impact structure located east of Gnaraloo (Iasky & Glikson, 2005). Gnargoo was measured to have a CCL of 92.0 cm, a CCW of 83.1 cm and was found upon the final stages of laying. The second turtle, tagged on 9 December 2017, was named Baiyungu, with the permission of the Aboriginal language group from the Gnaraloo-Ningaloo area, namely the Baiyungu people of Cardabia Station. Baiyungu was encountered emerging from the ocean and laid a total of 113 eggs, her CCL measured 93.5 cm and CCW 85.6 cm. Both satellite tags began working upon entry to the ocean and continued to work throughout and after the GTCP survey period. The condition of one of the tags was checked during Night Survey on 22 January 2018, when Baiyungu was observed nesting and laying 119 eggs. The tag and epoxy glue were still firmly fixed to the carapace, and while much of the anti-fouling was no longer present, there was no apparent algae growth on the tag or saltwater switches.

8.4.2 Internesting intervals

From the date of deployment, the satellite tags recorded both females returning to the GBR Survey Area to lay 3 more Nests. On 22 January 2018, Baiyungu was observed by the Night Survey team laying her last Nest. All other nesting data were derived from locations, wet/dry and haul-out data recorded by the satellite trackers, which reveal when a turtle is on land for an extended period of time. Unfortunately, as the wet/dry data for Gnargoo from 20 - 22 December 2017 was never transmitted, it is not possible to be sure of her nesting. Nevertheless, a reasonably good Class 2 fix (error radius: 268 m) located her on the beach just north of BP9 at 5 am on 22 January 2018; combined with her subsequent behaviour of starting her homeward migration, it seems reasonable to assume Gnargoo laid her last clutch on 22 January 2018.

It was not possible to determine whether both or either of the turtles laid a Nest before having a satellite tracker attached.

The first internesting interval was 15 days for Gnargoo and 16 days for Baiyungu. Both subsequent internesting intervals were 14 days each for both turtles. A general shortening of internesting intervals is often observed as the season progresses and the water temperatures increase (Hays et al., 2002; Sato et al., 1998; Strydom et al., 2017). The average water temperature was significantly lower during the first internesting interval than during the second or third internesting interval for both Gnargoo and Baiyungu ($p < 0.0001$ for all; **Table 7**, **Figure 35**). Linear regression reveals the internesting periods and water temperatures are inversely correlated ($r^2 = 0.79$, **Figure 36**). Average water temperatures between the first and last internesting interval in each turtle's internesting habitat increased by 1.2 °C.

Table 7: Duration of observed internesting intervals and mean SST for satellite tagged turtles in GBR Survey Area, 2017/18

GBR SURVEY AREA	INTERNESTING INTERVAL	SEA SURFACE TEMPERATURE [°C]	STANDARD DEVIATION	DURATION [DAYS]
GNARGOO	1	25.0	1.0	15
	2	25.8	1.1	14
	3	26.1	1.4	14
BAIYUNGU	1	25.0	0.8	16
	2	25.8	1.1	14
	3	26.2	1.2	14

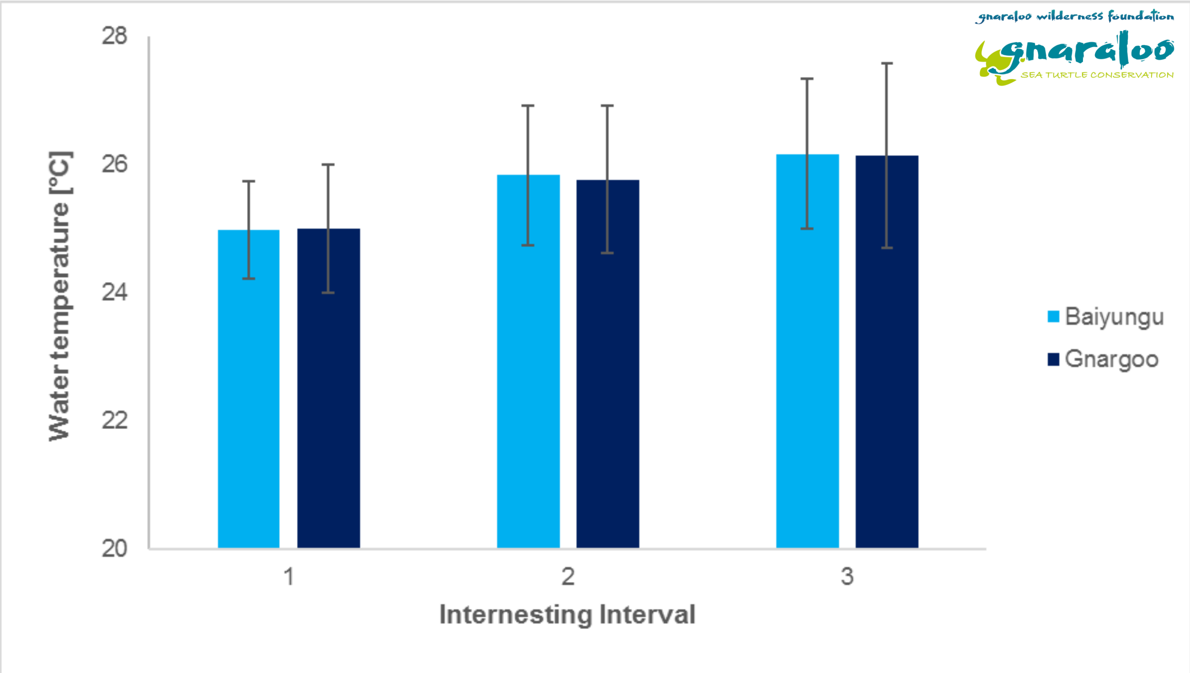

Figure 35: Sea surface temperatures recorded by satellite trackers during each Internesting interval of satellite tagged turtles in GBR Survey Area (8 Dec 2017 – 28 Jan 2018), 2017/18

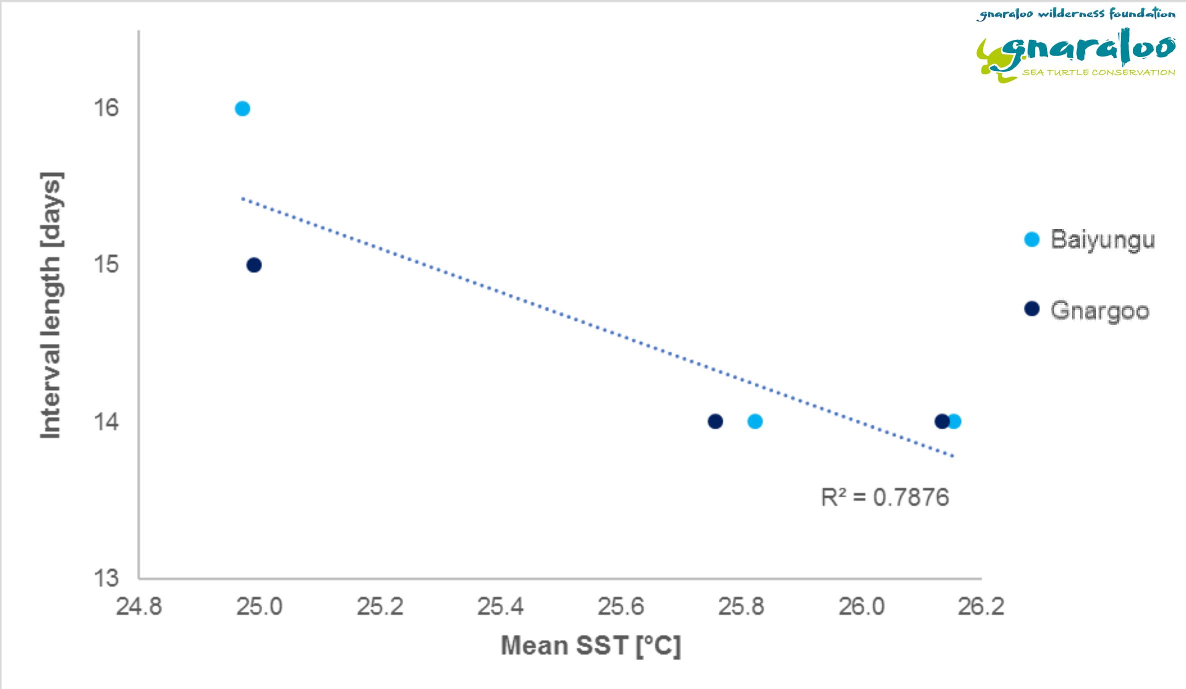

Figure 36: Correlation of internesting interval length and mean SST for the two satellite tagged turtles in GBR Survey Area (8 Dec 2017 – 22 Jan 2018), 2017/18

8.4.3 Internesting habitats

Both Gnargoo and Baiyungu spent the entirety of their internesting periods in the waters just off the GCFR Survey Area, but exclusively nested in the GBR Survey Area. This is similar to the loggerhead turtle 'Oceaneve' tagged during the season 2015/16, while the other turtles from that season either remained offshore in the GBR Survey Area or, in one case, laid clutches in both the GBR and GCFR Survey Areas.

8.4.4 Post-nesting migrations and home foraging sites

Gnargoo laid her last clutch in the GBR Survey Area on 22 January 2018. She started her homeward migration immediately after laying her last Nest (**Figure 37**). By 24 January 2018, she had travelled 90 km and was 8 km offshore. While staying close to the coast until passing Exmouth in WA, she then continued approximately 100 km offshore, passing to the west of Thevenard and Barrow Islands in WA. She continued to swim around 50 km per day, entering NT waters on 9 March 2018 and swimming across Beagle Bay to reach the Tiwi Islands in the NT on 14 March 2018. She continued her journey at the same pace, following the NT coast, before entering the Gulf of Carpentaria and Qld waters in the first weeks of April 2018. On 21 April 2018, after an 89-day migration of approximately 4,100 km, Gnargoo reached her foraging habitat in the eastern Gulf of Carpentaria, approximately 35 km offshore of the remote community of Aurukun in far north western Qld. Her foraging habitat is currently fairly large (15 x 35 km) in approximately 25 m deep water (**Figure 38**).

Baiyungu was observed laying her last clutch for the season on 22 January 2018, before returning to her internesting habitat in the GCFR Survey Area, where she stayed for another week. She then started her homeward migration on 29 January 2018 (**Figure 37**). At approximately 40 km per day, she travelled slower than Gnargoo and stayed much closer to the coast throughout her migration. She swam past Broome in WA during mid-March 2018 and came close to Darwin in the NT on 23 April 2018, before heading west along the southern coast of the Tiwi Islands in the NT. Once around the Tiwi Islands, she continued swimming east, reaching the Coburg Peninsula in the NT at the beginning of May 2018. After taking a shortcut through the Wessel Islands in the NT, she entered the Gulf of Carpentaria at the end of May 2018, increasing her swimming speed from approximately 30 km/day to 45 km/day. After a 131-day migration of approximately 4,700km, Baiyungu reached Gnargoo's foraging habitat on 8 June 2018 in the Gulf of Carpentaria in far north western Qld, but continued swimming closer to the coast. She has since moved slightly away from the coast, with her latest position (as at 15 June 2018) approximately 18 km offshore of the remote community of Aurukun in far north western Qld (**Figure 38**). As at 15 June 2018, Gnargoo and Baiyungu were 10 – 15 km apart, and the coming weeks will show whether their foraging habitats overlap or whether Baiyungu will stay closer to shore.

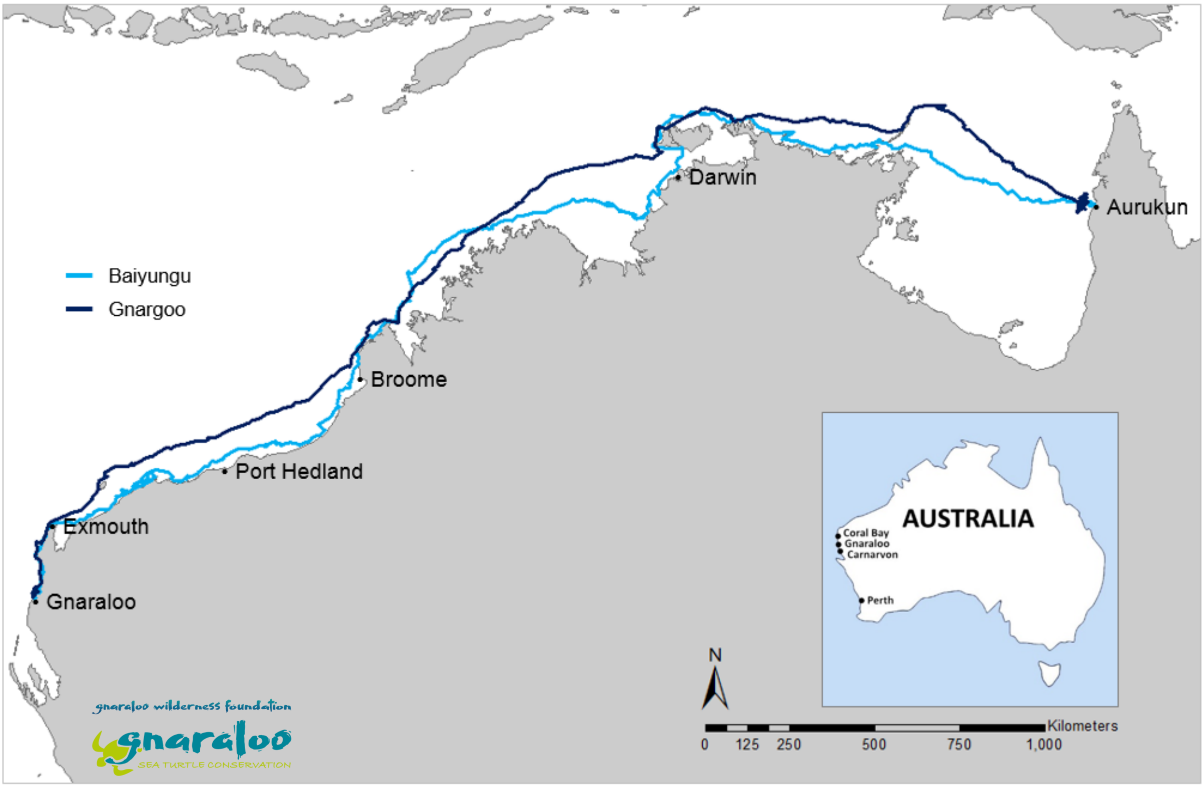

Figure 37: Migration of Gnargoo and Baiyungu (as at 15 June 2018), 2017/18

8.5 Discussion

8.5.1 Region specific hazards: derelict fishing gear

Approximately a third of the migration and foraging habitats of both satellite tagged turtles from Gnaraloo during 2017/18 lie in the Arafura Sea, which includes the Gulf of Carpentaria and the northern coast of Australia. While these tropical waters are extremely rich in marine resources and biodiversity, they also pose a significant threat to sea turtles and other marine life. Thousands of abandoned or lost fishing nets (ghost nets) are drifting in the waters of the Arafura Sea, often getting trapped in a gyre circling clockwise in the Gulf of Carpentaria (White, 2003). Floating in the water, the ghost nets lead to often fatal entanglements of sea turtles and other marine life (Gunn et al. 2010). Between 2000 and 2003, over 500 turtles entangled in ghost nests were recorded along the Qld coast of the Gulf of Carpentaria (Kiessling, 2003), where the foraging habitat is of Gnargoo and Baiyungu. While it is difficult to quantify the effect of derelict fishing gear on sea turtles, it is estimated that the threat is of similar order to that posed by prawn trawling prior to the introduction of turtle exclusion devices (Kiessling, 2003). By living and migrating thousands of kilometres in those waters, sea turtles, including the loggerheads breeding in the GBR Survey Area, are highly vulnerable to entanglement and subsequent deaths through fishing debris. This highlights the importance and necessity of comprehensive and multi-national approaches to sea turtle conservation, as it is not enough to focus all protection and management actions on nesting habitats of sea turtles.

Figure 38: Foraging habitats of Gnargoo and Baiyungu in far north western Queensland (at 15 June 2018), 2017/18

Note: Small map insert indicates the location of the large map.

8.5.2 Seaturtle.org and Turtle Tracker app

The GTCP launched the Turtle Tracker App[14] in mid-December 2015, which can be downloaded for free by the public to monitor the movements of its satellite tagged turtles.

[14] Developed by Brains in partnership with the GWF.

Gnargoo and Baiyungu were added to the app during December 2017.

Additionally, the GTCP has an established project on www.seaturtle.org (Western Australian Loggerheads – Gnaraloo Bay and Gnaraloo Cape Farquhar 2015 - 2018). Seaturtle.org automatically downloads the ARGOS Doppler data fixes from each satellite tracker as the location data becomes available. Through participating with seaturle.org, the GTCP shares information about the tracked turtles with the scientific world and the public. The migratory movements of Gnargoo and Baiyungu can be viewed on both the GTCP Turtle Tracker App on all smartphones and on www.seaturtle.org[15].

8.6 Conclusion

The findings of the satellite tracking of 2 loggerhead turtles that nested in the GBR Survey Area during the season 2017/18 offer valuable new knowledge of the foraging habitats used by some of the loggerhead turtles that nest at Gnaraloo. Previous satellite tracking undertaken by the GTCP in 2015 - 2017 revealed foraging grounds ranging from Shark Bay, approximately 250 km south of Gnaraloo, in WA all along the western coast of Australia, to Darwin (NT). The wide dispersion of foraging habitats along 4,000 km of Australia's western and northern coastline, including 3 States and Territories, highlights the importance and necessity of comprehensive and collaborative approaches to sea turtle conservation. As sea turtles spend most of their lives in foraging grounds, protection of these habitats is crucial and directly affects the number, health and ability to migrate and breed of resident sea turtles. For effective sea turtle conservation, it is therefore not enough to focus all protection and management actions on nesting habitats.

[15] http://www.seaturtle.org/tracking/?project_id=1149

9 SAMPLED NEST SURVEYS

9.1 Introduction

A variety of ecological and environmental factors can negatively affect successful incubation, hatching and emergence of sea turtle hatchlings from Nests. These include, but are not limited to: extreme sand temperatures, seawater inundation, Erosion, intrusion by plant roots, Disturbance by human activity (e.g. sand compaction), and Predation by native and feral animals (Dodd 1988; Miller et al., 2003). For effective conservation of sea turtle populations it is critical to quantify the impact of threats to turtle Nests and mitigate unsustainable threats when necessary.

For sea turtle rookeries in Australia, a key ecological threat is Predation by invasive species such as European red foxes, feral cats and wild dogs (Baldwin et al., 2003; Limpus, 2008; Hilmer et al., 2010). For example, on certain east coast mainland beaches, foxes were responsible for the destruction of 90 – 95 % of loggerhead turtle clutches in the late 1970s and early 1980s (Limpus, 2008). On the west coast, foxes have been significant predators of sea turtle eggs in the Northwest Cape region for decades, although the impact of fox Predation has been reduced there through a fox baiting program established by the Department of Conservation and Land Management (now DBCA) in 2003/04 (Limpus, 2008). At Gnaraloo, foxes affected a large proportion of sea turtle Nests in parts of the GBR Survey Area prior to the onset of feral animal control programs from 2008, which has successfully reduced Disturbance and Predation by feral animals on sea turtle Nests in the GBR Survey Area to 0 % for 8 consecutive years from 2010/11 – 2017/18. However, native predators such as golden ghost crabs and horned ghost crabs still impact turtle Nests at Gnaraloo (Hattingh et al., 2011). While a certain level of Predation by native predators was likely sustainable to historical sea turtle populations, it is unclear what level of Predation can be sustained by contemporary, depleted turtle populations in WA.

Environmental threats to sea turtle Nests in the GBR Survey Area include inundation associated with storms or tropical cyclones (Hattingh et al., 2011). Cyclones can significantly reduce turtle Hatching success and Emergence success, reduce survivorship through increased flooding and Erosion of Nests (Pike & Steiner, 2007; Van Houtan & Bass, 2007), and have caused a dramatic loss of turtle Nests at Gnaraloo in previous seasons (Hattingh et al., 2011) as well as in the greater Ningaloo region (Coote et al., 2013). Furthermore, the strong prevailing southerly winds (**Section 3.2**) lead to large amounts of sand movement in the littoral dune system within the GBR Survey Area, causing Nest suffocation or Erosion through shifting sands. Variation in sand height above the Nests may affect moisture and temperatures within the egg chamber, resulting in skewed sex ratios (Yntema & Mrosovsky, 1980) or even expose the eggs to lethal temperatures (i.e. > 33 °C; Fisher, 2014). Changes in Nest temperature will also affect the survival fitness (Fisher, 2014) and Incubation periods (Wyneken et al., 2013) of the eggs.

As it is not logistically possible to monitor every turtle Nest in the GBR Survey Area, a statistically representative subset of Nests has been marked as Sampled Nests by the GTCP during each season since 2011/12. Sampled Nests are monitored daily throughout the nesting season for a maximum period of 90 days, after which they are excavated.

Nest excavations allow estimation of clutch sizes and incubation success of Sampled Nests in the GBR Survey Area. Combined with the data collected throughout the Incubation period, the Nest excavations yield important insight into factors influencing Hatching success and Emergence success. Any significant changes in the reproductive success of turtles over time indicate potential problems with the rookery and impacts on the future nesting population. Quantified changes observed based on a long-term monitoring program provide an essential foundation for management decisions to address threats to the Nests and hatchlings and ensure the survival of the rookery's sea turtle population.

9.2 Objectives

The objectives of Sampled Nest surveys in the GBR Survey Area during 2017/18 were to:

- observe a statistically representative subset of Nests daily for the entire monitoring period to record their fate (i.e. whether they survive to emerge on the surface) as an indication of the fate of the entire Nest set;
- monitor the extent and impact of feral and native predators on turtle Nests;
- examine the extent and impact of environmental events on turtle Nests;
- determine the average clutch size of Nests;
- gain insight into factors influencing Hatching success and Emergence success of Nests.

9.3 Material and methods

The GTCP Procedure 2017/18 contains detailed methods. Briefly, the first 50 Nests recorded during GBR Day Surveys were selected to become Sampled Nests and marked using wooden stakes. The early Nests were selected to ensure monitoring for the full Incubation period as the seasonal work in the GBR Survey Area ended on 28 February. The first Sampled Nest was laid on 10 November 2017 and the last of the regular Sampled Nests was laid on 10 December 2017. An additional Nest laid on 24 December 2017 was staked as a Sampled Nest as it was suspected to be laid by a hawksbill turtle (based on a pronounced tail drag and relatively small track width of 57 cm), however, later analysis showed it was laid by Gnargoo, one of the satellite tagged loggerhead turtles. The Sampled Nests were monitored daily during Day Surveys (**Chapter 5**) for a maximum of 90 days (approximately 1 week longer than the maximum observed incubation time at Gnaraloo[16]; Hattingh et al*.,* 2010), or until 14 days after the first evidence of hatchling emergence on the surface. Sampled Nests were monitored in all Sub-sections of the GBR Survey Area.

9.3.1 Monitoring of Sampled Nests

Daily observations recorded Disturbance or Predation by feral and native animals, and environmental events within 1 m^2 of the suspected egg chamber. Nests were considered disturbed if signs of digging or crab burrows were apparent over the egg chamber, while Predation required clear evidence such as egg shells outside the Nest or predated hatchlings. Predated Nests were automatically considered to be disturbed also. Environmental events consisted of Inundation, with evidence of waves washed over the suspected egg chamber, and Erosion, defined as an exposed egg chamber due to wind or water. Length and intensity of Inundation was not considered as it could not be determined using the methods described here. Changes in sand height over the suspected egg chamber were recorded to the nearest cm. Changes of ≥ 20 cm in sand height at any time during the monitoring period were denoted as either suffocation by shifting dunes (**SSD**, +20 cm) or Erosion by shifting dunes (**ESD**, -20 cm) and may impact Nest incubation temperature, moisture, gas exchange and hatchling emergence (Miller et al., 2003). Sand height was monitored daily until the Nest was either excavated, showed signs of hatchling emergence on the surface (in which case the stake was moved directly behind the Nest depression) or the end of the survey period was reached.

Sampled Nests were also monitored for any evidence of hatchlings, such as hatchling tracks and live or dead hatchlings. If hatchlings were observed, the number of hatchlings entering the ocean, dead hatchlings, and predated hatchlings were recorded. In this report, Incubation period is defined as the period from oviposition to hatchling emergence on the surface (i.e. incubation-to-emergence period), a parameter commonly used in nesting

[16] Refer Footnote 18.

beach studies (Miller et al., 2003).

Nests were removed from the Sampled Nest subset if the stake was lost. Stakes that fell over without being moved from their original location were re-staked. Daily recording of environmental factors, Disturbance and Predation continued; however, changes in sand levels were not recorded anymore.

9.3.2 Data analysis

Statistical analysis was performed using the Data Analysis add-on package for Excel (Microsoft Office 2016). Direct comparisons of mean values were analysed using a t-test (two-sample assuming unequal variances, $\alpha = 0.05$). All data are given as mean ± SD.

9.3.3 Nest excavations

Sampled Nests were excavated either 14 days after the first hatchling emergence on the surface, or, in the absence of that, 90 days after being laid. No Sampled Nests were excavated after 28 February 2018, the end of the monitoring period in the GBR Survey Area.

For excavating, the sand was carefully removed by hand at the location of the suspected egg chamber (1 m west of the Sampled Nest stake) until eggs or eggshells were reached. Once the top of the egg chamber was reached, a measurement to the surface sand level was taken. All the contents of the egg chambers were removed, and the depth of the egg chamber to the surface sand level was taken.

The contents of the Nest were sorted into different categories (Miller, 1999; **Table 8**) and counted. Eggs with evidence of Predation only contributed to the total clutch count if not already counted in another category. The number of emerged hatchlings was estimated by subtracting the number of hatchlings (alive and dead) that were found in the Nest from the total number of empty shells (E = S-(L+D)). Live hatchlings just below the beach surface were included in the category of emerged hatchlings.

Table 8: Categories and definition of Nest contents for Nest excavations (Miller, 1999)

CLASSIFICATION	DESCRIPTION
Emerged (**E**)	Hatchlings leaving or departed from Nest
Shells (**S**)	Number of empty egg shells (> 50 % complete)
Live in Nest (**L**)	Live hatchlings left among the egg shells (not in neck of the nest)
Dead in Nest (**D**)	Dead hatchlings that have left their shells
Undeveloped (**UD**)	Unhatched eggs with no obvious embryo
Unhatched (**UH**)	Unhatched eggs with obvious embryo (excluding UHT)
Unhatched Term (**UHT**)	Unhatched apparently full-term embryo in egg shell or pipped (with small amount of yolk material)
Predated (**P**)	Open, nearly complete shells containing egg or embryo residue

Hatching success (number of hatchlings outside their shells) and Emergence success (number of hatchlings reaching the beach surface) were determined for all successfully excavated Nests, using the following equations (Miller J. D., 1999):

$$Hatching\ success\ (\%) = \frac{Shells}{Shells + UD + UH + UHT} \times 100$$

$$Emergence\ success\ (\%) = \frac{Shells - (L + D)}{Shells + UD + UH + UHT} \times 100$$

9.4 Results

9.4.1 Sample size

A total of 54 Nests in all Sub-sections in the GBR Survey Area were marked during the season 2017/18 (GBN – BP7: 15; BP7 – BP8: 2; BP8 – BP9: 37). Of these, 2 stakes were lost due to strong winds (both in BP8 – BP9) and daily monitoring was discontinued for those Nests; therefore, they are not included in the analyses. 7 stakes were knocked over by turtles or the wind (GBN – BP7: 2; BP8 – BP9: 5), but could be re-staked at the original location. On 2 stakes, the numbers became illegible towards the end of the survey period (BP8 – BP9), despite attempts of re-writing them daily. Monitoring for those Nests continued; however, no subsequent sand height measurements were taken (**Table 9**).

Table 9: Sampled Nests in GBR Sub-sections (1 Nov 2017 – 28 Feb 2018), 2017/18

SUB-SECTION	SAMPLED NESTS (SEASON START)	STAKES LOST – MONITORING STOPPED	SAND HEIGHT MEASUREMENTS STOPPED	TOTAL SAMPLED NESTS (SEASON END)
GBN – BP7	15	0	2	15
BP7 – BP8	2	0	0	2
BP8 – BP9	37	2	7	35
TOTAL	54	2	9	52

All Sampled Nests were laid by loggerhead turtles. Both of the Sampled Nests in Sub-section BP7 – BP8 were verified during Night Surveys as Nests. Turtles were encountered for 18 of the 37 Sampled Nests in Sub-section BP8 – BP9 during Night Surveys; 12 were observed laying eggs and verified as a Nest, while the other 6 were seen either covering, camouflaging or returning and were identified as a Nest by the Day Survey team. None of the Sampled Nests in Sub-section GBN – BP7 were verified.

Sampled Nests were monitored until they were excavated 2 weeks after evidence of emerged hatchlings on the surface was observed, 90 days after they were first laid, or until the end of the survey period on 28 February 2018. During the, season 2017/18, Sampled Nests were monitored for an average of 80.6 ± 14.6 days.

9.4.2 Nest Disturbance and Predation

No Sampled Nests were disturbed or predated by feral animals during the season 2017/18, despite feral cat tracks leading over some of the Sampled Nests on various occasions (**Section 4.4.1**). While egg and hatchling Predation by sea birds, primarily Silver Gulls (*Chroicocephalus novaehollandiae*), was recorded on multiple occasions throughout the season, the vast majority of Predation and Disturbance was the result of ghost crabs[17].

90.4 % (47 / 52) of all Sampled Nests were disturbed by ghost crabs in the GBR Survey Area (**Figure 39**). 93.3 % (14 / 15) of Sampled Nests were disturbed in Sub-section GBN – BP7; 100% (2/2) in Sub-section BP7 – BP8; and 88.6 % (31 / 35) in Sub-section BP8 –

[17] By definition, a predated Nest is also disturbed. However, for the purposes of this report, Disturbance and Predation are separately recorded.

BP9 (**Figure 40; Appendix A7**).

Crab Predation was recorded in 44.2 % (23 / 52) of all Sampled Nests in the GBR Survey Area, including 53.3 % (8 / 15) in Sub-section GBN – BP7; 100 % (2 / 2) in Sub-section BP7 – BP8; and 37.1 % (13 / 35) in Sub-section BP8 – BP9 (**Figure 40**, **Appendix A7**).

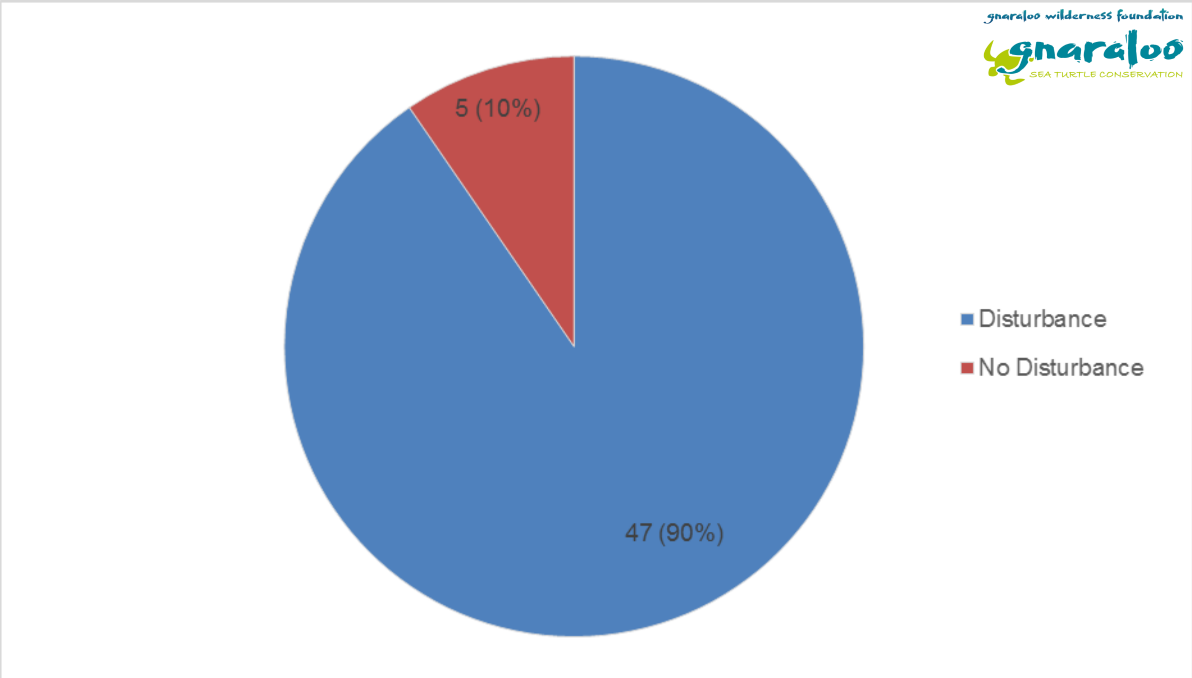

Figure 39: Ratio of Sampled Nests impacted by ghost crab Disturbance in GBR Survey Area (1 Nov - 28 Feb), 2017/18

Note: Predated Sampled Nests are included under Disturbance

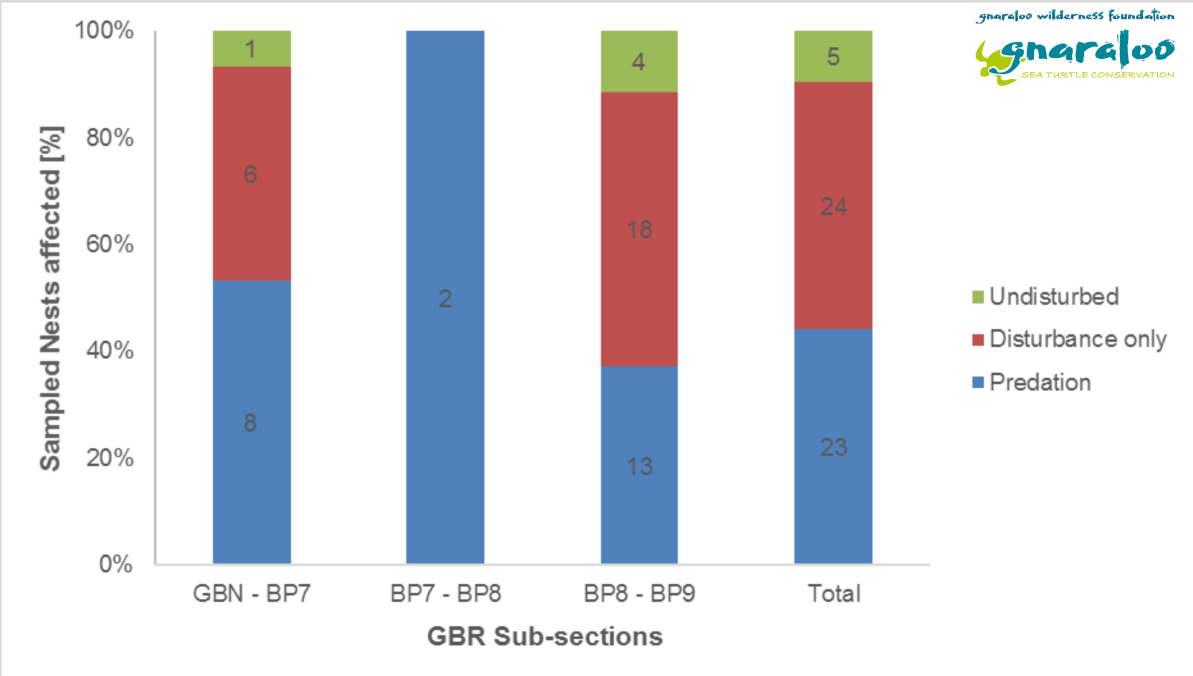

Figure 40: Sampled Nests impacted by ghost crabs in GBR Sub-sections (1 Nov - 28 Feb), 2017/18

9.4.2.1 7-year trends in crab activity

Sampled Nest Predation data have been systematically collected by the GTCP since the season 2011/12. Crab Disturbance and Predation have varied greatly over these 7 seasons (**Figure 41**). The season 2017/18 had the second highest number of Sampled Nests affected by Disturbance or Predation, with season 2011/12 having a higher overall rate of Disturbance and Predation. After two seasons (2014/15 – 2015/16) with lower crab impacts on Sampled Nests, Predation increased again during the past two seasons (2016/17 – 2017/18). It is not possible to determine a trend based on the current data.

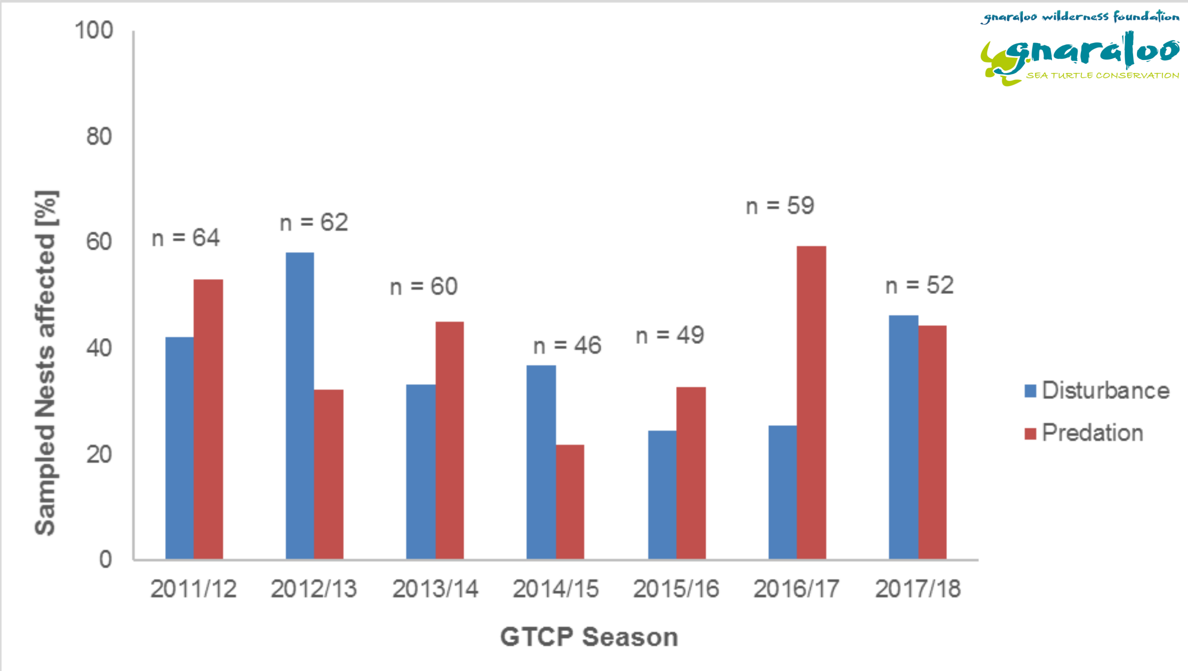

Figure 41: Sampled Nests impacted by ghost crabs in GBR Survey Area (1 Nov - 28 Feb), 2011/12 - 2017/18

Note: Sampled Nest Predation data were collected consistently from season 2011/12. A large proportion of Sampled Nests during season 2012/13 were washed out by tropical cyclone Nerelle. The data is included in this figure, but the Nests were monitored for varying, often short (i.e. several weeks) lengths of time depending on how long the Nests were laid before the cyclone. Thus, estimates of crab Disturbance and Predation impacts during season 2012/13 are likely low compared to seasons without cyclone activity.

9.4.3 Environmental impacts on Nests

9.4.3.1 Inundation and Erosion

Although no cyclones or significant storms occurred during the season 2017/18, 40.4 % (21 / 52) of Sampled Nests in the GBR Survey Area were inundated on at least one occasion (**Figure 42**). Inundation generally occurred during spring high tides. No Sampled Nests were affected by Erosion related to tides or storms.

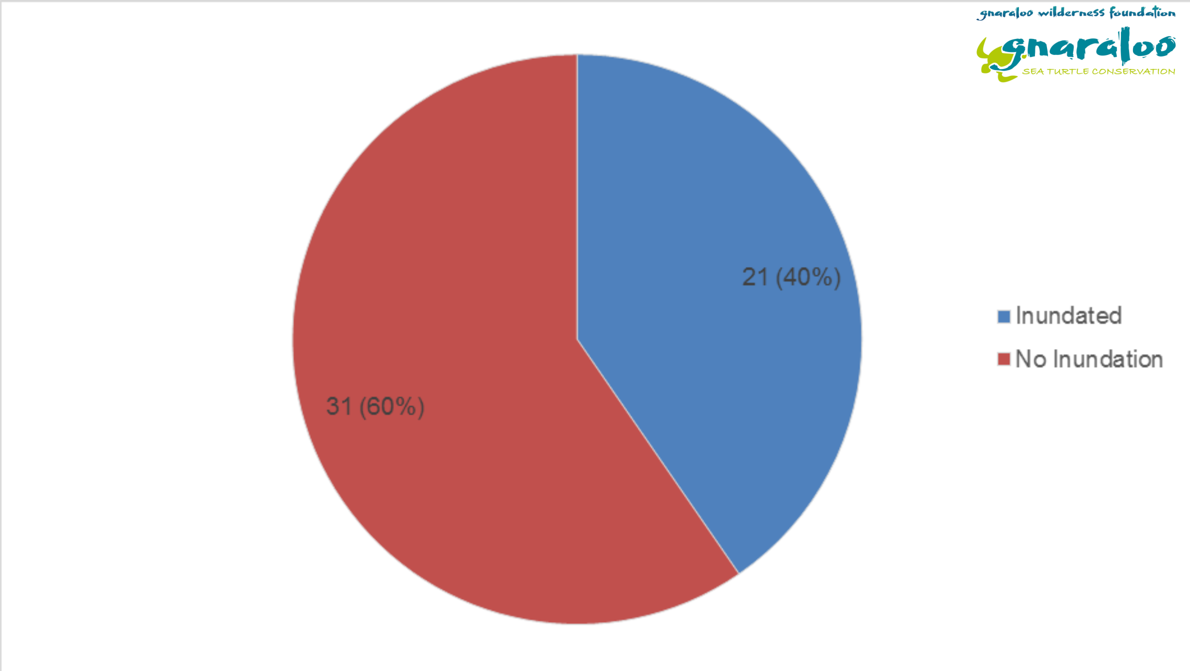

Figure 42: Ratio of Nests affected by Inundation in GBR Survey Area (1 Nov - 28 Feb), 2017/18

Sub-section BP8 – BP9 was most impacted by Inundation, with 70 inundation events affecting 42.9 % (15 / 35) of Sampled Nests. In Sub-section GBN – BP7, 26.7 % (4 / 15) were inundated, and both (100 %) Sampled Nests in Sub-section BP7 – BP8 were inundated on multiple occasions (**Appendix A8**). 8 Sampled Nests were inundated on one occasion only, while 13 Sampled Nests were inundated more than once. 2 Sampled Nests in Sub-section BP8 – BP9 were inundated on 13 occasions throughout the Incubation period (**Figure 43**).

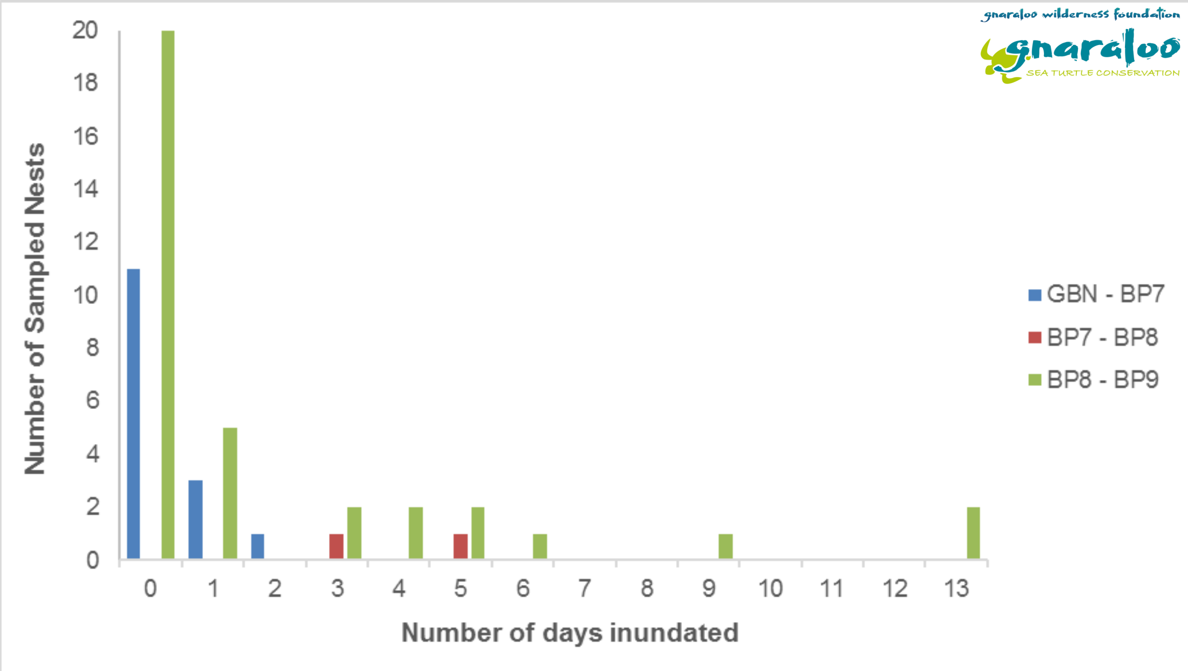

Figure 43: Frequency of Inundation of Sampled Nests in GBR Survey Area (1 Nov - 28 Feb), 2017/18

9.4.3.2 7-year trends in Inundation and Erosion

The rate of Inundation of Sampled Nests during the season 2017/18 was relatively high compared to previous seasons (**Figure 44**). Only two seasons (2011/12 – 2012/13) had more Sampled Nests inundated. Season 2012/13 was affected by tropical cyclone Nerelle. Erosion by tides or storms generally did not affect many Sampled Nests, with the exception of season 2012/13, when tropical cyclone Nerelle washed out large numbers of Sampled Nests.

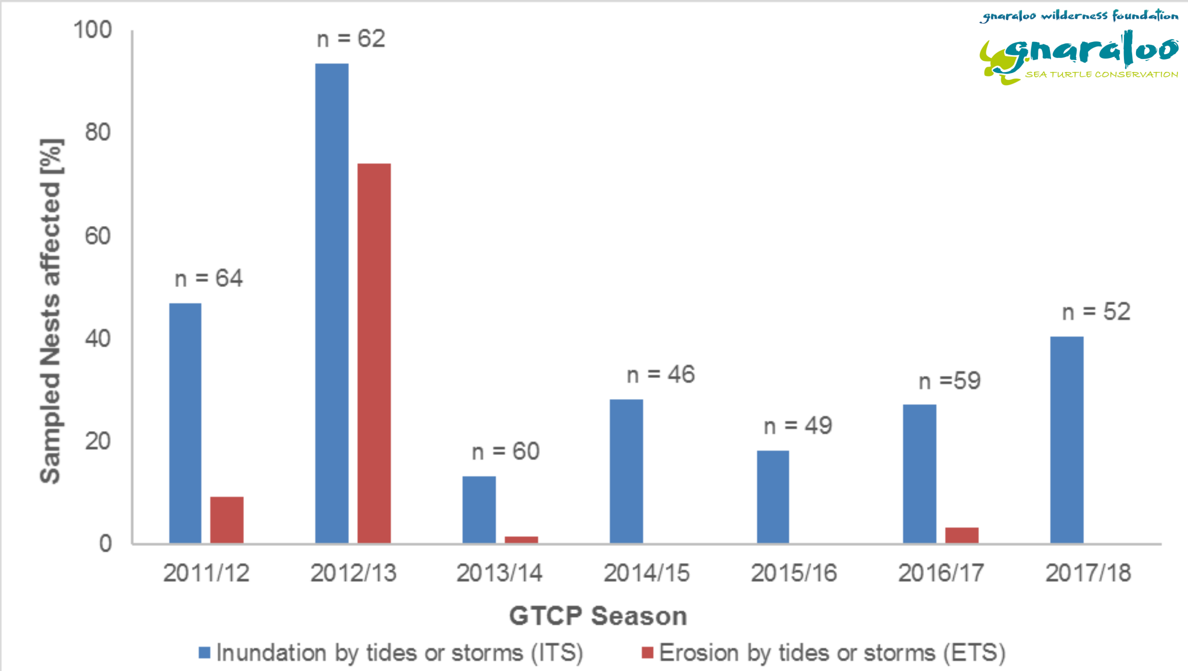

Figure 44: Sampled Nests affected by ITS and ETS in GBR Survey Area (1 Nov - 28 Feb), 2011/12 - 2017/18

9.4.3.3 Sand height changes

Sand height was monitored for 68.4 ± 18.3 (66 – 91) days throughout the GBR Survey Area. 9.6 % (5 / 52) of all Sampled Nests, all in Sub-section BP8 – BP9, experienced increases in sand height of ≥ 20 cm relative to initial levels, while 9.6 % (5 / 52) experienced decreases of ≥ 20 cm in sand height compared to initial levels. Sand heights fluctuated substantially for some Sampled Nests throughout the season 2017/18. The relative sand height fluctuated ≥ 20 cm for 30.8 % (16 / 52) of Sampled Nests throughout the monitoring period. Sand levels changed between 10 - 20 cm in 26.9 % (14 / 52) Sampled Nests; and 42.3 % (22 / 52) Sampled Nests had less than 10 cm change in sand levels throughout the monitoring period (**Figure 45, Appendix A8**). Final sand height levels ranged from -33 cm to +129 cm in the GBR Survey Area.

Changes in sand height were not compared across seasons 2010/11 – 2017/18 due to year-to-year differences in data collection methods.

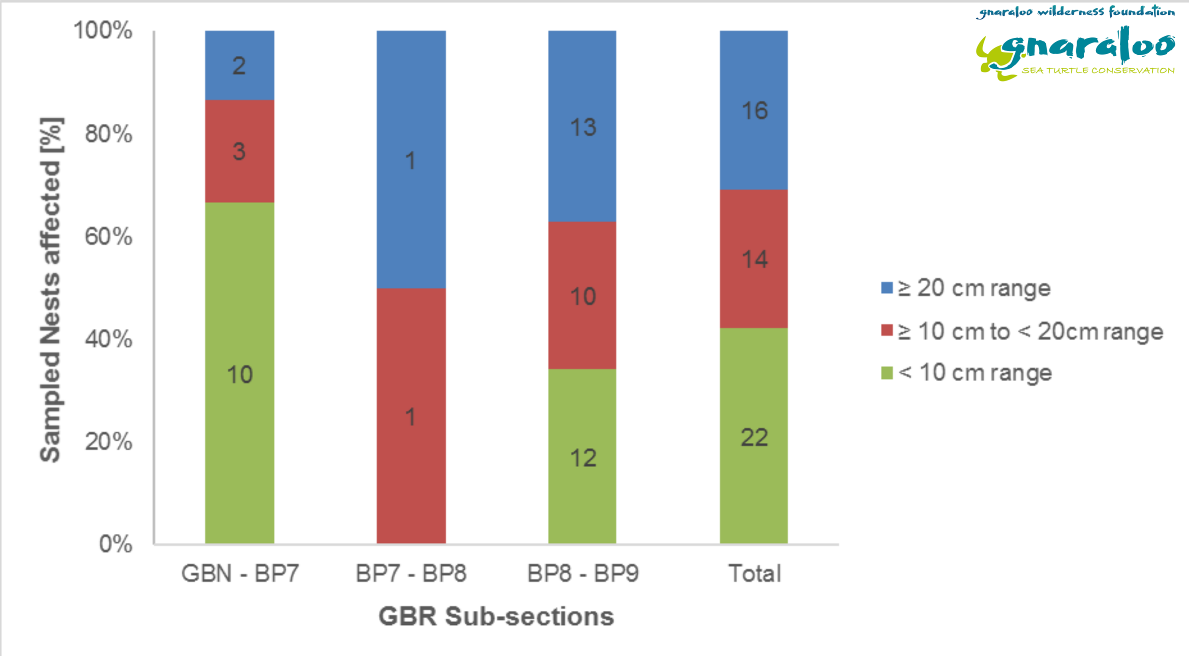

Figure 45: Sand height changes on Sampled Nests throughout the Incubation period in GBR Survey Area (1 Nov - 28 Feb), 2017/18

9.4.4 Incubation periods

Of all Sampled Nests, 59.6 % (31 / 52) showed evidence of hatchling emergence during the season 2017/18 (**Figure 46**). Evidence of hatchling emergence was recorded for 80.0 % (12 / 15) of Sampled Nests in Sub-section GBN – BP7; 50.0 % (1 / 2) in Sub-section BP7 – BP8; and for 51.4 % (18 / 35) in Sub-section BP8 – BP9.

The mean Incubation period during 2017/18 for the 31 Sampled Nests that showed evidence of hatchling emergence was 67.5 ± 5.0 days, ranging from 58 to 76 days[18]. Incubation periods for Sampled Nests laid in November 2017 (16, 70.2 ± 4.2 days) were significantly longer than for Sampled Nests laid in December 2017 (15, 64.0 ± 3.9 days, $p < 0.0001$; **Figure 47**).

[18] In comparison, during the season 2009/10, Incubation periods for loggerhead Nests in BP8 - BP9 ranged from 55 – 82 days, with the highest frequency of hatchling emergence at 60 - 70 days. Mean incubation time was 67.3 days. Nests laid earlier in the season (during November – December 2009) had longer incubation times (70.5 – 77.2 days) compared to those laid later in the season (during January – February 2010; 63.2 – 64.7 days).

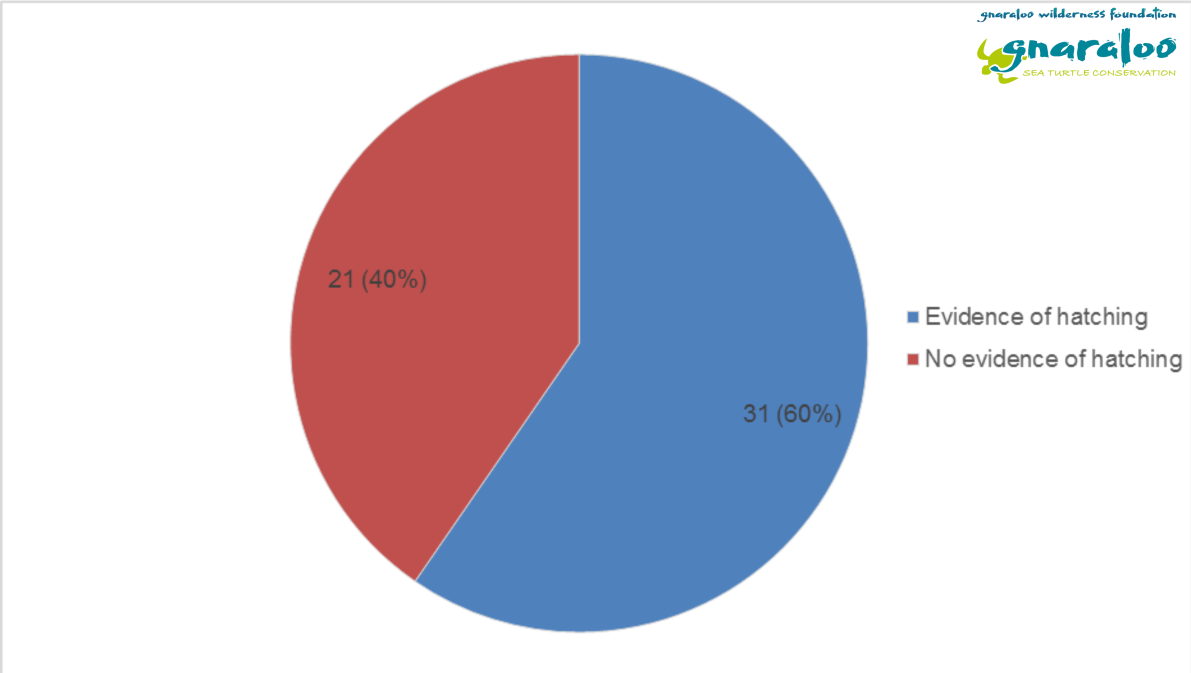

Figure 46: Ratio of Sampled Nests that showed evidence of hatchling emergence in GBR Survey Area (1 Nov - 28 Feb), 2017/18

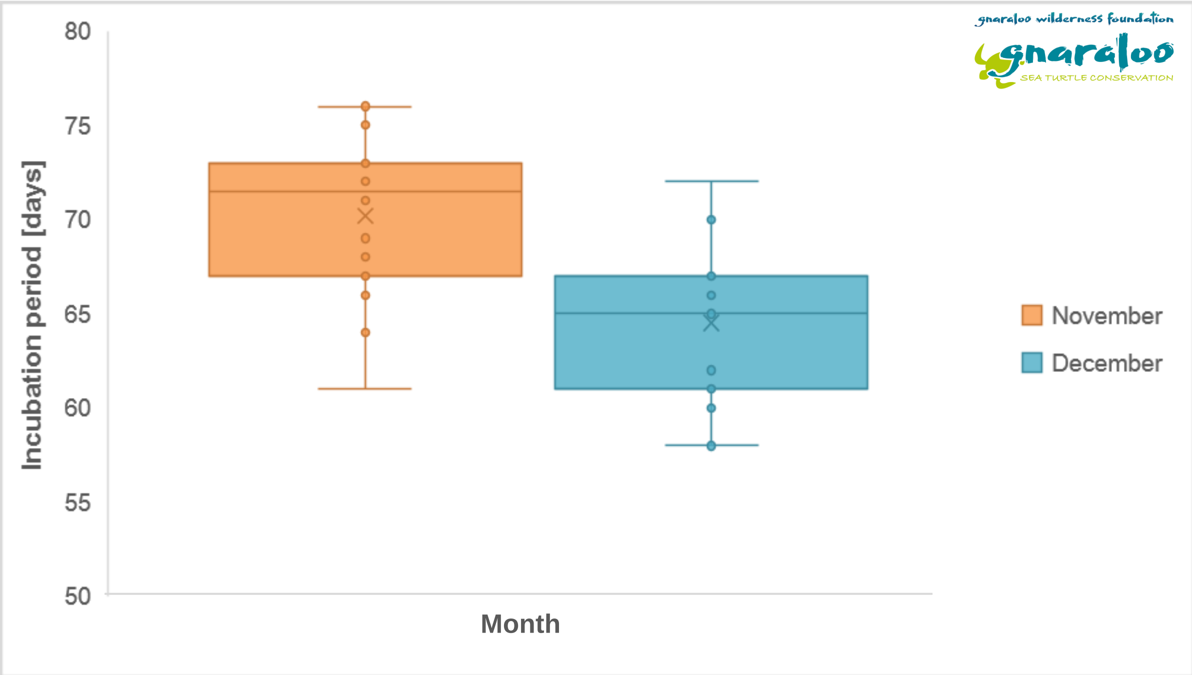

Figure 47: Incubation periods of Sampled Nests laid in November and December 2017 in GBR Survey Area, 2017/18

Note: x = mean value

9.4.5 Nest excavations

During the season 2017/18, a total of 41 Sampled Nests in the GBR Survey Area were excavated (**Appendix A6**). Additionally, 1 non-Sampled Nest was excavated after hatchling emergence was witnessed during a Day Survey.

Despite extensive digging, no egg chambers were found for 14.3 % (6 / 42) of all excavations, implying that they either may have been UNAs instead of Nests, or that the stake was not placed correctly behind the actual egg chamber during Day Survey. Of all excavated Nests, 26.2 % (11 / 42) did not have an intact egg chamber when excavated, revealing only a few small egg shell fragments, presumably due to crab Predation before, during or after hatching (i.e. coming out of the shell, rather than emerging on the surface). Therefore, only the 25 Nests (all in Sub-sections GBN – BP7 and BP8 – BP9) for which intact egg chambers were found, were included in further data analysis (**Figure 48**).

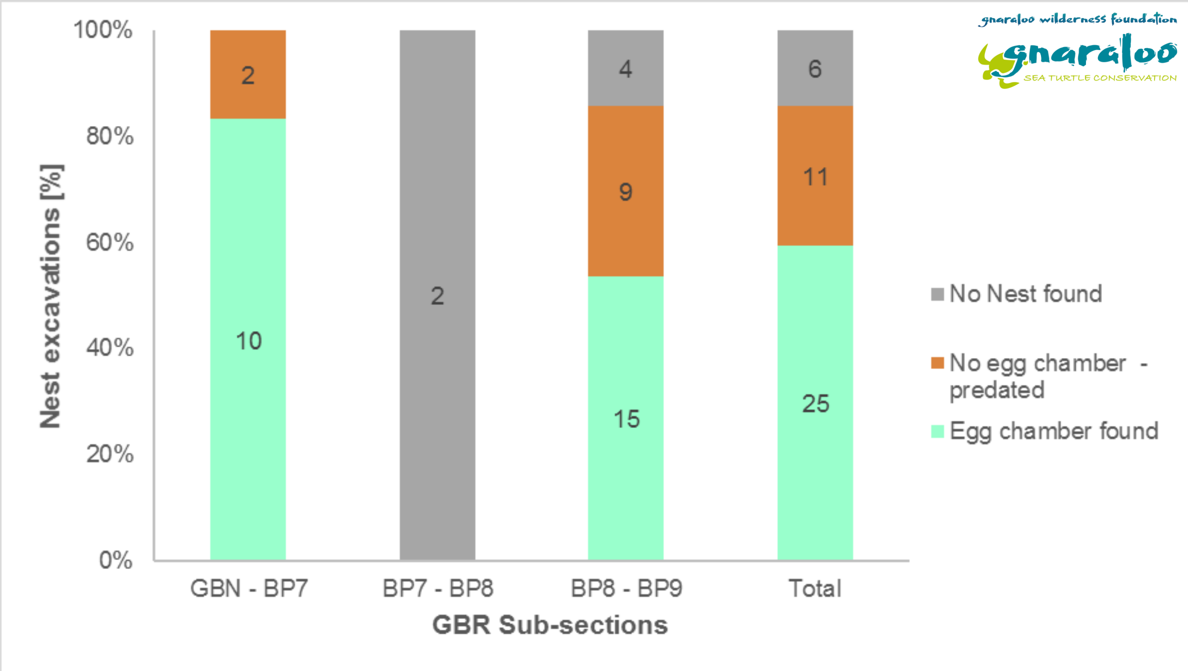

Figure 48: Findings of Sampled Nest excavations in GBR Survey Area (1 Nov - 28 Feb), 2017/18

9.4.5.1 Hatching success and Emergence success in excavated Nests

No difference in average Hatching success of the excavated Nests was found between Sub-sections GBN – BP7 and BP8 – BP9, with success rates of 80.6 ± 22.5 % and 80.5 ± 20.3 %, respectively ($p > 0.05$). The same results were found for Emergence success, with a success rate of 79.2 ± 22.1 % for Sub-section GBN – BP7; and 79.4 ± 20.4 % for Sub-section BP8 – BP9. No egg chambers were found during excavation of the 2 Sampled Nests in BP7 – BP8.

Over all, the GBR Survey Area produced a Hatching success of 80.5 ± 20.7%, and an Emergence success of 79.3 ± 20.6 % (**Figure 49**).

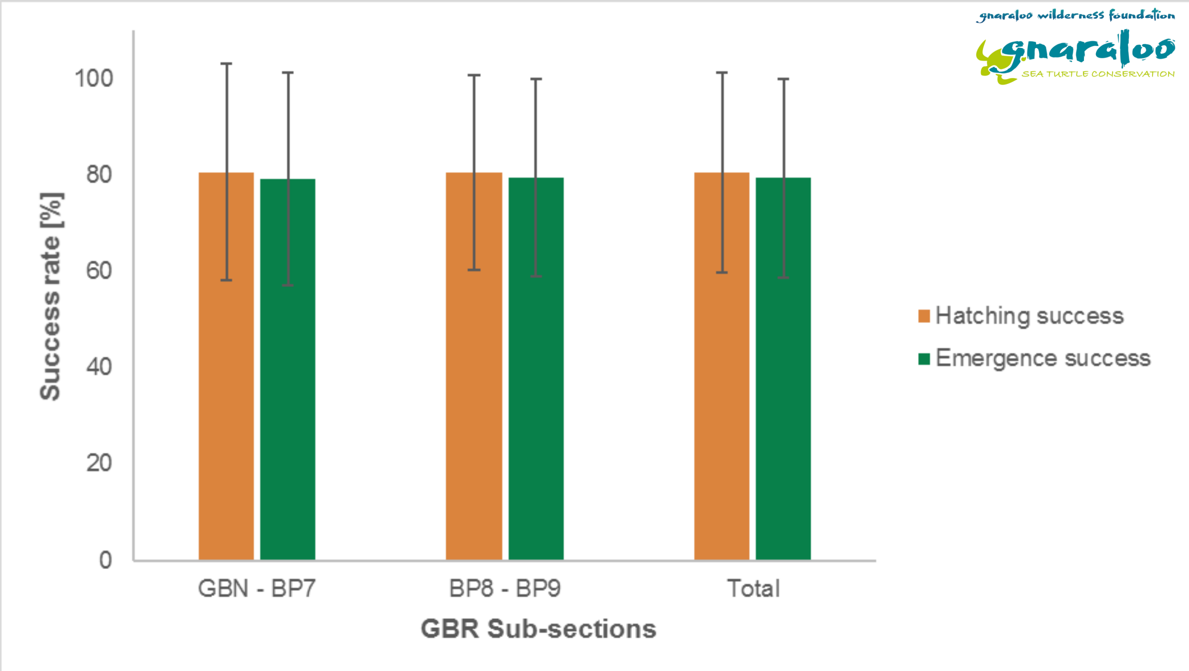

Figure 49: Hatching success and Emergence success of excavated Nests in GBR Sub-sections (1 Nov - 28 Feb), 2017/18

9.4.5.2 Characteristics of excavated Nests

The average estimated clutch size determined from Nest excavations in the GBR Survey Area was 115.4 ± 25.8 eggs, containing 94.0 ± 31.3 empty shell remnants. Clutch sizes and the number of empty shells did not vary between Sub-sections GBN – BP7 (118.5 ± 17.54 and 96.5 ± 32.9, respectively) and BP8 – BP9 (113.3 ± 30.5 and 92.3 ± 32.9, respectively; $p > 0.05$; **Figure 50**).

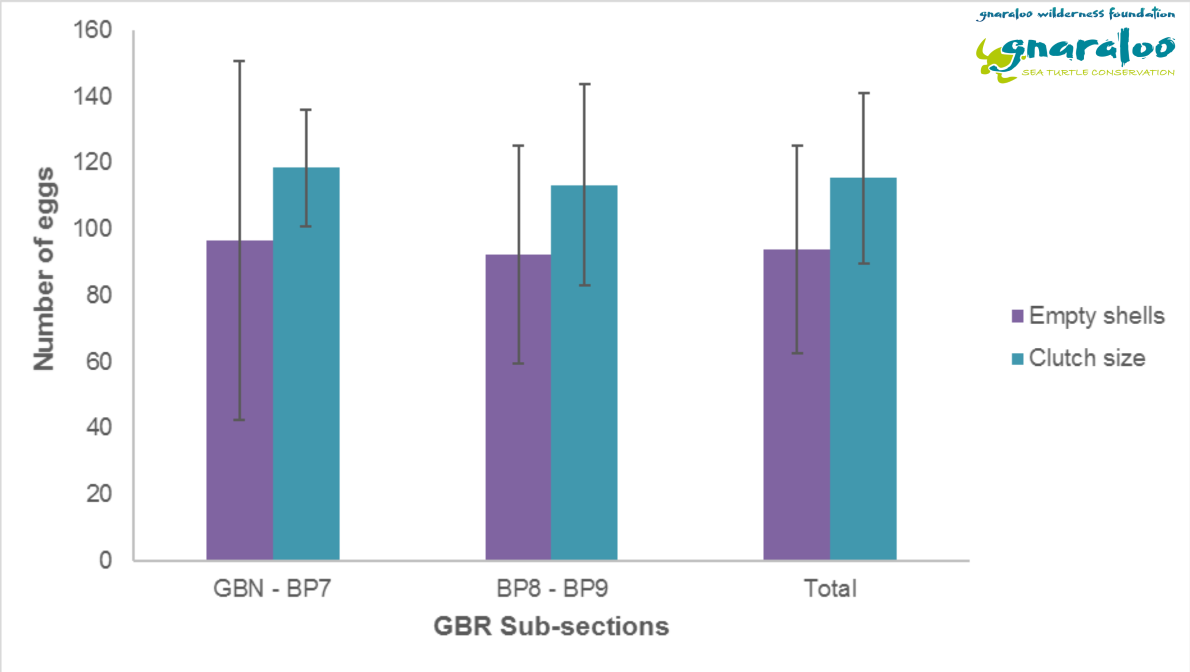

Figure 50: Clutch sizes and number of empty shells in excavated Nests in GBR Sub-sections (1 Nov - 28 Feb), 2017/18

The average depth to the top of the egg chamber in the GBR Survey Area was 31.5 ± 9 cm, while the depth to the bottom of the chamber was 57.2 ± 10 cm, resulting in an average egg chamber depth of 25.6 ± 10.4 cm. No significant differences were found for egg chamber depths of different Sub-sections ($p > 0.05$ for top of chamber, bottom of chamber, egg chamber depth).

The different contents of excavated Nests varied greatly between Nests (**Figure 51**). More Undeveloped eggs (10.8 ± 11.3) than Unhatched Term embryos (0.64 ± 1.04) or Live hatchlings (0.32 ± 0.85) were found in the Nests. Each Nest contained between 0 and 4 Dead hatchlings (mean: 1.1 ± 1.4). The numbers of Undeveloped eggs, Unhatched eggs and Predated eggs/hatchlings found in each Nest varied significantly as displayed by the outliers in **Figure 51**.

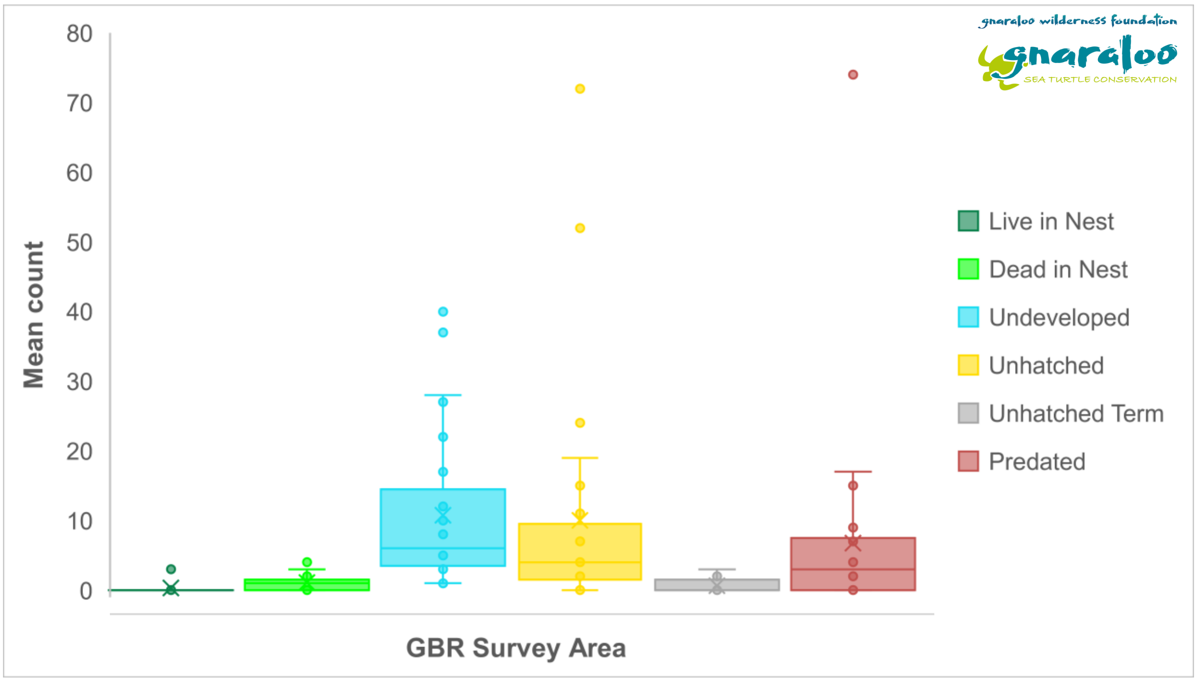

Figure 51: Contents of excavated Nests in GBR Survey Area (1 Nov - 28 Feb), 2017/18

Note: x = mean value

9.4.5.3 Crab impacts on excavated Nests

The Sampled Nests for which no proper egg chamber was found (11 / 42) had significantly more days of crab Disturbance and Predation recorded (21.5 ± 14.0 days), compared to Sampled Nests which had an intact egg chamber (25 / 42; 5.2 ± 4.4 days, $p < 0.01$; **Figure 52**).

9.4.5.4 Environmental impacts on excavated Nests

No correlations were observed for the excavated Nests (25 / 42) between Emergence success and final sand level or days of Inundation ($r^2 = 0.01$ and $r^2 = 0.006$, respectively).

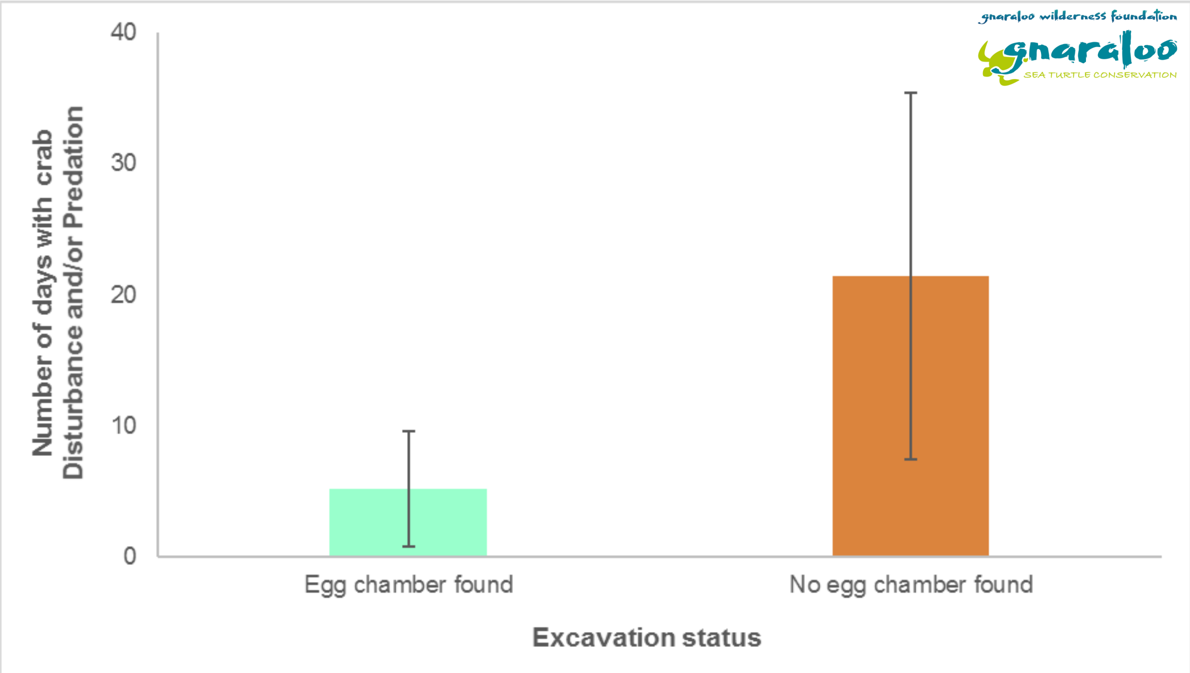

Figure 52: Crab impacts on excavated Nests in the GBR Survey Area (1 Nov - 28 Feb), 2017/18

9.4.6 Case studies

9.4.6.1 Nesting Activity 0017 (GBN – BP7), 7 December 2017

A loggerhead turtle Nest in Sub-section GBN – BP7 was identified by the Day Survey team on 7 December 2017. It was situated at the edge of vegetation, 8 m above the high tide line (-23.76697 °S, 113.55059°E). As the Nest was monitored throughout the season, it experienced 2 incidences of feral cat tracks across the Nest with no signs of Disturbance, as well as 1 incident of Disturbance by ghost crabs. During the monitoring period the sand height on the Nest did not change by more than 3 cm and on 5 February 2018, a single hatchling track was recorded emerging from the Nest. The Nest was excavated 14 days later, on 19 February 2018. The Nest excavation located the top of the egg chamber 28 cm below the surface, and the bottom of the chamber 52 cm below the surface, resulting in an egg chamber depth of 24 cm. The Nest contained 24 Shells, 1 Undeveloped egg and 72 Unhatched eggs. 74 eggs and Shells showed signs of Predation. All Unhatched eggs were noted as predated and this Nest recorded both the highest number of predated and Unhatched eggs of all the Nest excavations for season

2017/18.

9.4.6.2 Nesting Activity 0016 (BP8 – BP9), 23 November 2017

On 23 November 2017, this Sampled Nest was identified and staked in Sub-section BP8 – BP9. The Nest was located behind a small dune (-23.73360 °S,113.57587 °E), and laid by a loggerhead turtle as identified by the Day Survey team and verified by the Night Survey team. The Nest was sampled for 90 days and excavated on 21 February 2018, 14 days after the first signs of hatchling emergence. Throughout the monitoring period, the Nest recorded 19 days of Disturbance by crabs and 4 incidences of Inundation by the tide. On 27 January 2018, 8 cm of sand accumulated on the Nest in only 24 hours, and it was noted that the sand dune next to the Nest had begun shifting towards the Nest. Prior to this, the Nest had only experienced total sand height changes of between -3 and +13 cm, with a maximal daily change of 5 cm. Between 27 January - 8 February 2018, the dune continued to move over the Nest and the sand height increased from 21 cm to 129 cm, a total of 108 cm in 12 days. The final sand height measurement of 129 cm was the greatest sand height change recorded for all the Sampled Nests during 2017/18. On 7 February 2018, the Day Survey team recorded 1 hatchling emerge from the Nest, after 76 days of incubation, and the two following days Nest depressions were recorded on top of the dune. The excavation 14 days later could not locate the egg chamber due to the large amount of dry sand on top of the Nest. The excavation revealed a trail of 49 Dead hatchlings in the dune on top of the Nest. This was the highest number of Dead hatchlings found in any excavated Nest this season. As the egg chamber could not be located despite extensive efforts, the Nest was excluded from further data analysis.

9.4.6.3 Nesting Activity 0035 (BP8 – BP9), 29 November 2017

This Sampled Nest was identified and staked on 29 November 2017, located in Sub-section BP8 – BP9 at the edge of vegetation and 6 m above the high tide line (-23.728003 °S,113.57869 °E). A loggerhead turtle laid the Nest as identified by the Day Survey team and verified by the Night Survey team. During the monitoring period, the Nest experienced an overall fluctuation in sand height of 21 cm, with a minimum sand height of -11 cm and a maximum sand height of +10 cm. The Nest recorded 3 incidences of Disturbance by crabs and was inundated by the tide 5 times during the survey period. Although no hatchling emergence event was recorded for the Nest, potential Nest depressions were noted on two survey days (26 January and 9 February 2018). As such, the Nest was excavated on 28 February 2018, 90 days after having been laid. The Nest excavation resulted in 14 Shells, 1 Dead hatchling in the Nest, 12 Undeveloped eggs, 9 Predated and 24 Unhatched eggs. This Nest recorded one of the highest numbers of Unhatched eggs that were not predated upon, likely due to Inundation during the Incubation period.

9.5 Discussion

9.5.1 Ecological impacts on Sampled Nests

Predation of sea turtle Nests by feral animals is no longer an issue in the GBR Survey Area thanks to the impact of the consistent feral animal control programs at Gnaraloo since 2008. Native predators, specifically ghost crabs, are now the primary source of Disturbance and Predation of turtle Nests. Nest Disturbance and Predation by native crabs affected the vast majority of Sampled Nests during 2017/18. As the Nests reached the end of the Incubation period and hatchlings began to emerge on the surface, crab Disturbance and Predation often greatly increased. Significant crab Disturbance and Predation were also seen and recorded for many non-Sampled Nests during the time of hatchling emergence on the surface (note that GTCP surveys have ended on 28 February each year and the seasonal hatchling emergence period extends beyond this).

Little data is known regarding the turtle nesting numbers and impacts of predators in the GBR Survey Area prior to the start of the GTCP in 2008. However, it is known that sea turtle Nests were greatly disturbed and predated upon by introduced foxes before the start of the consistent feral animal control programs at Gnaraloo; thus, the current turtle nesting population in the GBR Survey Area is likely depleted compared to the historical population before the introduction of feral animals. Although the historic number and potentially higher density of sea turtle Nests within the GBR Survey Area may have been sustainable and capable of withstanding high rates of crab Predation, it remains unclear whether or not the currently depleted nesting turtle population can support the current, seemingly high Predation rates by crabs.

Nest excavations during the season 2017/18 did not deliver a conclusive answer on the magnitude of crab Predation impacts. While the rate of predated eggs in the egg chamber varied between 4.5 % and 7.8 %, this was only quantifiable for the 25 Nests where an egg chamber was still present at the time of excavation. 11 Nests only showed remnants of egg chambers, including a few dead hatchlings and pieces of egg shells, implying that the egg chambers were obliterated by ghost crabs. However, due to the current GTCP protocol of excavating 14 days after the first signs of hatchling emergence on the surface, it is impossible to determine whether the crabs predated the eggs before, during or after hatching (i.e. when they came out of the shell, before emerging on the surface). Observations during Day Surveys revealed a significant increase of local ghost crab activity when hatchlings were due to emerge from a Nest, with up to 30 burrows on top of the egg chamber. Egg shell fragments were frequently seen outside the Nest. But again, it is not possible to tell when the ghost crabs were most active, as it is possible that they were attracted by the large amount of organic material after the hatchlings emerged.

While the rate of Disturbance and Predation seems high in the GBR Survey Area, the actual impact of crabs has not been quantified. This is the case on many nesting beaches, as Predation of Nests and hatchlings by ghost crabs have been noted worldwide, but are rarely quantified (Ali & Ibrahim, 2002). To get a better understanding of the magnitude of crab Predation in the GBR Survey Area, further studies quantifying the percentage of eggs destroyed in each Nest and the number of hatchlings taken from each clutch are necessary. This information would provide important information on whether management intervention is needed to reduce crab Predation of sea turtle eggs and hatchlings in the GBR Survey Area.

9.5.2 Environmental impacts on Sampled Nests

Hatching success of loggerhead turtle Nests is determined by many environmental conditions, including temperature, Predation, sand water salinity and content, and Inundation (Foley et al., 2006). These factors affect moisture, gas exchange and temperature within the egg chamber (Miller et al., 2003). The frequency and severity of inundations as well as the speed with which the water can drain from the sand all play a part in the effect that Inundation has on the success of a Nest (Shaw, 2013). During incubation, there are critical periods in which the developing embryos are more vulnerable to environmental impacts. Studies in eastern Australia found early-term loggerhead embryos to be more vulnerable to Inundation than late-term embryos (Limpus, 1985). Prolonged Inundation can restrict gas exchange of developing embryos, causing asphyxiation. It also changes sand water salinity and sand water content, both of which influence the Hatching success of a Nest (Foley et al., 2006). However, Foley and colleagues (2006) also found that despite Inundation, some loggerhead turtle Nests still managed to reach a relatively high Hatching success.

Although no Nests were affected by cyclones or storm surges during 2017/18, almost half of the Sampled Nests were inundated by high tides. But while only 52.4 % of the inundated Sampled Nests displayed clear evidence of hatchling emergence on the surface, the Nest excavations (albeit a small sample of 25 Nests) did not reveal any relationship between Inundation and Hatching success. This may suggest that the beach characteristics in the GBR Survey Area, such as sand drainage, allow for a certain tolerance of Nests to Inundation. Importantly though, Nests beneath or close to the high tide line were not only inundated during the Incubation period, but also had a higher risk of Disturbance and Predation by ghost crabs, which tend to burrow near spring high tide lines (Ali & Ibrahim, 2002). It is important to keep in mind, however, that under current GTCP protocol, Inundation is defined as any amount of water washing over the Nest area. There is currently no quantification of the extent of Inundation within the egg chamber, and the impact of events recorded as Inundation on the actual Nests therefore remains unclear.

The GBR Survey Area is subject to strong prevailing southerly winds for much of the turtle nesting season (**Chapter 3**). As a result, the littoral sand dunes within the GBR Survey Area are highly mobile and shift substantially throughout the nesting season. While the precise impact of sand height fluctuations remains unknown, it is possible that changes in sand height of 20 cm or more have some influence on temperatures, moisture and gas exchange in the egg chamber. Interestingly, however, no correlation was found between Emergence success of excavated Nests and sand height changes at the time of hatchling emergence on the surface. The 3 excavated Nests with significantly lower Emergence success rates (32.4 %, 31.8 % and 24.7 %) than the rest (62.0 – 97.6 %) underwent changes of less than 4 cm in sand height compared to when the Nest was laid. Conversely, 2 Nests which lost 32 cm and 33 cm of sand throughout the Incubation period had Emergence success rates of 89.8 % and 62.0 %. Rather, the location on the beach might have impacted the 3 Nests with the low Emergence success rates, as they were all located at the back of the beach on relatively flat sections. As the nearly horizontal beach surface lies perpendicular to the midday sun, it is likely that sand temperatures for those Nests were higher compared to parts of the beach sloping towards the water. Combined with the relatively far distance to the water, the sand in and around the egg chamber may have become too dry and hot for ideal incubation conditions (Foley et al., 2006).

However, extreme changes in sand height, such as for Sampled Nest 0016 (BP8 – BP9, discussed above in the case studies) which accumulated more than 1 m of sand towards the end of the Incubation period, severely affected Emergence success and indicated the need for management action. Nests in South Florida that had 50 cm or more of extra sand deposited on them after a hurricane showed significantly reduced Emergence success (Milton et al., 2004). There is a strong link between clutch development and sand temperature during incubation (Zbinden et al., 2006), which is likely negatively affected by large amounts of extra sand on top of a Nest. Large amounts of extra sand present an immense obstacle to emerging hatchlings, as their way to the beach surface may double or even triple, increasing the risk of dehydration and extensive energy expenditure for the hatchlings. It is recommended that the issue of large accumulations of sand on top of egg chambers during the Incubation period in the GBR Survey Area be considered in future for management intervention.

9.5.3 Sampled Nest excavations

Although observational evidence of emerged hatchlings on the surface was present for 31 Sampled Nests (59.6 %), it is likely that hatchlings emerged from more Nests. Presently, evidence of hatchling emergence on the surface during Day Surveys is determined using a binary system and is only recorded when hatchlings or hatchling tracks are observed emerging from a Sampled Nest. This provides only a coarse indicator of Emergence success, limiting the ability to quantify the reproductive output of loggerhead turtles in the GBR Survey Area.

In contrast, results from Nest excavations indicated that likely all of the investigated Nests (25) hatched to some degree, with an overall Hatching success of 80.5 %. This is similar to Hatching success rates reported for undisturbed loggerhead turtle Nests on Dirk Hartog Island (70. 6 %) and in the Cape Range National Park (84.5 %; Trocini, 2013). Importantly, Hatching success calculations for the GBR Survey Area only took into account the Nests for which intact egg chambers were found, reducing the sample size from 42 to 25 and not taking into account Nests that appeared to have been highly predated by ghost crabs.

The Emergence success, defined as the number of hatchlings reaching the beach surface, was not notably different from the Hatching success, suggesting that for the GBR Survey Area, no significant impacts affect hatchlings from emerging from the Nest once hatched. These results are consistent with the guidelines laid out by Miller (1999), suggesting that Hatching success should be approximately 1 % higher than Emergence success. However, neither Hatching success nor Emergence success take into account the seemingly high

Predation rate of hatchlings in the GBR Survey Area by crabs once they emerged from the Nest.

Nest excavations give a more accurate and biologically meaningful indication of the reproductive success of a rookery, particularly when environmental conditions are often challenging as in the GBR Survey Area. Hatchling tracks in the GBR Survey Area can easily be obscured by excessive crab tracks and may be blown away by the wind before Day Survey, especially in Sampled Nests located in or near dunes of soft sand. Being able to determine the nesting or incubation success of a particular beach or sub-population allows effective implementation of management plans to best aid sea turtle conservation. As Nest excavations are continued, more information regarding Hatching success and Emergence success in the GBR will become available.

Critical decisions can be made in regard to the management of sea turtle nesting beaches based upon the data gained by the counting and categorising of the contents of Nests after hatching (Miller, 1999). Due to the Nesting Activity data correlation between Night and Day Surveys, egg chambers of the Sampled Nests could not be marked at the time of oviposition. As a consequence, it is possible that some of the Sampled Nests that were monitored were actually UNAs. If Nest excavations are to continue in the GBR Survey Area, the use of Nest tags would be beneficial. Nest tags, in the form of rope or coloured tape marked with the date, are inserted into the Nest during oviposition. In many cases, tags are not visible from the surface, which would still allow for the implementation of activity correlation between Day and Night Surveys (Miller, 1999). However, it remains possible that if ghost crabs predate an egg chamber they would also damage the Nest tag. In addition, it is recommended to verify the activity as a Nest during Day Surveys by carefully digging and locating an egg chamber. Nest tags can then be added to the Nest before covering up the eggs.

Nest excavations took place 14 day after observed hatchling emergence on the surface or at 90 days of incubation, which allowed for hatched Nests to be excessively predated by ghost crabs prior to excavations, contributing to the number of egg chambers that could not be located. Guidelines set out by the Florida Fish and Wildlife Conservation Commission (**FWC**) state that Nest located in cooler rookeries, such as in the GBR Survey Area, should be excavated at 80 days of incubation or 4 days post hatchling emergence on the surface (FWC, 2016). Proceeding with these guidelines in future seasons could increase excavation success.

9.6 Conclusion

Sampled Nests in the GBR Survey Area during the season 2017/18 seemed to be highly impacted by ghost crab Disturbance and Predation. However, impacts on hatchling survival and Emergence success should be quantified, and the relative impact of crab Predation compared to other rookeries along the Ningaloo Coast should be investigated in order to understand the significance and magnitude of crab Predation in the GBR Survey Area. Despite the absence of any cyclones and major storms, 40.4 % of all Sampled Nests were at least inundated once. Nevertheless, Nest excavations showed no correlation between Inundation and Emergence success. Emergence success was also not correlated with changes in sand level, except in extreme cases, where hatchlings failed to reach the surface of the beach due to more than 1 m of additional dry sand on top of the Nest. Nest excavations provided valuable insight into factors influencing the success of turtle Nests in the GBR Survey Area, but the impact of crab Predation needs to be better understood.

10 GCFR DAY SURVEYS

10.1 Introduction

Gnaraloo Cape Farquhar is a remote, undeveloped and uninhabited stretch of the Gnaraloo coastline, located 22 km north of the Gnaraloo Homestead (**Appendix A**). Aerial surveys conducted by the GTCP during the seasons 2009/10 and 2010/11 revealed evidence of sea turtle nesting on the beaches of Gnaraloo Cape Farquhar. Reconnaissance on-ground surveys of the Gnaraloo Cape Farquhar Rookery (**GCFR**) in 2011/12 recorded significant nesting activity, primarily by loggerhead turtles (Hattingh et al., 2012a, b, c; Riskas, 2014). On-ground surveys of 4 Sub-sections in the GCFR Survey Area continued for short investigatory periods from 2011/12 - 2013/14. The first consecutive 14-day survey of the 2 busiest Sub-sections of the previous 4 Sub-sections in the GCFR Survey Area was undertaken during the season 2014/15 during the suspected overlapping peak nesting time in the GBR Survey Area. The same survey protocol was repeated during the season 2015/16. Following the findings gained as a result, the survey period was extended to 21 consecutive days during the seasons 2016/17 - 2017/18.

The two - and - three week surveys of the 2 busiest Sub-sections of the GCFR Survey Area which is of similar length to the GBR Survey Area (7.1 km versus 6.7 km) allow comparison of the turtle activities and nesting abundance between the two rookeries. This will provide a better estimation of how many turtles nest in the Gnaraloo Cape Farquhar Rookery annually, and give an indication of its importance to the turtle populations of WA.

10.2 Objectives

The objectives of Day Surveys in the GCFR Survey Area during 2017/18 were to:

- monitor sea turtle Nesting Activities and species composition;
- assess spatio-temporal nesting patterns;
- compare the number of Nesting Activities in the GCFR Survey Area with those observed in the GBR Survey Area during overlapping monitoring periods over several years.

10.3 Material and methods

10.3.1 Study area

Gnaraloo Cape Farquhar is located adjacent to the NMP, Ningaloo Coast World Heritage Area and Ningaloo Coast National Heritage Listed Area. The structure of the coastline here ranges from shallow, protected bays with fringing coral reef to dynamic beaches with rolling waves and steep rocky outcrops.

In 2011/12, the GCFR was divided into 4 Sub-sections (approximately 14 km in length, adjacent to the Cape Farquhar Marine Sanctuary Zone of the NMP):

- Gnaraloo Farquhar South (**GFS**) to Gnaraloo Farquhar Hut (**GFH**; Sub-section 1);
- Gnaraloo Runway South (**GRS**) to Gnaraloo Farquhar Runway (**GFR**; Sub-section 2);
- Gnaraloo Farquhar Runway (**GFR**) to Gnaraloo Lagoon North (**GLN**; Sub-section 3);
- Gnaraloo Lagoon North (**GLN**) to Gnaraloo Farquhar North (**GFN**; Sub-section 4).

While most of the monitoring from 2011/12 – 2013/14 focussed on GCFR Sub-section 3, all 4 GCFR Sub-sections were monitored for a varying number of days (**Table 10,** Hattingh et al., 2012a, b, c, 2014). Since season 2014/15, GCFR Day Surveys occurred in Sub-sections 2 (GRS – GFR) and 3 (GFR – GLN) only, as they received the highest numbers of sea turtle nesting activities during previous seasons (Hattingh et al., 2014). GCFR Sub-sections 2 and 3 are 7.1 km in length (2.7 km and 4.4 km, respectively) and now referred to as the standard GCFR Survey Area (-23.61336° S; 113.64379° E to -23.57697° S; 113.69828° E, **Appendix A10**).

10.3.2 Survey protocol

The GCFR Survey Area was monitored for 21 consecutive days (27 December 2017 - 16 January 2018) during the GBR peak nesting period. Day Surveys followed the GBR Day Survey protocol (**Section 5.3.2**). Old turtle activities were marked off one day prior to Day

Surveys to ensure only new tracks were counted.

10.3.3 Feral animal activity, hatchling emergences, strandings and mortalities

Feral animal activity and turtle hatchling emergence events were recorded following the GTCP's feral animal MERI monitoring and GBR Day Survey protocols (**Chapters 4** and **5**, respectively). Turtle stranding and mortality events were documented and resolved following DBCA protocol.

10.3.4 Data analysis

Due to the changes in GCFR survey methods since 2011/12 (summarised in **Table 10**), comparisons between all seasons is not possible. The now standard GCFR Survey Area (namely Sub-sections 2 and 3) has been monitored for 14 consecutive days during the same time period from seasons 2014/15 – 2017/18, allowing comparisons for four consecutive years. An additional 7 days of monitoring were added during the seasons 2016/17 and 2017/18, permitting comparisons for 21 consecutive days over the same time period for those two seasons. All GCFR data was also compared to the corresponding time periods and seasons in the GBR Survey Area.

Table 10: Record of methodology changes for GCFR Day Surveys, 2011/12 – 2017/18

GTCP SEASON	NUMBER OF SURVEYS	DAYS PER SURVEY	TOTAL DAYS SURVEYED	SUB-SECTIONS SURVEYED	OLD ACTIVITIES RECORDED PRIOR TO SURVEY
2011/12	3	4	12	1, 2, 3, 4	Y
2012/13	4	4	16	1, 2, 3, 4	Y
2013/14	4	4	16	1, 2, 3, 4	Y
2014/15	1	14	14	2, 3	N
2015/16	1	14	14	2, 3	N
2016/17	1	21	21	2, 3	N
2017/18	1	21	21	2, 3	N

Statistical analysis of all data was performed using the Data Analysis add-on package for Excel (Microsoft Office 2016). Direct comparisons of mean values were analysed using a t-test (two-sample assuming unequal variances, α = 0.05). All data are given as mean ± SD.

10.3.5 GCFR Maps

A detailed description of the creation of maps can be found in the GTCP GIS Manual 2017/18. Briefly, GCFR maps (**Appendix A**) were created using ArcGIS Desktop 10.2.2 and the Spatial Analyst extension. The maps were created by projecting GPS co-ordinates recorded during Day Surveys onto the GDA 1994 (Map Grid of Australia Zone 49) co-ordinate system. To represent all the data collected throughout the monitoring period, the GCFR maps include a variety of point distribution maps and density hotspots. Point distribution maps were created by designating a single point per activity and allocating various colours in order to represent different categories of data. Density hotspots along the Survey Area were calculated using the kernel density model within the ArcGIS Spatial Analyst toolset. Using a selected radius of 100 m, the kernel density model calculated the number of point features within the specified radius of each cell generating a smooth raster showing areas of high density versus low density along the Survey Area.

10.4 Results

10.4.1 Nesting Activities and impacts on Nests

During the season 2017/18, 181 Nesting Activities were recorded in the GCFR Survey Area during the three-week monitoring period (27 December 2017 – 16 January 2018). All Nesting Activities observed were attributed to loggerhead turtles: including 71 Nests, 97 UNAs, 12 U-Tracks and 1 Ua (**Figure 53**), resulting in a Nesting success rate of 39.4 %.

92.3 % (167 / 181) of all Nesting Activities occurred within Sub-section 3 (GFR – GLN). 33 Nesting Activities (16 Nests) were recorded beneath the high-water mark of the beach, 105 Nesting Activities (41 Nests) within the edge of vegetation and 43 Nesting Activities (14 Nests) in the dunes. The 171 track widths recorded ranged from 46 cm to 83 cm (mean: 64 ± 6 cm).

During the two weeks from 27 December 2017 to 9 January 2018, 131 loggerhead turtle Nesting Activities were recorded: including 45 Nests, 78 UNAs and 8 U-Tracks. A Nesting success rate of 34.4 % was observed during this period.

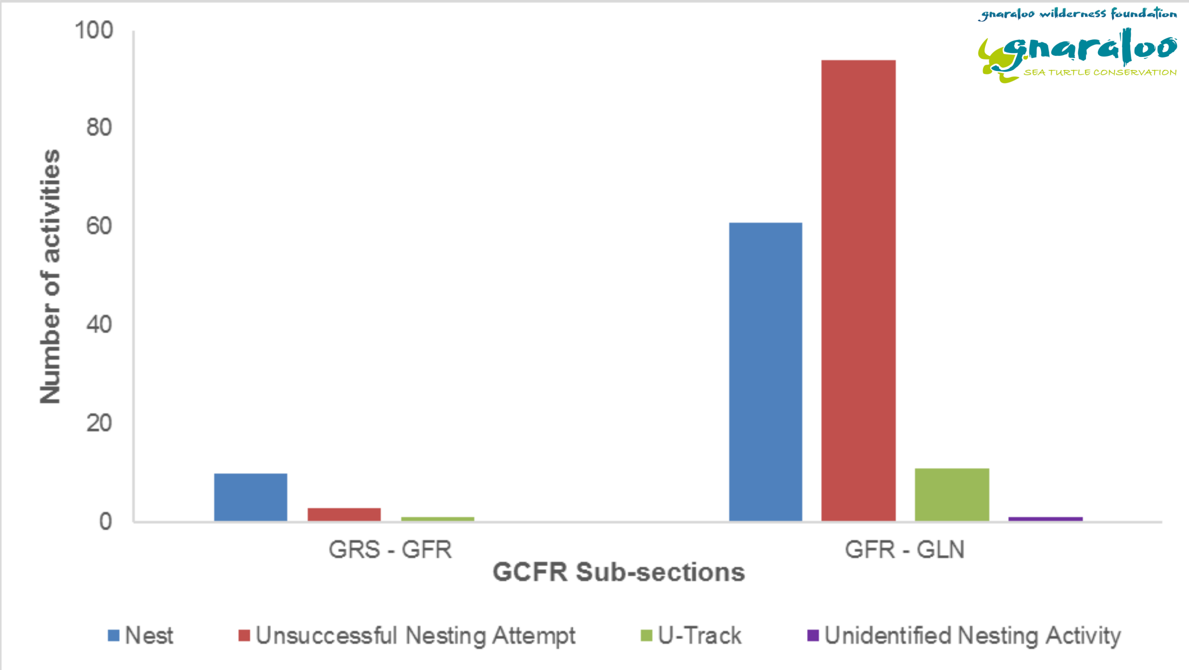

Figure 53: Nesting Activities in GCFR Sub-sections (27 Dec 2017 - 16 Jan 2018), 2017/18

No Disturbance or Predation of turtle Nests by feral animals were observed in the GCFR Survey Area during the monitoring period (21 days) for 2017/18. **Section 4.4.3** gives a more detailed account of feral animal activity in the GCFR Survey Area.

3 Nests were disturbed by ghost crabs on the morning after they were laid. 1 Nest was noted as predated as 1 eggshell was observed on top of the Nest and a further 10 crab burrows were located around the location of the egg chamber.

2 Nesting Activities (1 Nest and 1 Ua) were inundated by the high tide on the morning of initial recording. The 33 Nesting Activities (16 Nests, 12 UNAs, 4 U-Tracks and 1 Ua) that were observed beneath the high-water mark of the beach were noted to be at risk of inundation over following nights.

No mortalities, strandings or hatchling emergence events were recorded in the GCFR Survey Area during the monitoring period in 2017/18.

10.4.2 Multi-year trends in GCFR Survey Area

10.4.2.1 4-year comparison for 14 days

The number of Nesting Activities in the GCFR Survey Area has varied greatly during the two-week survey period for the seasons 2014/15 to 2017/18. Season 2014/15 recorded only 64 Nesting Activities, well below the average of 111 Nesting Activities during the two-week monitoring period for the four seasons. The numbers of Nesting Activities peaked in both 2015/16 (134) and 2017/18 (131), while season 2016/17 had slightly fewer (114) Nesting Activities (**Figure 54**).

The number of Nests was lowest during the season 2014/15 (33), before significantly increasing to 59 Nests during the season 2015/16. Despite a slight decrease over the seasons 2016/17 and 2017/18, Nest numbers stayed up (55 and 45, respectively; **Figure 54**).

Despite the low number of Nests, Nesting success was highest during the season 2014/15 (51.6%). Nesting success rates were slightly lower during the seasons 2015/16 (44.0 %) and 2016/17 (48.2 %), before dropping to 34.4 % during the season 2017/18 (**Figure 54**). Average Nesting success for the four seasons was 44.5 ± 7.5 % during the two-week monitoring period.

GCFR Sub-section 3 (GFR-GLN) consistently recorded significantly more Nesting Activities (92.9 ± 0.6 %) than Sub-Section 2 (GRS-GFR, 7.1 ± 0.6 %, $p < 0.01$). The average Nesting success in Sub-Section 2 (59.2 ± 7.9 %) was higher than in Sub-Section 3 (43.5 ± 6.7 %, $p < 0.05$).

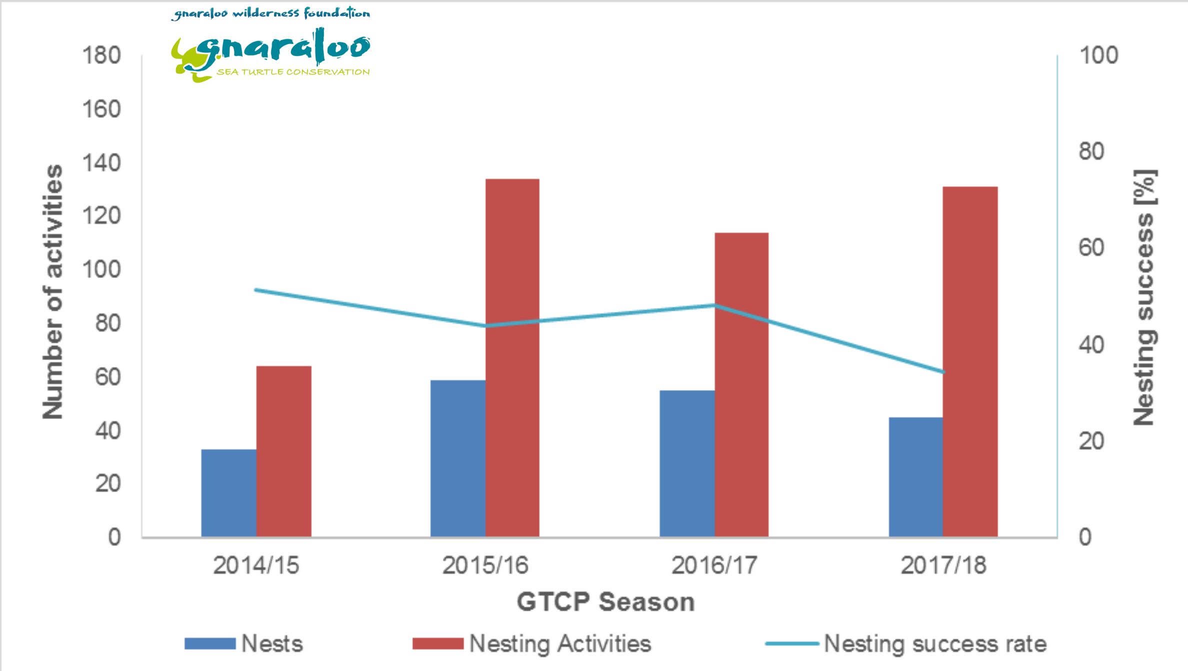

Figure 54: Nesting Activities (bars) and Nesting success (blue line) in GCFR Survey Area (27 Dec – 9 Jan), 2014/15 – 2017/18

Note: Number of Nesting Activities are listed on left Y-axis, Nesting success rate is listed on right Y-axis.

10.4.2.2 2-year comparison for 21 days

The total number of Nesting Activities for the three-week monitoring period does not differ greatly between seasons 2016/17 (172) and 2017/18 (181, **Figure 55**). However, the season 2016/17 recorded a much higher number of Nests (86) than the season 2017/18 (71; **Figure 55**). This resulted in a relatively high Nesting success rate for the season 2016/17 (50.0 %), while Nesting success was only 39.2 % for season 2017/18 (**Figure 55**).

Consistent with the two-week monitoring period, the total Nesting Activities occurring within GCFR Sub-Section 3 (92.9 ± 0.7 %) were significantly higher than in Sub-Section 2 (7.1 ± 0.7 %, $p < 0.05$). The Nesting success rate also remained higher within Sub-Section 2 (76.6 ± 5.2 %) compared to Sub-Section 3 (42.2 ± 5.6 %, $p < 0.05$).

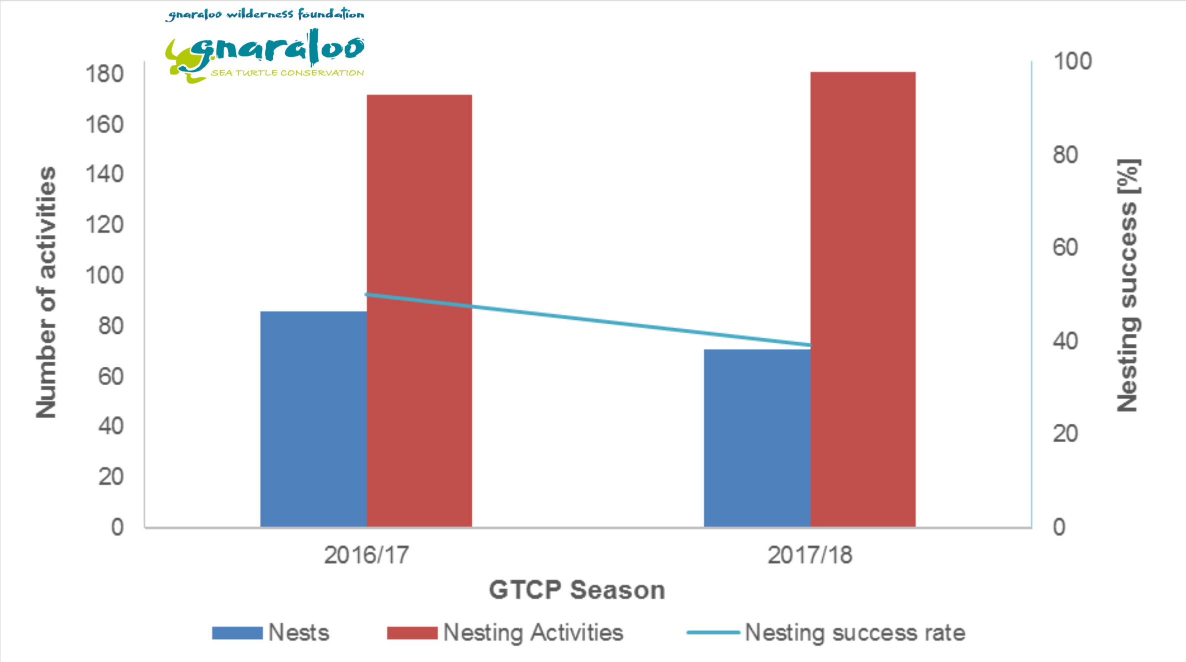

Figure 55: Nesting Activities (bars) and Nesting success (blue line) in GCFR Survey Area (27 Dec - 16 Jan), 2016/17 – 2017/18

Note: Number of Nesting Activities are listed on left Y-axis, Nesting success rate is listed on right Y-axis.

10.4.3 Comparison of GBR and GCFR Survey Areas

10.4.3.1 4-year comparison for 14 days

No consistent trends in Nesting Activities were observed during the two-week monitoring period from 2014/15 to 2017/18 (**Figure 56**). The GBR Survey Area recorded nearly double the number of Nesting Activities (119) of the GCFR Survey Area (64) in season 2014/15. Season 2015/16 showed the opposite pattern with 78 Nesting Activities recorded in the GBR Survey Area and 133 Nesting Activities recorded in the GCFR Survey Area. The differences between the rookeries became smaller in seasons 2016/17 and 2017/18, with 129 and 113 Nesting Activities recorded in the GBR Survey Area, and 114 and 131 Nesting Activities recorded in the GCFR Survey Area, respectively (**Figure 56**).

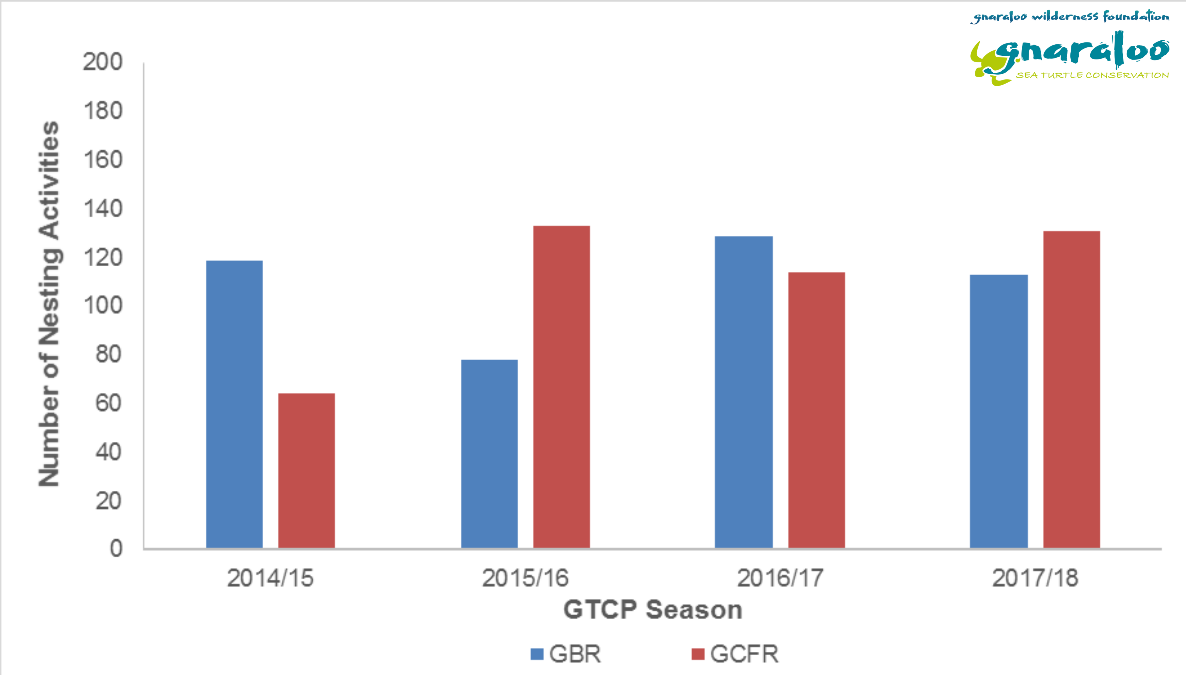

Figure 56: Comparison of Nesting Activities in GBR and GCFR Survey Areas (27 Dec - 9 Jan), 2014/15 – 2017/18

Despite the differences in Nesting Activity numbers, the GBR Survey Area generally received slightly more Nests (64.8 ± 12.5) than the GCFR Survey Area (48.0 ± 11.6), the only exception being the season 2015/16, in which Nest numbers were higher in the GCFR Survey Area (59) than in the GBR Survey Area (50; **Figure 57**).

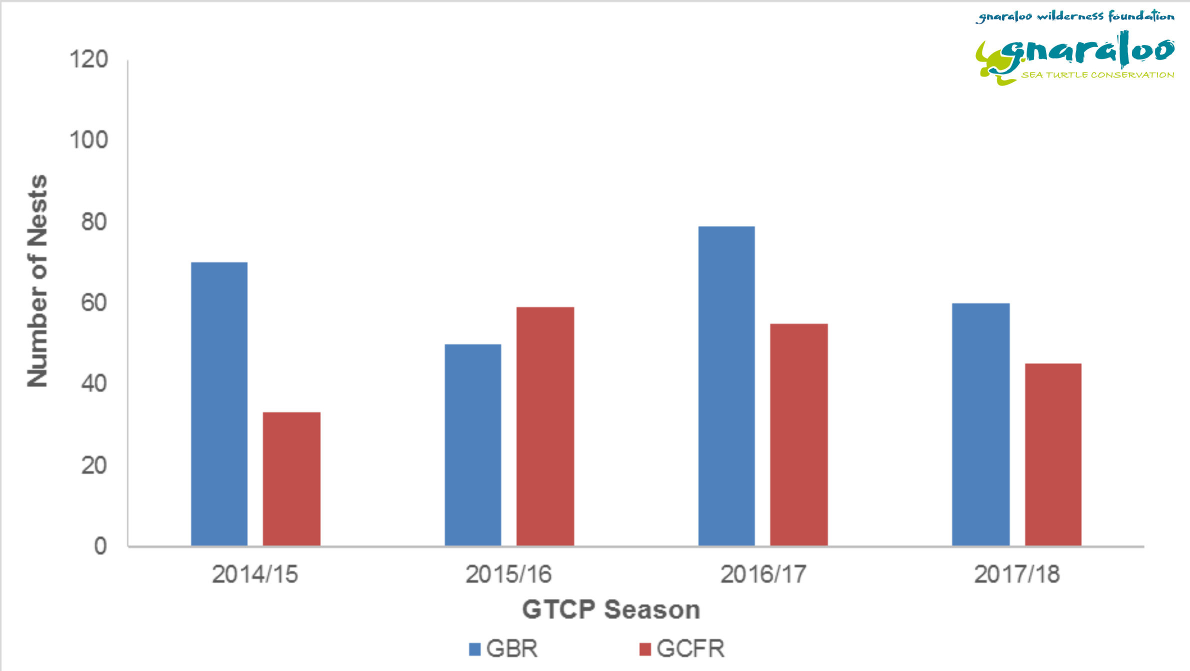

Figure 57: Comparison of Nests in GBR and GCFR Survey Areas (27 Dec - 9 Jan), 2014/15 – 2017/18

Nesting success rate was consistently higher in the GBR Survey Area (60.7 ± 4.9 %) than in the GCFR Survey Area (44.8 ± 6.7 %, $p < 0.05$, **Figure 58**). The difference in Nesting success between the two Survey Areas increased from 7.5 % in season 2014/15 to more than 17.5 % in the following seasons.

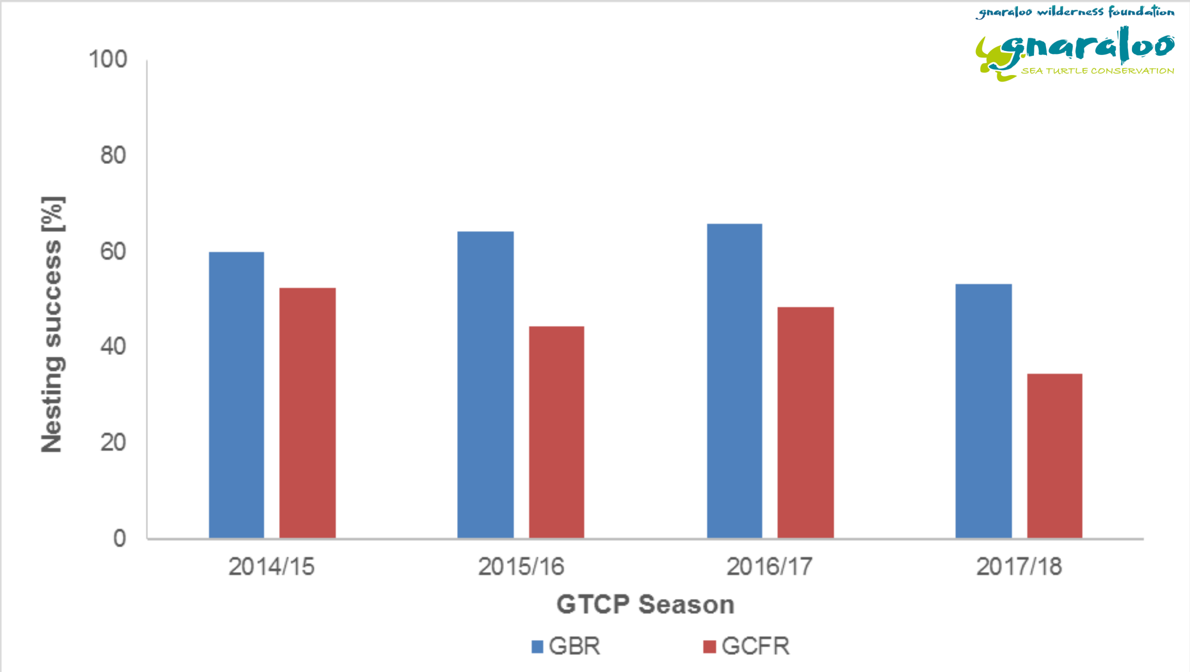

Figure 58: Comparison of Nesting success in GBR and GCFR Survey Areas (27 Dec - 9 Jan), 2014/15 – 2017/18

10.4.3.2 2-year comparison for 21 days

No trends in Nesting Activities in the two Survey Areas were apparent for the three-week monitoring period in seasons 2016/17 and 2017/18. While the GBR Survey Area recorded 9 % more Nesting Activities than the GCFR Survey Area in season 2016/17, the following season, Nesting Activities were 14.9 % lower in the GBR Survey Area than in the GCFR Survey Area (**Figure 59**).

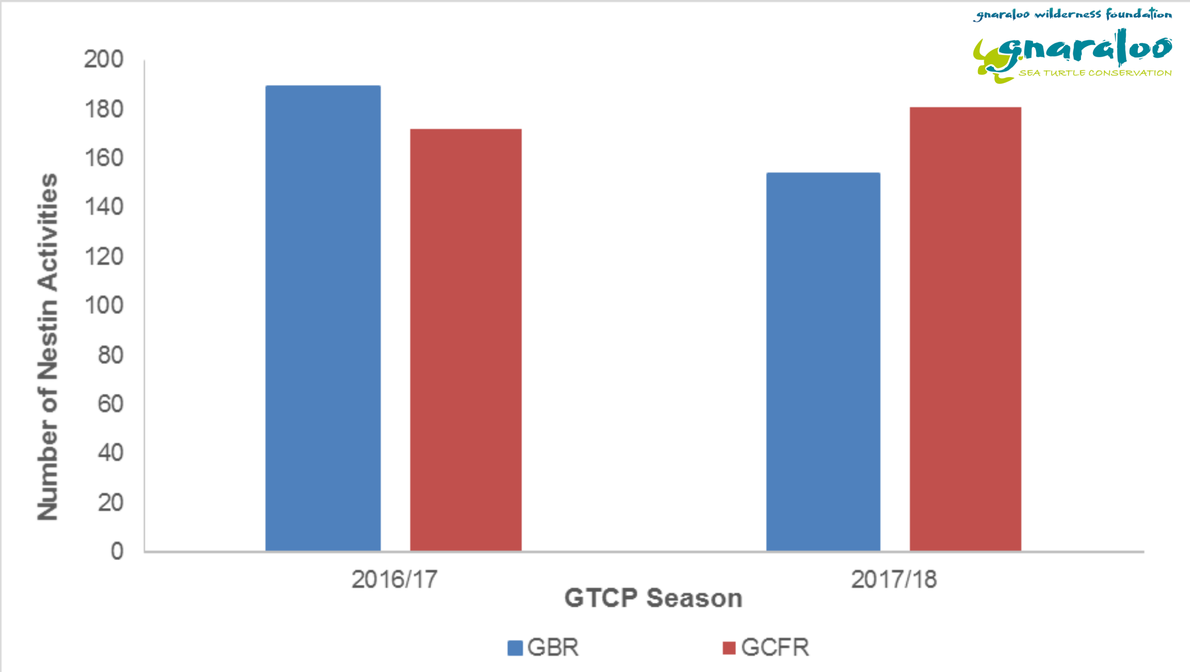

Figure 59: Comparison of Nesting Activities in GBR and GCFR Survey Areas (27 Dec - 16 Jan), 2016/17 – 2017/18

Nevertheless, the GBR Survey Area recorded more Nests in seasons 2016/17 and 2017/18 (113 and 81, respectively) than the GCFR Survey Area (86 and 71, respectively; **Figure 60**).

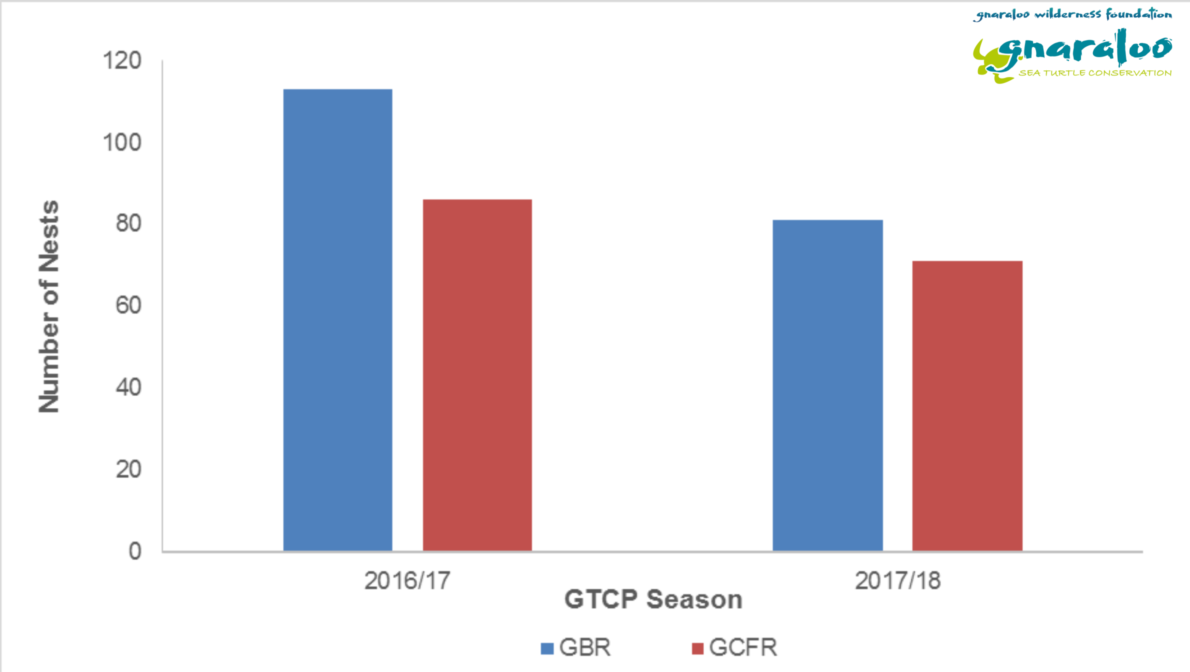

Figure 60: Comparison of Nests in GBR and GCFR Survey Areas (27 Dec - 16 Jan), 2016/17 – 2017/18

Nesting success rates were also consistently higher in the GBR Survey Area than in the GCFR Survey Area, with a mean Nesting success rate for the two seasons of 58.0 ± 5.4 % in the GBR Survey Area and 44.6 ± 5.3 % for the GCFR Survey Area (**Figure 61**).

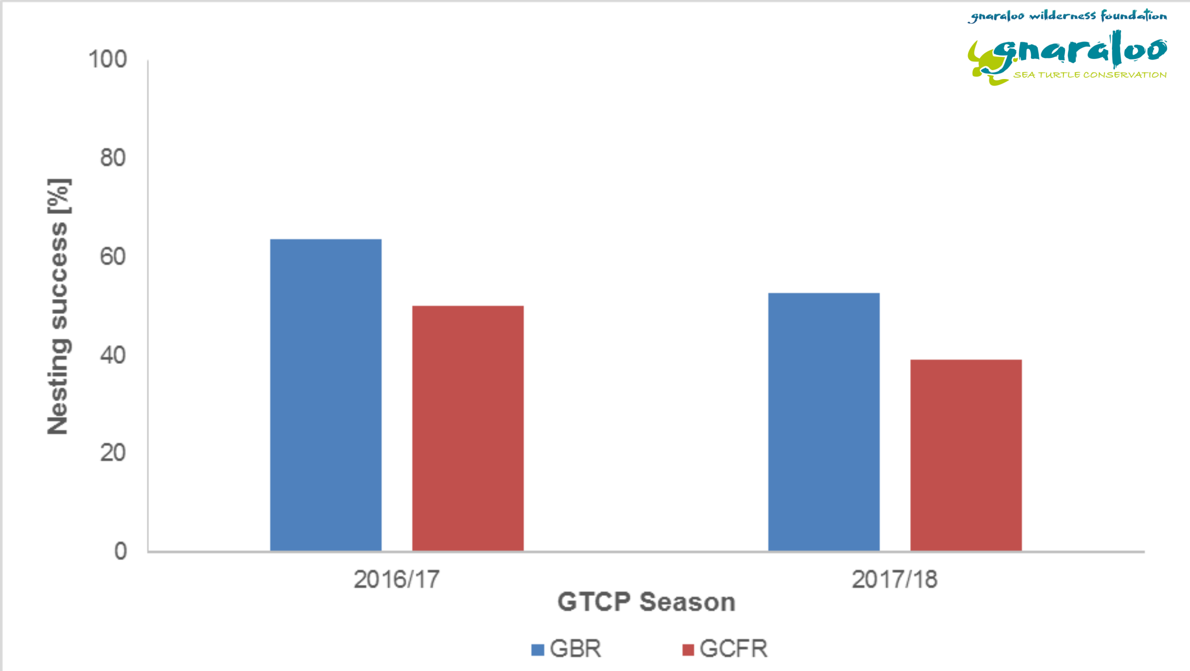

Figure 61: Comparison of Nesting success in GBR and GCFR Survey Areas (27 Dec - 16 Jan), 2016/17 – 2017/18

10.5 Discussion

10.5.1 Nesting Activities and impacts on Nests

As investigatory monitoring of the GCFR from 2011/12 to 2013/14 occurred at differing dates and for varying time periods and Sub-sections, these seasons are not considered in this report. Starting in season 2014/15, a survey period of two weeks which aligned with the peak nesting season at the GBR Survey Area was introduced as well as confining work to the busiest parts of the rookery. In season 2016/17, the monitoring period was extended for another week to better understand the importance of this rookery. It is likely that peak nesting periods in the GBR and GCFR Survey Areas occur during similar time periods; however, as no full season monitoring data is available yet for the GCFR Survey Area, it is unknown when the highest nesting density actually occurs in this rookery.

Loggerhead turtle nesting is not always successful and different reasons, such as disturbance by lighting or movement, unfavourable sand conditions, or obstacles can cause the turtles to abandon her nesting attempt (Miller et al., 2003). A particularly high number of UNAs was often observed in the GCFR Survey Area, resulting in a low overall Nesting success rate. As lighting and human disturbance cannot be factored into failed nesting attempts at the GCFR Survey Area, these behaviours can likely be attributed to unfavourable nesting beach conditions. A large part of GCFR Sub-section 2 (GRS – GFR) was comprised of either rocky outcrops or steep dunes, where high tides contributed to large escarpments and beach erosion. Consequently, turtles were 8 times more likely to nest in the alternative nesting area of GCFR Sub-section 3 (GFR – GLN) during the three-week monitoring period in season 2017/18. This is consistent with previous seasons, during which this Sub-section regularly recorded significantly more Nesting Activities and Nests than Sub-section 2. But while Sub-section 3 presents a seemingly more favourable nesting area with an elongated, gradually sloping beach and records the vast majority of Nesting Activities, its Nesting success rate has been consistently lower than the Nesting success in Sub-section 2. In season 2017/18, the Nesting success rate in Sub-section 3 was particularly low with only every third attempt resulting in a Nest, while in Sub-section 2, approximately every second attempt resulted in a Nest. The underlying reasons for this low Nesting success may lay in unsuitable beach substrate or distractions other than humans, but are not possible to determine without further investigation and monitoring.

10.5.2 Multi-year trends in GCFR Survey Area

Due to the short annual monitoring period and lack of long-term data, it is not yet possible to evaluate meaningful nesting trends or estimate the number of females nesting in the GCFR Survey Area.

Nesting success over the past four seasons since 2014/15 has generally been relatively low, with a particularly low Nesting success rate in season 2017/18. As there are no human disturbances present in the GCFR Survey Area (the area is closed to the public), further investigation may be warranted to investigate underlying reasons. Low Nesting success implies that a female turtle ready to lay her clutch has to expend extra energy for Unsuccessful Nesting Attempts (UNAs or UTs), before being able to lay her Nest. This may negatively impact the number of clutches she lays during a season, hence lowering the reproductive success of the rookery. Due to the short monitoring period, it is not possible to determine whether Nesting success fluctuates during the nesting season. As the monitoring period covers only two or three weeks in late December and early January, it coincides with the highest high tides (‘king tides’) of the year, which occur each year in early January when the Earth is closest to the Sun (Sumich, 1996; Thurman, 1994). The effect of those particularly high tides on turtles is not known, however, they are likely to create additional escarpments or may otherwise alter the beach unfavourably for sea turtle nesting.

Furthermore, a two - or - three week sampling window could experience relatively high or low levels of Nesting Activities in a given year just by chance, therefore year-to-year fluctuations in Nesting Activities should be interpreted cautiously.

10.5.3 Comparison of GBR and GCFR Survey Areas

Assuming the GBR and GCFR Survey Areas have similar peak nesting periods and nesting seasons of similar lengths, a slightly higher number of Nests seems to be laid in the GBR Survey Area. This may be attributed to more favourable beach conditions in the GBR Survey Area, which allow for higher Nesting success, meaning the turtles waste less time and energy trying to lay their clutch.

No consistent pattern and relationships between Nesting Activities in the GBR and GCFR Survey Areas could be discerned, suggesting the two rookeries may have limited overlap but rather contain independent nesting populations, despite reports of one turtle using both rookeries for nesting (Strydom et al., 2017). This is corroborated by the fact that none of the 5 turtles observed during GCFR Day Surveys carried flipper tags from GBR Night Surveys in 2017/18. In addition, both satellite tagged turtles from season 2017/18 only nested in the GBR Survey Area, despite spending their internesting intervals in the waters off the GCFR Survey Area. Continued Night Surveys and flipper tagging in both rookeries will be needed in order to determine if and how the two rookeries are connected, and compare long-term trends for the GBR and GCFR Survey Areas.

10.6 Conclusion

Day Surveys in the GCFR Survey Area during the two - or - three week monitoring period during 2014/15 – 2017/18 indicate that a comparable level of Nesting Activity occurs in the GBR Survey Area during the same period. Importantly though, the GBR Survey Area has a higher Nesting success and the number of Nests laid there is slightly higher than in the GCFR Survey Area, which has a relatively low Nesting success. Currently, the short monitoring period in the GCFR Survey Area precludes estimation of the number of individuals nesting in this rookery each season. Because of this, the significance of the GCFR Survey Area with respect to the overall southeast Indian Ocean loggerhead turtle RMU remains unknown. Still, it is clear that this remote stretch of mainland coast situated at the southern end of the Ningaloo coast hosts significant and previously underreported nesting aggregations of loggerhead turtles each year. Continued monitoring and flipper tagging in future may help elucidate how connected the Gnaraloo rookeries are in terms of nesting females. Anecdotal evidence suggests that the turtles are not likely to Nest in both rookeries, but further research is warranted to investigate whether the turtles might switch rookeries after failed nesting attempts due to unfavourable beach conditions.

11 EDUCATION AND COMMUNITY ENGAGEMENT

11.1 Introduction

Education and community engagement are two paramount pillars of the GTCP. Since its first outreach to schools during the season 2010/11, onsite and offsite education and community engagement has grown enormously in scope each season. From Kindergarten games to University lectures on complex sea turtle data, the depth and breadth of information exchange with the public has been limitless and ever increasing.

11.2 Outcomes

11.2.1 Onsite educational activities

A total of 42 people participated in GTCP onsite education and community engagement activities during the season 2017/18 (to 31 May 2018). Onsite engagement occurred with people ranging from 3 – 55 years of age, with the majority of participants being adults interested in sea turtle conservation (**Figure 62**). These participants comprised visitors who travelled to Gnaraloo for various recreational activities (e.g. windsurfing, fishing and surfing), some who came specifically to participate in the GTCP, a Government group (DBCA) and official representatives of another country (US Consulate General).

The nationalities of the onsite participants with the program included Australia, New Zealand, United States, Canada, Germany, Austria, France, Poland, Ireland and Mauritius. Most of the participants currently lived in Australia (WA: 30, Qld: 6) and a few came from overseas (Austria: 3, Germany: 2, France: 1; **Figure 63**). Some participants (21), mainly families with children, chose to not participate in field surveys, and were given more in-depth presentations about sea turtles and conservation. Of the other 21 participants, 15 participated in GBR Night Surveys and 11 in GBR Day Surveys, including 5 who participated in both GBR Day and Night Surveys (**Figure 64**). The number of people participating in GTCP onsite educational activities was lower during the season 2017/18 than in previous seasons, as no schools or large community groups visited Gnaraloo during the season.

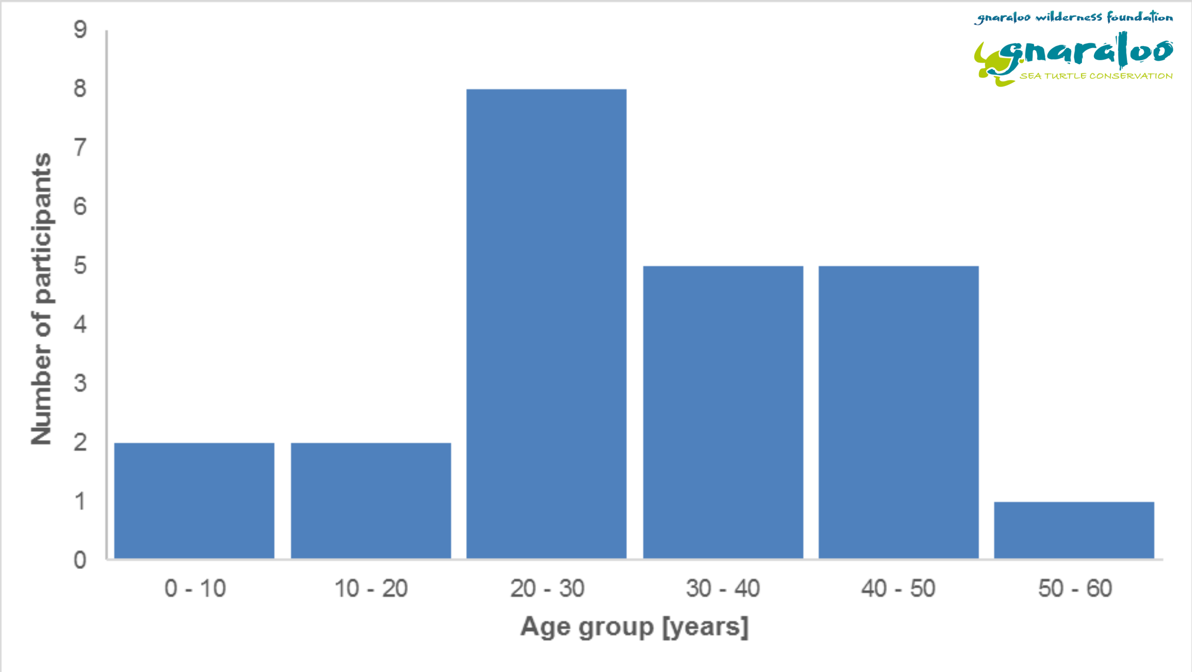

Figure 62: Age demographics of onsite participants with GTCP (1 Nov 2017 – 28 Feb 2018), 2017/18

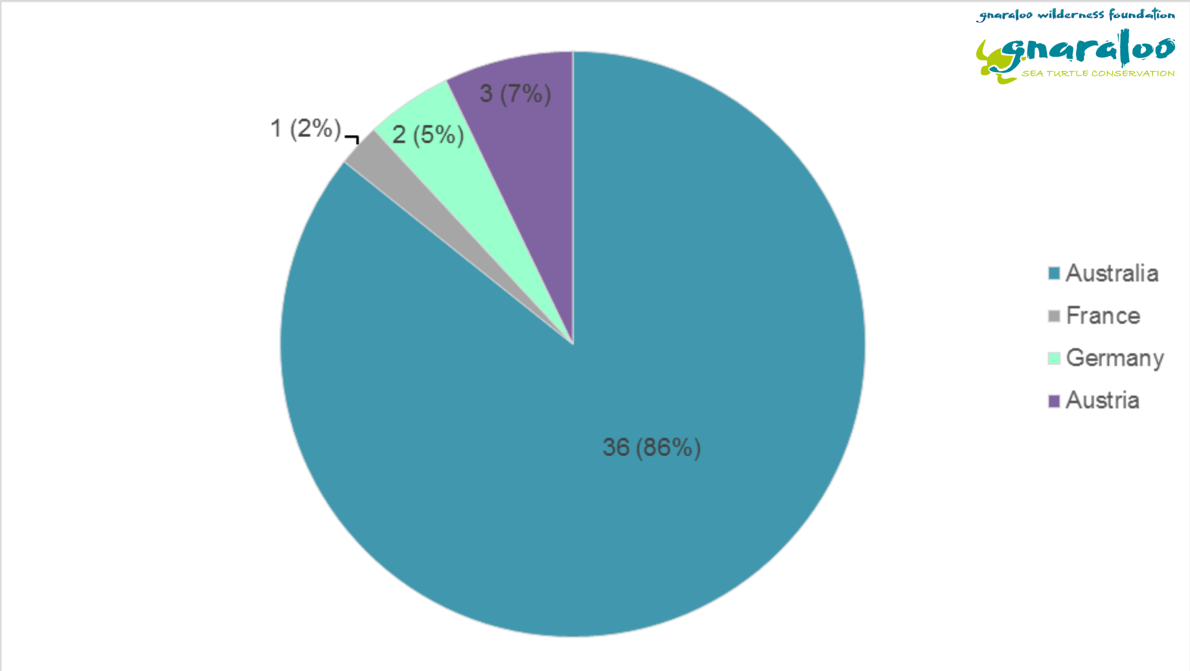

Figure 63: Country of residence of onsite participants with GTCP (1 Nov 2017 – 28 Feb 2018), 2017/18

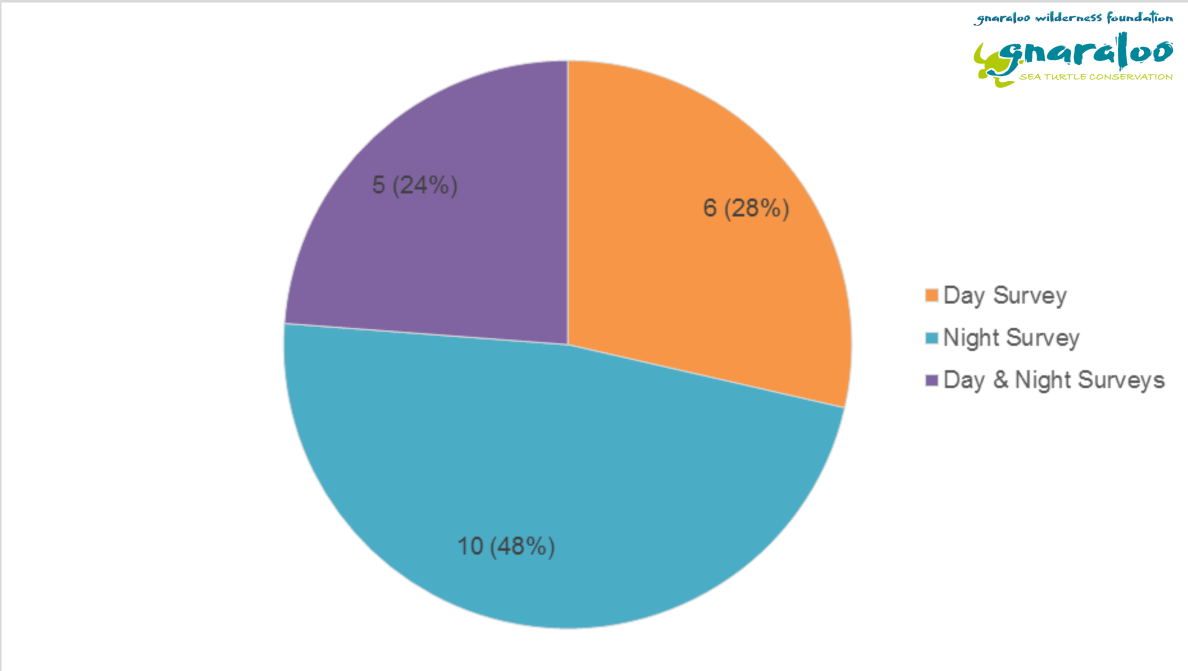

Figure 64: Preferences of onsite participants for GTCP Day and/or Night Surveys (1 Nov 2017 – 28 Feb 2018), 2017/18

11.2.2 Offsite educational activities

Offsite presentations (76) occurred from 1 June 2017 – 31 May 2018 by GTCP consultants and some team members. Presentations (61) were given to schools from primary to high school levels in Victoria and WA, to 2,624 students (6 - 18 years) and 118 teachers. Presentations (9) to colleges reached 900 students and 35 teachers. Presentations (4) at Universities, including a video presentation in Florida (USA), reached 345 students and 6 teachers. A presentation at the 2017 WA Threatened Species Forum (Geraldton, WA) was attended by 170 people. A community presentation to a turtle monitoring group in Qld reached 28 volunteers. A presentation was given to the US Consul General and staff, reaching 5 people (**Figure 65**).

The GTCP also had a profile on Skype in the Classroom (Microsoft Education; https://education.microsoft.com/gnaraloo) to reach out via free lessons to primary and high schools located elsewhere in Australia and around the world. From 1 June – 5 September 2017, the GTCP hosted 24 Skype lessons reaching 355 students and 37 teachers, including to classes in the USA, Sweden, Sri Lanka, New Zealand, Malaysia, Brazil, Egypt, India, Australia and Indonesia, with most Skype lessons to the latter three countries (**Figures 65, 66**).

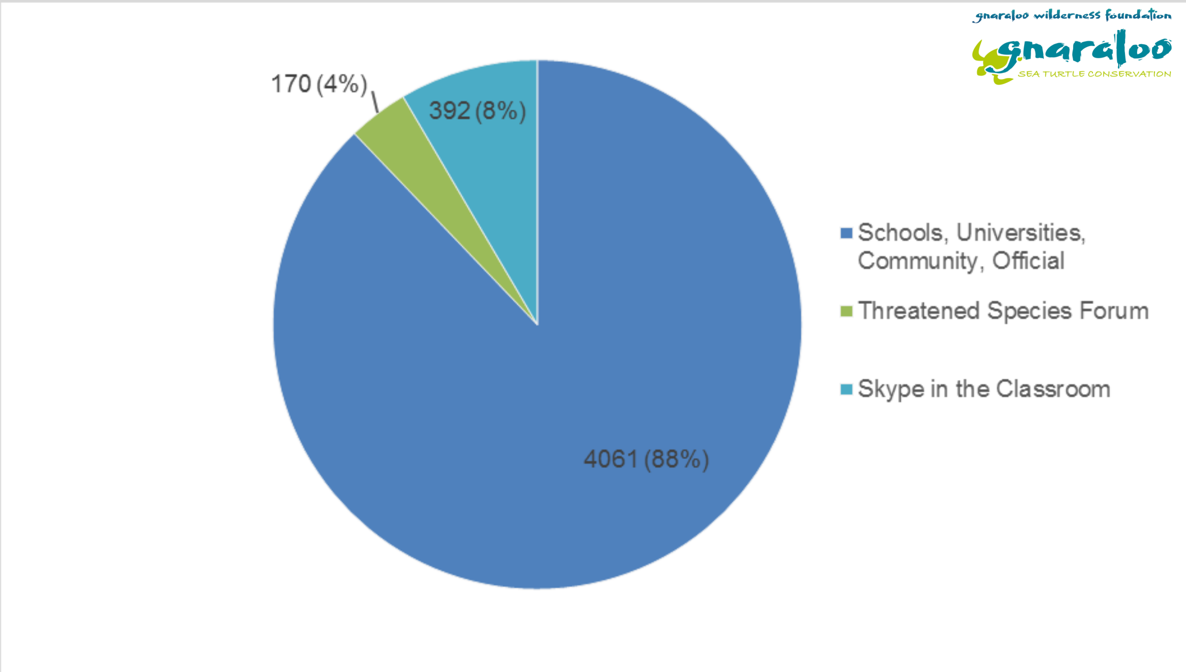

Figure 65: Offsite participants with GTCP (1 Jun 2017 – 31 May 2018), 2017/18

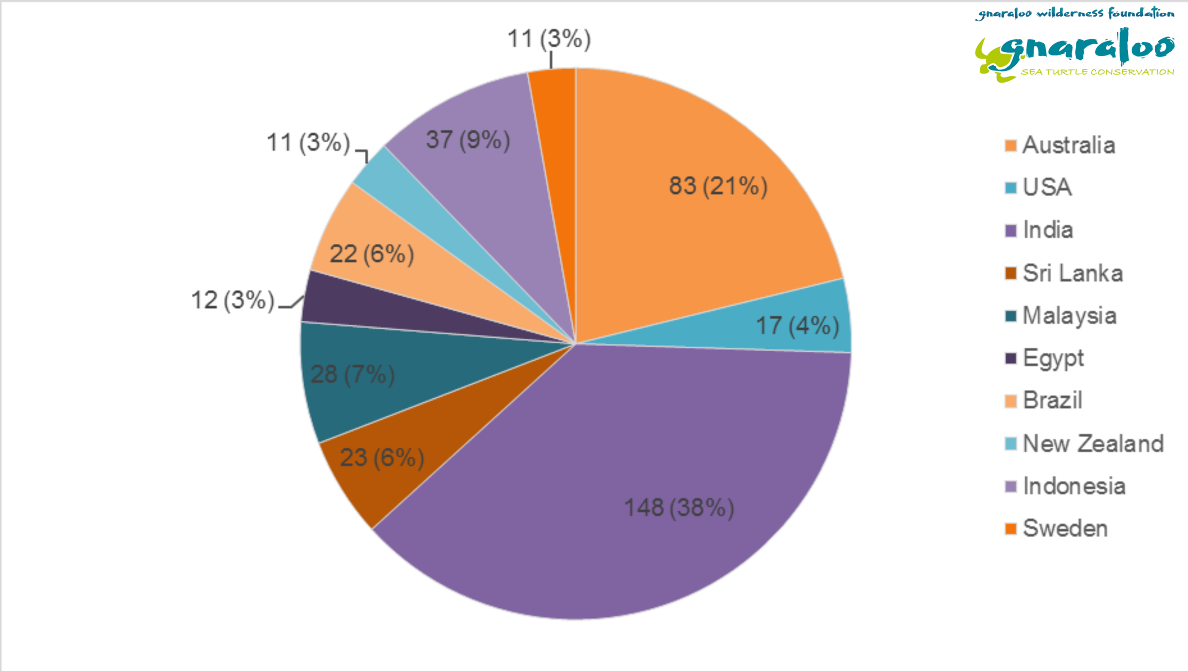

Figure 66: Nationalities reached through GTCP Skype in the Classroom lectures (1 Jun – 5 Sept 2017), 2017/18

11.3 Media-based activities

11.3.1 Field diaries

The field diaries with real time information from the field presented glimpses into the life and work of the GTCP field research team and were published on the GWF website (http://gnaraloo.org/news-from-the-field/) and GTCP Facebook page. During the season 2017/18, the volume of field diaries was increased with 38 published Field Diaries, including a 'World of Science' series answering common questions about scientific research on sea turtles.

11.3.2 Social media

The GTCP maintained an active Facebook page[19] that was updated regularly. As of 31

[19] https://www.facebook.com/gnaralooturtleconservationprogram

May 2018, the page had 3,892 followers. GTCP Facebook entries included 'Wildlife Wednesday' with 22 posts on both native and introduced fauna species at Gnaraloo. A week during January 2018 was designated "Wildlife Week" and 7 different native fauna species were highlighted on the GTCP Facebook wall. The GTCP and GWF also share information via Instagram, Twitter and YouTube.

11.3.3 Print media, radio and TV

The GTCP has been featured in a range of media articles and interviews since the beginning of the program. During the season 2017/18, the GTCP was featured in printed magazines, newspapers and books: including iHerp Issue 2, September/October 2017; Midwest Times, 15 March 2018; Geraldton Guardian, 13 April 2018; and the 'Natural World of the Kimberley' book (June 2018).

In 2017/18, various interviews occurred with GTCP team members, including by iHerp (25 October 2017[20]) and ABC Radio (Midwest and Wheatbelt; 6 April 2018). The TV station GWN 7 screened a story about the GTCP in a news program (10 April 2018).

11.4 Supplementary activities by GWF

The GWF is a nature-based not-for-profit organisation which raises awareness of the wilderness area at Gnaraloo, including its native flora and fauna, and dark skies. Its website was significantly expanded during the season 2017/18 to provide a space for all important records, findings and data of the GTCP to be catalogued or publicly available, including turtle related reports, published papers and extensive photo records of all GTCP seasons. The GWF website contains all Field diaries from previous seasons as well as those from the season 2017/18. The GWF website, through significant support from the GTCP research team (onsite and offsite), introduced a new forum with native fauna and flora species lists (terrestrial and marine) for Gnaraloo during 2017/18. as all species are interconnected and the better the health of the entire ecosystem, the better the environment for the Gnaraloo sea turtles.

The GWF supported the educational and outreach activities of the GTCP during 2015/16 - 2017/18 through fundraising activities with various partners, competitions and the development of communication tools such as brochures, stickers, posters, magnets, colour-in pages for younger

[20] https://www.spreaker.com/user/iherpaustralia/episode-1-interview-with-karen-hattingh-

students and a clothing range.

The GWF and its partner Brains created a documentary called 'The Mystery of the Gnaraloo Sea Turtles' during the seasons 2015/16 – 2016/17. The documentary tracks the journeys of the Gnaraloo loggerhead turtles and features the Gnaraloo landscape. During 2017/18, the GWF submitted the documentary for screening at various local, national and international venues, including the Fremantle Underwater Film Festival (**FUFF**; Australia), San Francisco International Ocean Film Festival (USA) and at the International Wildlife Film Festival (USA). The documentary also won an award during the season 2017/18 (The Ocean Science and Technology Award, FUFF, 5 January 2018).

Additionally, the GWF and its partner Soundwave Nomad Production released a web-based series on its website and social media platforms ('Keep Gnaraloo Wild', from February to April 2018). It comprised of 5 stories which featured the terrestrial and marine environments at Gnaraloo, including an overview of the GTCP[21].

11.5 Data sharing with others

The GTCP shared its data and program information with the public, scientific community and Government (local, national and international) via several online repositories. These include:

- Wildlife Licensing (DBCA, WA; State Government; https://wildlifelicensing.dpaw.wa.gov.au/);
- Coastal Research, Research information on Australia's Coasts (national; https://coastalresearch.csiro.au/?q=node/72);
- http://www.seaturtle.org/ (international);
- SWOT (international; http://www.seaturtlestatus.org/);
- Indian Ocean-South East Asian Turtle Memorandum of Understanding (international; http://www.ioseaturtles.org/).

11.6 Discussion

[21] https://www.facebook.com/turtlesgnaraloo/videos/1824971197538388/

The importance of education and community engagement is irrefutable. Sea turtles are sometimes called 'charismatic mega-fauna'. In other words, they are striking animals which naturally draw people's interest. While they may draw people's interest, it is the delivery of facts and education to people that leads to conservation of the species as a whole. Once people become aware of the anthropogenic threats to sea turtles, they become more aware of their behaviour and the damage they could cause to sea turtles. Plastic bags, fishing material, driving on nesting beaches and excess lighting on nesting beaches at night are all avoidable and sensible changes to make towards sea turtle conservation. Public education brings the community together: the young and eager learners, their parents, the general public, the private and commercial sectors, scientists and Government to better understand and protect the environment we live in.

During the season 2017/18, the community engagement program included an emphasis on onsite presentations and engagement of visitors, offsite presentations to schools and other groups, social media and website activity (including through field diaries), print media articles, TV appearance, radio interviews and data sharing with various organisations, databases and PhD students. Visitors were able to participate in GBR Day and Night Surveys as well as Nest excavations. Offsite presentations included in Victoria, Qld and WA. *Skype in the Classroom* (Microsoft Education), allowed communication with school groups of all ages and nationalities in Australia and worldwide. Through information sharing both nationally and internationally, the GTCP reached a wide audience to increase awareness about sea turtle conservation as a whole.

11.7 Conclusion

The GTCP's outreach activities during 2010/11 – 2016/17 were provided free of charge to all participants. Given the end of grant support as well as the previous significant financial support by the Gnaraloo Station Trust for the season 2018/19 (from 1 July 2018), small fees were asked during 2017/18 for onsite visitor participation with the program as an investment in its future. From 1 July 2018, the GTCP will no longer be able to provide the offsite school and public presentations free of charge as was given during 2010/11 – 2017/18. Education, engagement of and outreach to the community are important pillars of successful conservation strategies. The accessibility by the public to onsite activities related to sea turtle science and conservation at Gnaraloo, including participation in surveys, as well as the educational presentations and *Skype in the Classroom* lessons should be carried on in future to continue to build and raise community awareness of sea turtle biology and conservation.

12 ABBREVIATIONS

APMS	Animal Pest Management Services
BP7	Beach Point 7 (-23.75001º S; 113.56871º E)
BP8	Beach Point 8 (-23.73631º S; 113.57448º E)
BP9	Beach Point 9 (-23.72195º S; 113.57750º E)
CCL	Curved carapace length
CCW	Curved carapace width
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMS	Convention on the Conservation of Migratory Species of Wild Animals (also known as the Bonn Convention)
D	Dead in Nests (dead hatchlings that have left their shells)
DBCA	Department of Biodiversity, Conservation and Attractions, Western Australia
E	Emerged (hatchlings leaving or departed from Nest)
ECF	Estimated clutch frequency
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth)
ESD	Erosion by shifting dunes
ETS	Erosion by tides or storms
FUFF	Fremantle Underwater Film Festival
GBN	Gnaraloo Bay North (-23.76708º S, 113.54584º E)
GBR	Gnaraloo Bay Rookery
GCFR	Gnaraloo Cape Farquhar Rookery

GDA	Geocentric Datum of Australia
GFACP	Gnaraloo Feral Animal Control Program
GFR	Gnaraloo Farquhar Runway (-23.59641º S; 113.66083º E)
GLN	Gnaraloo Lagoon North (-23.57697º S; 113.69828º E)
GRS	Gnaraloo Runway South (-23.61336º S; 113.64379º E)
GTCP	Gnaraloo Turtle Conservation Program
GWF	Gnaraloo Wilderness Foundation
IOD	Indian Ocean Dipole
ITS	Inundation by tides or storms
IUCN	International Union for the Conservation of Nature
L	Live in Nest (live hatchlings left among the egg shells)
MERI	Monitoring, Evaluation, Reporting and Improvement
MNES	Matters of National Environmental Significance (EPBC Act)
MSZ	Marine Sanctuary Zone
NAD	Nesting Activity Determination
NMP	Ningaloo Marine Park
N	Nest
NT	Northern Territory
NTP	Ningaloo Turtle Program, Exmouth, Western Australia
P	Predated (open, nearly complete shells containing egg or embryo residue)
Qld	Queensland
RMU	Regional Management Unit

S	Number of empty shells
SD	Standard Deviation
SE	South east
SI	Species Identification
SSD	Suffocation by shifting dunes
SSE	South-south east
SST	Sea surface temperature
STEM	An acronym that refers to the academic disciplines of science, technology, engineering and mathematics
Ua	Unidentified Nesting Activity
UD	Undeveloped (unhatched eggs with no obvious embryo)
UH	Unhatched (unhatched eggs with obvious embryo)
UHT	Unhatched Term (unhatched apparently full-term embryo in egg shell or pipped (with small amount of yolk material))
UNA	Unsuccessful Nesting Attempt
UT	U-Track
WA	Western Australia

13 GLOSSARY

Clutch	All of the eggs deposited in a single Nest
Clutch frequency	Number of clutches laid per nesting season by an individual female
Day Survey	Morning turtle Nesting Activity monitoring in the GBR and/or the GCFR
Disturbance	Signs of digging or burrowing in the Nest area, without the presence of turtle eggshell fragments, whole turtle eggs, yolky turtle eggshells or dead hatchlings present at the surface, whether by native or feral predators
Ectotherm	An animal that is dependent on external sources of body heat as its internal physiological sources of heat are relatively small
Egg chamber	A deep hole dug by a female turtle into the primary body pit of a Nest using the turtle's back flippers, into which eggs are deposited
Emergence success	Proportion of hatchlings in a clutch that emerge from the Nest (i.e. onto the surface of the beach)
Epibiont	An organism that lives on the surface of another living organism (e.g. barnacles on turtle carapaces)
Erosion	Exposure of the egg chamber by environmental factors, for example, by tide, storm or wind related sand removal
Flipper tag	A metal tag with a unique ID number and return address that is applied to the turtle's front flipper
GBR Survey Area	The designated area for surveys within the GBR, from GBN to BP9
GCFR Survey Area	The designated area for surveys within the GCFR; since season 2014/15 this is from GRS to GLN
Hatching success	Proportion of hatchlings in a clutch that emerge from their shells (i.e. prior to reaching the surface of the beach)

Hatchling	A newly hatched turtle
Incubation period	Refer to 'Incubation – to - emergence period'
Incubation-to-emergence period	The time from oviposition to the hatchling emerging on the beach surface. This parameter is commonly used in nesting beach studies (Miller et al., 2003). Incubation period in this report refers to the incubation-to-emergence period.
Inundation	Indication of water reaching beyond the egg chamber on the surface of the beach as observed during Day Surveys. Length or intensity of inundation is not considered
Internesting interval	The period of time between a successful Nest and the next nesting attempt (successful or not)
Indian Ocean Dipole	Irregular oscillation of SST between the western and eastern Indian Ocean
Nest	A successful Nesting Activity that results in the laying of eggs
Nest detection bias	The likelihood of correctly identifying Nests during Day Surveys, by comparison of Day Survey data with independent, direct observations of Nesting Activities during Night Surveys
Nesting Activity	Any track or nesting attempt (i.e. Nest, Unsuccessful Nesting Attempt, U-Track or Unidentified nesting activity) created by a sea turtle
Nesting Activity Determination	Establishing the type of Nesting Activity (i.e. as a Nest, Unsuccessful Nesting Attempt, U-Track or Unidentified nesting activity) through track interpretations or direct visual observation
Nesting success	The proportion of sea turtle emergences that resulted in a Nest
Nest site selection	Selection of a site to dig a Nest and lay eggs on a nesting beach by a reproductively active adult female sea turtle
Night Survey	Night time visual monitoring of turtle nesting activity in the GBR Survey Area
Oviposition	Depositing or laying of eggs

p-value	Calculated probability to determine the significance of a result in statistical analysis, such as t-tests or linear regressions
Phenology	The study of cyclic and seasonal natural phenomena, especially in relation to climate and plant and animal life
Predation	Evidence of mortality at a turtle Nest (e.g. turtle eggshell fragments, whole turtle eggs, yolky turtle eggshells, dead hatchlings present at the surface, or an exposed egg chamber)
r^2	A statistic calculated in linear regression models that indicates the proportion of variation in the response variable explained by the model
Recruitment rate	The rate at which new individuals are added to a population; i.e. the rate at which freshly matured females are added to the current Gnaraloo nesting population
Remigration interval	The duration of the period between successive nesting seasons for individual females
Rookery	A breeding area for a large number of animals
Sampled Nests	A statistically representative subset of Nests in the standard survey area that are monitored daily throughout the monitoring period to identify and assess the extent and impact of ecological and environmental impacts on Nests
Sub-section	Sectors that the surveyed rookeries (GBR and GCFR Survey Areas) are divided into for easier data management
Survey Area	The stretches of beach in the GBR and GCFR that are surveyed by the GTCP Field Research Team for sea turtle Nesting Activities
Track Day	A day that recorded one or more tracks of a particular feral animal species was considered a single 'Track Day' for that species due to the inability to determine how many individuals were responsible for multiple tracks or track segments in the same day. As tracks from different species (fox, cat or dog) observed on the

	same day were counted as individual Track Days, it is possible to reach up to three Track Days for one survey day
Undeveloped	Unhatched eggs with no obvious embryo
Unhatched	Unhatched eggs with obvious embryo (excluding UHT)
Unhatched Term	Unhatched apparently full-term embryo in egg shell or pipped (with small amount of yolk material)
Unidentified Nesting Activity	A nesting attempt with no clear characteristics, preventing a researcher from assigning a category of N, UNA or U-Track
Unsuccessful Nesting Attempt	A nesting attempt during which the turtle does not deposit any eggs, but there is evidence of digging
U-Track	A nesting attempt with no evidence of digging

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APPENDICES

APPENDIX A: MAPS

APPENDIX B: WEATHER DATA

Table 11: Daily weather summary in GBR Survey Area, November 2017

DATE	TEMPERATURE [°C]					RAIN [mm]	WIND SPEED & DIRECTION [km/h]			
	MEAN	HIGH	TIME	LOW	TIME		MEAN	HIGH	TIME	DIRECTION
01/11/2017	25.1	36.2	11:00a	18.2	5:00a	0	13.5	37	6:00p	S
02/11/2017	25.3	35	12:00p	20.4	6:00a	0	15.6	40.2	3:00p	SSE
03/11/2017	22.6	30.1	11:00a	19	6:00a	0	16.1	43.5	4:00p	SSW
04/11/2017	22.2	27.4	10:00a	18.6	6:00a	0	18.5	41.8	4:00p	S
05/11/2017	22.2	25.2	12:00p	19.1	5:00a	0	16.1	38.6	3:00p	SW
06/11/2017	23	25.1	1:00p	21.1	2:00a	0	18	32.2	8:00p	WSW
07/11/2017	23.1	26.2	4:00p	19.7	7:00a	0	11.9	37	6:00p	SSW
08/11/2017	22.5	25.9	9:00a	19.9	1:00a	0	16.6	40.2	3:00p	SSW
09/11/2017	21.5	24.1	2:00p	18.1	6:00a	0	14.5	38.6	4:00p	SW
10/11/2017	21.8	24.5	11:00a	17.9	5:00a	0	12.6	35.4	5:00p	SSE
11/11/2017	22.2	25.7	3:00p	18.4	5:00a	0	13	35.4	5:00p	WSW
12/11/2017	22	25.3	2:00p	18.9	6:00a	0	19.6	49.9	5:00p	SSW
13/11/2017	22.4	26.3	10:00a	19.3	5:00a	0	22.4	53.1	3:00p	S
14/11/2017	22.6	26.1	9:00a	19.7	6:00a	0	23.3	51.5	6:00p	SSW
15/11/2017	23.1	25.9	1:00p	19.9	2:00a	0	16.6	35.4	7:00p	WSW
16/11/2017	23.7	25.8	2:00p	21.8	5:00a	0	16.4	37	6:00p	WSW
17/11/2017	23.1	25.8	2:00p	21	10:00a	0.2	11.4	32.2	7:00p	WSW
18/11/2017	22.3	25.1	12:00p	18.4	12:00m	0	19.3	41.8	3:00p	SW
19/11/2017	21.4	26.8	11:00a	15.4	6:00a	0	16.1	43.5	2:00p	SSW
20/11/2017	22	27.6	11:00a	18.3	6:00a	0	20.9	53.1	2:00p	S
21/11/2017	24.3	35.3	2:00p	18.3	6:00a	0	18.2	46.7	4:00p	SE
22/11/2017	27.6	39	12:00p	20.1	6:00a	0	17.4	45.1	4:00p	ESE
23/11/2017	28.1	40.4	11:00a	19.4	5:00a	0	12.4	40.2	11:00p	S
24/11/2017	24.5	28.6	9:00a	21.1	6:00a	0	18.2	48.3	5:00p	SSW
25/11/2017	22.8	26.8	9:00a	19.2	6:00a	0	18.5	46.7	2:00p	S
26/11/2017	22.3	25.2	2:00p	18.8	4:00a	0	20.9	46.7	12:00p	S
27/11/2017	22.2	25.3	1:00p	19.2	6:00a	0	18.7	45.1	4:00p	SSW
28/11/2017	22	25.8	10:00a	17.7	5:00a	0	19	53.1	3:00p	S
29/11/2017	22.4	29.2	1:00p	18.4	6:00a	0	20.9	56.3	4:00p	SSE
30/11/2017	23.4	32.1	3:00p	18.4	6:00a	0	21.1	46.7	4:00p	SSE

Table 12: Daily weather summary in GBR Survey Area, December 2017

DATE	TEMPERATURE [°C]					RAIN [mm]	WIND SPEED & DIRECTION [km/h]			
	MEAN	HIGH	TIME	LOW	TIME		MEAN	HIGH	TIME	DIRECTION
01/12/2017	26.1	37.9	1:00p	18.5	6:00a	0	20.1	41.8	11:00a	SE
02/12/2017	24.1	29.3	10:00a	20.3	7:00a	0.8	11.1	37	11:00p	WSW
03/12/2017	26.7	32.5	2:00p	22.4	1:00a	0	14.6	38.6	7:00p	SSE
04/12/2017	25.8	31.2	3:00p	23.3	7:00a	0.4	12.6	29	11:00a	ESE
05/12/2017	26.9	34.7	1:00p	23.2	12:00m	0	16.3	41.8	2:00p	ESE
06/12/2017	24.8	32.6	12:00p	21.3	6:00a	0	21.6	53.1	12:00p	SSE
07/12/2017	26.4	37.1	12:00p	21.2	2:00a	0	15.9	40.2	4:00p	S
08/12/2017	24.9	27.7	1:00p	21.6	6:00a	0	12.9	30.6	8:00p	W
09/12/2017	24.6	26.6	2:00p	22.7	3:00a	0	16.4	33.8	7:00p	W
10/12/2017	24.4	27.1	4:00p	20.1	6:00a	0	11.9	29	9:00p	W
11/12/2017	24.8	26.8	1:00p	22.5	12:00m	0	15.8	29	2:00p	W
12/12/2017	24.3	27.1	3:00p	22.1	12:00m	0	18.3	46.7	3:00p	SSW
13/12/2017	25.7	33.8	1:00p	21.3	2:00a	0	21.7	51.5	4:00p	S
14/12/2017	24.8	33.2	11:00a	20.6	6:00a	0	19.2	46.7	4:00p	SSW
15/12/2017	23.2	26.6	2:00p	18.7	6:00a	0	17.5	43.5	3:00p	SSW
16/12/2017	22.9	25.9	3:00p	19.7	5:00a	0	17.1	41.8	5:00p	SSE
17/12/2017	23.1	25.7	9:00a	20.3	1:00a	0	19.8	43.5	2:00p	SSW
18/12/2017	22.7	27.9	1:00p	19.4	5:00a	0	20.9	56.3	1:00p	SSE
19/12/2017	23.9	32.9	2:00p	18.9	6:00a	0	19.8	51.5	5:00p	SSE
20/12/2017	27.9	37.7	12:00p	19.9	6:00a	0	16.7	41.8	4:00p	ESE
21/12/2017	25.1	29.4	1:00p	18.8	6:00a	0	12.1	37	4:00p	SSW
22/12/2017	24.9	29.8	12:00p	21.5	3:00a	0	17.5	40.2	2:00p	SSW
23/12/2017	26.5	35.7	11:00a	21.4	6:00a	0	15.4	40.2	3:00p	S
24/12/2017	27.9	36	11:00a	24.1	4:00a	0	19.5	45.1	2:00p	SSE
25/12/2017	28.3	41.1	12:00p	22.2	5:00a	0	16.9	43.5	3:00p	SSW
26/12/2017	27.6	37.6	11:00a	22.9	3:00a	0	16.9	45.1	3:00p	S
27/12/2017	26.6	35.8	12:00p	21.9	12:00m	0	21.9	51.5	3:00p	SSE
28/12/2017	24.2	31.4	1:00p	20.4	6:00a	0	24.6	51.5	1:00p	SSE
29/12/2017	24.8	32.3	11:00a	19.6	6:00a	0	18.2	46.7	3:00p	S
30/12/2017	24.7	26.8	1:00p	22.6	2:00a	0	17.5	37	6:00p	SW
31/12/2017	25.7	29.7	8:00a	22.9	6:00a	0	12.6	37	4:00p	SSW

Table 13: Daily weather summary in GBR Survey Area, January 2018

DATE	TEMPERATURE [°C]					RAIN [mm]	WIND SPEED & DIRECTION [km/h]			
	MEAN	HIGH	TIME	LOW	TIME		MEAN	HIGH	TIME	DIRECTION
01/01/2018	26.5	35.7	10:00a	22.6	5:00a	0	14.3	38.6	5:00p	SSW
02/01/2018	26.1	29.3	1:00p	23.3	6:00a	0	11.6	32.2	6:00p	S
03/01/2018	26.6	30.8	4:00p	23.1	6:00a	0	14.3	40.2	4:00p	S
04/01/2018	30.1	42.6	11:00a	24.4	5:00a	0	14.6	37	2:00p	SSW
05/01/2018	29.7	37.3	10:00a	23.9	6:00a	0	17.7	46.7	3:00p	SSE
06/01/2018	27.1	37.4	12:00p	23	6:00a	0	20.8	49.9	4:00p	SSE
07/01/2018	26.2	33.7	11:00a	22.3	4:00a	0	19.2	46.7	4:00p	SSE
08/01/2018	24.4	29.7	10:00a	21.1	5:00a	0	17.7	43.5	1:00p	SSW
09/01/2018	24.1	27.2	1:00p	21.1	6:00a	0	17.2	43.5	3:00p	S
10/01/2018	24.2	28.8	10:00a	21.3	12:00m	0	21.6	49.9	5:00p	S
11/01/2018	25	32.7	3:00p	19.7	5:00a	0	22.4	51.5	5:00p	SSE
12/01/2018	26.9	36.8	2:00p	20.3	6:00a	0	22.7	48.3	3:00p	SE
13/01/2018	31.2	41	2:00p	24.2	2:00a	1.6	14.5	54.7	12:00p	ESE
14/01/2018	27.9	29.6	4:00a	26.1	12:00m	0	8.9	24.1	6:00p	NW
15/01/2018	26.9	29.4	11:00a	24.8	12:00m	0	11.4	27.4	4:00p	S
16/01/2018	26.2	29.1	3:00p	23.6	5:00a	0	14.2	37	4:00p	S
17/01/2018	26.5	31.5	10:00a	24	6:00a	0	16.4	43.5	4:00p	SSE
18/01/2018	26.7	33.4	11:00a	23.6	4:00a	0	19.5	49.9	3:00p	SSE
19/01/2018	27.1	33.4	10:00a	24.1	6:00a	0	15.1	43.5	4:00p	SSE
20/01/2018	27	29.9	3:00p	24.8	5:00a	0	18	49.9	5:00p	S
21/01/2018	27.7	36.6	1:00p	24.1	7:00a	1	16.3	43.5	5:00p	SSW
22/01/2018	28.4	37.7	1:00p	24.9	6:00a	0	16.6	41.8	6:00p	S
23/01/2018	28	33.7	10:00a	24.1	12:00m	0	18.3	43.5	11:00a	S
24/01/2018	26	29.8	4:00p	23.2	6:00a	0	19.6	48.3	3:00p	S
25/01/2018	25.3	30.6	10:00a	22.1	5:00a	0	20.3	48.3	1:00p	S
26/01/2018	25.4	29.6	9:00a	21.8	5:00a	0	20.4	43.5	4:00p	SSW
27/01/2018	25.6	30.8	10:00a	22.2	5:00a	0	22.4	53.1	12:00p	S
28/01/2018	25.6	33.1	1:00p	21.8	5:00a	0	24.1	56.3	2:00p	S
29/01/2018	28.8	38.1	11:00a	22.2	5:00a	0	16.6	49.9	3:00p	S
30/01/2018	31.2	37.5	2:00p	26.9	6:00a	0	15.9	45.1	8:00a	E
31/01/2018	27.2	34.1	1:00p	23.2	6:00a	0	19.8	51.5	4:00p	E

Table 14: Daily weather summary in GBR Survey Area, February 2018

DATE	TEMPERATURE [°C]					RAIN [mm]	WIND SPEED & DIRECTION [km/h]			
	MEAN	HIGH	TIME	LOW	TIME		MEAN	HIGH	TIME	DIRECTION
01/02/2018	26.2	33.8	12:00p	21.6	5:00a	0	14.6	43.5	4:00p	ESE
02/02/2018	24.8	27.2	2:00p	22.4	5:00a	0	18.2	40.2	12:00p	S
03/02/2018	24.7	27.7	2:00p	22.1	4:00a	0	19.6	46.7	12:00p	S
04/02/2018	24.5	27.7	9:00a	21.6	5:00a	0	24.1	51.5	3:00p	S
05/02/2018	25.6	30.9	10:00a	22.4	6:00a	0	20.9	48.3	2:00p	S
06/02/2018	27.4	34	10:00a	23.9	1:00a	0	17.4	41.8	4:00p	S
07/02/2018	26.7	33.8	11:00a	23.6	2:00a	0	19.5	48.3	2:00p	SSE
08/02/2018	26.2	30.8	10:00a	23.8	5:00a	0	15.3	41.8	5:00p	SSE
09/02/2018	26.3	29.3	2:00p	23.6	4:00a	0	19.8	49.9	5:00p	S
10/02/2018	27	33.8	12:00p	24	7:00a	0	15.3	45.1	3:00p	SSW
11/02/2018	27.7	33.5	10:00a	25	5:00a	0	11.7	37	5:00p	SSW
12/02/2018	26	28.1	8:00a	24.2	4:00a	0	11.6	32.2	4:00p	S
13/02/2018	27.1	34.1	11:00a	23.5	5:00a	0	17.5	48.3	5:00p	S
14/02/2018	28.7	38.3	12:00p	23.7	6:00a	0	19.3	49.9	5:00p	SSE
15/02/2018	29.1	40.6	11:00a	25.3	3:00a	0	15.8	43.5	2:00p	SE
16/02/2018	29.2	37.8	4:00p	25.8	1:00a	0	16.4	51.5	4:00p	S
17/02/2018	26	29.8	9:00a	22.3	12:00m	0	20	49.9	3:00p	SSW
18/02/2018	24.3	29.1	11:00a	21.4	4:00a	0	20.4	51.5	3:00p	S
19/02/2018	24.2	29.3	11:00a	20.4	6:00a	0	22.4	56.3	4:00p	S
20/02/2018	24.7	29.9	10:00a	22	6:00a	0	24.9	54.7	1:00p	SSE
21/02/2018	24.8	26.7	1:00p	22.6	4:00a	0	19.2	41.8	5:00p	SW
22/02/2018	25.2	27.4	1:00p	23	12:00m	0	20	35.4	2:00p	SW
23/02/2018	25.1	28.6	2:00p	21.9	6:00a	0	16.7	41.8	2:00p	S
24/02/2018	24.9	27.2	9:00a	22.2	3:00a	0	14.8	32.2	8:00p	SW
25/02/2018	25.4	27.8	1:00p	23.1	12:00m	0	15	33.8	5:00p	SW
26/02/2018	24.3	28	3:00p	21.5	6:00a	0	15.9	41.8	2:00p	SE
27/02/2018	24.2	31.7	2:00p	20	6:00a	0	19	57.9	2:00p	SE
28/02/2018	21.8	22.4	1:00a	21.3	5:00a	0	14.5	30.6	1:00a	SSE

Table 15: Daily weather summary in GCFR Survey Area, 27 December 2017 – 16 January 2018

DATE	TEMPERATURE [°C]					RAIN [mm]	WIND SPEED & DIRECTION [km/h]			
	MEAN	HIGH	TIME	LOW	TIME		MEAN	HIGH	TIME	DIRECTION
27/12/2017	27.3	30.6	5:00p	25.1	12:00m	0	15.8	37	7:00p	SSW
28/12/2017	27.3	36.8	1:00p	22.6	12:00m	0	17.5	45.1	3:00p	S
29/12/2017	24.7	32.7	2:00p	20.3	6:00a	0	19.6	48.3	2:00p	S
30/12/2017	24.7	31.8	11:00a	19.9	7:00a	0	15.3	45.1	4:00p	SSW
31/12/2017	24.7	27	8:00a	22.5	3:00a	0	15.3	30.6	3:00p	WSW
01/01/2018	26.7	33.9	10:00a	23.3	6:00a	0	11.6	38.6	4:00p	SW
02/01/2018	26.2	28.8	4:00p	24.1	6:00a	0	8.9	32.2	6:00p	WSW
03/01/2018	26.8	29.6	4:00p	23.5	6:00a	0	12.9	40.2	4:00p	SW
04/01/2018	30.3	42.9	11:00a	25.4	5:00a	0	12.2	38.6	3:00p	SW
05/01/2018	29.8	37.4	10:00a	24.3	7:00a	0	14	41.8	7:00p	SW
06/01/2018	27.9	38.6	1:00p	23.4	6:00a	0	16.1	45.1	4:00p	S
07/01/2018	26.7	34.1	12:00p	22.4	6:00a	0	16.1	41.8	3:00p	S
08/01/2018	24.7	29.3	10:00a	21.3	6:00a	0	15	40.2	1:00p	SSW
09/01/2018	24.4	27.7	2:00p	21.2	6:00a	0	14.5	41.8	5:00p	SW
10/01/2018	24.6	30.3	11:00a	21.6	5:00a	0	17.1	48.3	4:00p	SSW
11/01/2018	25.8	34.6	3:00p	20.4	6:00a	0	18	46.7	6:00p	S
12/01/2018	27.9	39.2	2:00p	20.7	6:00a	0	17.1	43.5	6:00p	S
13/01/2018	31.3	40.7	2:00p	24.6	1:00a	1.4	13.8	59.5	1:00p	E
14/01/2018	27.4	28.8	5:00a	26.1	1:00a	0	8.9	27.4	6:00p	NW
15/01/2018	26.8	28.9	2:00p	25.4	12:00m	0	10.1	29	6:00p	NNW
16/01/2018	24.4	25.4	1:00a	23.7	6:00a	0	0	6.4	4:00a	SSW

APPENDIX C: FLIPPER TAGGING DATA

Table 16: Flipper tag data of female loggerhead turtles in the GBR Survey Area, 2017/18

NO.	LEFT FLIPPER TAG ID	RIGHT FLIPPER TAG ID	TAGGING DATE	TURTLE SPECIES	CCL (cm)	CCW (cm)	BIOPSY NUMBER	IDENTIFYING FEATURES
1	WB1287	WB1288	03/12/2015	L	87.9	80.8		Sat tag turtle NERINE
2	WB15101	WB15102	21/11/2017	L	82.6	78.5	x	Right back flipper missing
3	WB15103	WB15104	22/11/2017	L	98.0	89.0	F6417	x
4	WB15105	WB15106	23/11/2017	L	89.0	81.5	x	x
5	WB15107	WB15108	26/11/2017	L	98.6	92.6	x	Small piece of left back flipper missing
6	WB15109	WB15110	26/11/2017	L	92.6	82.3	x	x
7	WB15111	WB15112	27/11/2017	L	97.8	89.2	F6500	x
8	WB15113	WB15114	29/11/2017	L	92.5	85.4	x	Small piece of carapace missing on right side
9	WB15115	WB15116	29/11/2017	L	88.6	83.4	x	x
10	WB15117	WB15118	30/11/2017	L	93.4	83.1	x	x
11	WB15119	WB15120	01/12/2017	L	94.2	81.5	F6445	x
12	WB15121	WB15122	01/12/2017	L	87.5	78.6	x	x
13	WB15123	WB15124	02/12/2017	L	95.6	82.3	F6438	Most of left back flipper missing
14	WB15125	WB15126	02/12/2017	L	89.1	78.3	F6430	x
15	WB15127	WB15129	02/12/2017	L	90.5	81.6	F6406	Large barnacles on head
16	WB15130	WB15131	03/12/2017	L	84.0	82.3	F6228	Barnacles on head
17	WB15132	WB15133	03/12/2017	L	93.2	84.0	F6481	x
18	WB15134	WB15135	06/12/2017	L	97.8	92.6	F6480	x
19	WB15136	WB15137	06/12/2017	L	93.7	85.0	F6415	Small head
20	WB15138	WB15139	08/12/2017	L	92.0	83.1	F6467	Sat tag turtle GNARGOO
21	WB15140	WB15141	09/12/2017	L	93.5	85.6	F6404	Sat tag turtle BAIYUNGU
22	WB15142	WB15143	11/12/2017	L	90.3	86.4	x	x
23	WB15144	WB15145	11/12/2017	L	89.0	84.5	x	Missing most of the left front flipper and a chunk of her carapace at the back on the right side
24	WB15146	WB15147	11/12/2017	L	86.8	76.8	x	x
25	WB15148	WB15149	12/12/2017	L	98.4	90.5	x	x
26	WB15150	WB15159	13/12/2017	L	97.3	x	x	x
27	WB15151	WB15152	07/12/2017	L	x	x	x	x
28	WB15153	WB15154	08/12/2017	L	91.8	80.0	F5994	Small notch from shell over right back flipper
29	WB15155	WB15156	10/12/2017	L	95.4	86.5	x	Large chunk missing from the right back flipper

NO.	LEFT FLIPPER TAG ID	RIGHT FLIPPER TAG ID	TAGGING DATE	TURTLE SPECIES	CCL (cm)	CCW (cm)	BIOPSY NUMBER	IDENTIFYING FEATURES
30	WB15157	WB15158	12/12/2017	L	94.0	83.5	F6563	Missing part of right back flipper
31	WB15160	WB15161	13/12/2017	L	85.3	78.5	x	x
32	WB15162	WB15163	13/12/2017	L	x	x	x	x
33	WB15164	WB15165	14/12/2017	L	86.2	81.0	F6381	Half of left front flipper missing
34	WB15166	WB15167	14/12/2017	L	97.5	x	F6473	Part of left front flipper missing
35	WB15168	WB15169	14/12/2017	L	92.5	82.5	F6583	x
36	WB15170	WB15171	14/12/2017	L	102.5	93.0	x	Two small holes at back end of carapace, either side of midline
37	WB15172	WB15173	14/12/2017	L	92.5	85.0	F6409	x
38	WB15175	WB15174	14/12/2017	L	97.8	90.0	x	x
39	WB15176	WB15177	15/12/2017	L	97.8	87.1	F6456	x
40	WB15178	WB15179	16/12/2017	L	84.0	77.1	F6574	x
41	WB15180	WB15181	16/12/2017	L	93.0	86.2	x	x
42	WB15182	WB15183	16/12/2017	L	92.5	80.0	x	Back edges of the carapace are jagged
43	WB15184	WB15185	16/12/2017	L	97.9	90.3	x	Missing part of right back flipper
44	WB15186	WB15187	17/12/2017	L	96.8	93.2	x	x
45	WB15188	WB15189	20/12/2017	L	93.1	79.0	x	x
46	WB15190	WB15191	17/12/2017	L	100.5	91.5	x	x
47	WB15192	WB15193	17/12/2017	L	87.2	77.6	x	Right back flipper missing
48	WB15194	WB15195	21/12/2017	L	99.3	87.7	x	x
49	WB15196	WB15197	21/12/2017	L	95.8	88.0	x	x
50	WB15201	WB15202	19/12/2017	L	96.2	92.3	x	x
51	WB15203	WB15204	21/12/2017	L	91.6	81.5	x	x
52	WB15205	WB15206	21/12/2017	L	91.5	x	x	x
53	WB15207	WB15208	26/01/2018	L	102.5	96.0	x	x

Notes:

1. Flipper tagging data for the 16 Gnaraloo satellite tagged loggerhead turtles from season 2015/16 is contained in Strydom et al., 2017.

2. L: Loggerhead turtle

APPENDIX D: PHOTO PLATES

1 Field researcher measuring CCL of a loggerhead turtle in GBR Survey Area, GTCP 2017/18

2 Field researchers excavating a Sampled Nest in GBR Survey Area, GTCP 2017/18

3 Sorting and counting findings after excavating a Sampled Nest in GBR Survey Area, GTCP 2017/18

4 Field researchers attaching a satellite tracker to Gnargoo in GBR Survey Area, GTCP 2017/18

5 Baiyungu returning to sea after being fitted with a satellite tracker in GBR Survey Area, GTCP 2017/18

6 Loggerhead hatchlings emerging from a Nest in GBR Survey Area, GTCP 2017/18

7 Field researcher presenting to high school students at Mater Dei College, Perth (WA), GTCP 2017/18

8 Field researcher presenting to volunteers of TurtleCare Sunshine Coast (Qld), GTCP 2017/18

9 GTCP scientific team during an onsite workshop at Gnaraloo, GTCP 2017/18

10 Field researchers presenting findings to DBCA at Gnaraloo, GTCP 2017/18

11 GWF Committee members presenting to the US Consulate General, Perth (WA), GTCP 2017/18

Photo 1: Field researcher measuring CCL of a loggerhead turtle in GBR Survey Area, GTCP 2017/18

Photo 2: Field researchers excavating a Sampled Nest in GBR Survey Area, GTCP 2017/18

Photo 3: Sorting and counting findings after excavating a Sampled Nest in GBR Survey Area, GTCP 2017/18

Photo 4: Field researchers attaching a satellite tracker to Gnargoo in GBR Survey Area, GTCP 2017/18

Photo 5: Baiyungu returning to sea after being fitted with a satellite tracker in GBR Survey Area, GTCP 2017/18

Photo 6: Loggerhead hatchlings emerging from a Nest in GBR Survey Area, GTCP 2017/18

Photo 7: Field researcher presenting to high school students at Mater Dei College, Perth (WA), GTCP 2017/18

Photo 8: Field researcher presenting to volunteers of TurtleCare Sunshine Coast (Qld), GTCP 2017/18

Photo 9: GTCP scientific team during an onsite workshop at Gnaraloo, GTCP 2017/18

Photo 10: Field researchers presenting findings to DBCA at Gnaraloo, GTCP 2017/18

Photo 11: GWF Committee members presenting to the US Consulate General, Perth (WA), GTCP 2017/18