SOUTHERN CROSS UNIVERSITY

SCHOOL OF ENVIRONMENT, SCIENCE AND ENGINEERING

LUNAR PHASE AND TIDAL INFLUENCE ON PEAK TIMING OF NESTING FLATBACK SEA TURTLES (*Natator depressus*), NORTHERN TERRITORY, AUSTRALIA

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Copyright declaration

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Abstract

The Flatback sea turtle, *Natator depressus*, is endemic to Australia and is confined to the continental shelf, extending to populations in south-east Queensland, around the Gulf of Carpentaria, through to the north-west shelf of Western Australia. Bare Sand Island (BSI), 65km south-west of Darwin, is a winter nesting site for a population of flatback turtles belonging to the Northern Territory genetic stock. Sea turtle nesting behaviour is greatly unknown, however is likely linked to lunar phase and cycle, which influence tidal activity. Environmental cues may aid in synchronising nesting within populations and benefit the production of offspring by coordinating nesting cycles with favourable conditions. Monitoring was conducted over a seven-week nesting season on BSI in June and July to identify any pattern in nesting abundance. Moon phase was observed to establish any correlation between nesting flatback turtles and the associated tidal cycle; spring and neap. Sky glow was observed for a two-week period in July to detect patterns in nesting abundance relative to moon brightness. Irrespective of brightness, greater numbers of nesting *N. depressus* were observed 1 to 2 days prior and post spring tides on a new and full moon. Findings were consistent when compared with nesting patterns from a flatback rookery on Delambre Island, WA, however further investigation is required to understand the influence of the tidal regime and synchrony of populations to environmental factors.

Keywords

Natator depressus, Flatback turtle, tidal cycle, lunar cycle, Bare Sand Island, nesting

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1. Introduction

1.1 *Natator depressus* biology and ecology

The northern Australian coastline supports globally significant populations of four species of sea turtle, including the Flatback turtle, *Natator depressus* (Hamann, Schauble, Simon, Johnson, Evans, Dorr, Kennett 2006; Chatto, Baker 2008). *N. depressus* are endemic to Australia and confined to the continental shelf, extending to populations in south-east Queensland, around the Gulf of Carpentaria, through to the north-west shelf of Western Australia (Limpus 2007; Whiting, Thomson, Chaloupka, Limpus 2008).

Flatback turtles are distinguished from other marine turtle species, by their low, flattened carapace with four central costal scutes. They are olive-grey in appearance and at maturity, are an average of 92cm and 90kg (Limpus 2009; Pritchard, Mortimer 1999). Unlike other sea turtle species, *N. depressus* lack an oceanic phase in their life cycle and forage widely across the continental shelf and into Papua New Guinea and Indonesian waters (Groom, Griffiths, Chaloupka 2017; White, Gill 2007). Flatback turtles feed primarily on sub-tidal, soft bottomed benthic habitats and while diet is not widely known, are thought to be carnivorous, feeding on invertebrates (Leis 2009; Limpus 2007). Flatback sea turtles are commonly less studied then other marine turtles in Australian waters, however increasing literature is beginning to emerge.

Four genetic stocks of *N. depressus* have been identified; Gulf of Carpentaria, eastern Australia, western-Northern Territory and Western Australia (WA) (Limpus 2007). The Northern Territory (NT) stock extends from Torres Strait to the NT -Western Australian border (Groom *et al.* 2017). While geographical distribution is known, detailed information on nesting sites and foraging areas are limited to only a few locations (Hamman *et al.* 2006). Genetic variability has been observed amongst the four stocks and further studies are underway to explore the genetic variability among stocks (Pendoley *et al.* 2014; Tucker *et al*. 2014). Differences in morphology and timing of nesting among *N. depressus* stocks have been identified (Pendoley *et al.* 2014). Due to the intermittent behaviour of sea turtle nesting among regions, and among genetically distinct populations, identifying patterns in nesting require consecutive annual sampling (Whiting, Chaloupka, Limpus 2013).

Sampling design for the monitoring of migratory species is confined for species like sea turtles where nesting occurs within a restricted timeframe, on both a daily and, seasonal scale, in addition to numerous remote locations (Whiting *et al*. 2013). Variability is expected between seasons, as is changes in temporal distribution caused by currently unexplained biological limitations (Whiting *et al*. 2013). Temporal variability in nesting abundance makes it difficult to apply management strategies that best-fit the populations, and sub-populations of a location.

1.1.1 *Breeding strategies of* N. depressus

There is a paucity of literature on flatback turtle nesting behaviour. Understanding the biological parameters of a population is important for long-term management goals of the species (Pendoley, Whittock, Vitenbergs, Bell 2016). The nesting ecology of flatback turtles varies regionally within Australia, as nesting season is dependent on latitude and the environmental conditions conducive to offspring production (Leis 2009; Tucker, Whiting, Mitchell, Berry, FitzSimmons, Pendoley 2014; Whiting, Chaloupka, Limpus 2013). Sea turtles that use the NT coastline as their nesting site have different nesting behaviour to those that nest in south-east Qld locations and along the Western Australian coastline. This is because populations at higher latitudes, utilise a winter nesting season, where those further south along the Qld and WA coastlines experience a summer nesting season (Whiting *et al.* 2008; Guinea, Ryan, Umback, Hills 2001). Bare Sand Island (BSI), NT, experiences year-round nesting with a peak during winter and lower nest density during summer (Limpus 2007; Guinea, Ryan, Umback, Hills 2001).

It is known that the nesting environment significantly influences the embryonic development of turtle eggs and survival and success of a population, however, little is known about the environmental variances that influence the time nesting occurs (Banister, Holland, Farrelly 2016). Nest temperature determines the sex of the embryo, while moisture, vegetation and sediment material may influence development and hatchling fitness (Banister *et al.* 2016; Limpus 2007). *N. depressus* show a high fidelity to their chosen nesting beach, returning for successive clutches within a season, and for subsequent seasons, however, it has been observed that some of the population nest on nearby beaches also (Bannister *et al*. 2016; Whittock, Pendoley, Hamann 2014; Guinea. M, personal communication 2018). *N. depressus* lay between 1-4 (mean 2.8) clutches of eggs and spend several months in surrounding waters in close proximity of their nesting beach (Department of Environment and Energy 2018). Flatback turtles exhibit an inter-nesting period; defined as the period between a successful clutch and the successive nesting attempt, of 15-19 days (Limpus 2007; Whittock *et al*. 2014). A study by Bannister *et al*. (2016) found that the mean inter-nesting period for *N. depressus* on BSI was 19 days (±1.58) with the minimum and maximum being 15 and 37 respectively.

1.1.2 Environmental cues

Daily and seasonal environmental cues trigger behaviour in animals, guiding life history processes, such as reproduction and biological clock control (Pike 2008; Naylor 2001). The key environmental cues that trigger nesting in sea turtles is not yet understood and may fall under one of two categories; atmospheric; (i.e. moon phase), or oceanic (tidal activity) (Pike 2008). A study undertaken by Leis (2009) on flatback populations on Crab Island in northern Qld indicated that daily variation in nesting abundance was substantial. While sea turtle nesting behaviour is greatly unknown, it is likely linked to lunar phase and cycle, which determines tidal activity globally. This indicates influence from both atmospheric and oceanic environmental conditions (Witt 2013; Pike 2008). Cues may aid in synchronising nesting within populations, or sub-populations, and benefit the production of offspring by coordinating nesting cycles with favourable conditions (Pike 2008).

Many studies have attempted to identify nesting pattern relationships with moon and tidal phase, but results have been inconclusive (Burney *et al*. 1990; Frazer 1983). Moreover, there is little literature on the emergence patterns and times of nesting events of the flatback sea turtle (Welsh *et al.* 2009; Pike 2008). Animal behaviour and response to lunar conditions have been explored by McDowall (1969) who stated that aquatic animals are impacted by the moon due to the occurrence of tides (Eduardo 2011). In addition to selecting appropriate tides, it seems that generally sea turtles exhibit variable behaviour dependent on lunar phase and visibility (Law, Clovis, Lalsingh, Downie 2010; Witt 2013). The lunar cycle causes change in the environment that may be perceived by turtles, including brightness (percentage (%) moon coverage or sky glow), visibility and gravitational changes (Law *et al.* 2010). Aside from tidal activity and lunar phase, further environmental influence such as ocean current, temperature, beach slope and weather conditions may also affect emergence patterns (Burney *et al*. 1990; Welsh *et al.* 2009; Pike 2008).

Though typically nocturnal nesters, sea turtles can respond to direct cues, like moonlight, or indirect cues, associated with monthly variation in tidal amplitudes; spring and neap tides (Naylor 2001; Welsh, Tucker 2009). Spring tides occur on a new and full moon phase and deliver the greatest difference of water between high and low tides. Spring tides have been observed to correlate with inflated nesting numbers (Ekanayake, Ranawana, Kapurusinghe, Premakumara, Saman 2002; Frazer 1983). A study on the impact of lunar cycle on nesting behaviour of sea turtles in Sri Lanka found that there was no significant correlation between the number of nesting females and the lunar cycle; or any influence by tidal rhythm on nesting abundance (Ekanayake *et al.* 2002). However, a study on a loggerhead rookery in Florida confirmed that over a season there was a higher density of turtles nesting, corresponding to a new or full moon (Burney, Mattison, Fisher 1990). This was also the case for an increase in loggerhead turtle nesting numbers with higher tidal amplitudes in Georgia USA (Frazer 1983).

1.1.3 Moon phase and vulgar establishment

The lunar cycle takes place every 29.5 days, where the moon completes eight phases from a new moon through waxing and waning phases. Moon phase directly and indirectly influences the marine environment through illumination (brightness) and tidal intensity. Differences in tides can be lunar-daily (24.84 hours), semilunar (14.8 days) and lunar-monthly (29.5 days) (McDowall 1969; Eduardo 2011). Animal behaviour has been shown to correlate with monthly lunar and semilunar rhythms, while also correlating with tides in coastal locations (Naylor 2001).

Vulgar establishment, also known as intertidal interval, dictates the average interval of time which occurs between the moons upper transit and the next subsequent high tide following the transit (Queensland Government 2018). By determining the vulgar establishment for spring tides on Bare Sand Island and various other nesting sites, it enables testing of tidal superiority over darkness in cueing flatback turtle nesting. Using this analysis, populations within the same region, including nation-wide populations, can be compared with one another to identify differences in timing of nesting which can then be used to adapt specific management plans for those regions.

1.1.4 Bare Sand Island

Among nesting sites within the Northern Territory stock, is Bare Sand Island, a sand island located within Fog Bay, an extensive coastal flood plain extending 65km south-west of Darwin, NT (Northern Territory Government 2018). The Northern Territory government have declared BSI an area of national and international significance due to the ecological values of the island, creating the need for appropriate management in cooperation with traditional owners (Northern Territory Government 2018). Large regions of the NT coastline are under the ownership of Aboriginal people, generating the essential need for their involvement in any management or conservation of sea turtles (Hamman *et al.* 2006).

Larrakia are the traditional owners of Bare Sand Island (known traditionally as Ngulbitjik) and the island is listed as a category 6 land-use zone (sacred site) and managed under category 7; dictating that access is to be in accordance with the Northern Territory Aboriginal Sacred Sites Act (1989) (Northern Land Council 2018) (Fig.13; see appendix). Annual monitoring of *N. depressus* began in 1996 on BSI through research carried out by AusTurtle organisation to observe breeding populations and hatchling success of flatback turtles (AusTurtle 2006). Permits are issued to AusTurtle annually by the Kenbi custodians of Larrakia land and sea country to allow research on the island. The island is not only an important site for nesting turtles, but surrounding waters are a refuge for foraging Hawksbill (*Eretmochelys imbricata*) and Green (*Chelonia mydas*) turtles, both which are listed as *Vulnerable* under the EPBC Act 1999 (AusTurtle Pty Ltd 2018). Contributing to the ecological significance of BSI is the sporadic nesting of the Olive Ridley sea turtle (*Lepidochelys olivacea*), recognised nationally as *Endangered* (EPBC Act 1999) and *Vulnerable* under Northern Territory legislation (Territory Parks and Wildlife Conservation Act 2000).

1.2 Conservation status and management of *Natator depressus* in Australia

N. depressus populations are listed as *Vulnerable* under the Environmental Protection of Biodiversity and Conservation Act 1999 (EPBC 1999) and are considered 'data deficient' under Northern Territory legislation and the International Union for the Conservation of Nature (IUCN) red list for threatened species (Pendoley, Whittock, Vitenbergs, Bell 2016; International Union for the Conservation of Nature 2018). Conservation efforts of sea turtles are focussed heavily on breeding and nesting beaches, as they often concentrate large numbers of individuals in one location (Thums, Rossendell, Guinea, Ferreira 2018). Spatial distribution, habitat use, and behaviour are often overlooked areas of importance for turtles as nesting beaches are more readily accessible than surrounding waters, particularly in the Northern Territory (Pendoley, Whittock, Vitenbergs, Bell 2016; (Thums *et al.* 2018).

Developing a robust record of the temporal pattern of turtle nesting events is imperative to determine periods of time when, and places where, additional management is required to protect turtles and their eggs during peaks in nesting (Welsh *et al*. 2009). By defining unknown parameters that underpin peak nesting abundance in locations, management strategies can ensure any influencing factors that contribute to lower density numbers, for example, excessive brightness, or anthropogenic disturbance are removed from important sites.

1.3 Aims and objectives

The aim of this study is to assess the abundance of nesting Flatback sea turtles on Bare Sand Island, Northern Territory, and investigate the environmental cues that influence peak nesting periods.

The specific objectives of this study were to:

- Quantify seasonal flatback turtle nesting numbers on Bare Sand Island;
- Identify the peak in nesting season over June and July;
- Determine any relationship between nesting turtle abundance and moon phase;
- Obtain vulgar establishment for spring tides on Bare Sand Island for comparison with Western Australian stocks (Delambre Island);
- Examine the relationship between tidal phase and nesting turtle abundance;
- To determine if tidal anomalies (spring or neap tides) affect the abundance of Flatback turtles nesting on Bare Sand Island;
- Assess the correlation between sky brightness and timing of turtle emergence;
- To test the superiority of tides over darkness in initiating flatback turtle nesting.

2. Methods

2.1 Study site

The study was undertaken at Bare Sand Island (12º32.4´S, 130º25.0´E) in Fog Bay, Northern Territory, Australia, in June and July 2018. Bare Sand Island (BSI) is located ~50km west of Darwin, Northern Territory and is approximately 1.8km in circumference (Fig 1). The island is situated toward the end of a chain of eight islands collectively known as the Quail Island Group and sits upon rocky reef. Sparse vegetation consists of low-lying shrubs and grasses and one singular tree. The western side of the island, and longest stretch of beach faces the Timor Sea, while the eastern side faces Quail Island and Little Wooded Islands (Fig 2). The western-facing beach is comprised of fine sand with gentle slope toward the dunal system, while steeper dunes, a narrower stretch of beach, coarser sand and a rocky intertidal zone characterise the eastern side. The islands beaches are split into sectors for monitoring and data collection purposes (Fig 2).

Figure 1. Location of Bare Sand Island, Northern Territory. Bottom right-hand side inset: location within Australia (Googlemaps 2018).

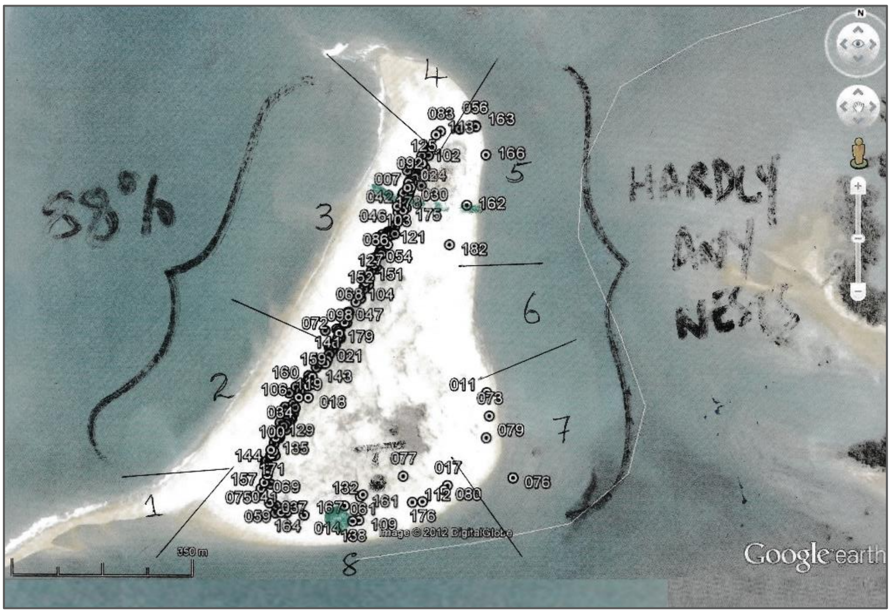

Figure 2. Locations of sectors on Bare Sand Island, Northern Territory. Note: location of nest sites from 2003 nest analysis where 88% of successful nests were in sectors 2 and 3 (Guinea M).

2.2 Survey methodology

2.2.1 Nesting abundance

Surveys were conducted throughout June and July 2018 for seven weeks. Monitoring aimed to capture data from the peak nesting season on BSI. Nightly surveys were conducted two hours either side of the evening high tide, and twice if the high tides coincided with early afternoon and early morning. The time a turtle was encountered was noted in 24-hour time and remained at the same date for that night; i.e. if a turtle was on the beach at 0100 on the 2nd of July, it would be recorded for 0100 on the 1st July.

Biometric data was collected from all nesting turtles and included; curved carapace length (CCL), curved carapace width (CCW), nest and egg temperature (ºC). Activity undertaken, disturbance (if any) and presence of any barnacles or damage to the turtle were recorded. The location of a successful nest was recorded using a GPS (Garmin) and the beach morphology and vegetation was observed (Fig. 12; see appendix). A successful nest was defined as a nesting attempt that resulted in the deposition of eggs. Analysis for this report was restricted to nesting abundance.

2.2.2 Tag series data

T, K, and QA titanium tags were issued from the Queensland Government for use on BSI turtle populations. Successively numbered tags were applied for first-time nesters or re-applied for recurring turtles who had lost tags. Tagging aimed to minimise disturbance of nesting turtles by being undertaken after deposition of eggs or when returning to the water.

2.2.3 Sky glow and brightness measures

A Unihedron Skyglow Quality Meter was used to measure sky brightness at the time of high tide every night from the same location (sector 2/3 marker, mid-beach) (Fig 2). Readings were taken in magnitudes arcseconds^2, a logarithmic measurement which were converted to cd/m^2 for analysis. Magnitudes are defined to be a factor of 100(1/5) in received photons. Cloud cover interference was observed and documented if applicable.

2.2.4 Vulgar establishment data

Vulgar establishment was determined for Bare Sand Island and Delambre Island for comparison. Delambre Island (20º26´48.2´´S, 117º4´41.9´´E), situated in the Dampier Archipelago has been identified as an important nesting site for flatback turtles (Kregor, Stanley, Liddelow 2005; Morris 2004). Delambre Island is a nesting site for four species of sea turtle with a nesting season that extends from September – April with a peak abundance in December and January (Morris 2004; Guinea. M, personal communication 2018). This island was used as an index site to compare vulgar establishment with BSI over peak nesting periods to establish any synchrony among populations.

Tides were observed for Fish Reef (12°025'.0 S, 130°025'.0 E) which is the closest monitoring station to Bare Sand Island, while tide readings for Delambre Island were taken for the nearest monitoring station, Point Walcott (20°035'.0 S 117° 011'0 E). Moon set and moon rise times were observed via the Tides Planner (Imray 2018) application. Heavens Above (Peat 2018) was used for illumination (% cover of moon), and maximum altitude data for vulgar establishment analysis.

3. Results

3.1 Nesting abundance

3.1.1 *Total nesting abundance*

Flatback turtles nested 51 nights out of a total 54 nights monitored over June and July, with a mean 8.9 turtles per night. Largest frequencies occurred on nights directly before and after both new and full moon phases (Fig. 3, 4; Table 1). Missed turtles account for 3.2% of total turtles during June and July.

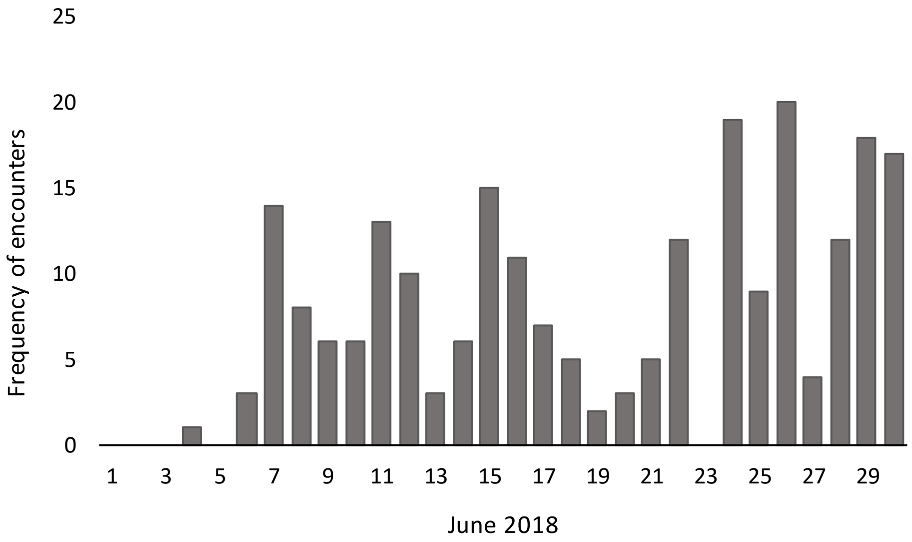

Figure 3. Frequency (*n* =122) of encounters of nesting *N. depressus* emerging during June 2018.

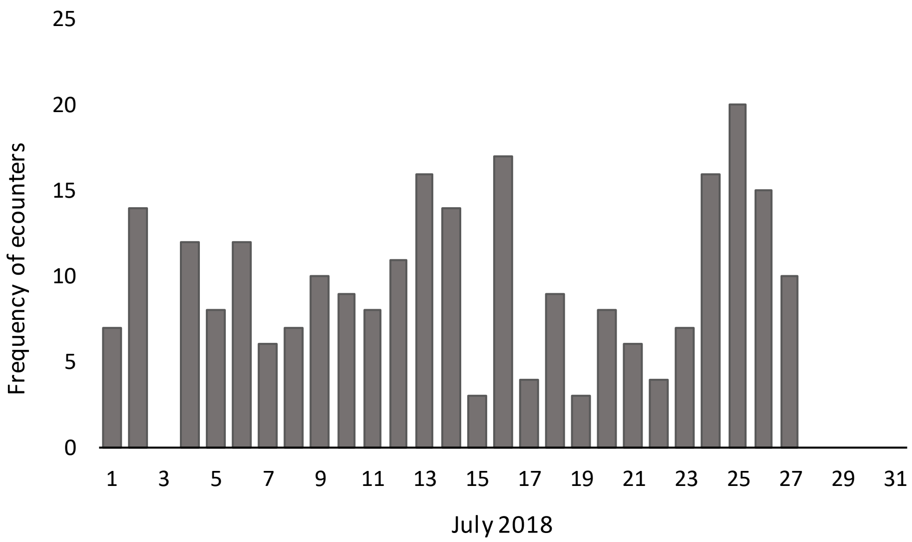

Figure 4. Frequency (*n* = 256) of encounters of nesting *N. depressus* emerging during July 2018.

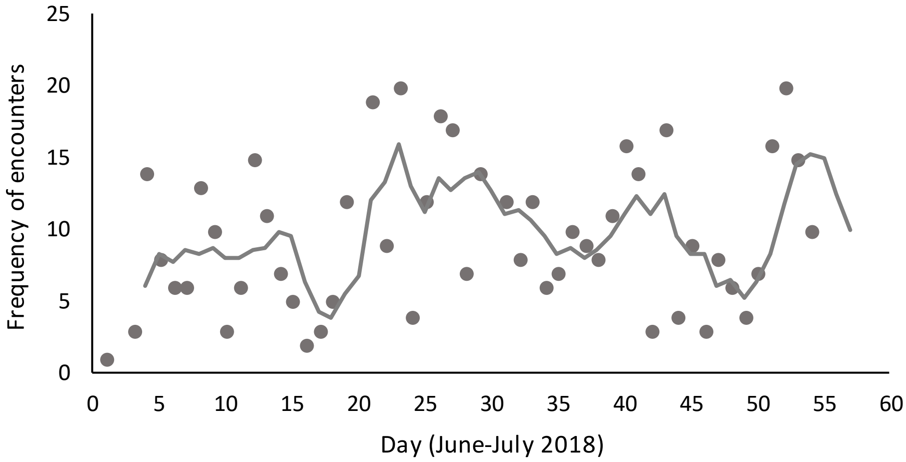

Figure 5. Number of daily nesting encounters over the seven-week peak nesting period, showing the four-point centred moving average for the season on Bare Sand Island.

Table 1. Lunar phase and date occurring for June and July 2018.

Month	Date	Moon phase
June	7	Third quarter
	14	New moon
	20	First quarter
	28	Full moon
July	6	Third quarter
	13	New moon
	20	First quarter
	28	Full moon

3.1.2 Time of nesting

Peak timing of nesting was between 1800 – 2200 hrs and accounted for 58.4% of the nesting activity. A second nesting peak, to a lesser extent, occurred between 0200 – 0500 hrs (21.1% of nesting activity) before decreasing again before dawn (Fig.6).

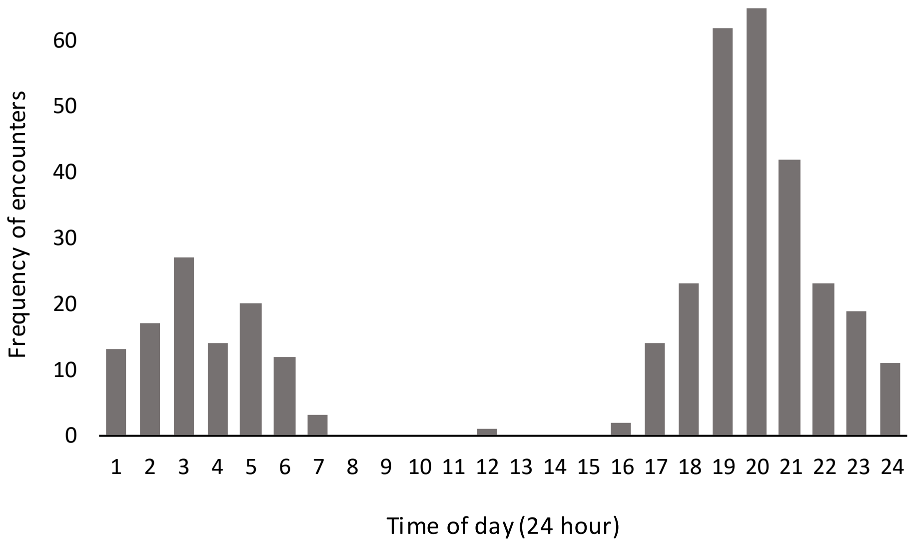

Figure 6. Frequency (n = 368) of encounters of nesting *N. depressus* emerging over a 24-hour period during June and July 2018.

3.2 Environmental cues

3.2.1 Tides

The tides on BSI throughout the season ranged from a minimum of 0.4 m to a maximum of 6.8 m. Nesting occurred predominately within two hours either side of the high tide, as 96.8% of turtles nesting were observed during the 4-hour monitoring period. The greatest number on turtles emerging to nest over both June and July were encountered on predominantly outgoing tides (Fig. 7, 8).

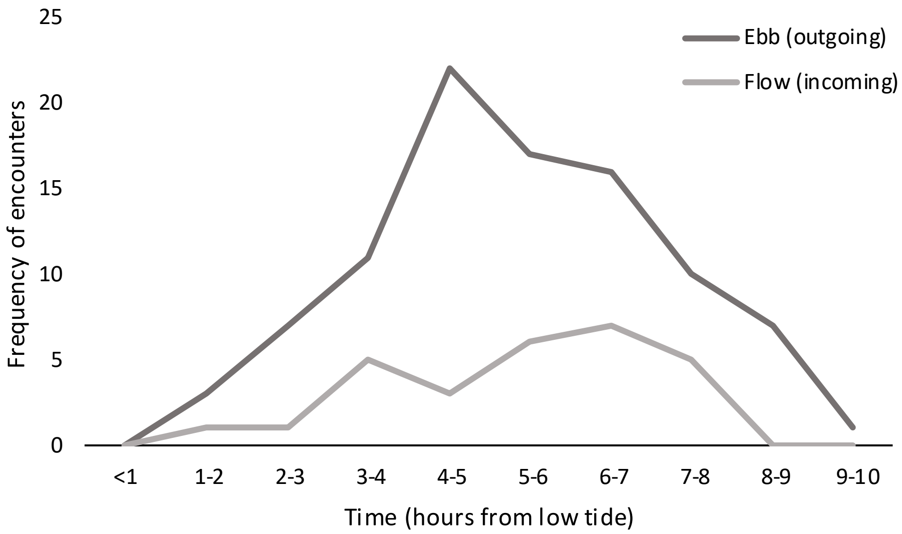

Figure 7. The time (hours from low tide) of nesting *N. depressus* emerging on ebb and flow tides on Bare Sand Island in June 2018.

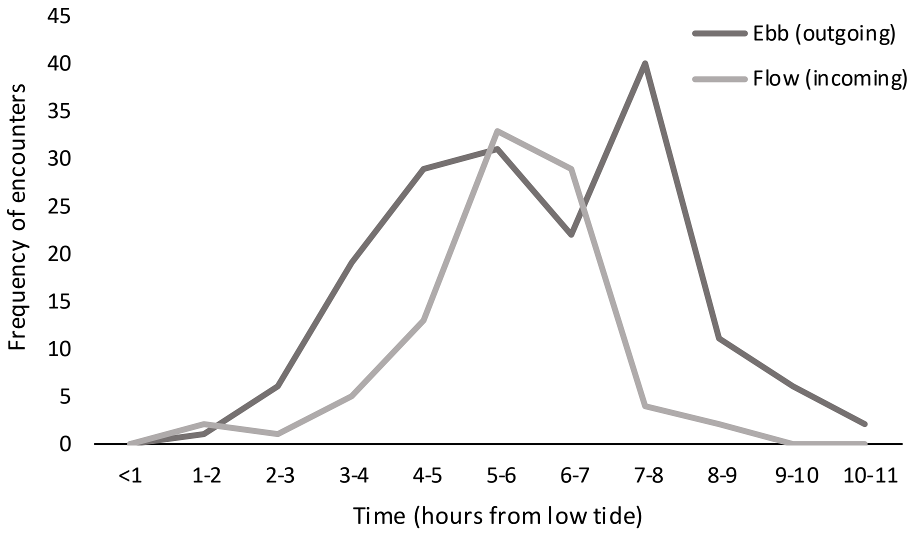

Figure 8. The time (hours from low tide) of nesting *N. depressus* emerging on ebb and flow tides on Bare Sand Island in July 2018.

3.2.2 Vulgar establishment

The high tide on Bare Sand Island follows the moon transit by 4 hours and 52 min (mean), 3 hrs, 29 min during neap tides and extends to 6 hours, 9 min during spring tides (Fig. 9; Table 2). During spring tides, the high tide coincides with sunset and when nesting begins to peak at ~1600-1700 hrs (Fig. 6).

In comparison, the high tide at Delambre Island follows the transit of the moon by 8 hours and 54 minutes (mean), with a 7 hr, 18 min and 10 hrs, 36 min during neap and spring tides respectively (Table 2). The spring tides here coincide with midnight, which also aligns with peak nesting time at this location, 2100 – 0100 hours.

Table 2. The mean, minimum and maximum vulgar establishment values for Bare Sand and Delambre Islands over one month during their respective peak season.

	Bare Sand Island, NT	**Delambre Island, WA**
Average	4 hrs, 52.2 m	8 hrs, 54 m
Minimum (June/November)	3 hrs, 29.4 m	7 hrs, 18 m
Maximum (June/November)	6 hrs, 9.6 m	10 hrs, 36.6 m

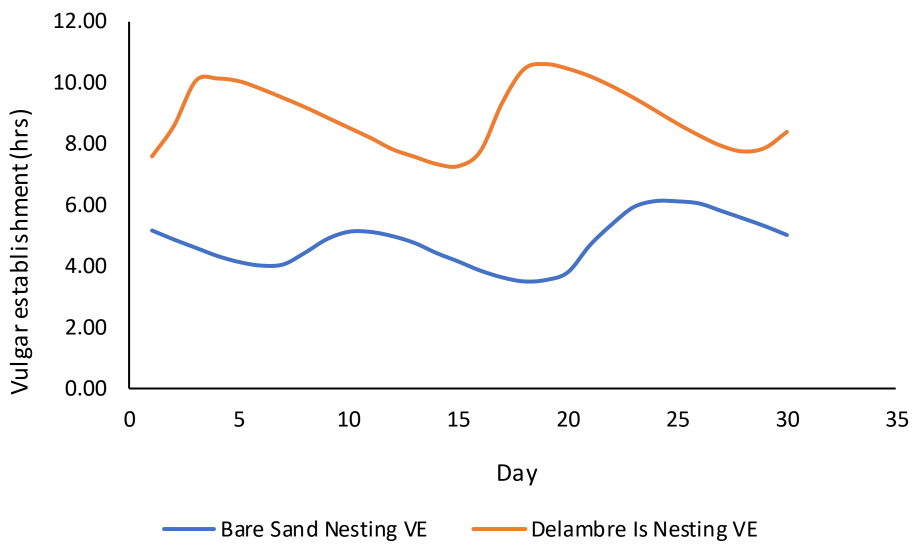

Figure 9. Vulgar establishment over one month during nesting season for Bare Sand Island and Delambre Island (Guinea M).

3.2.3 Sky brightness

Highest frequency of nesting attempts was recorded on nights with a decrease in illumination from moon coverage, but not on all occasions (Fig. 11). The peaks of nesting were around the 14th and 27th of each month, concurring with the new and full moon phases (Fig. 5; Fig. 10; Table 1). Average nests laid were higher around waxing and waning crescent and waning gibbous moon phases (Fig. 10).

Sky glow measurements taken for a two-week period from 16-28 July also show a decrease in turtles encountered when sky glow was brighter (0.006 cd/m^2) during the first quarter moon phase at high tide and increased during nights before the full moon when sky glow readings measured less brightness (~ 0.002. cd/m^2) (Fig. 11).

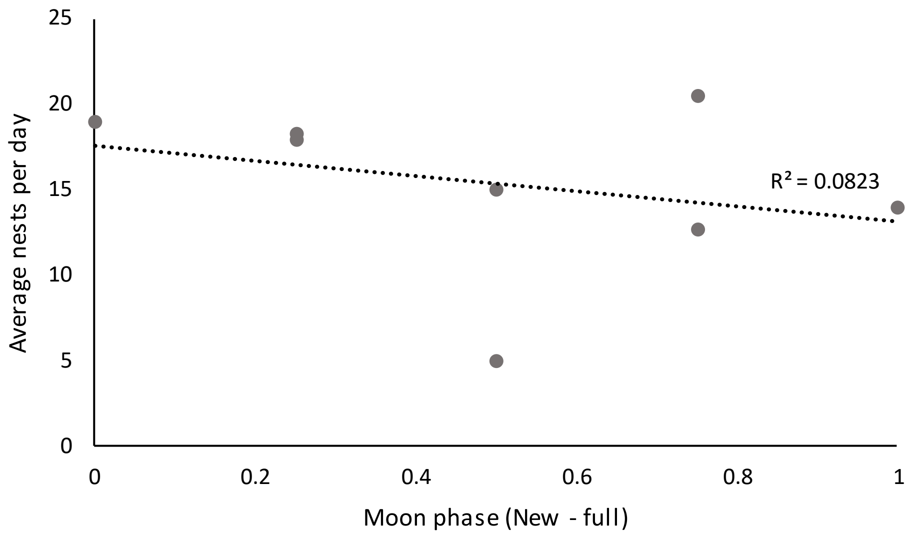

Figure 10. Average nests laid over the season associated with moon phase (0,0.25,0.5,0.75,1; new, waning and waxing crescent, first and third quarter, waning and waxing gibbous and full moon phase respectively).

Table 3. Moon phase and associated category.

First Quarter	0.5
Waxing crescent	0.25
New	0
Waning crescent	0.25
Third quarter	0.5
Waning gibbous	0.75
Full	1
Waxing gibbous	0.75

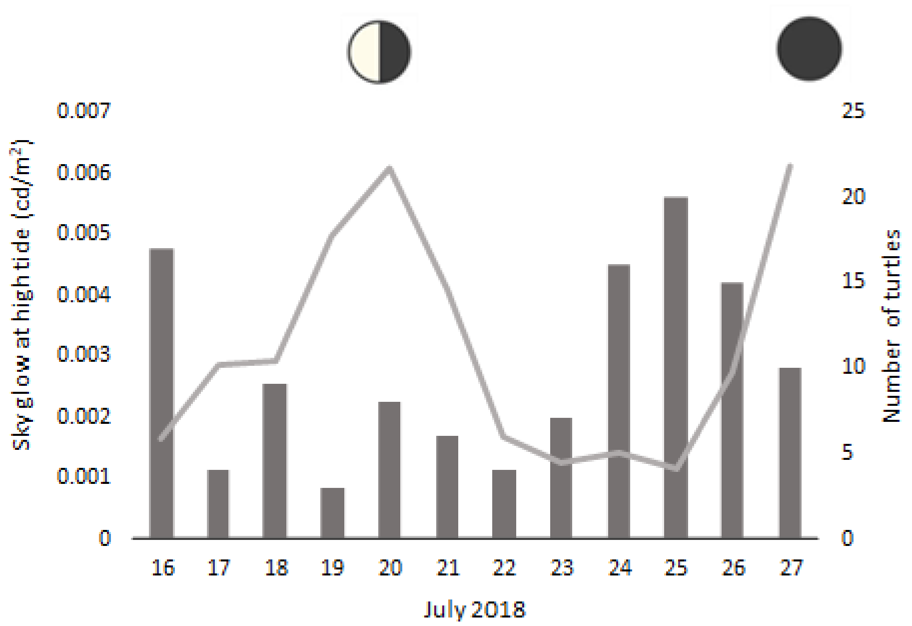

Figure 11. Sky glow (cd/m^2) at high tide and frequency of nesting *N. depressus* encountered between 16 and 27 July 2018 on Bare Sand Island with reference to moon phase. Full moon and lunar eclipse occurred July 27, 2018.

4. Discussion

4.1 Nesting abundance

4.1.1 Total nesting abundance

The nighty average of turtles (8.9 turtles per night) is high compared with neighbouring winter-nesting rookeries; with Cape Domett (mean 6.4-10.2 turtles per night) and Kakadu (mean 2.7-5.1 turtles per night) (Whiting *et al.* 2008). BSI displays an average nesting range in line with other rookeries in the same sub-population, including West Island, Greenhill Island and Field Island, all which experience, on average, ≤ 10 turtles per night (Groom *et al*. 2017). Majority of nests were located within sectors 1-3 on the western-facing beach, towards open ocean (Fig. 2). This is consistent with preferred beach type found by Pritchard *et al.* (1999), demonstrating that *N. depressus* favour large open beaches, on islands, or mainland where reef habitat can be avoided (Pritchard *et al*. 1999). Flatback turtles nesting on islands in the Dampier Archipelago are more common on islands open to deep water also (Morris 2004). The predominant sectors (1-3) characterised by western-facing, wide sloping beach, was also found to be favoured by flatback turtles on crab Island, Gulf of Carpentaria, where highest number of nesting attempts were observed on beaches with similar morphology (Leis 2009).

It was expected that for every night where there is an increase in nesting abundance, a peak will again occur again in ~14 - 19 days due to the inter-nesting period of *N. depressus.* This can be seen in total abundance figures where there are roughly 2 peaks within a month, coinciding with a new and full moon (Fig 5). As investigated by Whiting *et al*. (2013), seasonal length of the nesting period has a significant effect on the number of individuals captured for data collection for rookeries with longer seasons rather than a short season. BSI experiences a short peak nesting season, that to date, seems indicative of an annual pattern, meaning results collected primarily during peak season can be used as baseline data for successive years.

4.1.2 Time of nesting

The temporal distribution of peak nesting varies between rookeries, although, many studies suggest timing of nesting is influenced by tides rather than sky glow or brightness (Frazer 1983; Pike 2008). Walsh *et al*. (2009) found emergence events of nesting loggerhead turtles maintained a bimodal pattern, with an initial increase after dusk until 2300, with a second increase from 0100 hrs until dawn. This is consistent with findings from BSI, as a similar bimodal pattern occurred; with the major peak from 1800 – 2200 hrs (58.4% of nesting activity), and a second peak from 0200 hrs until just before dawn (0500 hrs) (21.1% of nesting activity) (Fig.6). On Delambre Island, the peak timing of nesting occurs between 2100 – 0100 hrs, giving a difference of approximately 3 hours lag time (Fig. 14; see appendix) (Guinea M 2017). Both periods extend up to 4 hours of nesting activity. Peak timing of nesting for populations on Crab Island was between 1200 – 2400 hr, with nesting after midnight uncommon. Nesting activity on Crab Island has been characterised by diurnal and nocturnal variation, with afternoon/daylight nesting occurring only if night high tides were unsuitable (Leis 2009).

Assumptions are made for times observed in this study, as time is taken from when an animal is first encountered on the beach, which may not be the initial time she emerged from the water. On the predominant nesting beach on BSI, it takes ~ 20 minutes for the turtle to emerge from the water and crawl up to where she will begin body pitting to nest (Guinea, personal communication 2018). The time point data collected may indicate the time when the turtle was depositing her eggs, rather than the time she emerged from the waterline. The time taken to crawl up the beach is also dependent on the tidal cycle and amplitude; high or low, and spring or neap. The effect of high and low tides have a limitation associated with them, in that the turtle will take a longer or shorter period of time to crawl up beach; thus creating the need to identify her at the water's edge immediately, or standardise the time an animal was encountered (if already laying) with an average amount of time taken to make her way up the beach (Whiting *et al*. 2013). The time taken for a turtle to crawl up the nesting beach has many factors associated with it; vegetation, sand composition, presence of debris and the age of the turtle. Also relevant to include as a factor, would be the stage the turtle is in, regarding her inter-nesting period, as those who are at the beginning of the season are likely to have more reserved energy than those laying their final clutch.

Monitoring and patrol coverage may explain the variability in time precision, and account for turtles missed, as several turtles began emerging at ≥2 hours prior to high tide in the last week of July.

4.2 Environmental cues

4.2.1 Tides

Bare Sand Island experiences semi-diurnal tidal activity, with a tidal range reaching up to 8 meters (AusTurtle Pty Ltd 2018). Flatback turtles nesting on BSI, come ashore in greater numbers at high tides, coinciding with spring tides. Peak flatback sea turtle nesting activity in Cape Lambert, WA, coincide with the time of high tide during spring tides also (Guinea 2017). In WA, the moon rises at low tide, while at Bare Sand Island the moon rises closer to high tide during spring tides.

Leis (2009) suggests that patterns observed on Crab Island indicate nesting abundance is influenced by tidal phase. Nesting emergences on Crab Island coincide with the high tide before midnight, aligning with the peak time being 1200 – 2400 (Leis 2009). An increase in nesting activity was observed during the two weeks prior to a spring tide when tidal heights were increasing, however numbers would decrease before the spring tide occurred (Leis 2009). Similarly, nesting hawksbill turtle populations on Milman Island in the northern Great Barrier Reef (nGBR) have been found to directly attempt peak nesting with high tides that occur before midnight also (Dobbs *et al*. 1999) Highest nesting numbers were recorded on days 2-3 days prior to neap tides, followed by a subsequent peak on the spring tide cycle (Leis 2009). Morris (2004) stated that nesting activity at Delambre Island and associated islands within the Dampier Archipelago appears to increase during neap tides, rather than spring tides, contrary to what is occurring on BSI with resonance with spring tides. (Fig. 5).

A study on nesting populations in the West Indies found no correlation between nesting activity of leatherback turtles and moon phase, nor nesting abundance and tides (Law *et al.* 2010). Leatherback turtles have been observed by Witt (2009) to increase in nesting numbers on days where a neap tide occurred, although conversely, the same species was also observed at an increased number on days when spring tides occurred in French Guiana (Law *et al.* 2010). Law *et al.* 2010 found in conjunction with spring tides, leatherback turtles had an increased emergence associated with a falling high tide, concurrent with findings from BSI (Fig. 7, 8).

Turtles nesting at high tide eliminate the need for a longer crawl up the beach, then what they would at low tide. Any increase in distance the turtle must undertake to suitable nesting habitat, the more vulnerable they are to predation, exhaustion and interference by anthropogenic impact and disturbance (Ekanayake *et al*. 2002; Law *et al*. 2010; Frazer 1983). Animal behaviour and activity has been linked to environmental synchronisation and suggests that natural rhythm stimulates the patterns and trends animals follow (McDowall 1969; Guinea, personal communication). In this case, it is likely sea turtles are influenced by tidal rhythm (diurnal, tidal and semilunar) to a greater degree than moonlight. Burney *et al*. (1990) stated that the moon light is not the influencing factor in initiating nesting, but rather the moons influence on the tides. This resonates with findings from BSI with the peak abundance of nests coinciding with high tides. New and full moon phase is seemingly the driving factor of nesting timing, rather than the brightness associated with the moon phase.

4.2.2 Vulgar establishment

Vulgar establishment dictates the average interval of time which occurs between the moons upper transit and the next subsequent high tide following the transit. The vulgar establishment data collected indicates that tides are superior in synchronising the timing of nesting for flatback turtles over sky brightness as higher numbers of turtles came up on high tide nights, regardless of sky glow. The tidal interval reinforced the peak abundance of nesting in BSI and Delambre Island locations. On Delambre Island, peak timing of nesting occurs between 2100 – 0100, resulting in a difference of approximately 3-4 hours lag time behind BSI populations. Both periods extend to 4 hours of nesting activity, which means the turtles are primarily following the high tide at both locations, eliminating the influence of moon light as a nesting cue (Fig. 9).

4.3 Management implications

4.3.1 Bare Sand Island management area

Integrated management of BSI is required to ensure the sacred site is upheld and ecological significance of the island remains, while allowing recreational use to occur. Disturbance of nesting sea turtles increase on weekends and during holiday periods with visitors accessing the island easily by boat and yacht. As flatback sea turtles came up on the beach nightly, regardless of moon phase, it would not be beneficial to tailor nightly patrols and monitoring survey effort to coincide with moon cycle. As noted during field work, it would be advantageous to increase survey hours on nights leading up to and days post spring tides on a new and full moon.

4.3.2 Limitations and future direction

A range of limitations were acknowledged prior to undertaking this study, as more were identified throughout the process. Inconsistent methods of data collection have been identified in numerous studies that focus on environmental factors influencing sea turtle nesting abundance (Burney *et al*. 1990; Whiting *et al.* 2013). Human error in data collection and inconsistent methods in dictating time of emergence is a factor in determining temporal patterns. Although data was collected over a short nesting period, at a singular location, this data provides additional baseline observations that can be used in conjunction with existing and emerging knowledge to aid in managing nesting areas under threat.

The results of this study looking at synchronisation of nesting to tides over moon phase, poses additional questions in what cues are sea turtles using to nest, associated with tides. It seems flatback sea turtles have a preferred beach morphology, looking at beach locations across studies, which potentially, could identify factors in nesting; can turtles hear beach rubble and coarser sand material when tides are higher (i.e. spring tides)? And, as wave dominated beaches face the open ocean, as found to be favoured nesting sites of *N. depressus,* are these factors also linked to nesting behaviour? Further research questions need to be developed with ongoing monitoring to provide insight into these emerging areas of animal behaviour in sea turtles.

5. Conclusion

The influence of the moon as an environmental cue in initiating sea turtle nesting is indicative through the tides; not sky glow or brightness associated with phases. Irrespective of brightness, greater numbers of nesting *N. depressus* were observed 1 to 2 days prior and post spring tides on a new and full moon phase. Findings were consistent when compared with nesting patterns from a flatback rookery on Delambre Island, WA, however additional investigation is required to understand the influence of the tidal regime and synchrony of populations.

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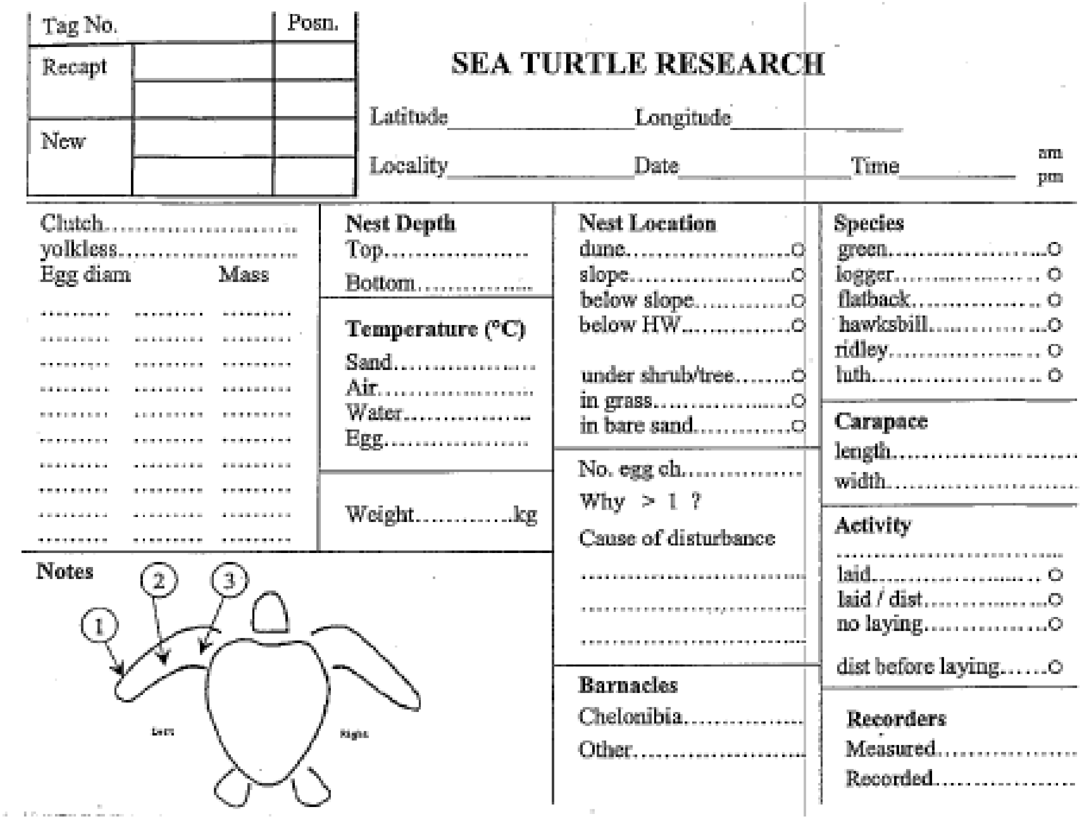
7. Appendix



Tag No. | Posn.
Recapt
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SEA TURTLE RESEARCH

Latitude ______ Longitude ______

Locality ______ Date ______ Time ______ am pm

Clutch……………………
yolkless……………………
Egg diam Mass

Nest Depth
Top………………
Bottom……………

Temperature (°C)
Sand………………
Air………………
Water………………
Egg………………

Weight…………kg

Nest Location
dune……………O
slope……………O
below slope……………O
below HW……………O
under shrub/tree……O
in grass……………O
in bare sand……………O

No. egg ch……………
Why > 1 ?
Cause of disturbance

Barnacles
Chelonibia……………
Other……………

Species
green……………O
logger……………O
flatback……………O
hawksbill……………O
ridley……………O
luth……………O

Carapace
length……………
width……………

Activity
laid……………O
laid / dist……………O
no laying……………O
dist before laying……O

Recorders
Measured……………
Recorded……………

Notes

Figure 12. AusTurtle Sea turtle research data sheet for use on Bare Sand Island, Northern Territory, Australia.

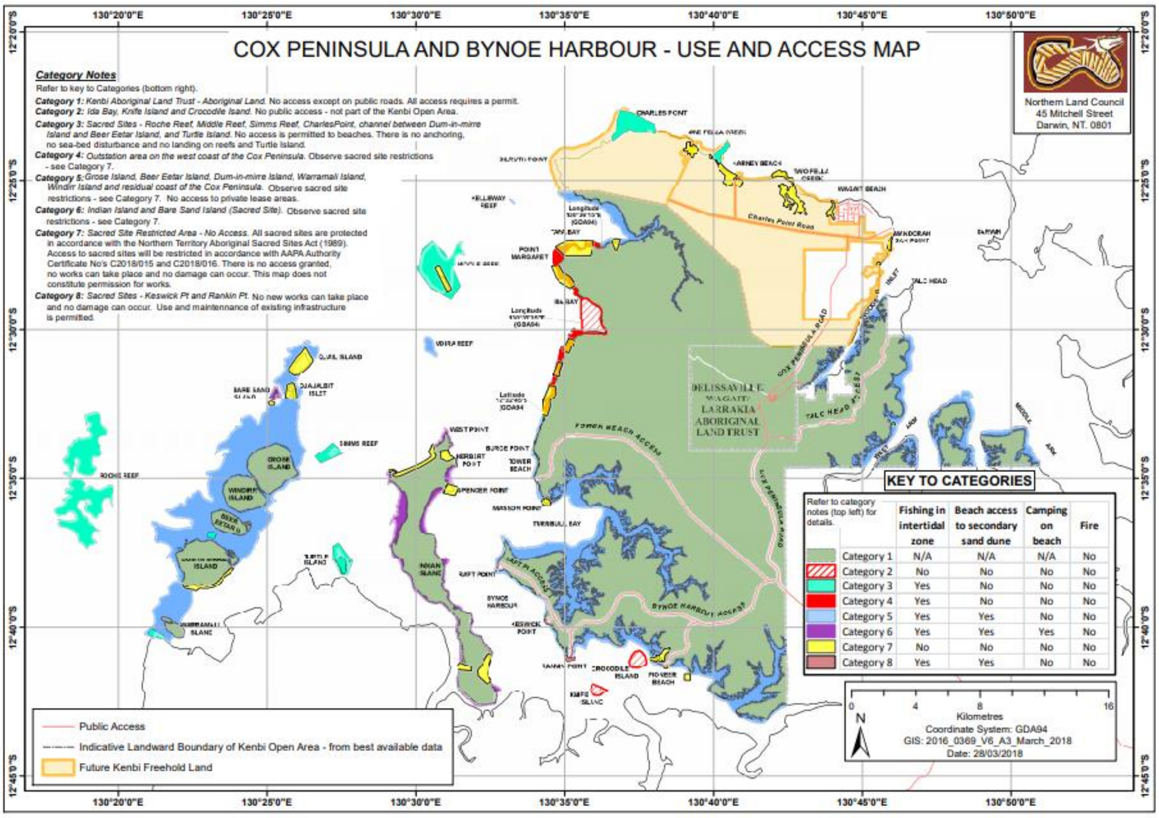

Figure 13. Cox Peninsula and Bynoe Harbour access areas under the Kenbi Open Area Declaration. Bare Sand Island is listed as a category 6 area; *Sacred Site Restricted Area* (See category 7 restrictions; below).

Category 7: All sacred sites are protected Sacred Site Restricted Area - No Access. in accordance with the Northern Territory Aboriginal Sacred Sites Act (1989). Access to sacred sites will be restricted in accordance with AAPA Authority Certificate No's C2018/015 and C2018/016. There is no access granted, no works can take place and no damage can occur. This map does not constitute permission for works (Northern Land Council 2018).

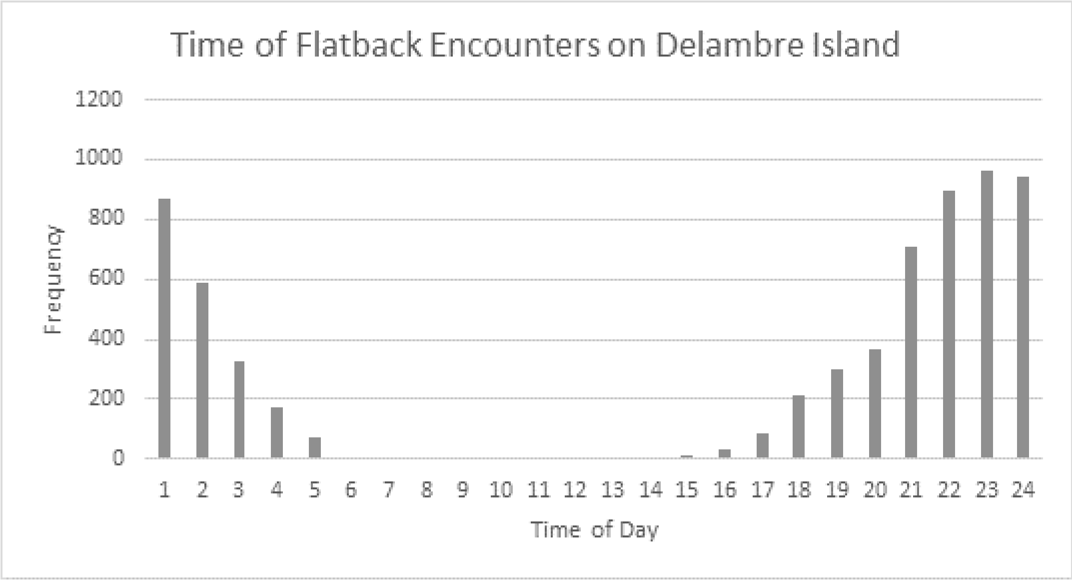

Figure 14. Frequency of encounters of nesting flatback turtles in the 24-hour cycle on Delembre Island, WA (Taken from; Guinea. M. (2017). Rio Tinto Cape Lambert Port B – Ecosystems research monitoring plan, Project 4A. [Unpublished]).