Biological Conservation 236 (2019) 571–579

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

High predation of marine turtle hatchlings near a coastal jetty

Phillipa Wilson[a,b,*], Michele Thums[b], Charitha Pattiaratchi[a], Scott Whiting[c], Kellie Pendoley[d], Luciana C. Ferreira[b], Mark Meekan[b]

[a] *Oceans Graduate School and the UWA Oceans Institute, The University of Western Australia, 35 Stirling Highway, Perth, Western Australia 6009, Australia*
[b] *Australian Institute of Marine Science, Indian Ocean Marine Research Centre, The University of Western Australia (M096), 35 Stirling Highway, Perth, Western Australia 6009, Australia*
[c] *Marine Science Program, Department of Biodiversity, Conservation and Attractions, 17 Dick Perry Avenue, Kensington, Western Australia 6151, Australia*
[d] *Pendoley Environmental, 12A Pitt Way, Booragoon, Western Australia 6154, Australia*

ARTICLE INFO

Keywords:
Acoustic telemetry
Natator depressus
In-water movement
Light pollution
Coastal development
Predator-prey

ABSTRACT

Growing human populations are driving the development of coastal infrastructure such as port facilities. Here, we used passive acoustic telemetry to examine the effects of a jetty and artificial light on the rates of predation of flatback turtle (*Natator depressus*) hatchlings as they disperse through nearshore waters. When released near a jetty, around 70% of the tagged hatchlings were predated before they could transit the nearshore, irrespective of the presence or absence of artificial light. Only 3 to 23% of hatchlings encountered predators at a second study site nearby where there was no jetty and a similar amount of nesting activity. Evidence for predation was provided by rapid tag detachment due to prey handling by a predator or the extensive movement of the tags within the receiver array suggesting that the tag (and hatchling) was inside the stomach of a predator. We found that 70% of the fish predators that consumed tags used the jetty as a refuge during the day and expanded their range along nearshore waters at night, predating on hatchlings in areas adjacent to the jetty with the highest nesting density. Sampling of potential predators including lutjanid reef fishes under the jetty revealed the presence of turtle hatchlings in their gut contents. By providing daytime refuges for predators, nearshore structures such as jetties have the potential to concentrate predators and they may pose a significant threat to populations of vulnerable species. Such effects must be taken into consideration when assessing the environmental impacts associated with these structures.

1. Introduction

In all ecosystems, predation is a key process that drives the dynamics of populations and structures communities (Estes, 1996; Preisser et al., 2005). Similar to many marine organisms, the life history stage in marine turtles immediately following hatching is likely to be the most vulnerable to predators (Heithaus, 2013). After successfully traversing the nesting beach, hatchling turtles enter nearshore waters where rates of predation within the first hour are thought to be high (Stancyk, 1982). However, relatively few studies have measured predation during this time and those that have done so have typically been confounded by the presence of an observer. In the past, the size of available tags relative to the small size of hatchlings has prevented passive tracking, so that most studies have used active tracking techniques where hatchlings have been followed by a snorkeler or observer on a small vessel (dinghy or kayak) (Frick, 1976; Witherington and Salmon, 1992; Gyuris, 1994; Pilcher et al., 2000; Stewart and Wyneken, 2004; Whelan and Wyneken, 2007). Most of these studies have reported levels of mortality below 10%, with some exceptions (e.g. Gyuris, 1994; Pilcher et al., 2000 and Reising et al., 2015). However, the presence of an observer (and a vessel) is likely to influence both the process of predation (Frick, 1976; Nowak et al., 2014) and also the behaviour of the turtle (Hendrickson, 1958). Given their relative sizes, predators such as reef fishes are likely to be very wary of the boat or snorkeler following the hatchling (Milinski, 1986). Indeed, some species have been reported to retreat or drop hatchlings when approached by a snorkeler (Frick, 1976). For these reasons, it is possible that active tracking may underestimate levels of hatchling predation in

---

* Corresponding author at: Oceans Graduate School and the UWA Oceans Institute, The University of Western Australia, 35 Stirling Highway, Perth, Western Australia 6009, Australia.

E-mail addresses: phillipa.wilson@research.uwa.edu.au (P. Wilson), m.thums@aims.gov.au (M. Thums), chari.pattiaratchi@uwa.edu.au (C. Pattiaratchi), scott.whiting@dbca.wa.gov.au (S. Whiting), kellie.pendoley@penv.com.au (K. Pendoley), l.ferreira@aims.gov.au (L.C. Ferreira), m.meekan@aims.gov.au (M. Meekan).

https://doi.org/10.1016/j.biocon.2019.04.015
Received 19 December 2018; Received in revised form 13 March 2019; Accepted 18 April 2019

the nearshore.

The recent development of small acoustic tags combined with passive acoustic receiver arrays has now enabled the remote study of the movement patterns of turtle hatchlings as they disperse through the nearshore (Thums et al., 2013; Thums et al., 2016; Wilson et al., 2018). Research using this technology has shown that within 300 m of the shoreline, turtle hatchlings take a fast, directed path offshore, transiting these waters in about 10 to 15 min. Importantly, tracks that do not follow these characteristic offshore routes, but in contrast linger and frequently change in direction, speed and tortuosity of movement, can provide evidence of consumption of tagged hatchlings by predators (Thums et al., 2016). Additionally, tags that cease movement can also represent predation where the tag is removed during prey handling by a predator (Khan et al., 2016). Thus, tracking hatchlings in a receiver array can monitor the movement of both hatchlings and their predators and allow for the calculation of predation rates, which are key questions in the movement ecology of marine megafauna (Hays et al., 2016).

Earlier studies have shown that hatchlings are predated more frequently in the nearshore when close to, or crossing, reef habitat (Frick, 1976; Witherington and Salmon, 1992; Gyuris, 1994; Pilcher et al., 2000), whereas predation tends to be lower when hatchlings cross areas of sand (Stewart and Wyneken, 2004; Whelan and Wyneken, 2007). This implies that rates of predation may be highest where benthic habitats provide refuges for fish. Given that man-made structures such as jetties, wharves, offshore platforms and pipelines are also known to support and attract large numbers of fish (Bohnsack, 1989; Rilov and Benayahu, 2000; Claisse et al., 2014; McLean et al., 2017), it seems possible that these could also increase predation rates on turtle hatchlings. Additionally, for navigation and/or operations during the night, these structures are often required to be lit, which can also attract large-bodied predatory fish (Becker et al., 2013). This could further increase predation rates on hatchlings as they are also attracted towards light sources at night (Thums et al., 2016; Wilson et al., 2018).

Here, we investigate the impacts of a jetty with artificial lights on the predation and nearshore movements of hatchlings of the endemic flatback turtle, *Natator depressus*, in northern Australia. Light pollution and the development of coastal infrastructure such as jetties and port facilities are recognised as primary threats to marine turtles around the world (Wallace et al., 2011). Several large rookeries of the flatback turtle are located close to industrial developments (Kamrowski et al., 2014) where large jetties have been built for the shipping of mineral and petroleum resources (Drenth, 2007; Department of Environment and Energy, 2017). Consequently, the possibility that these structures are attracting hatchlings (due to lighting) and fish (due to cover) and increasing hatchling predation rates, remains an unresolved and concerning question for the global management of turtle populations. We used acoustic tags and passive receiver arrays to document in-water predation on turtle hatchlings at differing distances from a jetty and in the presence and absence of artificial light. We hypothesised that predation rates would be higher closer to the jetty as it would provide cover for fish predators and that the attraction of hatchlings to lights on the jetty might increase this phenomenon. We also hypothesised that the attraction of hatchlings to light might decline with distance from the light source.

2. Materials and methods

2.1. Study site

The study was conducted on the south-eastern side of Thevenard Island (21.456°S, 115.002°E), approximately 30 km offshore from the town of Onslow, Western Australia (Fig. 1) where a flatback turtle nesting beach is located. Limestone reefs surround the island and beaches provide nesting habitat for green (*Chelonia mydas*), flatback (*N. depressus*) and hawksbill (*Eretmochelys imbricata*) turtles. We made use of a 90 m-long open pile jetty (constructed in 1991), that forms part of a recently decommissioned oil production facility. We deployed amber filtered light-emitting diode (LED) light fixtures as a proxy for the decommissioned high pressure sodium lights. The original lights varied in intensity (70-watt and 250-watt) (K. Pendoley pers. comm) so we replicated this where possible by adding 6 × 50 watt, 1 × 70 watt, 2 × 100 watt and 1 × 120 watt amber filtered white LEDs to the structure.

2.2. Hatchling capture

Flatback hatchlings were obtained from the nesting beach east of the jetty for use in the tracking study (Fig. 1). The beach was monitored at night for evidence of newly emerged hatchlings or a cone-shaped depression in the sand, which indicates that hatchlings are about to emerge (Witherington and Salmon, 1992). When tracks were found, they were followed back to their nest and hatchlings were collected either as they emerged or from near the surface of the nest and placed in a cloth bag. They were transferred to an insulated box and kept in a dark, quiet room at ambient temperature until later that night or the following night before being tagged and released as part of the experiment. Hatchlings detained overnight were left undisturbed to avoid stimulating group activity. Straight carapace length (SCL), width (SCW) (± 0.1 cm) and body mass (± 0.1 g) of each hatchling were measured using digital calipers and a digital scale.

2.3. Acoustic tracking

Hatchlings were tracked using uniquely coded acoustic tags (Vemco V5: 180 kHz, 0.65 g in air, 0.38 g in water, 12.7 mm long, 4.3 mm diameter with a 5–10 s transmission rate). Tags were positioned vertically with the transducer pointing down (Thums et al., 2016) and attached to the underside of hatchlings using a small drop of fast-acting epoxy (Selleys Araldite 5 Minute or 90 Seconds Adhesive) (Fig. 1) and allowed to cure until it was firm (~10 mins). The transmitters weighed 2% (weight in air) of the mean (± SD) weight (32.9 ± 4.1 g) of hatchlings.

Three arrays of 12 (4 × 3) omnidirectional acoustic receivers (Vemco VR2W) were deployed on the sea floor to calculate geographic positions of hatchlings instrumented with tags as they moved through the nearshore zone; one over bare sand centred 400 m from the jetty, one over reef habitat centred 200 m from the jetty and one over sand containing numerous concrete piles centred at the jetty (0 m) (Fig. 1). Acoustic receivers were spaced 30 m apart, with the first line beginning approximately 20 m from the shore (Fig. 1). The spacing of receivers was determined so they had overlapping detection ranges which allowed the calculation of each hatchling's geographic positions as they swam through the array (Appendix A). To determine the influence of potentially variable oceanography on hatchling movement, an Acoustic Doppler Current Profiler (ADCP, Teledyne RD Instrument) was deployed in the nearshore to measure current speed and direction, wave period, height and direction, water temperature and depth (black cross, Fig. 1). The current speed and direction, water depth and temperature was measured every 2 min (1 min mean sampling at 1 Hz). The directional waves were measured every hour based on 20 min burst sampling at 2 Hz. We obtained data on wind speed and direction at Onslow airport (recorded every minute) from The Bureau of Meteorology (www.bom.gov.au).

Hatchlings were tracked over 3 consecutive nights around the new moon, following moon set on the 26th February 2017 after 23:00 Australian Western Standard Time (AWST = GMT +8), on the ebb tide each night (Table A.1). The timing of experiments was dictated by having complete darkness, adequate water depth, and consistent tide conditions, and also being within the timeframe when flatback hatchlings usually emerge from their nests (Limpus, 1971) and within the peak hatching season for this site (S. Whiting pers. comm). High

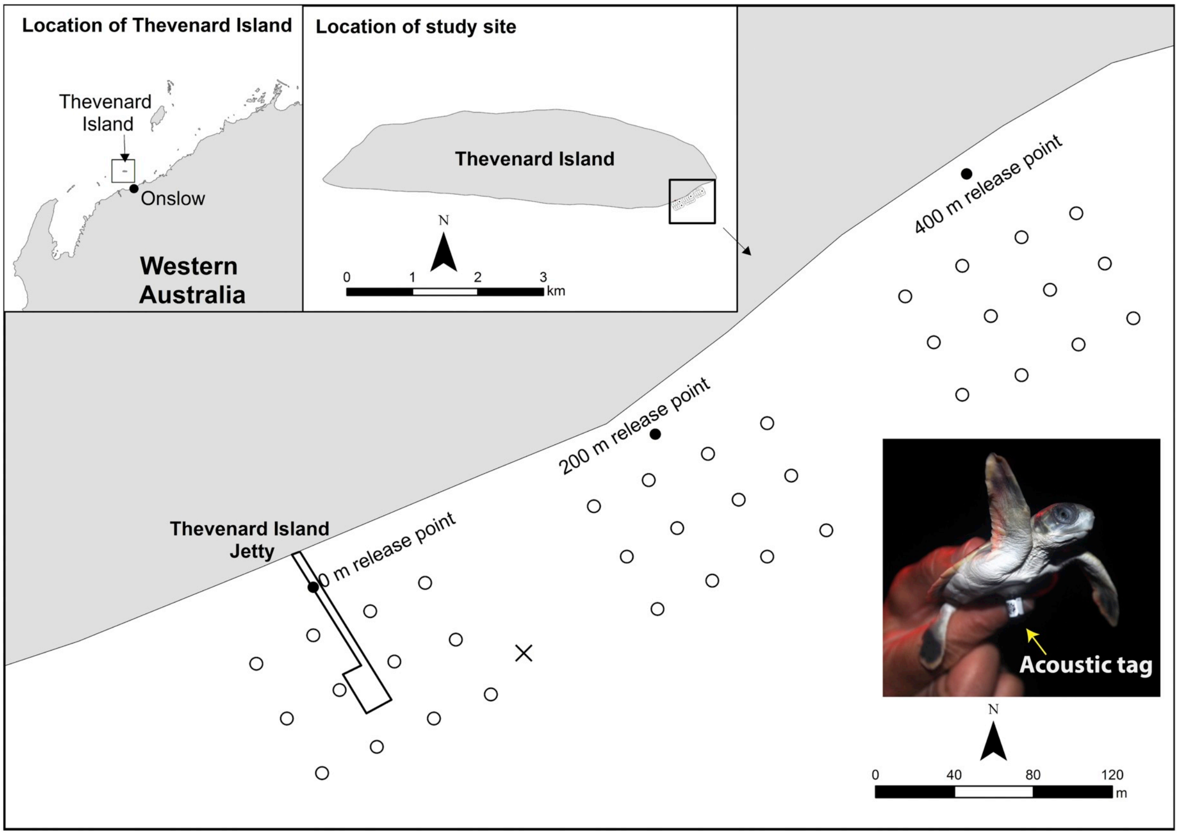

Fig. 1. The acoustic tracking array design used to track hatchlings in nearshore waters off Thevenard Island in Western Australia, with the open circles representing receivers (30 m apart), each with a co-located synctag to synchronize the internal clocks of the receivers. Position of the Acoustic Doppler Current Profiler (to measure current and wave parameters) is shown as a black cross. Experimental lights were located on the jetty (outlined in black) facing northeast. The beach is shown in grey and the hatchling release points at the 3 locations as black circles. Image: a flatback turtle hatchling with a Vemco V5 acoustic tag attached.

water occurred at 23:22 (2.48 m), 00:01 (2.56 m), and 00:37 (2.58 m) AWST respectively, over the 3 nights. Hatchlings were released with the jetty lights turned on and under ambient conditions (lights off) each night, at each of the 3 distances (0, 200, 400 m) from the jetty (Fig. 1). A total of 10 hatchlings (n = 3–4 per night) were released at each of the distances in each light treatment across the 3 nights (with the exception of the 0 m release point where 11 were released) (Table A.1). All hatchlings were released in the water at ~0.5 m depth on the ebb tide and they were held just below the water surface for a few seconds to invoke the swimming response prior to release. They were not given the opportunity to crawl to the water as the position of the tag prevented terrestrial locomotion. In any event, a beach crawl is not a prerequisite for orientation at sea in other species of turtle (Lohmann et al., 1990).

For each treatment (lights on or off) and at each distance (0, 200 and 400 m), 2 pairs (or 1 pair and 1 individual when only 3 were released) of tagged hatchlings were released every 10 min into the array and tracked for up to 80 min, giving those hatchlings released at 50 min a maximum of 30 min to swim through the array before switching treatments (Wilson et al., 2018) (Fig. 1, Table A.1). The order of the treatments (lights on/off) was randomised each night, however if we started with lights on we waited an hour after the last pair was released, giving those hatchlings released at 50 min a maximum of 60 min to swim through the array before switching the lights off.

Prior to the passive acoustic tracking, hatchlings instrumented and un-instrumented with dummy acoustic tags (identical size and shape to the V5 tags) were followed by kayak during the day to test if carrying the tag affected swimming ability (in 2016) and to test for any difference in the adherence of the tag to the hatchlings between the two glue types (in 2017) (Appendix B).

2.4. Data analysis

Acoustic receivers were recovered and downloaded the day after the last experiment and data was sent to Vemco for calculation of geographic positions of hatchlings as they swam through the array. The movement patterns of tags over time were assessed to allocate each tag to one of 3 categories (attached, detached, ingested). Hatchling tracks were assigned to the category 'attached' (tag still attached) if the movement patterns were as expected for a hatchling swimming away from a beach, i.e. turtles moved offshore or towards the jetty lights in a relatively fast and directed manner and after approximately 10 to 15 min their tags were never heard from again as they left the array on their way to deeper waters (Thums et al., 2016; Wilson et al., 2018). Unexpected movement patterns (categories 'detached' or ingested') were considered to be the result of predation and were firstly characterised by the tags remaining within the array for much longer than the expected 10 to 15 mins of a turtle hatchling. Movement patterns from tags 'ingested' by predators were unlike those expected of hatchlings swimming away from a beach. These tracks showed extensive longshore movements over multiple hours, indicating that the tag was no longer attached to a turtle, but the tag and turtle were now inside the stomach of a predator. Tags that 'detached' from a turtle inside the array were indicated by 100 s or 1000s of clustered detections that were mostly heard on a small (1–4) number of receivers, or multiple positions in the same location or detections over an extended period of time.

2.5. Attraction to jetty lights

Tracks of tags assigned to the category 'attached' were used to calculate how many hatchlings were attracted to the jetty lights from each of the three locations (0, 200, 400 m from the jetty) by counting the number of individuals that moved towards the jetty.

2.6. Predation rates and predator identification

The proportion of hatchlings consumed by predators in each light (on and off) and distance (0, 200 and 400 m) treatment was calculated by dividing the total number of turtles released in each treatment by the number of tags assigned to 'detached' and 'ingested' categories. Whether or not the hatchling was predated (0 = survived, 1 = predated) was then used as a response variable in a suite of generalised additive mixed models (GAMMs) with a binomial error distribution to examine the relationship with light treatment (categorical: on, off), distance from the jetty (categorical: 0, 200, 400 m), length of holding time (categorical: 0 or 1 day), nest (categorical: 1 to 5) and the continuous variables SCW, SCL and body mass (Table A.1). The *gamm* function in the *mgcv* library (Wood, 2017) in R (R Core Team, 2015) was used to fit models using a function developed by Fisher et al. (2018). The maximum number of predictors to include in any one model was restricted to 1 due to the low sample sizes across all the predictor variables. All continuous predictors were modelled as smooths, using a cubic regression spline, with k restricted to 5 to reduce overfitting. Model selection was then achieved by ranking each model using the AIC_c, and their relative model weight, the AIC_c weight ($wAIC_c$). For all models, night was included as a random effect to account for non-independence of observations across the three experimental nights.

Unbaited remote underwater videos (RUVs) were deployed under the jetty during the day to compile a species list and to calculate the relative abundance of the potential predators in the study area (Cappo et al., 2003). They were constructed of a metal frame equipped with GoPro Hero cameras within waterproof housings. Each RUV was equipped with a white light dive torch (Tovatec Fusion 530) in an attempt to aid visibility under the jetty. The light was attached at the top and in the middle of the RUV frame. Six, one-hour video samples were collected during the day, over 2 days, with deployment locations randomised under the jetty. Videos were analysed using EventMeasure software (www.seagis.com.au). For each video, fish were identified to species where possible using field identification guides (Allen, 2009; Allen et al., 2015) and online sources, the Atlas of Living Australia (www.ala.org.au) and Fishes of Australia (www.fishesofaustralia.net.au). The maximum number of fish for each species observed at the same time (MaxN) was recorded as a measure of relative abundance (Cappo et al., 2003). On one occasion after the experiment, fish remains (two individuals; mangrove jack *Lutjanus argentimaculatus*) caught by recreational fishers at the jetty were inspected for evidence of turtle hatchlings in their stomach contents.

2.7. Movement patterns of predators

Movement patterns of predators (category 'ingested') were assessed visually to determine if tags were expelled from the predator during the study period by plotting all tag positions over time. A tag was assumed expelled when it transitioned from being mobile to permanently stationary. Positions after the tag was expelled were not included in subsequent analyses.

To assess the patterns of space use of predators that ingested a turtle (and a tag), we calculated the 50% and 95% utilisation distributions (UD) of each individual during the day and at night separately over the entire study period, using the Biased Random Bridge Kernel method with a 5 m square grid implemented in the function *BRB* of the R package *adehabitatHR* (Calenge, 2015). Two smoothing parameters needed to be set: T_{max}, which assigns an upper limit for the time spent between consecutive positions so that steps longer than this are not included in the analysis to avoid unrealistic estimations of UDs (Benhamou, 2011); and hmin, which was calculated as the median value of the positional error associated with all positions from each predator. T_{max} was set to 100 min to account for when animals left the array for long periods and the time gap between consecutive days/nights for animals tracked over multiple calendar days. Sunrise and sunset times (obtained from Geosciences Australia) were used to assign positions to either day or night. In order to identify potential predator hotspots, the UDs for each tag were overlaid and the number of animals with overlapping UDs in each 5 m grid cell was counted (Thums et al., 2018). Principal component analysis (PCA) was also used to group these predators based on variables calculated from their position estimates including mean travel speed (distance divided by the time difference between successive positions), residency index (number of hours the predator was present divided by the number of hours the area was monitored), home range (50% UD) and distance travelled (standardised by the number of hours present) (see Appendix C for details).

2.8. Turtle nesting activity

Nesting activity of flatback, green and hawksbill turtles was monitored in the 2016/17 season by the Department of Biodiversity, Conservation and Attractions (Unpublished data, DBCA). Flatback turtle nesting on beaches adjacent to the study site and whole-of-island track counts (including false crawls, which are unsuccessful nesting attempts) of all three species were used to determine areas where nesting was concentrated, and thus the areas where hatchlings were likely to be most abundant. We calculated the 25% and 50% UD of nesting activity in a 5 m square grid using both the locations of successful flatback turtle nests adjacent to our study site and the locations of turtle tracks from all three species around the island perimeter. Kernel density was implemented using R packages *ks* (Duong, 2018) and *adehabitatHR* (Calenge, 2015). The *kde* function was used with an unconstrained plug-in selector for bandwidth that controls the smoothness of the kernel density around the location points and was estimated using the function *Hpi* (Duong, 2018).

3. Results

3.1. Environmental conditions during the study period

Ocean currents were tidally modulated and flowed to the west-southwest (mean (± SD) direction 249.0 ± 6.9°) during the study period with a mean speed of 0.13 ± 0.03 $m\,s^{-1}$ (Fig. A.1). Waves approached mainly from the east (median 104° bearing, ranging from 70 to 128°) with a mean height of 0.17 ± 0.07 m (Fig. A.1). Mean water depth during the experiment was 2.63 ± 0.11 m and water temperature was 30.34 ± 0.17 °C (Fig. A.1). Wind speed was higher on Night 1 (27.1 ± 6.3 $km\,h^{-1}$) than it was on the other nights (Night 2: 8.5 ± 3.4 $km\,h^{-1}$, Night 3: 12.2 ± 3.6 $km\,h^{-1}$). Across all nights, wind speed ranged from 0 to 57 $km\,h^{-1}$ (median of 13 $km\,h^{-1}$) and mostly approached from an easterly direction (Fig. A.1). Wind and wave direction turned more towards the east-southeast on Night 3. Median wave period was 2.15 s, but ranged from 1.5 to 3.1 s (Fig. A.1).

3.2. Acoustic tracking

Acoustic tags were attached to 61 hatchlings that were collected from a total of 5 nests (Table A.1). Hatchlings measured on average (mean ± SD) 59.7 ± 2.5 mm SCL, 47.6 ± 2.9 mm SCW, and weighed 32.9 ± 4.1 g (Table A.1). Acoustic detections were recorded from all tags (ranging from 34 to 14,522 detections). From these detections, geographic positions were calculated for the 61 tags as they moved through the array, resulting in 2 to 2687 positions for each tag (Dataset: https://apps.aims.gov.au/metadata/view/6a2eb0bb-feb8-4729-bfa0-610ec4222553). In addition, one tag attached to a flatback turtle hatchling released in an experiment conducted on the north-western

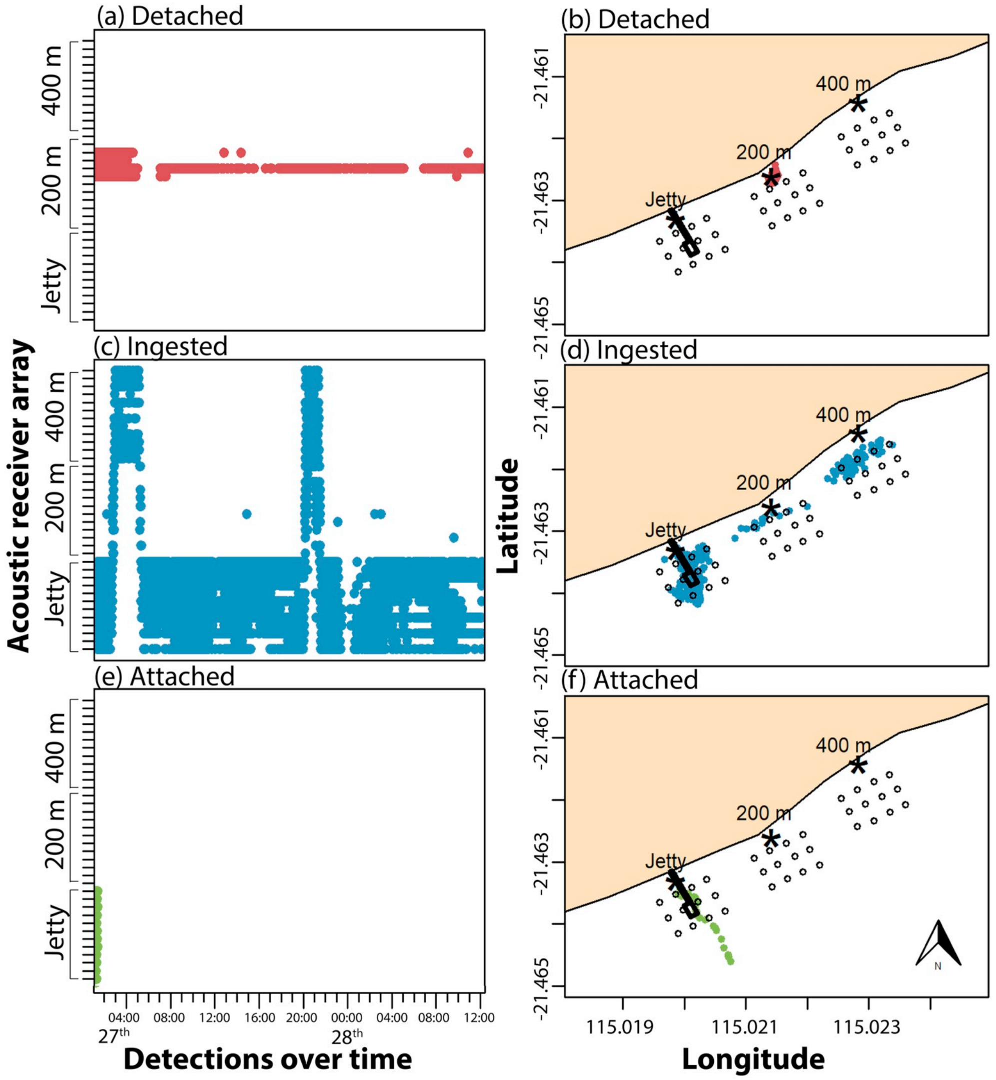

Fig. 2. Representative examples of acoustic detection patterns over a 35 h period (left panel) and the corresponding calculated positions (right panel) from one individual assigned to each category; 'detached' (a and b, tag knocked off during predator attack), 'ingested' (c and d, tag ingested by predator) and 'attached' (e and f, turtle that successfully transited the array). Left panel shows when each tag was detected on each of the 12 receivers (represented by the tick marks on the y-axis in a, c, e) at each array (jetty/0 m, reef/200 m, sand/400 m). Right panels show the calculated positions of these same individuals shown in the left panel with acoustic receivers shown as open circles and the hatchling release points shown by the asterix. The tags in each category were detected in the array for 3763 min (63 h) (a and b, 'detached'), 2089 min (35 h) (c and d, 'ingested') and 11.5 min (e and f, 'attached').

side of the island on the 20th February 2017 (Fig. A.2) was detected three days later in the study site on the south-eastern side of the island. The movement patterns of the tag suggested the turtle (and its tag) was consumed by a predator and as it was detected swimming through our study site during the experiment based at the jetty, it was included in the analysis of predator behaviour. A total of 1812 detections were recorded for this animal and resulted in 192 geographic positions.

3.3. Predation rates

Forty-four of the original 61 turtles (72% of tagged hatchlings) released in this experiment were assigned to categories ‘detached’ (21 or 34%) or ‘ingested’ (23 or 38%) (Fig. 2a-d, Table A.2). Of the 21 detached tags (Fig. 2a-b), 18 detached close to the point of release (within ~30 m) and the remaining 3 detached at distances up to 100 m away from the release point. The 23 ingested tags allowed us to track the movement of the hatchling predators (Fig. 2c-d). All of these predation events also occurred near the release point. The tag from the north-western side of the island was also included in the analysis of predator behaviour giving a sample size of 24 ‘ingested’ tags. Maximum time that the predators were located in the tracking area ranged in duration from 1.42 h to 72.13 h (study end).

The strongest predictor of hatchling predation was distance from the jetty ($w\mathrm{AIC_c} = 0.99$), with this model explaining 24% of the deviance and there was no evidence to suggest that predation rates were influenced by the other predictors; presence of artificial light, length of holding time, or hatchling size (Table A.3). Predation events (detached and ingested tags) were highest at the 200 and 400 m arrays and lowest at the jetty, with predation events occurring in 95% of the 20 hatchlings released at the 200 m array (reef habitat), 80% of the 20 hatchlings released at the 400 m array (bare sand), and 43% of the 21 hatchlings released at the jetty (0 m) (Fig. 3, Table A.2). When the results from all 3 distances were pooled, predation events were similar when lights were on and off (73% vs 71% predated, respectively). When combining both light on and off (ambient) treatments, predation events occurred in approximately 72% of all releases of tagged turtles during this study (Fig. 3, Table A.2).

3.4. Hatchling attraction to lights

Tracks of 17 of the 61 turtles were assigned to the category ‘attached’ as they produced positions and detection patterns expected of hatchlings swimming through the nearshore (Fig. 2e-f, Table A.2). Tracks ranged in duration from 1 to 16 min. Eight of these hatchlings were tracked when the jetty lights were turned on ($n = 4$ at 0 m, 1 at 200 m and 3 at 400 m) (Fig. A.3a) and 9 were tracked when the jetty lights were off ($n = 8$ at 0 m and 1 at 400 m) (Fig. A.3b). Due to the rapid and high level of predation at the 200 and 400 m release locations, the sample size was too low to assess hatchling attraction to lights on the jetty.

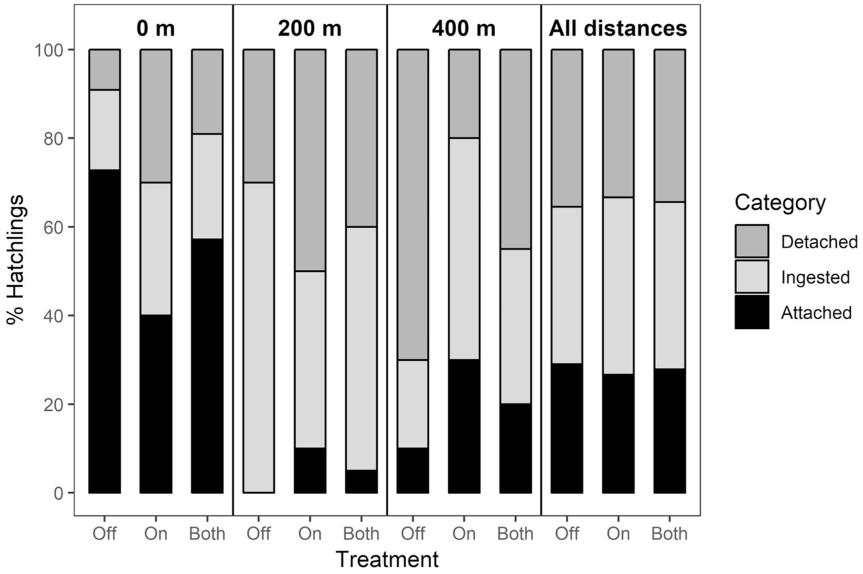

Fig. 3. The proportion of tags assigned to each category (attached/detached/ingested) for each treatment (light off: off, light on: on, light on and off combined: both) and at each distance (0 m: jetty, 200 m: reef, 400 m: sand) and for all distances combined.

Fig. 4. Photographs showing (a) schools of mangrove jack (*Lutjanus argentimaculatus*) under the jetty and (b) flatback turtle hatchlings in the stomach of a mangrove jack.

3.5. Predator identification

The RUVS recorded 19 species of fish under the jetty during the day (Table A.4). The most abundant fish were mangrove jack (*Lutjanus argentimaculatus*; mean MaxN (± SD) 15.2 ± 14.1), goldlined spinefoot (*Siganus lineatus*; mean 19.7 ± 13.9), western yellowfin bream (*Acanthopagrus morrisoni*; mean 7.8 ± 7.4), bigeye trevally (*Caranx sexfasciatus*; mean 8.2 ± 8.8) and golden trevally (*Gnathanodon speciosus*; mean 8.2 ± 7.4) and they all schooled under the jetty (Fig. 4a, Table A.4). The stomachs of two mangrove jack (~400 mm total length) that had been captured at the jetty by recreational fisherman each contained two whole flatback turtle hatchlings (Fig. 4b).

3.6. Predator behaviour

Four predators expelled their tags within the acoustic array during the experiment. Time taken to expel the tag ranged from 19 to 37 h (grey bars: Fig. A.4a). The longest documented retention time was 168 h (~1 week) from a predator first detected in another experiment on the north-western side of the island (Fig. A.2).

Twenty of the 24 predators that ingested tags were present in the tracking array during the day and the majority (*n* = 18) had home ranges (95% UD) that were restricted to the jetty (Fig. 5a). The median 95% UD for individual predators during the day was 835 m^2, ranging from 480 to 45,312 m^2 (Table A.5). At night, individual predators did not restrict their movement to the jetty, but utilised larger areas; with a median 95% UD of 18,973 m^2, ranging from 5299 to 87,181 m^2 (Fig. 5b, Table A.5). All of the predators that ingested tags (*n* = 24) were present at night, with the 400 m release point and the offshore end of the jetty having the highest density of predators (Fig. 5b).

Principal component analysis (Table A.6) indicated that there were three groups of predators (Appendix C, Fig. A.4b). Group 1 (70.8% of predators) were generally associated with lower average speeds and had high residency to the study area (Table A.5). All predators in this group remained under the jetty during the day and utilised a greater area at night (Fig. A.5a–b, see ES1 for an example of the movement patterns of two individuals assigned to this group). Predators in Group 2 (25% of predators) and Group 3 (4.2% of predators) mostly appeared at night and were generally associated with higher average speeds, with the predator in Group 3 utilising a larger area than predators in Group 2 (Table A.5, Fig. A.5c–f, see ES2 for an example of the movement patterns of two individuals assigned to Group 2).

3.7. Flatback turtle nesting and general turtle activity

Core flatback turtle nesting (25% UD) occurred on beaches adjacent to the 200 and 400 m release points and the 50% UD extended almost the entire length of the tracking area (Fig. 6a). At night, most of the

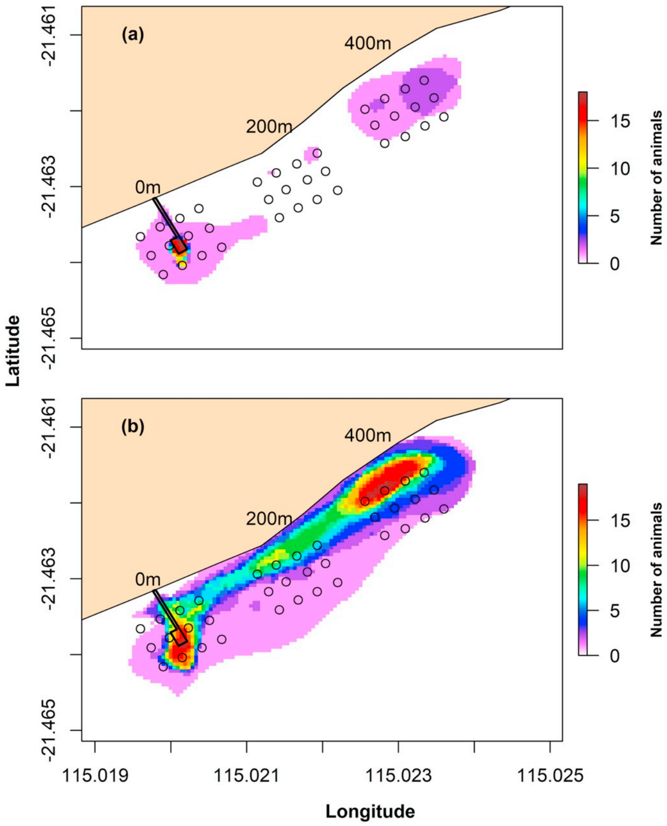

Fig. 5. The number of individual predator 95% Biased Random Bridge utilisation distributions overlapping in each 5 m grid cell during (a) the day and (b) at night. A total of 20 predators were present during the day and 24 were present at night.

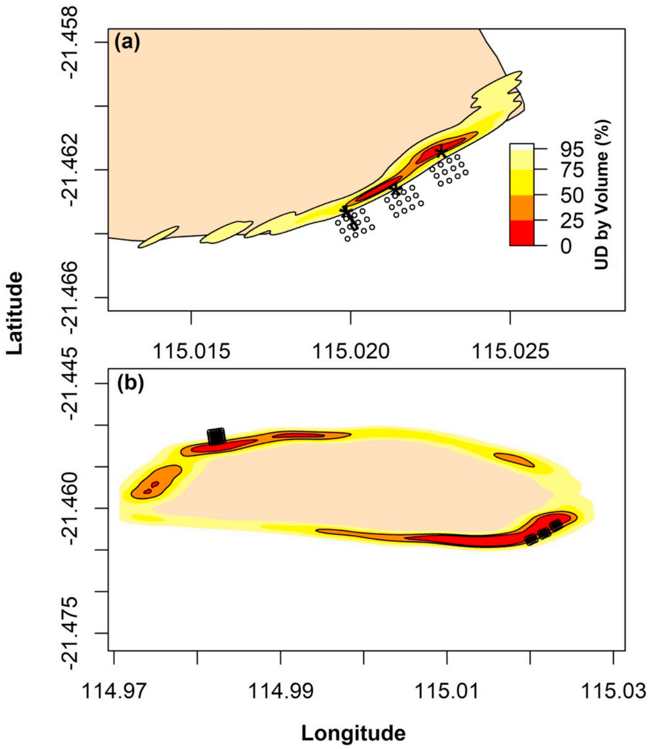

Fig. 6. Utilisation distribution of (a) flatback turtle nests and (b) all (green, hawksbill, flatback) turtle tracks marked by GPS from 19 November 2016–17 December 2016. The jetty is outlined in black in (a) and black stars are the hatchling release points. Open circles (a) or black squares (b) are the acoustic receivers (study site on the south-eastern side of Thevenard Island). Also shown in (b) is a receiver array on the north-western side of the island deployed in February 2016 by Wilson et al. (2018).

predators that ingested tags occupied waters adjacent to this area, particularly the 400 m release point (Fig. 5b). The UD of nesting activity of all species combined (flatback, green, hawksbill) over the whole island is shown in Fig. 6b. Core areas of activity (25% UD) occurred on the south-eastern and north-western sections of Thevenard Island.

4. Discussion

We used a passive acoustic tracking array to quantify rates of predation of marine turtle hatchlings in the nearshore with and without artificial lighting. Predation events were high across the study area (72%), but we found no obvious impact of artificial light on predation rates. This level of predation was substantially higher than that occurring at equivalent sites on the other side of the island (3–23%) where there was no jetty (Wilson et al., 2018; Appendix D, Fig. A.6). The RUV deployments showed that high numbers of predatory fish resided under the jetty during the day. Tracking of predators that had ingested tagged hatchlings and predator home range analysis, revealed that although the jetty offered refuge to predatory fishes during the daytime, they ranged more widely at night when hatchlings usually enter the water, causing the higher levels of predation we observed at greater distances (200 and 400 m) from the jetty. We contend that the additional habitat provided by the jetty may have increased the density of predatory fishes in the area and is likely to be responsible for the higher levels of predation we observed at this study site.

Movement patterns of tracked animals provided clear evidence of predation. Directed movements towards open water are typical of turtle hatchlings dispersing under "normal" conditions (Witherington, 1991; Thums et al., 2016; Wilson et al., 2018). In contrast, many of the tracks displayed longshore and tortuous movements, with individuals remaining in the area of the study site for up to 72 h, rather than dispersing offshore. Some tags (n = 21) were immediately detached, and we contend that this probably occurred due to prey handling by a predator given that the external and vertical placement of tags made them likely to be easily dislodged during a predator strike (Fig. 1). Our experiments clearly showed that tag detachments were not likely to be caused by failure of the glue (Appendix B). This is supported by similar hatchling tracking studies using identical attachment methods that report very low detachment rates (3%) (Wilson et al., 2018) or no tag detachment (Thums et al., 2016). Detachments also occurred immediately on release, again suggestive of predator attack. Although it is possible that turtles could have survived an initial attack that removed the tag, it seems very likely that once a predator had located a hatchling, it would be subject to successive attacks that would ultimately prove fatal. Evidence that this is the case is provided by some active tracking studies of hatchlings where mortality was preceded by multiple attacks by a predator (Gyuris, 1994).

A total of 70% of the predators that consumed tags remained under the jetty during the day and ranged more widely through the array at night. Video footage revealed large schools of lutjanids (snappers), carangids (trevally), sparids (bream) and siganids (rabbitfish) taking refuge under the jetty during the day. Of these, it is most likely that predators of hatchlings were members of the lutjanid (particularly mangrove jack, *L. argentimaculatus*) and carangid families, as both are nocturnal predators that remain in relatively inactive schools during the day (Hobson, 1965). The remaining families had smaller gapes and were herbivorous (siganids) or benthic feeders (sparids). Confirmation that lutjanids were predators was provided by the discovery of hatchlings in the stomach contents of mangrove jacks caught by anglers at the jetty (Fig. 4b).

Utilisation distributions of predators at night showed selection of an area of bare sand close to the 400 m release point and the outer end of the jetty. Analysis of nesting locations from the 2016/17 season revealed that the sandy area near the 400 m release point was adjacent to core nesting habitat for flatback turtles. This suggests that predators were moving to particular locations where hatchlings were likely to be more abundant to increase their chances of finding prey. Similar behaviour by predators has been observed in Antigua in the West Indies, where predation rates on hatchlings were also higher in waters adjacent to beaches where turtle nests were concentrated (Reising et al., 2015).

The high rate of predation (72%) that we recorded is much greater than levels reported at nesting beaches in Florida, USA (4.6–6.7%; Witherington and Salmon, 1992; Stewart and Wyneken, 2004; Whelan and Wyneken, 2007) and on Heron Island, Australia (mean predation rates 31%; Gyuris, 1994). It is also higher than predation rates recorded at turtle hatchery release sites in Sabah, Malaysia (40–60%, Pilcher et al., 2000) and Florida, USA (26%; Wyneken et al., 2000) but similar to predation rates recorded at a nesting beach in Antigua, West Indies (25–88%; Reising et al., 2015). The level of hatchling predation at a site is thought to be related to the number of predators in the area (i.e. a function of habitat availability and type – reef, sand) (Witherington and Salmon, 1992), the density of hatchlings entering the sea at any one time (Pilcher et al., 2000) and the density of nests on the beaches (Glenn, 1996; Reising et al., 2015). Turtles nest around the entire perimeter of Thevenard Island, and whole-of-island track counts revealed that turtle activity is concentrated on the south-eastern beaches adjacent to our acoustic tracking site and also on the north-western side of the island adjacent to natural reef where hatchlings were tracked in the presence and absence of artificial light on 8–10 February 2016 (Wilson et al., 2018) and 20–21 February 2017 (Appendix D). For hatchlings released under ambient conditions (i.e. with no artificial light) in each of these experiments, predation was much greater on the south-eastern side of the island where the jetty was present (71%) than at the site on the north-western side of the island where there was no jetty (10% in 2016 and 2017) (Wilson et al., 2018; Appendix D). As both of these sites are preferred nesting habitat (Fig. 6b), the difference in predation between the two sites is unlikely to be driven by differences in the density of hatchlings entering the sea; it is more likely determined by the presence of the jetty providing additional habitat and thus a higher number of predators in the area.

As artificial light is known to attract hatchlings at sea (Thums et al., 2016; Wilson et al., 2018), we hypothesised that lights on the jetty would increase predation rates through hatchlings lingering in the predator-rich nearshore zone and/or through the attraction of predators (and hatchlings) to the light. We also hypothesised that hatchling attraction might decline with distance from the light source. However, most hatchlings encountered predators before they had a chance to transit the array so that predation rates were similar (around 70%) with and without artificial light. In addition, only 3 of the surviving hatchlings swam towards the jetty when the lights were on (one released from each location) (Fig. A.3a). Although it is possible that light does indeed influence predation, and that attraction to lights is likely to decline with distance, the rapid and high predation rate of hatchlings resulted in an inadequate sample size to test this hypothesis. In any event, our study showed that the shelter provided by the jetty increased predation on hatchlings up to at least 400 m away from the structure, and these effects were far greater than those of light pollution.

5. Conclusions

The impact of nearshore structures such as jetties on populations of marine turtles is largely unquantified. Our study suggests that they may pose a significant threat to the conservation and management of populations by sheltering predators that consume vulnerable hatchlings and likely other reef biota outside of the turtle hatching season. Although this predator addition and concentration may be localised, given the global footprint of such coastal infrastructure, the ecosystem effects may not be trivial, especially if they occur adjacent to environmentally sensitive or vulnerable areas. It is important to recognise that the jetty in our study was relatively small (< 100 m in length) compared to port infrastructure that exists in northern Australia and many other localities throughout the tropics to support the export of mineral resources (Drenth, 2007; National Geospatial-Intelligence Agency, 2017). Jetties in these ports can be > 2 km in length and are part of a facility that usually includes large groyne walls, multiple piles and fenders that can also act as shelter sites for predatory fishes. Importantly, these operational facilities are typically closed to fishing (unlike the jetty studied here) which is likely to increase the abundance and diversity of predatory fishes, as they effectively become no-take marine reserves (Schroeder and Love, 2004; Claisse et al., 2014). Our study shows that where these facilities occur near turtle nesting beaches they are likely to significantly increase the mortality of hatchling turtles at a critical bottleneck in their life history.

Management agencies that oversee the instillation of jetties and other port facilities on or near turtle nesting beaches should recognise and account for the potential of these structures to act as predation sinks for newly hatched turtles transiting the nearshore. Similarly, planning decisions on decommissioning of coastal infrastructure must consider the long-term consequences for nesting populations of turtles if these facilities are not removed.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2019.04.015.

Acknowledgements

We thank S. Warburton, A. Mason and M. Vo for their assistance in field experiments, C. Speed for lending RUVs, B. Vaughan and M. Birt for assisting with fish identification, V. Udyawer for providing R code for track animations, and to H. Pederson, M. Heupel, R. Harcourt, G. Hays and the anonymous reviewers for their valuable advice. We also thank DBCA staff and volunteers for collecting the nesting distribution data used here. All research protocols included in this paper have been approved by the Western Australia Department of Biodiversity, Conservation and Attractions (license number SF011007, SC001430, SC001447), the University of Western Australia Animal Ethics Committee (RA/3/100/1423) and by the Department of Biodiversity, Conservation and Attractions Animal Ethics Committee (2016-18) and comply with the Animal Welfare Act 2002 (Western Australia) and the requirements of the Australian code for the care and use of animals for scientific purposes.

Funding

P.W. was supported by a University Postgraduate Award Scholarship from the University of Western Australia. Project funding was provided predominantly from the Department of Biodiversity, Conservation and Attractions with contributions from all author organisations.

References

Allen, G.R., 2009. Field Guide to Marine Fishes of Tropical Australia and South-East Asia, fourth edition. Western Australian Museum, Welshpool, Western Australia.
Allen, G., Steene, R., Humann, P., DeLoach, N., 2015. Reef Fish Identification Tropical Pacific. New World Publications, INC, Jacksonville, Florida USA.
Becker, A., Whitfield, A.K., Cowley, P.D., Jarnegren, J., Naesje, T.F., 2013. Potential effects of artificial light associated with anthropogenic infrastructure on the abundance and foraging behaviour of estuary-associated fishes. J. Appl. Ecol. 50, 43–50. https://doi.org/10.1111/1365-2664.12024.
Benhamou, S., 2011. Dynamic approach to space and habitat use based on biased random bridges. PLoS One 6, 1–8. https://doi.org/10.1371/journal.pone.0014592.
Bohnsack, J.A., 1989. Are high densities of fishes at artificial reefs the result of habitat limitation or behavioural preference? Bull. Mar. Sci. 44, 631–645.
Calenge, C., 2015. Home range estimation in R: the adehabitatHR package. R package version 0.4.15. https://cran.r-project.org/package=adehabitatHR.
Cappo, M., Harvey, E., Malcolm, H., Speare, P., 2003. Potential of video techniques to monitor diversity, abundance and size of fish in studies of marine protected areas. In:

Beumer, J.P., Grant, A., Smith, D.C. (Eds.), Aquatic Protected Areas. What works best and how do we know?, Cairns edition. volume 1. University of Queensland, Queensland, pp. 455–464.

Claisse, J.T., Pondella II, D.J., Love, M., Zahn, L.A., Williams, C.M., Williams, J.P., Bull, A.S., 2014. Oil platforms off California are among the most productive marine fish habitats globally. Proc. Natl. Acad. Sci. 111, 15462–15467. https://doi.org/10.1073/pnas.1411477111.

Department of Environment and Energy, 2017. Recovery Plan for Marine Turtles in Australia, Commonwealth of Australia 2017. Department of Environment and Energy, Canberra.

Drenth, M., 2007. Petroleum and Minerals Industries in the Northwest Marine Region: A Report to the Department of Environment, Water, Heritage and the Arts. IRC Global Risk Management, West Perth, Western Australia.

Duong, T., 2018. Kernel smoothing. R package version 1.11.2. https://cran.r-project.org/web/packages/ks/ks.pdf.

Estes, J.A., 1996. Predators and ecosystem management. Wildl. Soc. Bull. 24, 390–396.

Fisher, R., Wilson, S.K., Sin, T.M., Lee, A.C., Langlois, T.J., 2018. A simple function for full subsets multiple regression in ecology with R. Ecol. Evol. 8, 6104–6113. https://doi.org/10.1002/ece3.4134.

Frick, J., 1976. Orientation and behaviour of hatchling green turtles (*Chelonia mydas*) in the sea. Anim. Behav. 24, 849–857. https://doi.org/10.1016/S0003-3472(76)80015-2.

Glenn, L., 1996. The consequences of human manipulation of the coastal environment on hatchling loggerhead sea turtles (*Caretta caretta*, L). In: Byles, R., Fernandez, Y. (Eds.), Proceedings of the Sixteenth Annual Symposium on Sea Turtle Biology and Conservation. U.S. Department of Commerce, pp. 58–59.

Gyuris, E., 1994. The rate of predation by fishes on hatchlings of the green turtle (*Chelonia mydas*). Coral Reefs 13, 137–144. https://doi.org/10.1007/BF00301189.

Hays, G.C., Ferreira, L.C., Sequeira, A.M.M., Meekan, M.G., Duarte, C.M., Bailey, H., Bailleul, F., Don Bowen, W., Julian Caley, M., Costa, D.P., Eguiluz, V.M., Fossette, S., Friedlaender, A.S., Gales, N., Gleiss, A.C., Gunn, J., Harcourt, R., Hazen, E.L., Heithaus, M.R., Heupel, M., Holland, K., Horning, M., Jonsen, I., Kooyman, G.L., Lowe, C.G., Madsen, P.T., Marsh, H., Phillips, R.A., Righton, D., Ropert-Coudert, Y., Sato, K., Shaffer, S.A., Simpfendorfer, C.A., Sims, D.W., Skomal, G., Takahashi, A., Trathan, P.N., Wikelski, M., Womble, J.N., Thums, M., 2016. Key questions in marine megafauna movement ecology. Trends Ecol. Evol. 31, 463–475. https://doi.org/10.1016/j.tree.2016.02.015.

Heithaus, M.R., 2013. Predators, prey, and the ecological roles of sea turtles. In: Wyneken, J., Lohmann, K.J., Musick, J.A. (Eds.), The Biology of Sea Turtles, 3rd edition. CRC Press, Boca Raton, FL, pp. 250–284.

Hendrickson, J.R., 1958. The green sea turtle, *Chelonia mydas* (Linn.) in Malaya and Sarawak. Proc. Zool. Soc. London 130, 455–535.

Hobson, E.S., 1965. Diurnal-nocturnal activity of some inshore fishes in the Gulf of California. Copeia (3), 291–302.

Kamrowski, R.L., Limpus, C., Jones, R., Anderson, S., Hamann, M., 2014. Temporal changes in artificial light exposure of marine turtle nesting areas. Glob. Chang. Biol. 20, 2437–2449. https://doi.org/10.1111/gcb.12503.

Khan, J.A., Welsh, J.Q., Bellwood, D.R., 2016. Using passive acoustic telemetry to infer mortality events in adult herbivorous coral reef fishes. Coral Reefs 35, 411–420. https://doi.org/10.1007/s00338-015-1387-7.

Limpus, C.J., 1971. The flatback turtle, Chelonia depressa Garman in Southeast Queensland, Australia. Herpetologica 27, 431–446.

Lohmann, K.J., Salmon, M., Wyneken, J., 1990. Functional autonomy of land an sea orientation systems in sea turtle hatchlings. Biol. Bull. 179, 214–218. https://doi.org/10.2307/1541772.

McLean, D.L., Partridge, J.C., Bond, T., Birt, M.J., Bornt, K.R., Langlois, T.J., 2017. Using industry ROV videos to assess fish associations with subsea pipelines. Cont. Shelf Res. 141, 76–97. https://doi.org/10.1016/j.csr.2017.05.006.

Milinski, M., 1986. Constraints placed by predators on feeding behaviour. In: Pilcher, T. (Ed.), The Behaviour of Teleost Fishes. Billing & Sons Limited, Worcester, Great Britain, pp. 236–252.

National Geospatial-Intelligence Agency, 2017. World Port Index. National Geospatial-Intelligence Agency, Springfield, Vienna.

Nowak, K., le Roux, A., Richards, S.A., Scheijen, C.P.J., Hill, R.A. 2014. Human observers impact habituated samango monkeys' perceived landscape of fear. Behav. Ecol. 25, 1199–1204. https//doi.org/10.1093/beheco/aru110.

Pilcher, N.J., Enderby, S., Stringell, T., Bateman, L., 2000. Nearshore turtle hatchling distribution and predation. In: Pilcher, N., Ismail, G. (Eds.), Sea Turtles of the Indo-Pacific: Research Management and Conservation. Proceedings of the Second ASEAN Symposium and Workshop on Sea Turtle Biology and Conservation. ASEAN Academic Press, London, pp. 151–166.

Preisser, E.L., Bolnick, D.I., Benard, M.F., 2005. Scared to death? The effects of intimidation and consumption in predator-prey interactions. Ecology 86, 501–509. https://doi.org/10.1890/04-0719.

R Core Team, 2015. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Reising, M., Salmon, M., Stapleton, S., 2015. Hawksbill nest site selection affects hatchling survival at a rookery in Antigua, West Indies. Endanger. Species Res. 29, 179–187. https://doi.org/10.3354/esr00708.

Rilov, G., Benayahu, Y., 2000. Fish assemblage on natural versus vertical artificial reefs: the rehabilitation perspective. Mar. Biol. 136, 931–942.

Schroeder, D.M., Love, M.S., 2004. Ecological and political issues surrounding decommissioning of offshore oil facilities in the Southern California Bight. Ocean Coast. Manag. 47, 21–48. https://doi.org/10.1016/j.ocecoaman.2004.03.002.

Stancyk, S.E., 1982. Non-human predators of sea turtles and their control. In: Bjorndal, K.A. (Ed.), Biology and Conservation of Sea Turtles, revised edition. Smithsonian, Washington and London, pp. 139–152.

Stewart, K.R., Wyneken, J., 2004. Predation risk to loggerhead hatchlings at a high-density nesting beach in Southeast Florida. Bull. Mar. Sci. 74, 325–335.

Thums, M., Whiting, S.D., Reisser, J.W., Pendoley, K.L., Pattiaratchi, C.B., Harcourt, R.G., McMahon, C.R., Meekan, M.G., 2013. Tracking sea turtle hatchlings — a pilot study using acoustic telemetry. J. Exp. Mar. Biol. Ecol. 440, 156–163. https://doi.org/10.1016/j.jembe.2012.12.006.

Thums, M., Whiting, S.D., Reisser, J., Pendoley, K.L., Pattiaratchi, C.B., Proietti, M., Hetzel, Y., Fisher, R., Meekan, M.G., 2016. Artificial light on water attracts turtle hatchlings during their near shore transit. R. Soc. Open Sci. 3, 160142. https://doi.org/10.1098/rsos.160142.

Thums, M., Rossendell, J., Guinea, M., Ferreira, L.C., 2018. Horizontal and vertical movement behaviour of flatback turtles and spatial overlap with industrial development. Mar. Ecol. Prog. Ser. 602, 237–253. https://doi.org/10.3354/meps12650.

Wallace, B.P., DiMatteo, A.D., Bolten, A.B., Chaloupka, M.Y., Hutchinson, B.J., Abreu-Grobois, F.A., Mortimer, J.A., Seminoff, J.A., Amorocho, D., Bjorndal, K.A., Bourjea, J., Bowen, B.W., Duenas, R.B., Casale, P., Choudhury, B.C., Costa, A., Dutton, P.H., Fallabrino, A., Finkbeiner, E.M., Girard, A., Girondot, M., Hamann, M., Hurley, B.J., Lopez-Mendilaharsu, M., Marcovaldi, M.A., Musick, J.A., Nel, R., Pilcher, N.J., Troeng, S., Witherington, B., Mast, R.B., 2011. Global conservation priorities for marine turtles. PLoS One 6, 1–14. https://doi.org/10.1371/journal.pone.0024510.

Whelan, C.L., Wyneken, J., 2007. Estimating predation levels and site-specific survival of hatchling loggerhead seaturtles (*Caretta caretta*) from South Florida beaches. Copeia 2007, 745–754. https://doi.org/10.1643/0045-8511(2007)2007[745:eplass]2.0.co;2.

Wilson, P., Thums, M., Pattiaratchi, C., Meekan, M.G., Pendoley, K., Fisher, R., Whiting, S., 2018. Artificial light disrupts the nearshore dispersal of neonate flatback turtles (*Natator depressus*). Mar. Ecol. Prog. Ser. 600, 179–192. https://doi.org/10.3354/meps12649.

Witherington, B.E., 1991. Orientation of hatchling loggerhead turtles at sea off artificially lighted and dark beaches. J. Exp. Mar. Biol. Ecol. 149, 1–11. https://doi.org/10.1016/0022-0981(91)90113-b.

Witherington, B.E., Salmon, M., 1992. Predation on loggerhead turtle hatchlings after entering the sea. J. Herpetol. 26, 226–228. https://doi.org/10.2307/1564869.

Wood, S., 2017. Mixed GAM Computation Vehicle with GCV/AIC/REML Smoothness Estimation. R Package Version 1.8–17. https://cran.r-project.org/packages=mgcv.pdf.

Wyneken, J., Fisher, L., Salmon, M., Weege, S., 2000. Managing relocated sea turtle nests in open-beach hatcheries. Lessons in hatchery design and implementation in Hillsboro Beach, Broward County, Florida. In: Kalb, H., Wibbels, T. (Eds.), Proceedings of the Nineteenth Annual Symposium on Sea Turtle Conservation and Biology. U.S. Department of Commerce, pp. 193–194.