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Understanding the early offshore migration patterns of turtle hatchlings and the effects of anthropogenic light – a pilot study

Michele Thums[1,2], Mark Meekan[2], Scott Whiting[3], Julia Reisser[1], Kellie Pendoley[4], Rob Harcourt[5], Clive McMahon[6] and Chari Pattiaratchi[1]

[1]School of Environmental Systems Engineering and the UWA Oceans Institute, University of Western Australia (M470), 35 Stirling Highway, Crawley WA 6009

[2]Australian Institute of Marine Science, UWA Oceans Institute (MO96), 35 Stirling Highway, Crawley WA 6009

[3]Marine Science Program, Department of Environment and Conservation, Locked Bag 104, Bentley Delivery Centre WA 6983

[4]Pendoley Environmental Pty Ltd 61 Kishorn Street, Mount Pleasant WA 6153

[5]Graduate School of the Environment, Macquarie University, North Ryde NSW 2109

[6]School for Environmental Research, Institute of Advanced Studies, Charles Darwin University, Darwin, Northern Territory 0909, Australia.

Executive summary

- We report the results of a pilot study on in-water movement of flatback turtle (*Natator depressus*) hatchlings conducted at Eco-Beach (Lat 18º19.767'S, Long 122º04.939'E), WA, January 2012.

- Our study tested the effectiveness of acoustic tracking technology as a means of quantifying turtle hatchling movement (initially flatback turtles) and test for the influence of artificial lighting on turtle hatchling in-water movement.

- New advances in technology have overcome the main issue hindering acoustic tracking of turtle hatchlings – the size of transmitters. Transmitters used in our study were only 0.4 g, approximately 1 % of the body mass of the hatchlings. The small size and weight of the transmitters meant that they did not impede either swimming or buoyancy of the turtles to which they were attached. Acoustic tracking is routinely used to monitor fish movements, but this study is the first one to apply this technology to turtle hatchlings.

- We used both manual and automated acoustic tracking technology. Automated tracking consisted of an array of 18 monitoring receivers set up in the surf zone at Eco Beach to detect signals from miniature, acoustic coded transmitters attached to 26 turtle hatchlings released into the array. We released hatchlings into the array either in the presence, or in the absence, of artificial lighting. We also fitted three turtle hatchlings with coded acoustic transmitters and then followed them in a small boat using a mobile acoustic receiver with directional hydrophone.

- Our pilot study has shown that acoustic tracking technology is an effective way to track turtle hatchlings as they leave nesting beaches and swim offshore.

- Of the 26 individuals tagged and released in the study area, 22 were recorded by our tracking array.

- Artificial lights did not affect the swimming of hatchlings through the surf zone, with turtles largely travelling against the direction of wave propagation. However, a larger receiver array, extending beyond the surf zone is needed to conclusively determine whether artificial light has effects on in-water movement beyond the surf zone. Using the mobile acoustic receiver, we were able to track turtles 1-2 km from shore.

- The tracking equipment is relatively inexpensive and can be deployed and retrieved with ease by hand, in this case from the shore, or alternatively from a boat.

- Our pilot study shows that acoustic tracking can be a simple, cheap and effective tool for monitoring the in-water movements of newly-hatched turtles and is particularly useful for addressing questions related to the effect of light on navigation by turtle hatchlings. Data provided by the technique will be essential for the appropriate planning of new industrial developments and in particular management of the type and positioning of lights in relation to turtle nesting beaches.

Introduction

Under natural conditions, most turtles hatch at night and show an innate and well-directed orientation toward the water, relying mostly on light cues (lighter horizon) (Witherington & Martin 1996; Salmon 2003; Lorne & Salmon 2007). However, artificial lighting on beaches is strongly attractive to hatchlings and can cause hatchlings to move in the wrong direction and interfere with their ability to orient in a constant direction (Witherington & Martin 1996). Delays in the journey from nest to sea caused by artificial light sources can lead to death from exhaustion, dehydration and predation (Witherington & Martin 1996).

While the problems caused by artificial light for the transit of turtles hatchlings from the nest to the water's edge are well-known (Witherington & Martin 1996; Salmon, Witherington & Elvidge 2000; Pendoley 2005), of greater potential importance is the effect of light pollution on hatchling behaviour once they enter the water. The near shore environment is host to many predators (reef fishes, sharks etc.) capable of consuming hatchling turtles. Predation risk is greatest close to shore where turtle hatchlings must pass over shallow reef environments before reaching the relative safety of deeper water (Salmon *et al.* 2009). If light pollution disrupts the orientation and swimming behaviour of hatchlings once they enter the water, causing them to linger in these risky environments, it may adversely affect rates of survivorship, that are already low (Parmenter & Limpus 1995) and ultimately threaten the future viability of populations.

Light pollution can be generated by residential and tourism infrastructure as well as large industrial developments, such as gas and oil infrastructure or port facilities, which are often lit throughout the night. The North West Shelf of Western Australia supports large and growing gas and oil processing operations, with more large-scale developments planned or well underway. It is also an area with many important turtle rookeries and a significant proportion of nesting turtles are already exposed to artificial light sources (Pendoley 2005).

There have been no empirical studies to determine whether light disrupts the movement of turtles once they enter the water from hatching beaches. This is because until very recently, we lacked the tracking technology that would allow hatchlings to be tagged so that they could be followed in near shore waters without significantly impeding their swimming or buoyancy. However, new advances in acoustic tracking have overcome this issue; tags are now as small as 0.4 g and 12 mm long, allowing hatchlings to be tracked without adverse effects on their locomotion. Acoustic tracking has routinely been used to monitor fish movements but this study is the first to apply this technology to turtle hatchlings.

Here, we describe the results of a pilot study that 1) tested the effectiveness of this new acoustic technology for tracking the in-water movement of hatchling turtles; 2) examined the influence of artificial lighting on in-water movement of hatchlings at the point of entry to the sea from the nesting beach and 3) provide an understanding of the oceanographic factors that influence their movement.

Methods

Study site and description of tracking methods

We used both automated and manual acoustic tracking technology (Vemco Ltd, Halifax, Canada) to track flatback turtle (*Natator depressus*) hatchlings at Eco Beach (Latitude 18º19.767'S and Longitude 122º04.939'E), approximately 130 km south west of Broome, Western Australia (Figure 1).

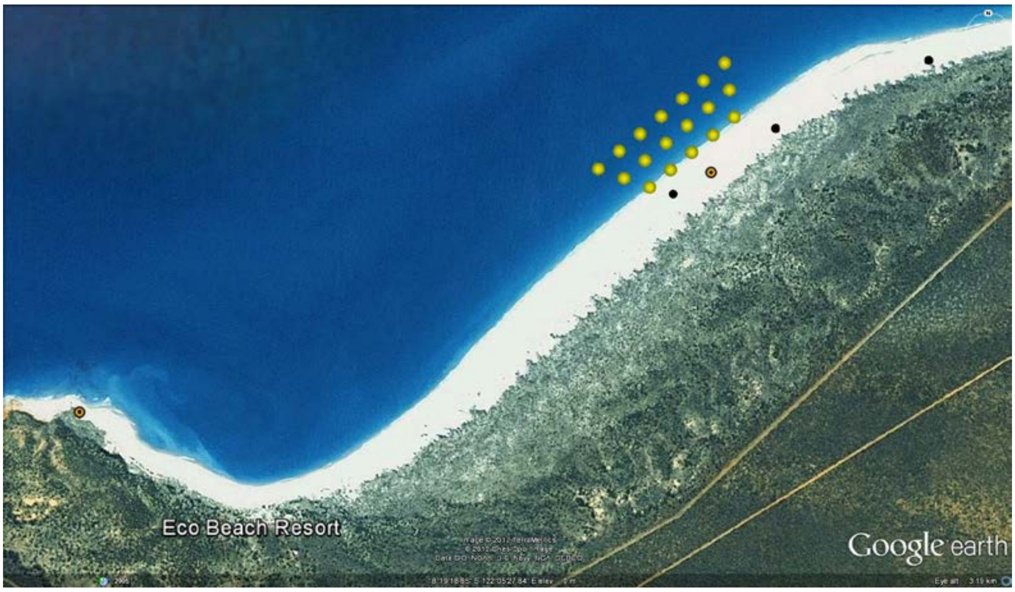

Figure 1. Google Earth image showing the acoustic tracking array location (yellow points), hatchling nest positions (black points), and light positions (orange points).

Automated tracking consisted of an array of 18 VR2W monitoring receivers set up in the surf zone (Figure. 1) to detect signals from miniature, acoustic coded transmitters attached to turtle hatchlings released into the array. In theory, as a hatchling with an acoustic transmitter passes within ~100 - 200m diameter circle centred on a receiver, the date and time of this animal should be recorded. This is known as "a detection" (Figure 2). We set out to not only get detections on single receivers but to obtain accurate positions of the turtles moving through the array. This is done by using the VR2W positioning system (VPS) (Vemco Ltd, Halifax, Canada) (Figure 3). Positions (5 m accuracy) can be calculated if there are at least three detections of a tag by time-synchronised receivers (Figure 3). These detections can be converted into positions using differences in arrival times of the same signal at different receivers.

The receivers were deployed as a patchwork of nearly equilateral triangles with a reference synch tag (allows the synching of time logged by each receiver in the network) co-located with each receiver. The spacing of the receivers was determined by first doing a range test, which helps to determine the detection radius of each acoustic receiver. This distance varies for each site due to differences in environmental noise (waves, boats, animals, etc) which may mask acoustic signals. The majority of transmissions (70 %) were detected within a radius of 100 m, therefore all receivers were stationed 100 m apart.

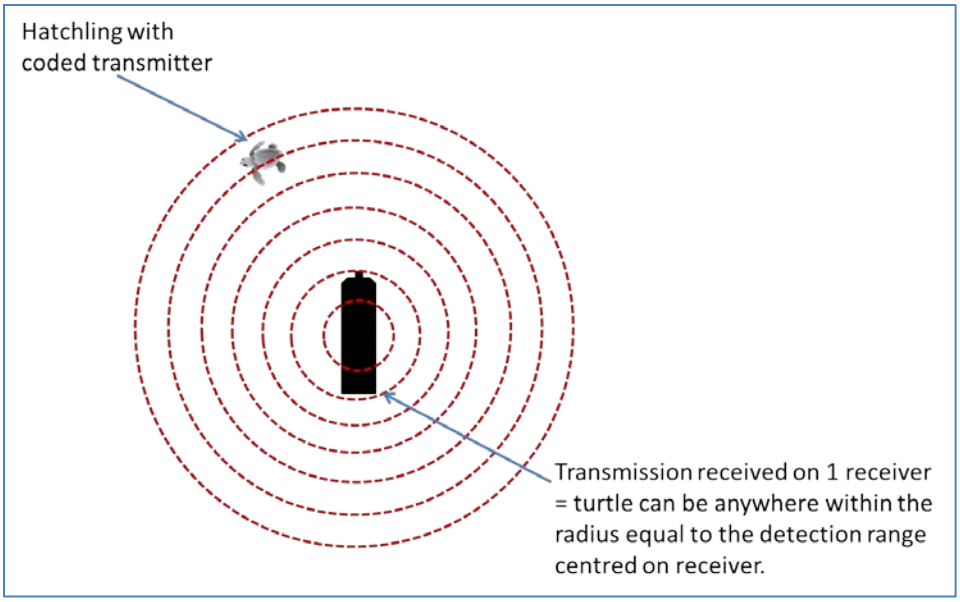

Figure 2. Diagram showing a detection on one VR2W receiver.

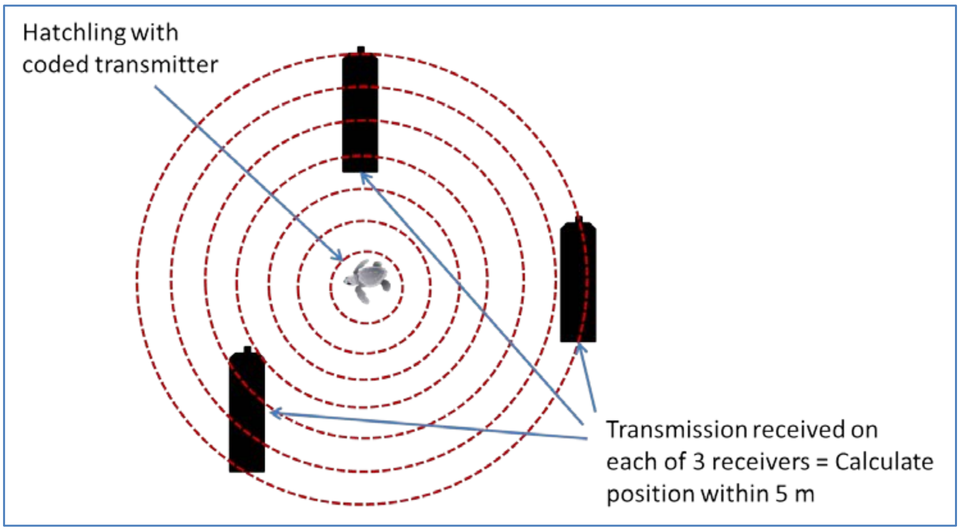

Figure 3. Diagram showing how the VR2W positioning system (VPS) works. The receivers will detect the signal transmitted by the turtle transmitter if they are within the radius of the detection range centred on the turtle

Each receiver was cable tied to a 2.4 m star picket that had been previously hammered into the sand so that the resulting height of the picket was approximately 1 m (Figure 4). The synch tag was attached to the star picket with a 50 cm length of thick monofilament with a float at the top attached with a small aluminium crimp.

For manual tracking we used a VR100 mobile acoustic receiver and directional hydrophone (Vemco Ltd, Halifax, Canada). We fitted each of three turtle hatchlings with a coded transmitter and then followed them in a small boat using the VR100. In this way we were able to follow the turtles well beyond the array and into open water. The boat remained at a distance of 10 - 20 m from the turtle during the manual tracking. In addition to the V5 transmitter, a piece of flagging tape was glued to the turtle's back to aid tracking through visual detection. The VR100 detected the signals emitted by the turtle transmitter and the directional hydrophone was used to determine the direction of the turtle to allow it to be followed. The VR100 stored the detections, along with the date/time and GPS location of the receiver at the time of the detection. These data were then downloaded and the tracks reconstructed. The turtles were tracked at low tide on 1st February, between 06:00 and 11:00 hrs.

Figure 4. One of the receivers attached to a star picket. Michele holds up the synch tag (circled in red) with float attached with a piece of thick monofilament line.

Animal handling and transmitter deployment

We tracked 29 hatchlings from three separate nests using the newly-available V5 miniature acoustic transmitters (Vemco Ltd, Halifax, Canada). These are the smallest tracking device currently on the market, being only 0.4 g in water and 12 mm in length and 5 mm diameter (cylinder shape with one end flattened slightly) (Figure 5a). These transmitters were approximately 1.08 % of the turtle's body mass. This was well below the 3% threshold of body mass where negative effects on buoyancy and swimming are thought to begin to occur (Phillips, Xavier & Croxall 2003; Casper 2009). Twenty six of the instrumented hatchlings were released into the tracking array and the remaining three were released at the edge of the receiver array and tracked manually.

Nest positions and hatching dates were obtained from Conservation Volunteers Australia (CVA) who monitor flatback nests here along a 12 km section of beach heading north from Cape Villaret. A plastic mesh fence 20 cm high and 8 m in diameter was erected around each of the known nests several days before expected hatching date to capture hatchlings for the experiment. Nests were checked hourly from 20:00 to 03:00 and again at 06:00. Once hatchlings were discovered, they were collected and kept in an esky with a moist sand floor in a cool, dark room until the following high tide and then released (one nest had to kept for two nights due to unfavourable conditions). For each hatchling we measured the straight carapace length and width with digital callipers (± 0.01 cm) and the body mass on a digital scale (± 0.1 g) (Appendix 1). Scutes were counted (vertebral, post vertebral, costal, marginal, infra marginal, prefrontal, post ocular and post parietal) and only hatchlings with normal scale counts were selected for transmitter deployment. The transmitters were glued to the turtle's underside using a small drop of Vetbond™; a non-toxic, fast-acting adhesive used for veterinary procedures (Fig 5b). We tested the glue by gluing the tag to one hatchling and placing it in an esky of seawater for 2 hours. The transmitters were glued to the hatchlings just prior to release.

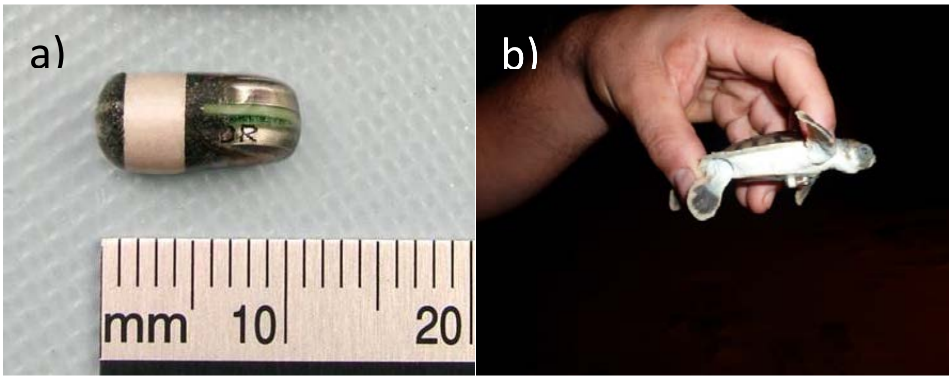

Figure 5. a) The Vemco V5 acoustic transmitter and b) a flatback turtle hatchling with transmitter attached.

Light experiment

Eco Beach is a remote location and the only artificial light source in the vicinity is a resort hotel. However, the resort was closed for operation during the time that the experiment was conducted so few lights were on and as these were low wattage we did not expect any effect on orientation of turtle hatchlings. A low light glow from Broome, 42.6 km to the north east was visible on the horizon.

Hatchlings from three different nests were instrumented with V5 transmitters (Appendix 1). We released these hatchlings into the array under natural conditions and with artificial lights present over three nights (Appendix 1). All turtles were released into the array at the water's edge at the point on the shore in line with the middle receiver on the first line of the array (Figure 1).Lighting consisted of two sodium vapour lights (200 and 400 watts) placed side by side, powered by a generator. The plan was to set up lights on a boat moored at the edge of the array and then release the turtles into the array. However large swells (due to a nearby tropical low and tropical cyclone Iggy to the south) prevented this and we were forced to improvise. On the night of the 27th January, the lights were erected on rocks 2.1 km from the array (Figure 1). The turtles in the no light treatment were released into the array half an hour before high tide. Half an hour after high tide the lights were switched on and the turtles in the light treatment released into the array and the lights switched off 90 minutes later. On the night of the 28th January we were not able to do both treatments, due to bad weather and large swells. On this night turtles were only released in the no-light treatment half an hour before high tide. The following night, lights were erected on the beach in front of the array (Figure 1 & 6) and turtles in the light treatment released half an hour before high tide. In order to allow the turtles time to travel into the array before potentially being attracted back on shore by the lights, we allowed lags of 6, 12 and 18 minutes respectively before switching on the lights (Appendix 1). As before, the lights remained on for 90 minutes.

Figure 6. Light set up for the experiment conducted on 29th January.

Data analysis

The receivers in the array were retrieved at the completion of the experiments and the data from the receivers downloaded. The detection data were analysed using a kernel density analysis to determine the receivers that had the most detections and thus give an indication of the path taken by the turtles and their residence patterns within the array. We also plotted the detections on each receiver per minute to indicate the path taken by each individual. The detection data was then sent to VEMCO for turtle positions to be calculated so that the actual track taken by each turtle could be reconstructed and the turtles heading and orientation analysed (Vemco do not provide the algorithms for users to do this analysis as it is commercially sensitive).

Results

Transmitter deployment

Tags were still attached to hatchlings and showed no signs of coming free after 2 hours of in-water deployment. The hatchlings appeared to behave normally, without any signs of adverse impact from carrying the tag. Based on previous studies, we estimated that tags would come free after 1-2 weeks (Gaskill 2011).

Automated tracking

A total of 1328 detections were recorded for the 22 of the 26 hatchlings released into the array. All receivers in the array had detections, except receiver 1. The turtles with no detections were likely carried by strong longshore currents out of the array. Detected turtles spent a mean duration of 16.63 ± 5.89 minutes in the array. A tropical low to the north and Tropical Cyclone Iggy further down the coast created high winds and large swells, causing the detection range of the receivers to be hampered by increased wave noise and probably increased sand particles suspended in the water column. This resulted in a lower detection range for the receivers closer to the shore and this was manifest in lower number of detections on these receivers. Receivers in the line closest to shore had a total of 13 detections, while the second and third line of receivers had 325 and 990 detections respectively. Very few turtle positions were able to be calculated by Vemco due to the reduction in detection range (for positioning, detections on three receivers is required).

Light experiment

Given that very few turtle positions were able to be calculated, we were limited in our ability to test for a change in heading and direction of turtles in relation to light. Vemco were only able to calculate 3 positions for each of turtles 1013 and 1016, all in the first no light treatment. The track of both turtles showed that they moved in a west south west direction. Based on the detections on single receivers, we could not discern any effect of the artificial light sources on turtle movement within the array, with the majority of detections falling on receivers 14, 15, 16 and 17 and to a lesser extent 3 (Figure 7). There was no difference in the time the hatchlings spent in the array during light and no light treatments (Figure 8). There was a difference in the time spent in the array between experiments but this was probably related to the increasing swell and wave energy in the array due to the influence of the tropical low and TC Iggy. Hatchlings followed a predominantly westerly direction from the release point, either west north west or west south west regardless of the position of artificial light (figures 9 – 12).

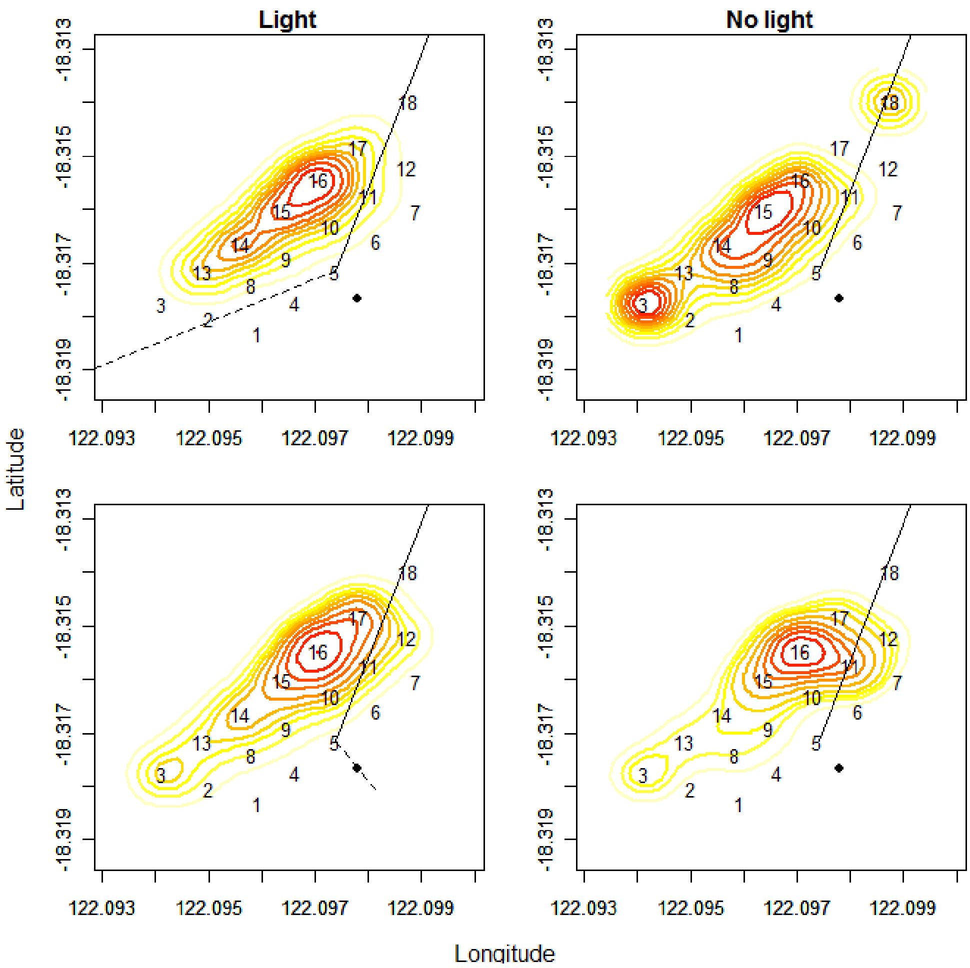

Figure 7. Kernel density plot of turtle hatchling detection density on each of the receivers (numbered) for light treatments in the left panel and no light treatment in the right panel. Warmer colours correspond to more points. The black dot is the release point. Solid line is the direction of Broome; dashed line shows the direction of the artificial lights in each of the experiments with artificial light.

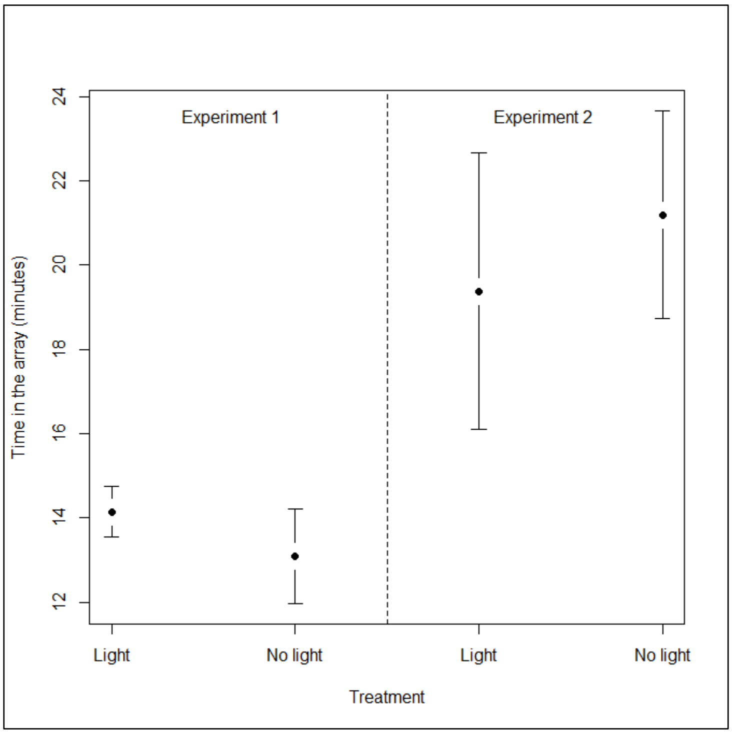

Figure 8. Mean and standard error of time turtle hatchlings spent in the tracking array for each of the treatments for each of the experiments.

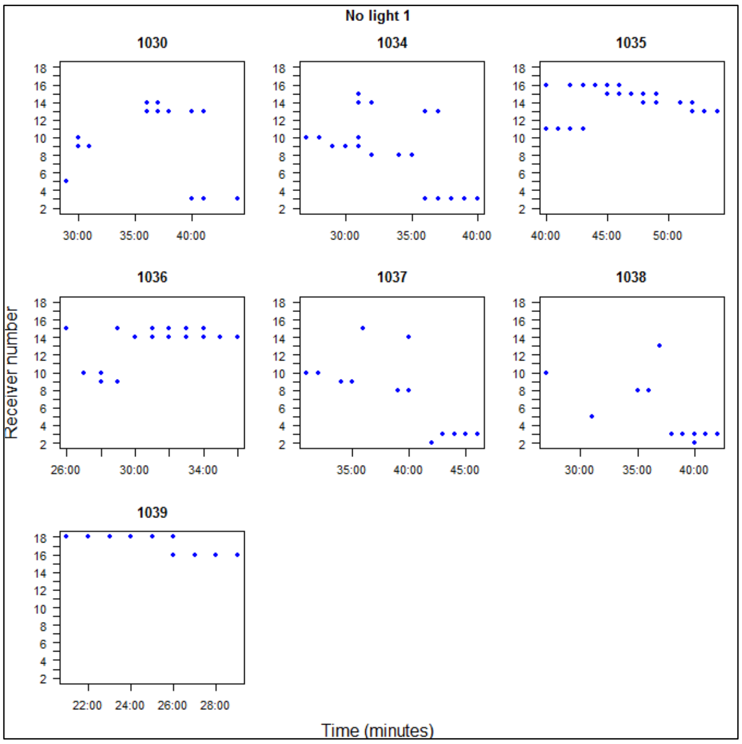

Figure 9. The detections per minute for each of the receivers for each individual hatchling in the first no light experiment. From this data we can get an indication of the direction taken through the array. Note: there were no detections on receiver 1.

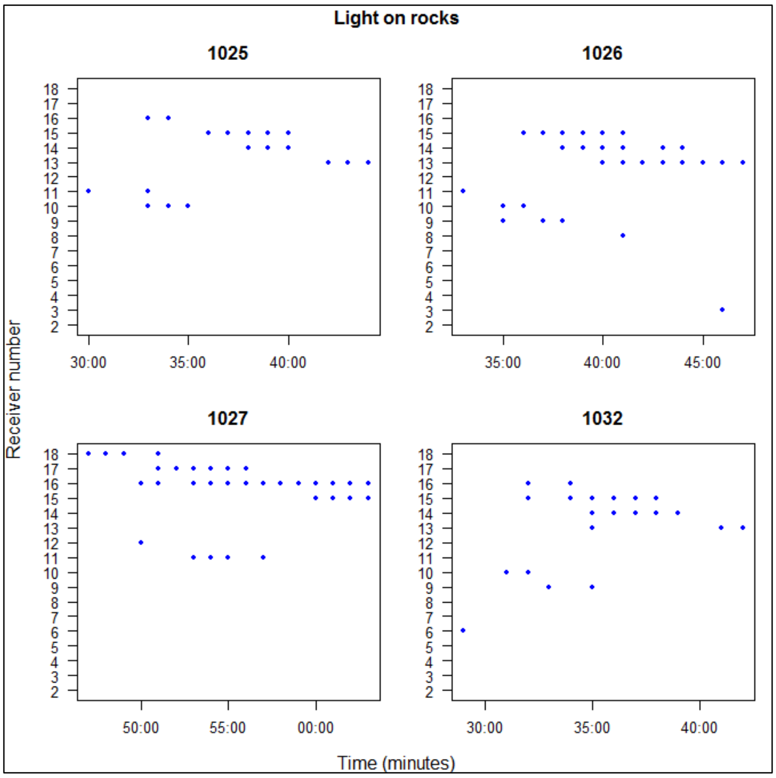

Figure 10. The detections per minute for each of the receivers for each individual hatchling in the first light experiment. From this data we can get an indication of the direction taken through the array.

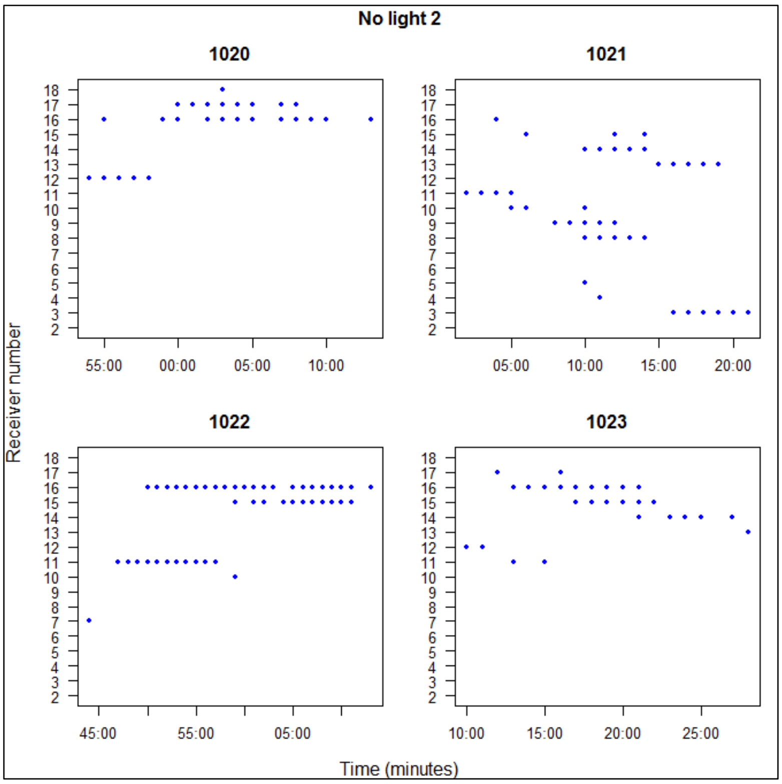

Figure 11. The detections per minute for each of the receivers for each individual hatchling in the second no light experiment. From this data we can get an indication of the direction taken through the array.

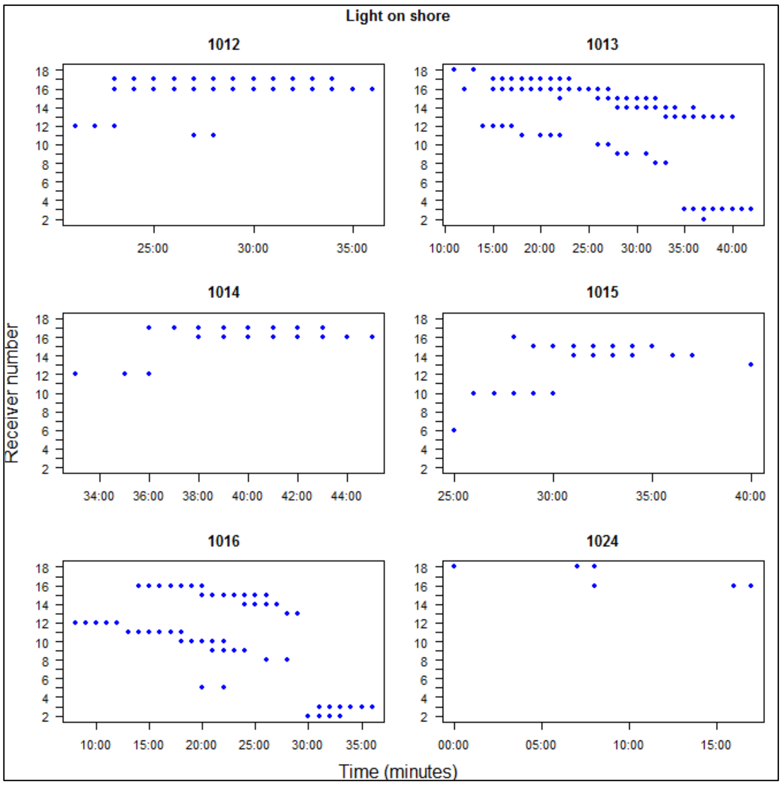

Figure 12. The detections per minute for each of the receivers for each individual hatchling in the second no light experiment. From this data we can get an indication of the direction taken through the array.

Manual tracking

The three tagged turtles were tracked manually for 127, 81 and 5 min respectively. The turtle followed for 127 minutes was 2.38 km off shore and headed in a north-west direction from the release point when we stopped tracking (Figure 13). The second turtle was 922 m from shore heading in a north-north-west direction at the last detection (Figure 13). The waves were largely west-north-west, indicating that these hatchlings travelled against the direction of wave propagation.

Figure 13. Two tracks of turtle hatchlings manually tracked with an acoustic receiver and directional hydrophone. Tracks are shown in yellow, grey dots represent the automated tracking array and black dots represent the nest sites.

Discussion

This is the first time that acoustic telemetry has been used to track free-ranging turtle hatchlings in water. Our study shows that it is an effective means of following hatchlings and opens the possibility to examine the factors determining locomotion and orientation of hatchlings immediately following their entry into the water. Importantly, the small size and weight of the transmitters did not impede the swimming, or the buoyancy of the tagged turtles. We found that, at least in the surf zone, artificial lights did not affect movement, with the turtles largely travelling against the direction of wave propagation. The array was deployed and retrieved with relative ease, in this case by hand, but in deeper environments (>30 m) this could be done from a small boat. Manual acoustic tracking allowed the hatchlings to be tracked beyond the receiver array and in the future this method could be used to quantify the factors that influence their movement over larger (1 - 10s of km) spatial scales, such as currents, waves and magnetic fields.

Our results provide information critical to the planning of larger-scale and longer-term studies. The surf zone where we worked was a challenging environment in which to use an acoustic array, but despite the problems this created we successfully detected nearly all of the tagged turtles released into the array. Improvements in detection range and the ability to calculate turtle positions with 5 m accuracy could be made by simple changes to the experimental design including: 1) placing the receiver array in deeper water, further from shore or with a smaller distance between receivers in high energy environments and 2) use of this array in calmer waters or choosing the timing of the experiment carefully to coincide with the best weather conditions.

We found no effects of artificial light on movement of turtle hatchlings, however this result was in part confounded by our improvised experimental design and the lack of large numbers of accurate turtle positions. Again, improvements to the experimental design outlined above will allow us to conclusively answer this question in the future. It is entirely possible that the direction of wave propagation is an overriding cue for turtle hatchlings when in the surf zone, but once beyond this area, artificial lights may be more influential. Use of a larger receiver array, extending beyond the surf zone will help to elucidate the effect of light on in-water movement.

In conclusion, we have shown that acoustic tracking has great potential as a means to understand the initial offshore movement of turtle hatchlings and answer specific questions relating to the effect of artificial light sources – information essential for management of turtles to ensure the persistence of populations. A larger tracking array, combined with improvements in array design gleaned from this pilot study and the concurrent collection of oceanographic data will allow us to quantify the effect of artificial lighting on turtle hatchlings. The results of such studies will be important in the planning of new developments and the type and positioning of lights in relation to turtle nesting beaches. The approach will also provide an understanding of the environmental factors that influence their movement offshore, such as wave direction and currents. These data can then be used to model turtle hatchling movement over larger spatial scales and understand the initial stages of the turtle “lost years”.

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Appendix 1. Details of turtle hatchlings released into the tracking array. SCL = straight carapace length and SCW = straight carapace width.

ID	Treatment	Date	Time	Nest	Hatch date	SCL (mm)	SCW (mm)	Mass (g)
1037	No light	27 Jan	00:10	1	26 Jan	57.3	44.9	31.9
1038	No light	27 Jan	00:10	1	26 Jan	60.1	52.0	33.8
1034	No light	27 Jan	00:10	1	26 Jan	58.4	50.6	31.1
1039	No light	27 Jan	00:10	1	26 Jan	60.6	49.2	36.1
1036	No light	27 Jan	00:10	1	26 Jan	59.7	50.2	35.2
1030	No light	27 Jan	00:10	1	26 Jan	57.5	46.3	33.4
1035	No light	27 Jan	00:10	1	26 Jan	60.0	50.2	37.1
Mean ± SD						**59.1 ± 1.3**	**49.1 ± 2.5**	**34.1 ± 2.2**
1032	Light	27 Jan	01:10	1	26 Jan	59.8	49.5	33.4
1033	Light	27 Jan	01:10	1	26 Jan	54.0	45.3	31.6
1027	Light	27 Jan	01:10	1	26 Jan	58.2	48.9	34.5
1025	Light	27 Jan	01:10	1	26 Jan	60.7	49.4	36.2
1029	Light	27 Jan	01:10	1	26 Jan	56.7	46.6	35.0
1026	Light	27 Jan	01:10	1	26 Jan	56.2	46.4	33.0
Mean ± SD						**57.6 ± 2.5**	**47.7 ± 1.8**	**34.0± 1.6**
1018	No light	28 Jan	00:40	2	27 Jan	61.5	51.9	35.6
1028	No light	28 Jan	00:40	2	27 Jan	60.1	51.6	36.2
1022	No light	28 Jan	00:40	2	27 Jan	60.4	51.6	34.5
1020	No light	28 Jan	00:40	2	27 Jan	60.1	50.6	35.4
1023	No light	28 Jan	00:40	2	27 Jan	59.9	50.8	36.2
1021	No light	28 Jan	00:40	2	27 Jan	61.5	51.3	37.7
Mean ± SD						**60.6 ± 0.7**	**51.3 ± 0.5**	**35.9 ± 1.1**
1024	Light	29 Jan	01:09	2	27 Jan	61.5	49.9	36.6
1016	Light	29 Jan	01:09	2	27 Jan	61.3	52.6	36.0
1013	Light	29 Jan	01:15	2	27 Jan	61.1	52.9	36.0
1014	Light	29 Jan	01:15	2	27 Jan	61.3	50.8	36.2
1012	Light	29 Jan	01:22	2	27 Jan	61.4	51.3	36.8
1015	Light	29 Jan	01:22	2	27 Jan	62.2	51.3	36.0
1017	Light	29 Jan	01:22	2	27 Jan	60.5	50.4	36.4
Mean ± SD						**61.3 ± 0.5**	**51.3 ±1.1**	**36.3 ± 0.3**
Mean ± SD						**59.7± 2.0**	**49.9 ± 2.2**	**35.1 ± 1.8**