Final report on inter-nesting habitat use by flatback turtles from the Curtis Island rookery- 2013 to 2015

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This report has been produced for the Ecosystem Research and Monitoring Program Advisory Panel as part of Gladstone Ports Corporation's Ecosystem Research and Monitoring Program. The study was undertaken through a Consultancy Agreement (CA13002463) between Gladstone Ports Corporation and James Cook University to Increase understanding of flatback turtle habitat use in the Port Curtis and Port Alma region: using satellite telemetry.

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Executive summary

Marine turtles lay several clutches of eggs in a breeding season at intervals of around 14 days. After laying her first clutch, a female turtle will generally remain close to the nesting beach and the period between a turtle laying one clutch and her attempt at a subsequent clutch is known as the re-nesting period and the period between a females arrival at and departure from a nesting beach is her inter-nesting perion.

We used GPS satellite tags to examine the movement patterns of female turtles nesting at Curtis Island to understand the extent to which flatback turtles used the Port of Gladstone and Port of Rockhampton regions during their inter-nesting period. This report summarises data collected from November 2013 to January 2016.

Eleven flatback turtles were caught each year between 2013 and 2015 on the southern beach of Curtis Island after they completed nesting. They were each fitted with a satellite tag configured to transmit GPS location and depth via satellite.

Thirty of the 33 turtles laid further clutches of eggs in the Curtis Island region, thus providing data on habitat use during their inter-nesting period. To understand how the flatback turtles used the inter-nesting habitat we examined the distribution and density of GPS locations for each turtle to determine core habitat use areas - 50% or 95% core habitat use areas explain where an individual turtle spends 50 or 95% of its time.

The size of the core habitat used by the 30 turtles during the inter-nesting period ranged from 6 to 458 km^2 (50%) and 51 to 1501 km^2 (95%). The overall combined mean area used by the turtles was similar between years.

All of the 30 turtles spent some of their time within the waters of the Port of Gladstone and in 2015 one turtle spent its first re-nesting period (between clutches 1 and 2) within the Port of Rockhampton. Six turtles spent at least half of their time using the waters within the Port of Gladstone. Twenty turtles that used the Port of Gladstone spent at least some of their time within 100 m of vessel transit lanes. Ten turtles (all from 2014) used the passage between Curtis and Facing Islands to move to and from the nesting beach and the sheltered waters inside of the Port of Gladstone.

The average maximum water depth the flatback turtles used during their 2014 and 2015 inter-nesting periods was 22.3 m and the average depth was 12.3 m (± 3.9). Overall, the turtles spent 10% of their time in water depths less than 2 m and half of their time at depths between 10 and 20 m. A comparison of home range area and bathymetry indicates that the turtles spend most of their time on the bottom.

Based on the home range analysis, it is clear that the waters immediately offshore of Curtis and Facing Islands, the waters along the southern coast of Facing Island and the waters between Facing Island and the mainland are all important habitat for inter-nesting flatback turtles. It would be reasonable to assume that adult female flatback turtles will be present in these areas from October to January each year.

Introduction

Gladstone Ports Corporation (GPC) manages the development and operation of facilities and services within the Port of Gladstone, including the Western Basin Dredging and Disposal Project - WBDDP) that occurred from 2011 to 2013. The purpose of the dredging project was to deepen and widen existing shipping channels and swing basins and to create new shipping channels, swing basins and berth pockets.

To undertake these dredging activities, GPC had to meet a number of environmental conditions, one of which was the development and implementation of an Ecosystem Research and Monitoring Program (ERMP). The ERMP was developed to acquire a detailed ecological understanding of the marine environment of the Port of Gladstone and the Port of Rockhampton, including The Narrows and the Western Basin. In particular, the ERMP sought information to monitor, manage and/or improve the regional marine environment and to offset potential impacts from the project on listed threatened and migratory species and values of the Great Barrier Reef World Heritage Area and National Heritage Place.

The flatback turtle (*Natator depressus*) is sea turtle species that is endemic to Australia and nests on tropical beaches from southern Queensland mid-latitudes of Western Australia. There are currently five distinct geographical populations and the flatbacks of the central Queensland coast form one population (Limpus 2009). Studies employing external flipper tags revealed flatbacks nest up to four times during a breeding season and they take between 9 and 20 days to produce a clutch of eggs. The species is listed as a vulnerable under the Queensland Nature Conservation Act 1992 and the Australian Environmental Protection and Biodiversity Conservation Act 1999. Although the species has been studied since the late 1960s little is known of their in-water behaviour. Including how they use the coastal habitats during the nesting season. Data reported in 2007 from low accuracy satellite tags deployed on two female flatback turtles indicated that breeding turtles could use the Port Curtis area (Sperling 2007) potentially exposing them to risks associated with ports and shipping. Therefore, we deployed GPS linked satellite tags on breeding flatback turtles over three years and examined the data for high-resolution movement, behaviour, and habitat use in the Port of Gladstone, Port of Rockhampton and The Narrows, all within the ERMP survey area (Figure 1). Ultimately, this work will increase the understanding of flatback turtle use of marine habitats in the Gladstone region.

Methods

The research team comprised PhD students and staff from James Cook University and assistance in the field was provided by volunteers for the Queensland Department of Environment and Heritage Protection’s (EHP’s) marine turtle project, local residents and staff from the Queensland Parks and Wildlife (QPWS) in Gladstone. All turtles were encountered during surveys conducted on South End Beach on Curtis Island (Figure 1).

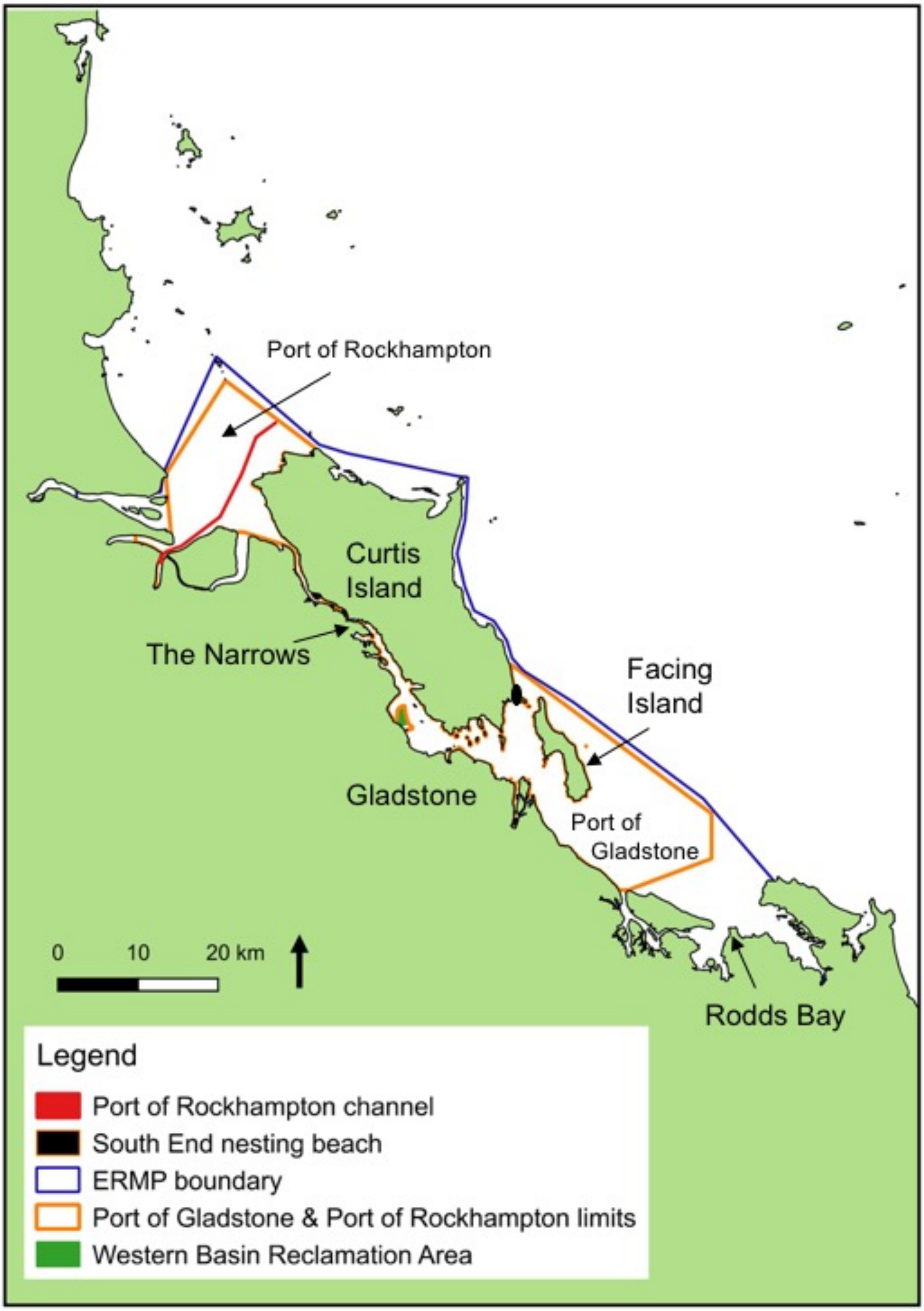

Figure 1. Map of the study region

Data collection

During November or December in each year (2013, 2014 and 2015), 11 flatback turtles were caught after they had completed a nesting event and restrained by hand. Each of the turtles were then tagged with individually numbered flipper and PIT tags as per the Queensland turtle research project, or had the numbers of existing tags recorded. They were then measured for curved carapace length (CCL) and fitted with satellite tags. The turtles were fitted and tracked by using 'Wildlife Computers – SPLASH10 FastLoc' satellite tag and harness following the methods of Whittock *et al.* (2014) (Figure 2). Because we attached tags to the turtles after they had laid a clutch of eggs, we define the inter-nesting period as the number of days between the date of tag attachment (i.e. laying a clutch of eggs) and the date the turtle departs on a migration towards a foraging destination. We acknowledge that because we don't know whether an individual had laid a clutch of eggs prior to us attaching the tags, especially in 2013, the length of the inter-nesting periods are likely an underestimate. The period of time between clutches is regarded as the re-nesting period and the duration of the re-nesting interval is the number of days between a turtle laying a clutch of eggs and her arrival at the beach for a subsequent clutch – regardless of whether she was successful. Re-nesting intervals were calculated using either confirmed on-beach nesting events or GPS haul out signals indicating the turtle was on a beach within a biologically appropriate timeframe of between 9 and 20 days (Hamann *et al.* 2003; Whittock *et al.* 2014). In 2013, the tags were deployed between November 25 and 29, in 2014 they were deployed between November 14 and 18 and in 2015, ten tags were deployed between November 6 and 10 and one tag was deployed in early December (Table 1). Three of the turtles tagged in 2013 migrated immediately and thus did not have a re-nesting period and thus were not included in any of the analysis.

Figure 2. A female flatback turtle being fitted with a harness-mounted GPS satellite tag (top). The tags were pre-attached to the plates (bottom left) making the attachment time < 10 minutes from capture. The harness straps attach to a steel ring on the plastron (bottom right) with a corrodible link expected to release around eight months.

Table 1. Capture history for the flatback turtles fitted with satellite transmitters at Curtis Island, 2013 to 2015

Flipper tag number (EHP primary tag)	ARGOS satellite tag number	Date tagged	Curved carapace length (cm)
2013			
QA30770	134189	26 November	95.5
K43635	134190	27 November	94.6
T85646	134191	26 November	97.6
T97108	134192	25 November	98.7
QA18561	134193	25 November	Not measured
T20452	134194	26 November	95.6
T97111	134195	26 November	99.4
K44384	134196	26 November	97.7
QA30752	134197	26 November	90.1
T97125	134198	25 November	Not measured
T85652	134199	25 November	91.8
2014			
QA20377	141738	14 November	91.6
QA20379	141739	15 November	92.3
T85633	141740	13 November	98.9
QA20400	141741	13 November	99.2
QA20381	141742	17 November	94.3
T15866	141743	16 November	92.9
K43572	141744	18 November	89.4
QA20398	141745	18 November	91.8
QA20383	141746	18 November	93.1
T97209	141747	18 November	97.8
QA20388	141748	18 November	93.8
2015			
QA23239	152710	10 November	95.4
K33707	152711	9 November	93.3
T85690	152712	6 November	93.5
QA30727	152713	10 November	Not measured
QA46070	152714	6 November	91.3
K43686	152715	6 November	92.1
K19907	152716	8 November	99.3
QA10095	152717	9 November	92.8
QA30747	152718	8 November	Not measured
QA30764	152719	8 November	Not measured
T97111	152720	30 November	Not measured

Data filtering

Satellite location data were downloaded using the Wildlife Computers online data portal, or using a computer interface if the turtles were intercepted on the beach. The collection of data on the beach directly from the tag ensured the entire dataset was obtained and not just the subset transmitted via satellite. The GPS location data were filtered to remove erroneous data points as outlined in Shimada *et al.* (2012) and Gredzens *et al.* (2014). In particular, we removed duplicate locations, GPS locations derived using <4 satellites, and locations with the number of satellites equalling four, with a cos angle ≥0 and speed between successive points of >1.8 km/h because these represent biologically improbable movements. Data points transmitted while the turtle was on land for nesting were retained so we could determine inter-nesting intervals, but they were excluded from in the inter-nesting home range analysis.

Home range calculations

The filtered data were used to calculate the median position for every six-hour period over a 24-hour period. This time frame was selected to ensure a sample size greater than 30 was available for kernel analysis (Whittock *et al*. 2014). GPS coordinates were converted into UTM format using LOTE software to enable us to calculate distance and speed. The home ranges of each turtle and their movement pathways were calculated using Geospatial Modelling Environment to create a Kernel Density Estimate (KDE). Least-squares cross-validation was determined to be the most appropriate bandwidth selector as it had the least amount of overshoot and exaggeration for this type of dataset (Horne & Garton 2006). KDEs and isopleths of the 95% and 50% utilisation distributions were calculated for each inter-nesting interval and nesting season (Gredzens *et al*. 2014). One-way ANOVAs with a type I error rate of 0.05 were calculated for the size of the 95% and 50% utilisation distributions between successive inter-nesting intervals; and for the size of the 95% and 50% utilisation distributions to compare data across nesting seasons. Tukey's HSD Post Hoc tests were applied to any significant interactions. The 95% and 50% home range estimates related to the areas turtles spend 95% and 50% of their time.

Dive data

The dive data were summarised in six-hour bins by depth band and percentage of time spent at these depths; 0-2 m, 2-4 m, 4-6 m, 8-10 m, 10-12 m, 12-15 m, 15-20 m, 20-25 m, 25-30 m, 30-35 m, 35-40 m, 40-45 m, 45+ m. Six hourly bins are set by the tag manufacturer and are the minimum time period for which data are available. These data were transmitted via ARGOS during 2013 but it was not sufficient quality and quantity to enable analysis, as there were fewer than five six-hour bins of data transmitted. Nine turtles in 2014 and 2015 had at least one re-nesting interval of complete data downloaded directly from the tags. This gave us at approximately 14 days of complete six-hour bins (4 per day).

Water depth

A bathymetry layer with 100 m resolution for the region was sourced from Deep Reef (https://www.deepreef.org/bathymetry.html). Preferred depth zones of each turtle were determined by overlaying bathymetry data with the six-hour binned turtle GPS locations during each individual's inter-nesting period and calculating a water depth value for each GPS location (as per Gredzens *et al*. 2014). Hence, we can extract a depth value for each six-hour GPS location (= four depth values per day) The bathymetry layer was reclassed into 5 m depth contours for a *chi-square*- analysis and the area of each 5 m depth zone was calculated. The number of six-hour binned turtle GPS locations within each depth zone were also calculated. To determine whether flatback turtles prefer deeper water during the inter-nesting period, a *chi-square*- test compared the observed frequency of the turtles in different water depths and the proportion of different water depths present in the area contained in the collective home range use polygon, constructed by connecting the outermost locations from all turtle's data.

Turtle interactions with shipping vessels and port activity

Shipping vessel movement

Vessel location data for commercial vessels in the Gladstone region were obtained for the duration of each nesting season (October to December) from the Australian Maritime Safety Authority (AMSA) vessel traffic database. Stationary vessels (speed <1 knot) were removed from the dataset, as a stationary vessel posed minimal risk to turtles. Vessel speed was not further considered because commercial vessels used designated transit areas so high (>10 knots) and low (<10 knots) speed commercial vessels used the same spaces. A polygon that encompassed the commercial vessel transit areas within the port area was constructed in ArcGIS.

A one-way ANOVA with a type I error rate of 0.05 was used to determine if there was a significant difference in the proportion of the collective (i.e. all turtle data combined) home ranges that occurred inside the Port of Gladstone between nesting seasons and the proportion of the home ranges that were inside the shipping lane between years.

Results

Inter-nesting behaviour and home range estimates

Thirty-three turtles were tagged and 30 remained in the area to lay additional clutches. All turtles left the Curtis Island area within two days of laying their final clutch, the mean departure date was December 13 and 90% of the turtles left before December 23. The nesting habits of flatback turtles in the Gladstone region differed among individual turtles and years. In all seasons, the turtles laid most of their clutches on Curtis Island. However, in 2014, one female (T97209) laid a clutch of eggs on Facing Island and another laid two clutches of eggs on the beach at Rodds Bay to the south of Gladstone (see Figures 1 and 4). The duration of re-nesting intervals ranged from the biological minimum (9 days) to 30 days (Table 2). To determine the number of clutches that females laid per year, we only used telemetry data from 2014 and 2015 because in 2013 the turtles were not tagged until late in November and we likely missed their earlier clutches of eggs. Further, we also did not include one turtle (T97111)) tagged late in the season in 2015 and two turtles (K19907 and QA10095) for which tracking devices were removed because of damaged harnesses. Based on satellite telemetry data from 2014 (n=11) and 2015 (n=10), flatback turtles from Curtis Island laid an average of 3.2 ± 0.6 clutches (3 ± 0.5 in 2014/15 and 3.4 ± 0.7 in 2015/16).

Table 2. Capture and re-capture history for the flatback turtles fitted with satellite transmitters after they nested at South End Beach, Curtis Island. In 2013, the turtles were tagged later in the season and thus it is likely that we missed the first clutch(es) for these individual turtles.

Flipper tag number (EHP primary tag)	**Date tagged**	**Date(s) of next clutch laid**	**Number of clutches based on satellite derived data and on beach sighting**
2013			
QA30770*	26 Nov	13 Dec	2+
K43635	27 Nov	12 Dec	2+
T85646	26 Nov	Did not return	1+
T97108	25 Nov	Did not return	1+
QA18561	25 Nov	Did not return	1+
T20452	26 Nov	11 Dec & 26 Dec	3+
T97111	26 Nov	11 Dec	2+
K44384	26 Nov	11 Dec	2+
QA30752*	26 Nov	12 Dec & 26 Dec	3+
T97125	25 Nov	11 Dec	2+
T85652	25 Nov	11 Dec	2+
2014			
QA20377	14 Nov	26 Nov & 11 Dec	3
QA20379	15 Nov	29 Nov, 12 Dec & 31 Dec	4
T85633	13 Nov	29 Nov & 14 Dec	3
QA20400	13 Nov	1 Dec & 15 Dec	3
QA20381	17 Nov	30 Nov & 17 Dec	3
T15866	16 Nov	1 Dec	2
K43572	18 Nov	6 Dec & 20 Dec	3
QA20398	18 Nov	6 Dec	2
QA20383	18 Nov	1 Dec, 14 Dec & 28 Dec	4
T97209	18 Nov	3 Dec & 20 Dec	3
QA20388	18 Nov	7 Dec & 22 Dec	3
2015			
QA23239	10 Nov	25 Nov & 9 Dec	3
K33707	9 Nov	23 Nov, 9 Dec & 18 Dec	4
T85690	6 Nov	6 Dec	2
QA30727	10 Nov	26 Nov, 10 Dec, 23 Dec	4
QA46070	6 Nov	23 Nov & 5 Dec	3
K43686	6 Nov	21 Nov, 6 Dec & 25 Dec	4
K19907	8 Nov	25 Nov & 7 Dec	3
QA10095	9 Nov	24 Nov & 7 Dec	3
QA30747	8 Nov	24 Nov, 8 Dec & 23 Dec	4
QA30764	8 Nov	25 Nov, 7 Dec & 22 Dec	4
T97111	30 Nov	9 Dec & 24 Dec	3+

Satellite tag performance

In 2013, we used Wildlife Computers tags (SPLASH10-F-297A). These were upgraded to a larger model in 2014 and 2015 (SPLASH10-F-296A). The mean number of filtered GPS locations retained for analysis for the turtles during the inter-nesting period was 106 (6 per day) in 2013 and 150 (5 per day) in 2014. In 2015, we received more data because all but one of the turtles had their GPS data downloaded from the beach. This allowed us to receive the entire set of locations rather than the sub-set transmitted by satellite in 2013 and 2014. The mean number of locations in 2015 was 623 (19 per day) (Table 3).

Overall home ranges

The 95 and 50% inter-nesting home ranges for individual turtles ranged from 51 to 1501 km^2 and 6 to 458 km^2 respectively. There was a high degree of variability in the average size of the 95% and 50% home ranges per season; from 51 km^2 to 1501 km^2, and 6 km^2 to 458 km^2, respectively (Table 4, Figure 3). There was no statistical relationship between the total length of time for which an individual was tracked and her 95% or 50% home range area, or when in the season an inter-nesting interval started and the size of the 95% or 50% home range area (ANOVA $F=1.13$, $p=0.257$, $df=57$). There was no statistically significant difference in the size of the 95% or 50% home ranges across years for all turtles combined (ANOVA $F = 2.70$, $p>0.1$ $df=3,27$, Figures 4,5,6, 7a,b).

Table 4. Overall size of the 95% and 50% home ranges for turtles breeding in the 2013, 2014 and 2015 seasons.

	2013	**2014**	**2015**
95% home range	375 ± 214 (147-692) km^2	346 ± 428 (59-1501) km^2	452 ± 444 (51-1049) km^2
50% home range	92 ± 57 (34-130) km^2	92 ±133 (15-458) km^2	77 ± 68 (6-176) km^2

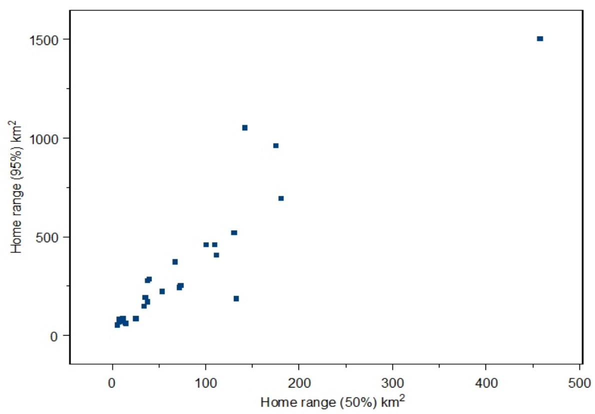

Figure 3. Variation in home range size, and the relationship between 50% and 95% home range areas for flatback turtles tracked between 2013 and 2015

Table 3. Average number of filtered GPS locations retained for the turtles that remained in the inter-nesting habitat. The most accurate GPS locations are approximately ±50 m.

Flipper tag number	**Days tracked during the nesting period**	**Total number of GPS locations for the inter-nesting**	**GPS locations per day for the inter-nesting period**
QA30770	18	124	7
K43635	16	71	4
T20452	15	101	7
T97111	15	101	7
K44384	15	101	7
QA30752	45	123	3
T97125	16	126	8
T85652	15	106	7
2013 average		**106**	**6**
QA20377	27	129	5
QA20379	46	220	5
T85633	31	115	4
QA20400	32	142	4
QA20381	30	166	6
T15866	13	85	7
K43572	32	186	6
QA20398	18	45	3
QA20383	38	206	6
T97209	30	173	6
QA20388	34	185	5
2014 average		**150**	**5**
QA23239	32	509	16
K33707	39	613	16
T85690	13	370	29
QA30727	49	711	15
QA46070	29	283	10
K43686	49	1039	21
K19907	29	866	30
QA10095	28	828	30
QA30747	43	607	14
QA30764	45	823	10
T97111	25	213	9
2015 average		**623**	**19**

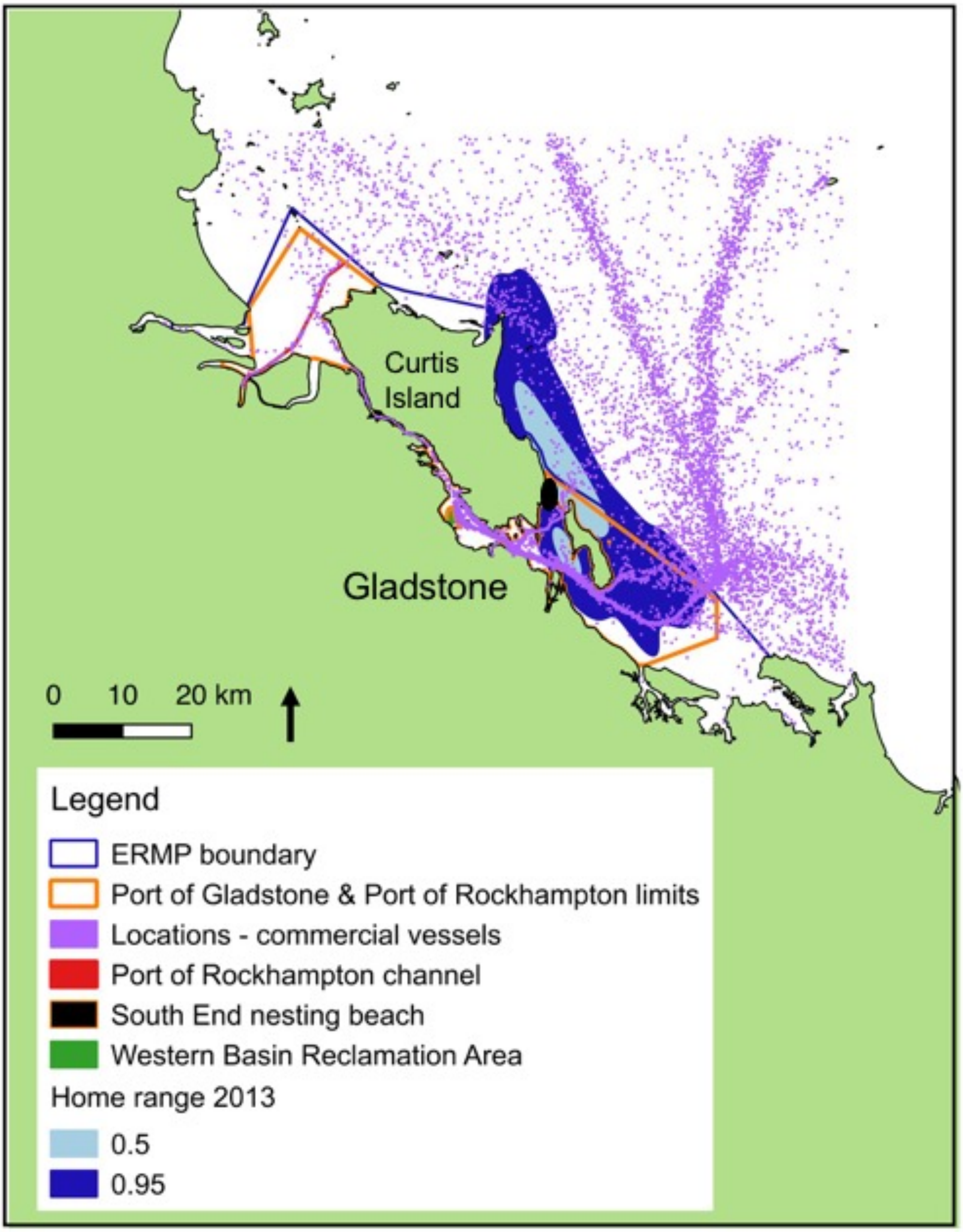

Figure 4. Habitat use areas for eight flatback turtles tracked during their inter-nesting period(s) during November and December 2013. The dark and light blue areas indicate habitat that the turtles used 95% and 50% of their time respectively.

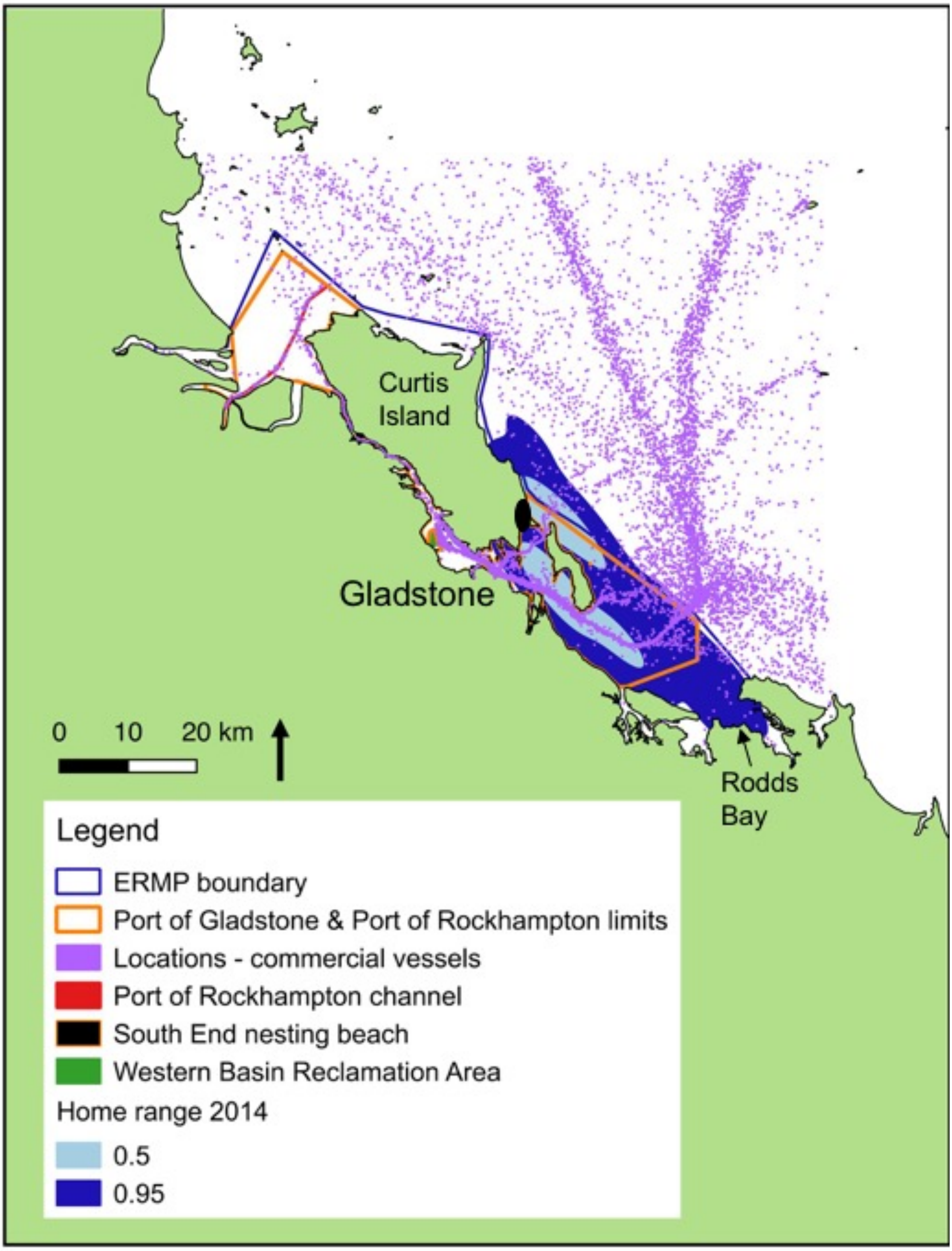

Figure 5. Habitat use areas for 11 flatback turtles tracked during their inter-nesting period(s) during November and December 2014. The dark and light blue areas indicate habitat that the turtles used 95% and 50% of their time respectively.

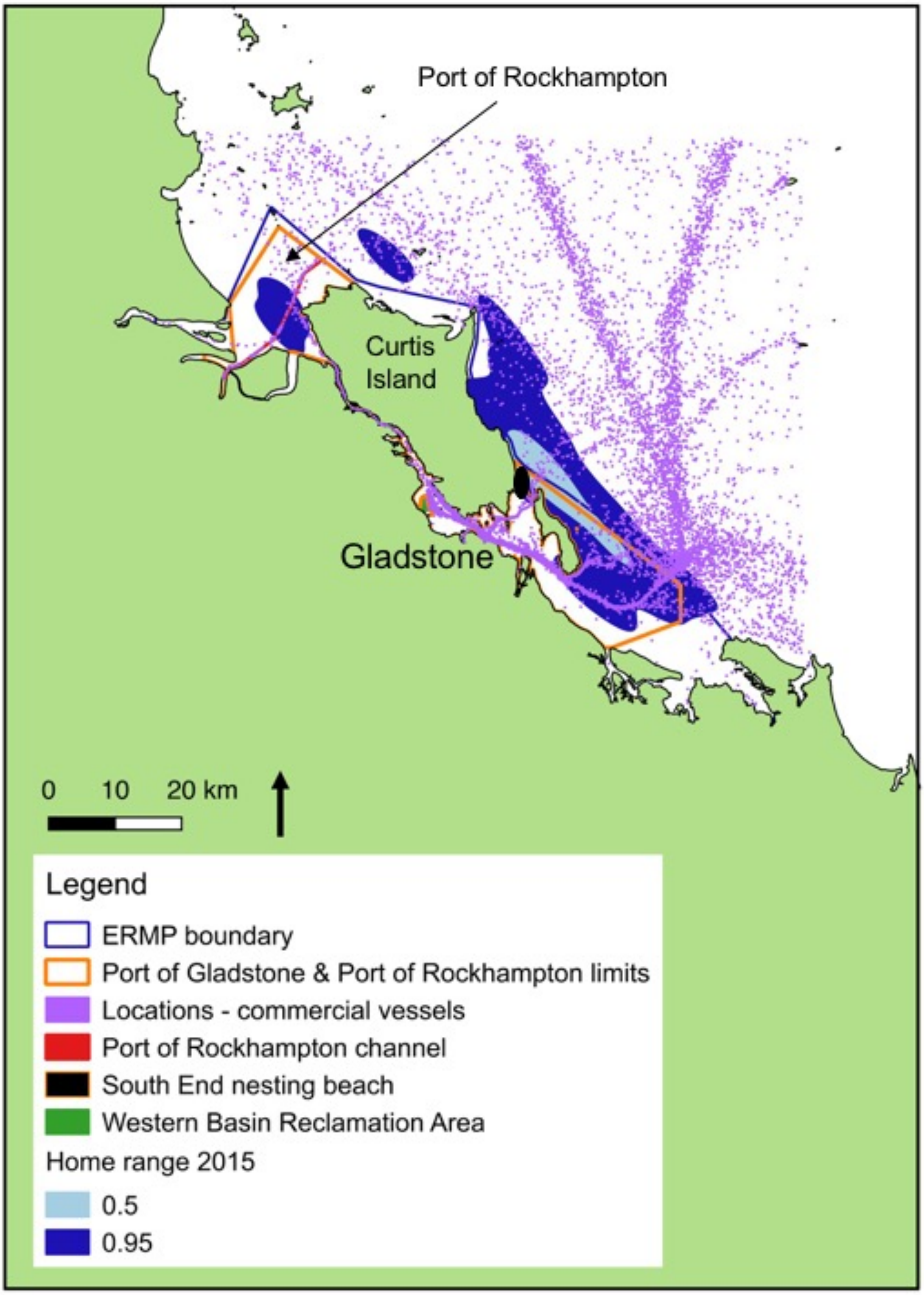

Figure 6. Habitat use areas for 11 flatback turtles tracked during their inter-nesting period(s) during November and December 2015. The dark and light blue areas indicate habitat that the turtles used 95% and 50% of their time respectively.

Variation in home range size within a season

In 2013, one of the eight females was tracked for three successive re-nesting periods – i.e. she laid at least four clutches of eggs. The turtle used the largest area of habitat between her 1st and 2nd clutches (Table 5). Her core (50%) habitat (i.e. habitat used between clutches 2 and 3 and 3 and 4) overlapped by 100% for all three periods and there was 100 % overlap of habitat used between the 2nd and 3rd period with the first.

Table 5. Comparison of the size (km^2) of inter-nesting habitat used in consecutive re-nesting periods for turtles tracked in 2013.

	Re-nesting period 1		**Re-nesting period 2**		**Re-nesting period 3**	
	95%	**50%**	**95%**	**50%**	**95%**	**50%**
QA30752	475	94	23	3	49	3

In 2014, we tracked six individuals for two successive re-nesting periods and three individuals for three successive re-nesting periods (Table 6). In general, there was a high (>80%) level of overlap between both 50% and 95% KDEs across home ranges for individuals tracked across successive inter-nesting periods, implying that turtles were using very similar space between laying each of their clutches. There were two exceptions – turtle T85633 spent its first re-nesting period (between clutches 1 and 2) inside waters of the Port of Gladstone between Facing Island and the mainland and its second re-nesting period was spent in the waters to the north of Curtis Island, approximately 50 km away from the nesting beach – partially within the Port of Gladstone and the ERMP survey area. Turtle QA20383 was tracked for three re-nesting periods and the habitat the turtle used between clutches 1 and 2 had a 10% overlap with the habitat she used in between her next two clutches.

Table 6. Comparison of the size (km^2) of inter-nesting habitat used in consecutive re-nesting periods for turtles tracked in 2014.

	Re-nesting period 1		**Re-nesting period 2**		**Re-nesting period 3**	
	95%	**50%**	**95%**	**50%**	**95%**	**50%**
QA20377	58	17	58	17	No data	No data
T85633	381	110	1501	458	No data	No data
QA20400	235	75	89	23	No data	No data
QA20381	292	75	275	41	No data	No data
K43572	195	64	492	151	No data	No data
T97209	540	99	319	41	No data	No data
QA20388	359	99	257	58	No data	No data
QA20379	350	82	230	64	376	104
QA20383	522	104	407	87	301	75

In 2015, we tracked five individuals for two successive re-nesting periods and four individuals for three successive re-nesting periods (Table 7). Similar to 2014, there was a high (>80%) level of overlap between 50% and 95% KDEs across home ranges for individuals tracked across successive re-nesting periods, implying that turtles were using very similar space between laying each of their clutches (for example turtle K43686; Figure 6a). Again, there were two exceptions – turtle QA30747 spent its first re--nesting period (between clutches 1 and 2) to the north of Curtis Island, and within the Port of Rockhampton. Then she spent her second two re-nesting periods in habitat between Facing Island and the mainland. Turtle T97111 (Figure 6b) spent its first re-nesting period offshore from Curtis Island, outside the Port of Gladstone, and its second re-nesting period in habitat between Facing Island and the mainland, inside Port of Gladstone.

Table 7. Comparison of the size (km^2) of inter-nesting habitat used in consecutive re-nesting periods for turtles tracked in 2015.

	Inter-nesting period 1		**Inter-nesting period 2**		**Inter-nesting period 3**	
	95%	**50%**	**95%**	**50%**	**95%**	**50%**
QA23239	453	21	486	86	No data	No data
QA46070	781	33	222	70	No data	No data
K19907	514	21	349	12	No data	No data
QA10095	267	8	431	12	No data	No data
T97111	987	49	1028	41	No data	No data
QA30727	1468	37	959	33	1499	57
K43686	350	12	390	12	411	20
QA30747	1049	90	534	16	493	20
QA30764	1460	49	493	12	895	82

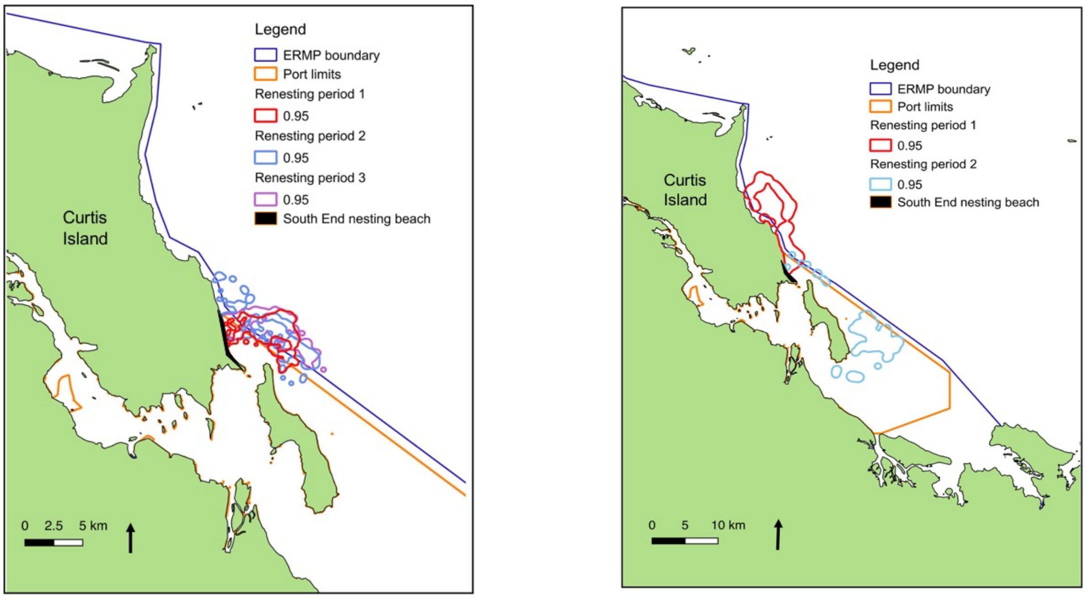

Figure 7. Habitat use (95% contours) by two flatback turtles during their inter-nesting period in 2015 – showing similarity in habitat use between three re-nesting periods – turtle 152715 (a) and difference of habitat use between two re-nesting periods – turtle 152720 (b).

Use of Port waters by flatback turtles during the nesting season

All of the 30 flatback turtles tracked during their inter-nesting period used the habitats within the ERMP Survey/Study area and the Port of Gladstone waters and in 2015 one turtle spent its first re-nesting period (between clutches 1 and 2) to the north of Curtis Island, within the Port of Rockhampton (Figure 4). No turtles used the narrows. At an individual turtle scale – the size of area within the Port of Gladstone used by turtles varied from <1 to 1142 km^2 for the 95% home range area and <1 to 70 km^2 for the core (50%) area. Within a year, the average proportion of the 95% home range occurring within the Port of Gladstone area varied between 14% (2013) and 51% in 2014, and the proportion of the 50% home range occurring within the Port of Gladstone area varied between 17% (2013) to 60% in 2014. The proportion of the 95% home range within the Port of Gladstone was significantly different among nesting seasons (ANOVA, F=7.1, p=0.002, df=2). The turtles had a smaller proportion of the 95% home range inside the Port of Gladstone in the 2013 and 2015 nesting seasons than the 2014 nesting season (Tukey's, q=-7.76, df=41, n=31). There was no significant difference in the proportion of the 50% home range inside the Port of Gladstone between nesting seasons (ANOVA, F=3.16, p=0.06, df=2).

Overlap between inter-nesting flatbacks and shipping vessels

Twenty-two of the 30 flatback turtles tracked during their inter-nesting period used habitat within 100 m of the area most frequently used by commercial vessels. At an individual turtle scale – the size of area used that was within 100 m of the areas within the Port of Gladstone and the Port of Rockhampton most frequently used by commercial vessels varied from <0.1 to 121 km^2 for the 95% home range area and <0.1 to 6 km^2 for the core (50%) area. The proportion of the 50% home range areas which overlapped with commercial vessel transit lanes varied from <0.6 to 4% (mean 2%). There was no significant difference in the proportion of the 95% or 50% home range which occurred inside the shipping lanes between nesting seasons ($ANOVA_{95\%}$, F=2.71, p=0.08, df=2).

Diving behaviour and use of water depth

We received full (complete 24 hour) dive profiles from nine individuals in both 2014 and 2015 for at least one of their re-nesting periods. In 2013, no turtles were intercepted on the beach to obtain the full profiles. The maximum depth recorded by the dive loggers was 45 m in 2014 and 25 m in 2015. Turtles in both years spent approximately half (44% in 2014 and 56% in 2015) of their time in water between 10 and 20 m deep. The depth occupied by nesting flatbacks varied significantly among years (ANOVA, F=151.09, p≈0, df=2). Female flatback turtles occupied deeper, on average, water during the 2014 nesting season than in 2015 (Figure 7). A *chi-square* test of independence was performed to determine if the nesting turtles preferred certain depths over the range of depths available to them. Turtles had a significant preference for depths between 5 m and 20 m, χ^2 (df = 7, n = 9342) = 21244, p < 0.001). When turtles were within the Port of Gladstone there was no significant difference between the most common maximum dive depth used and the mean water depth used (t-test, t = 1.54, p = 0.06, df = 262), indicating that when turtles where at the bottoms of their dives and presumably resting, they were on, or close to, the bottom.

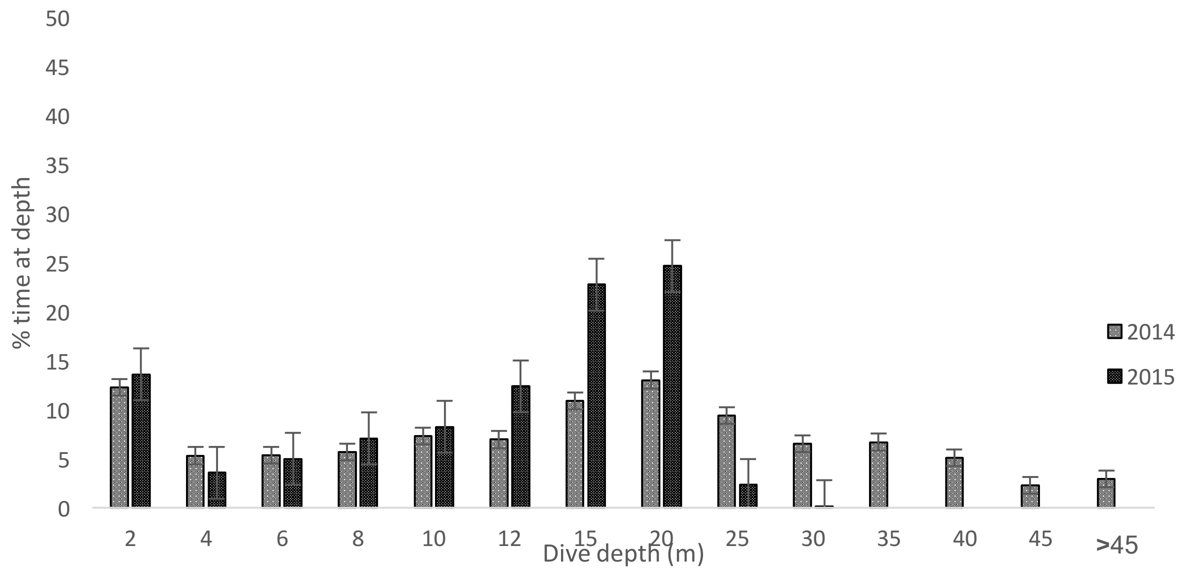

Figure 8 Time-at-depth (TAD) distributions for turtles in 2014 and 2015 (n = 9 in both years).

Dive duration

There was a relatively even spread of dive durations across the turtles. The median dive duration was 35 to 40 minutes in 2014 and 45 to 50 minutes in 2015. However, because depth data is collected every 10 seconds and then pooled into six-hour bins, these data likely misrepresents diving behaviour. For example, in 2014 approximately 25% of dives were longer than one hour and the median dive duration was 35 minutes, thus some surfacing events were possibly missed by the loggers because the turtles surfaced and the recording intervals missed them.

Migration information

Migration data were obtained for 31 of the 33 turtles we tracked and 27 reached a foraging destination (Table 8). Each of the 27 turtles migrated between 170 and 1223 km to the north and all remained in the Great Barrier Reef World Heritage Area. The tracking data reveal three important foraging regions for flatback turtles from Curtis Island (1) Shoalwater Bay, (2) between Shoalwater Bay and the Whitsunday Islands and (3) the far northern Great Barrier Reef between Cape Tribulation and Bathurst Bay (Figure 8). The information on migration and foraging area dispersal did not change the known extent of foraging for the flatback turtle in Queensland (Limpus 2009).

Table 8. Migration and foraging endpoints for the flatback turtles fitted with satellite transmitters at Curtis Island, 2013 to 2015.

Flipper tag number (EHP primary tag)	ARGOS satellite tag number	Foraging location
2013		
QA30770	134189	Whitsunday Islands
K43635	134190	Inside Shoalwater Bay
T85646	134191	Inside Shoalwater Bay
T97108	134192	Northern Shoalwater Bay
QA18561	134193	Northern Shoalwater Bay
T20452	134194	Bedwell Island group
T97111	134195	Inside Shoalwater Bay
K44384	134196	Northern Shoalwater Bay
QA30752	134197	Hay Point region
T97125	134198	Whitsunday Islands
T85652	134199	Capricorn Channel
2014		
QA20377	141738	Northern Shoalwater Bay
QA20379	141739	Bathurst Bay
T85633	141740	Northern Shoalwater Bay
QA20400	141741	Inside Shoalwater Bay
QA20381	141742	Cape Flattery
T15866	141743	Did not reach a foraging area
K43572	141744	Whitsunday Islands
QA20398	141745	Did not reach a foraging area
QA20383	141746	Cape Flattery
T97209	141747	Cape Tribulation
QA20388	141748	Upstart Bay
2015		
QA23239	152710	Did not reach a foraging area
K33707	152711	Northern Shoalwater Bay
T85690	152712	Bedwell group
QA30727	152713	Bedwell group
QA46070	152714	Cape Gloucester
K43686	152715	Northern Shoalwater Bay
K19907	152716	Not tracked on a migration
QA10095	152717	Not tracked on a migration
QA30747	152718	Northern Shoalwater Bay
QA30764	152719	Did not reach a foraging area
T97111	152720	Repulse Bay

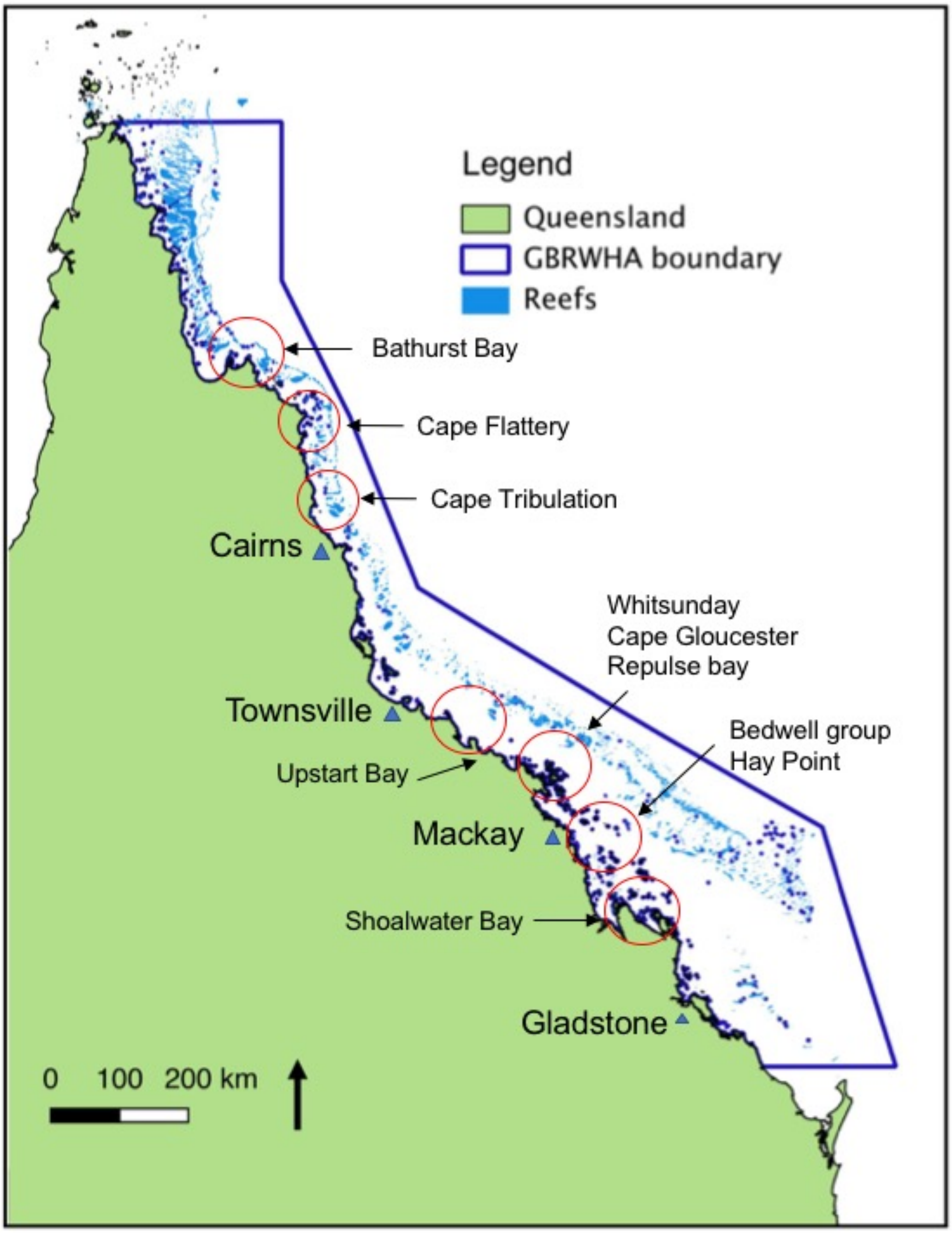

Figure 8 General distribution of foraging areas for the flatback turtles tracked from Curtis Island 2013 to 2015.

Discussion

We attached satellite tags to 33 flatback turtles as they completed laying a clutch of eggs at Curtis Island. Of these, three turtles migrated immediately and we did not obtain data on inter-nesting habitat use. Thirty turtles remained in the area to lay another clutch. Inter-nesting habitat use and home range calculations were completed for each of them. Our data indicate that the use of waters within the Port of Gladstone varied across individuals and years. More turtles used habitats within the Port of Gladstone in 2014 than in the other two years and the degree to which individual turtles used the Port of Gladstone's habitats varied from negligible (<0.01% of their home range) to 90% of the 95% home range area. Overall, all 30 turtles spent some of their inter-nesting period within the waters of the Port of Gladstone and six turtles spent over 50% of their time within the Port.

The size of the core habitat used by the 30 turtles during the inter-nesting period ranged from 6 to 458 km^2 (50%) and 51 to 1501 km^2 (95%). These areas are within the range reported by other research on flatback turtles (Whittock *et al*. 2014). On average turtles used a similar area of habitat each year, but turtles in 2014 spent more time in the Port of Gladstone than turtles tracked in 2013 or 2015. Also, in 2013, most of the individuals spent their inter-nesting period in habitat along the east coast of Curtis Island, to the north of the nesting beach, and in the other two years the turtles mainly aggregated along the south coast of Facing Island and between Facing Island and the mainland. This degree of inter-annual variation in inter-nesting habitat use has been previously recorded in flatback turtles in Western Australia (Whittock *et al*. 2014). Suggested reasons for the variation include local weather fluctuations and their influence on sea surface temperatures and wind patterns, changes to fine-scale water currents and individual variation in habitat preferences. These would all make interesting avenues for further research, and doing so would require individuals to be tracked across multiple breeding seasons.

The tags used were able to collect dive data every 10 seconds. The data were then transmitted in bins of six hours. Hence the fine scale dive data needed to accurately quantify diving behaviour were not available. However, we extracted the full dive profiles (i.e. 4 bins of data per day) for 18 turtles for at least one of their re-nesting intervals and we were able to compare the location data to bathymetry data at 100 m resolution. The turtles used the entire depth column, but spent around 10% of their time close to the surface and around 50% of their time at depths of 10 to 20 m. The bathymetry data indicated that turtles showed a preference for water between 5 and 25 m deep and when combining the binned dive data and the bathymetry data it is clear that turtles spend most of their time close to the maximum depth – i.e. on, or close to, the bottom. This is a similar result to Sperling (2007).

Overall, approximately 48% of all habitat used by the turtles was located within the Port of Gladstone limits and 10% of their time in the upper part of the water column, potentially basking and exposing themselves to anthropogenic impacts from commercial and recreational vessel use. This has implications for mitigating future impacts to flatback turtles in relation to marine-based activities. Yet, while many of the turtles used the waters of the Port of Gladstone, none of the turtles we tagged were injured during the inter-nesting period and there have been no signs of increased strandings of injured or deceased flatback turtles on the shoreline of the Gladstone region between 2005 and 2010 (Biddle and Limpus 2011). It could be that injured or dead turtles are too badly damaged to float ashore, but because we have tracked around 20% of the nesting population and none of our tracked turtles have been injured it is unlikely that vessel strike [assuming 2013 to 2015 levels of vessel activity] is a key issue for flatback turtles during their inter-nesting period.

Around the southern portion of Facing Island and the northern portion of Curtis Island, the home ranges appear disjunct and not connected when calculating the home ranges. While the raw data of turtles in this region contained numerous data points, a significant portion of these data were of too poor a quality to be used in the home range analysis. The location of Curtis Island and Facing Islands mean turtles in waters to the south of Facing Island are exposed to wind speeds from the Pacific Ocean of between 20-40 km/h from multiple directions, with the strongest wind speed coming from the east – to southeast. The poorer quality data from turtles while they are in more exposed locations compared to when they were in the sheltered areas may have been a result of animals spending less time at the surface as they were swimming or interference from strong wind and waves limiting the total available time a tag's salt water switch is above the water and able to send a transmission. To some degree future tagging projects will not have this issue because transmission intervals on the tags can be as low as 15 seconds compared to the 45 second intervals used on tags in our study. The relationship between local weather events on data quantity and quality would be useful avenues for further investigation.

Overall, inter-nesting flatback turtles are present within the ERMP survey area, Curtis Island and the Port of Gladstone region between late October and late December. Only one turtle used the Port of Rockhampton, and not for her entire inter-nesting period and no turtles used the narrows or the western basin reclamation area. Our satellite tracking results indicate that individuals lay an average of 3 to 4 clutches of eggs per year, which is similar to results of beach-based monitoring of the same genetic stock (Limpus *et al*. 2016). Most of the 30 inter-nesting females we tracked used habitats within the Port of Gladstone and the ERMP survey areas and used habitat close to the commercial vessel transit lanes. Hence, the current study has provided required information on usage of the ERMP area by interesting flatback turtles. Future studies if conducted may focus on:

1. Tracking turtles that have been tracked before to examine fidelity of site use
2. Conduct on-ground, or aerial beach surveys to examine how many turtles use the beach at Rodds Bay and Facing island
3. With the rapid increase in the availability and resolution of oceanographic data it may be possible in a few years to examine the movements and preferred habitats of the interesting turtles with micro-scale depth (e.g. 10m resolution), water currents or exposure to waves/wind to explore the more specific habitat needs of flatback turtles during their interesting period.

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