

Fossette et al. Using Aerial Photogrammetry to Assess Stock-Wide Marine Turtle Nesting Distribution, Abundance and Cumulative Exposure to Industrial Activity

Supplementary Materials

Supplementary Figures

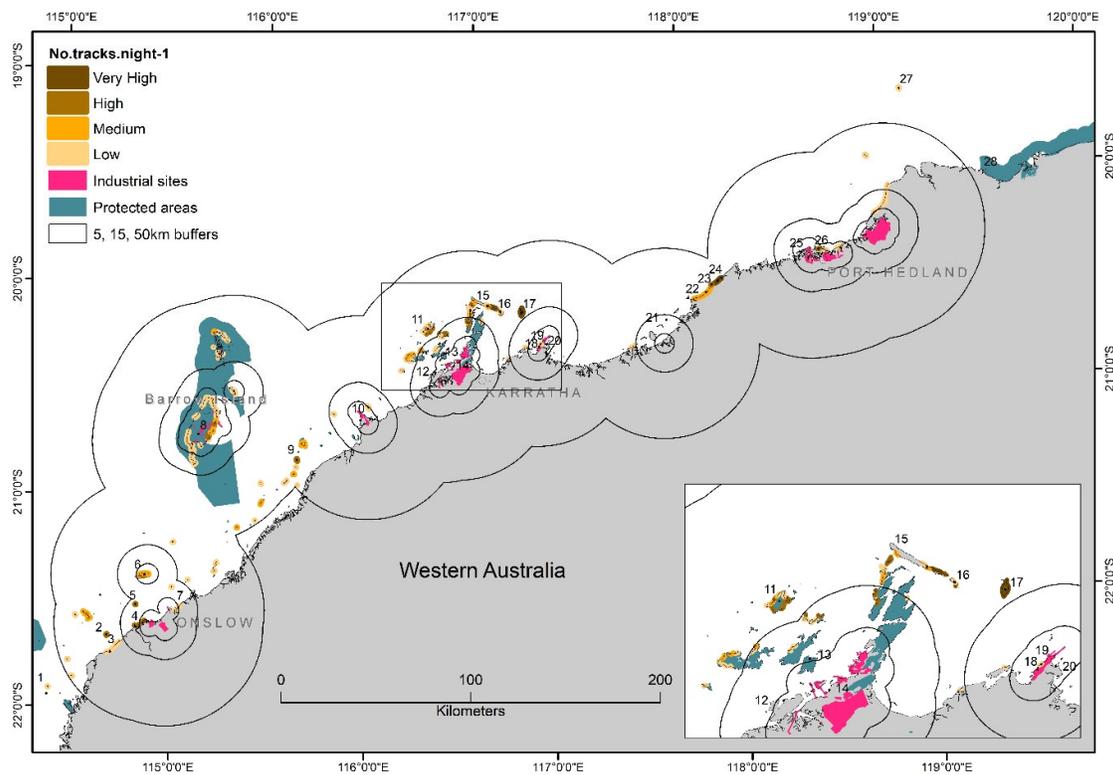


Figure 1. Abundance (number of tracks.night⁻¹) estimates of new (< 12 h old) flatback turtle tracks at beaches in the Pilbara region of Western Australia obtained via digital aerial photography between 29th November and 6th December 2016. Spatial exposure to industrial activity and inclusion in protected areas illustrated as defined in the legend. Footprints of industrial sites are shown in pink with a 15 km buffer (black line). Protected areas are show in green. (1) Y island, (2) Locker Island, (3) Urala Beach, (4) Ashburton Delta, (5) Ashburton Island, (6) Thevenard Island, (7) Beadon Creek - Onslow, (8) Barrow Island, (9) Long Island, (10) Cape Preston, (11) Rosemary Island, (12) West Intercourse Island, (13) East Lewis Island, (14) Dampier town, (15) Legendre Island, (16) Hauy Island, (17) Delambre Island, (18) Cape Lambert, (19) Bells Beach, (20) Point Samson, (21) Forestier Islands, (22) Cape Cossigny- Mundabullangana, (23) Cowrie Beach West - Mundabullangana, (24) Cowrie Beach Main - Mundabullangana, (25) Downes Island, (26) Cemetery Beach-Port Hedland, (27) Bedout Island, and (28) Mulla Mulla Downs Creek. Inset map (grey rectangle) highlights beaches 11 to 20.

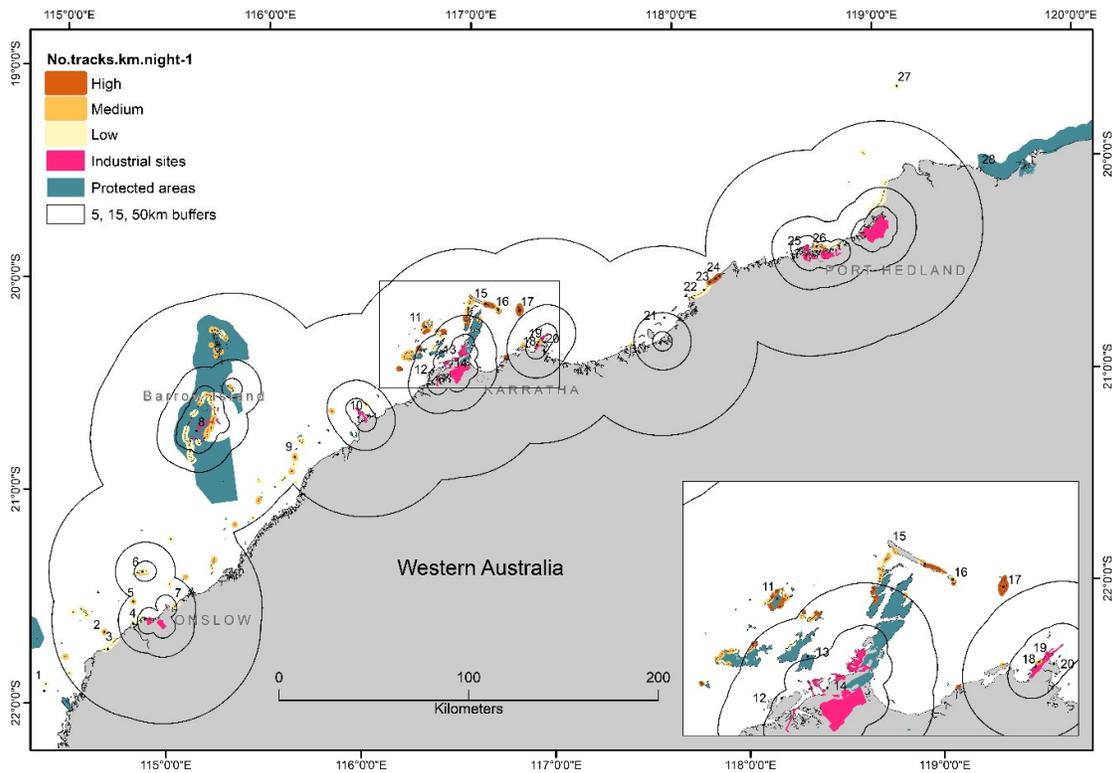


Figure 2. Estimated density ($\text{tracks.km}^{-1}.\text{night}^{-1}$) of new (<12 h old) flatback tracks at beaches in the Pilbara region of Western Australia surveyed with digital aerial photography between 29th November and 6th December 2016. Spatial exposure to industrial activity and inclusion in protected areas illustrated as defined in the legend. Footprints of industrial sites are shown in pink with 5, 15 and 50 km buffers (black lines). Protected areas are shown in green. (1) Y island, (2) Locker Island, (3) Urala Beach, (4) Ashburton Delta, (5) Ashburton Island, (6) Thevenard Island, (7) Beadon Creek - Onslow, (8) Barrow Island, (9) Long Island, (10) Cape Preston, (11) Rosemary Island, (12) West Intercourse Island, (13) East Lewis Island, (14) Dampier town, (15) Legendre Island, (16) Hauy Island, (17) Delambre Island, (18) Cape Lambert, (19) Bells Beach, (20) Point Samson, (21) Forestier Islands, (22) Cape Cossigny- Mundabullangana, (23) Cowrie Beach West - Mundabullangana, (24) Cowrie Beach Main - Mundabullangana, (25) Downes Island, (26) Cemetery Beach-Port Hedland, (27) Bedout Island, and (28) Mulla Mulla Downs Creek. Inset map (grey rectangle) highlights beaches 11 to 20.

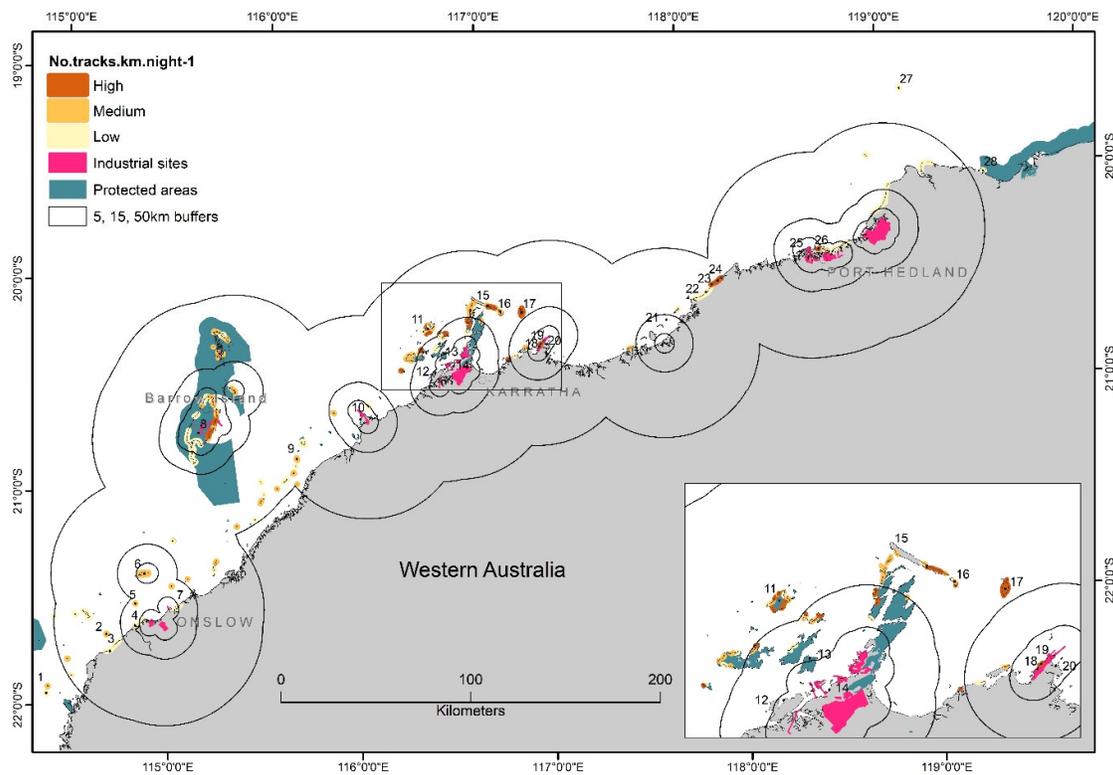


Figure 3. Estimated density ($\text{tracks.km}^{-1}.\text{night}^{-1}$) of fresh (0–36 h old) flatback tracks at beaches in the Pilbara region of Western Australia surveyed with digital aerial photography between 29th November and 6th December 2016. Spatial exposure to industrial activity and inclusion in protected areas illustrated as defined in the legend. Footprints of industrial sites are shown in pink with 5, 15 and 50 km buffer (black lines). Protected areas are show in green. (1) Y island, (2) Locker Island, (3) Urala Beach, (4) Ashburton Delta, (5) Ashburton Island, (6) Thevenard Island, (7) Beadon Creek - Onslow, (8) Barrow Island, (9) Long Island, (10) Cape Preston, (11) Rosemary Island, (12) West Intercourse Island, (13) East Lewis Island, (14) Dampier town, (15) Legendre Island, (16) Hauy Island, (17) Delambre Island, (18) Cape Lambert, (19) Bells Beach, (20) Point Samson, (21) Forestier Islands, (22) Cape Cossigny- Mundabullangana, (23) Cowrie Beach West - Mundabullangana, (24) Cowrie Beach Main - Mundabullangana, (25) Downes Island, (26) Cemetery Beach-Port Hedland, (27) Bedout Island, and (28) Mulla Mulla Downs Creek. Inset map (grey rectangle) highlights beaches 11 to 20.

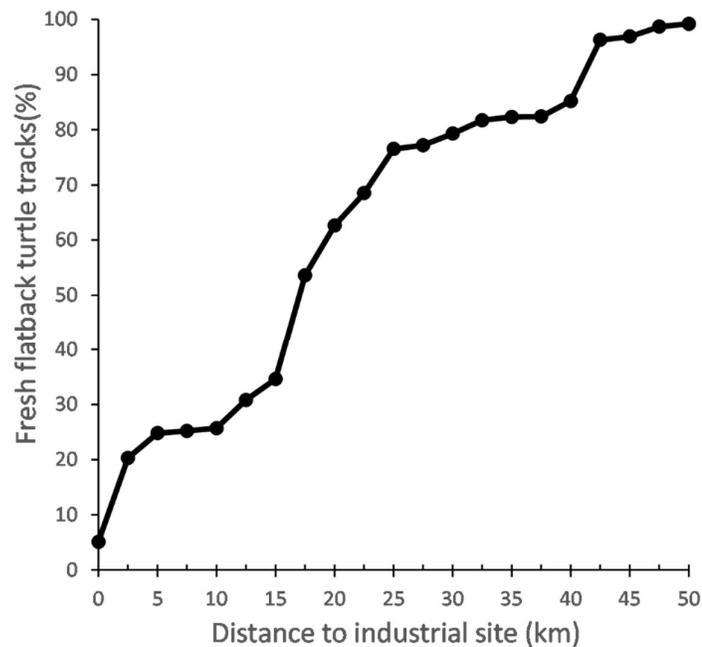


Figure S4: Percentage of the flatback turtle stock (using number of fresh (0–36 h old) tracks.night⁻¹ per beach as a proxy) of the Pilbara region of Western Australia located within an increasing radius of a major industrial site. At 50 km, 99.2% of the stock is encompassed.

Supplementary Methods

Ground-truthing

Flatback turtle nesting activity is monitored annually at six locations on the North West Shelf (Barrow Island, Thevenard Island, Delambre Island, Cemetery Beach, Bells Beach, Mundabullangana). Ground tally of new flatback tracks were obtained from the respective programs monitoring these rookeries: Pendoley Environmental/Chevron for Barrow Island and Mundabullangana Care for Hedland for Cemetery Beach, DBCA/West Pilbara Program for Bells Beach, DBCA/North West Shelf Flatback Turtle Conservation Program for Thevenard Island and Delambre Island. Comparison of ground and aerial turtle track counts recorded on the same morning at these six locations were made.

There was a significant positive linear relationship between the ground survey flatback track tally and the aerial tally of both new flatback tracks ($r_s = 0.83$, $p = 0.04$, $R = 0.85$, $p = 0.03$, $n = 6$) and fresh flatback tracks (i.e. new + “age-unsure”) ($r_s = 0.83$, $p = 0.04$, $R = 0.90$, $p = 0.01$, $n = 6$).

There was on average $19.5 \pm 21.0\%$ (median = 11.7%; range = 0.0–61.9%, $n = 6$) difference between the ground survey track tally and the aerial tally of new flatback tracks and $33.4 \pm 24.0\%$ (median = 37.5%; range = 3.2–66.7%, $n = 6$) difference between the ground survey track tally and the aerial tally of fresh flatback tracks at six rookeries (Figure A1).

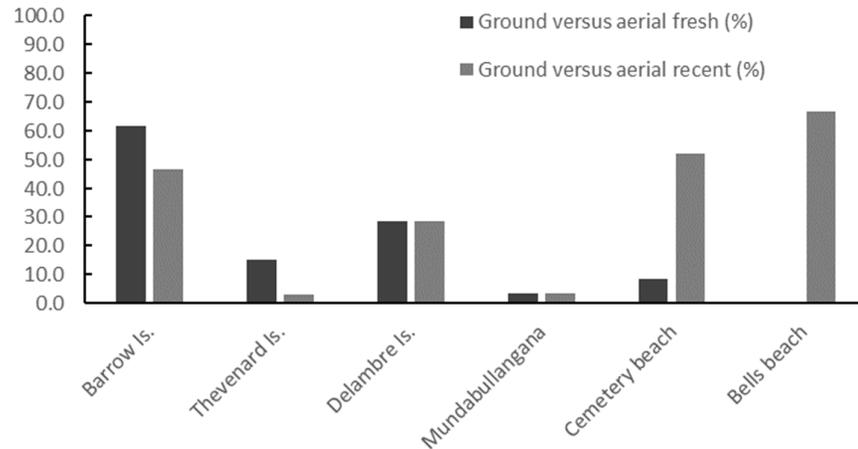


Figure 5. Differences (in %) between aerial and ground tally of fresh and new flatback tracks recorded on the same morning in the monitored area of five North West Shelf rookeries: Barrow Island, Thevenard Island, Delambre Island, Mundabullangana Cemetery Beach (Port Hedland) and Bells Beach.

Inter-observer difference

For seven rookeries (Barrow Island, Delambre Island, Thevenard Island, Rosemary Is, Legendre Island, Cemetery Beach, Mundabullangana), counts were independently undertaken by two observers (observer 1: S.F. and observer 2: A.V.) and compared to each other in order to estimate inter-observer error. The results are presented in Table A2.

A total of 796 flatback tracks were recorded by observer 1 across the seven rookeries. Of those, 90.1% were considered as new and 9.9% as ‘age unsure’. Observer 2 recorded a total of 882 flatback tracks, 60.9% were considered as “new” and 39.1% as “age unsure”.

There was a significant positive relationship between the track counts of the two observers in terms of fresh flatback tracks.night⁻¹ at each rookery ($r_s = 0.86$, $p = 0.01$, $n = 7$) and of new flatback tracks.night⁻¹ at each rookery ($r_s = 0.89$, $p = 0.007$, $n = 7$).

There was a $34.0 \pm 20.3\%$ (range = 5.5–66.7%) difference between observer 1 (S.F) and 2 (A.V) regarding the total (i.e. new + “age-unsure”) number of flatback tracks.night⁻¹. There was a $28.3 \pm 18.4\%$ (range = 1.0–52.6%) difference between observer 1 (S.F) and 2 (A.V) regarding the new number of flatback tracks.night⁻¹. Observer 2’s new counts were consistently lower than observer 1’s.

The smallest differences in terms of number of new flatback tracks.night⁻¹ were observed at Barrow island (96 and 95 tracks recorded by observer 1 and 2, respectively) and Delambre Island (222 and 207 for observer 1 and 2, respectively). The largest difference was observed at Legendre Island (52.6%) due to observer 2 having recorded a higher proportion of hawksbill tracks than observer 1. Large differences were also observed at Mundabullangana (43.8%) and Thevenard Island (44.2%). At Mundabullangana, the difference was due to observer 2 having recorded a larger proportion of “age unsure” tracks than observer 1. At Thevenard Island, observer 2 recorded a larger proportion of “age unsure” tracks than observer 1 but also a slightly larger proportion of green turtle tracks.

The proportional sizes of the rookeries in terms of number of new flatback tracks compared to the total number of new flatback tracks for the seven rookeries were very similar between the two observers with a mean difference of only $3.4 \pm 2.4\%$ (range = 0.1–7.6%).

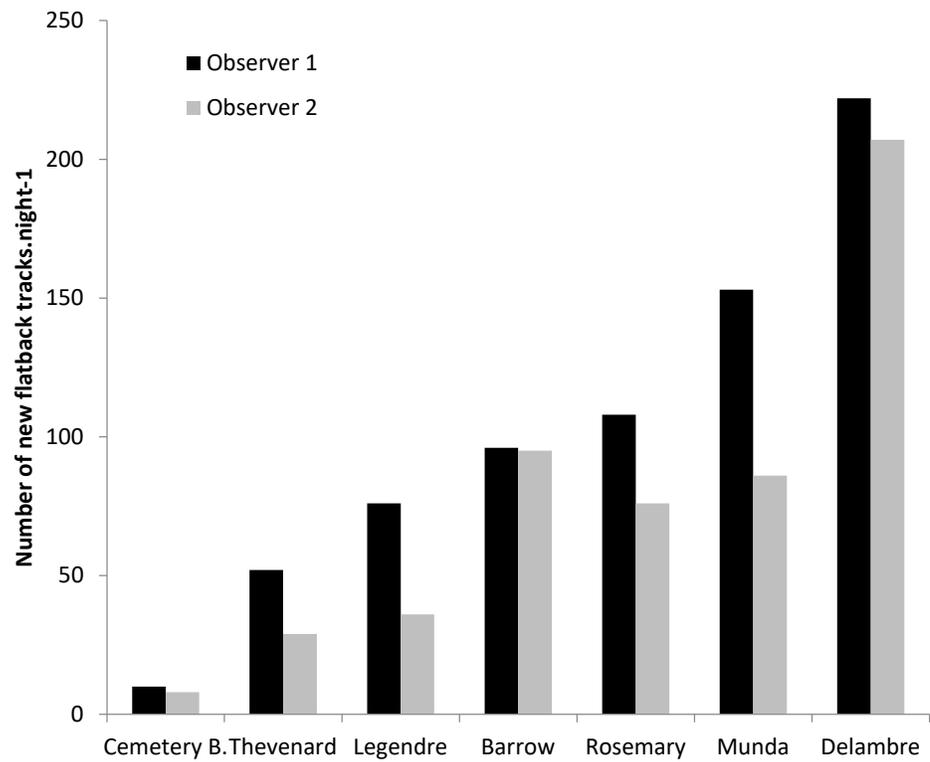


Figure 6. Inter-observer difference in the number of new flatback tracks.night⁻¹ at seven rookeries: Cemetery Beach (Port Hedland), Thevenard Island, Legendre Island, Barrow Island, Rosemary Island, Mundabullangana and Delambre Island, by two independent observers (observer 1: S.F. and observer 2: A.V.). Nd: *Natator depressus* (flatback turtle), Ei: *Eretmochelys imbricata* (hawksbill turtle), and Cm: *Chelonia mydas* (green turtle).

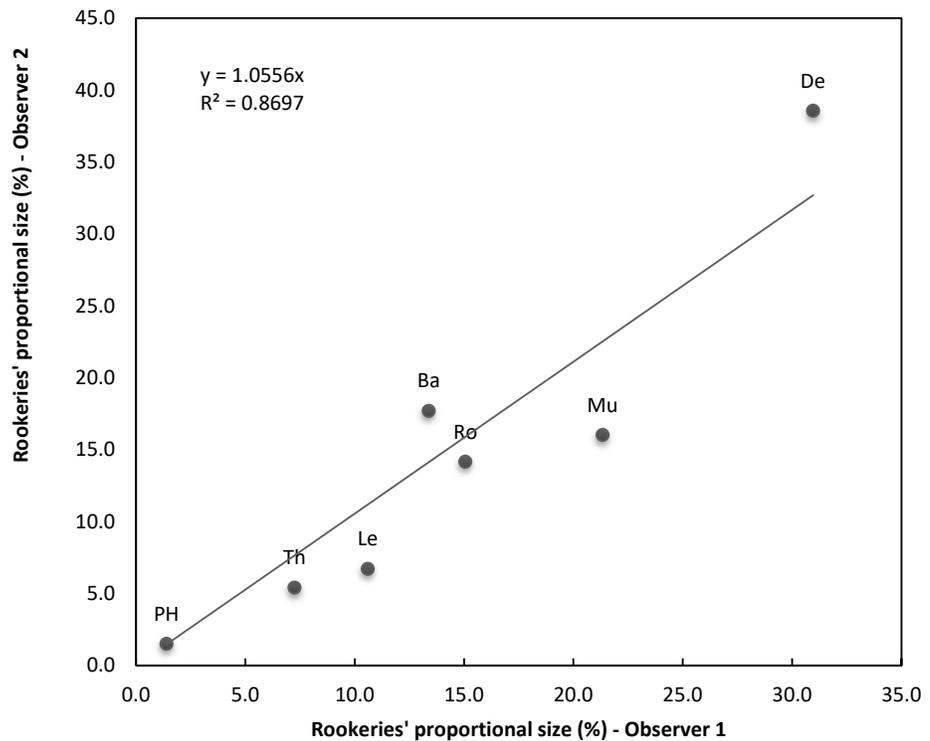


Figure 7. Linear relationship between the proportional sizes of seven rookeries calculated for observer 1 (S.F.) and observer 2 (A.V.). Proportional sizes of the rookeries were calculated as number of new flatback tracks at a rookery divided by the total number of new flatback tracks at all seven rookeries (PH: Port Hedland, Th: Thevenard Island, Le: Legendre Island, Ba: Barrow Island, Ro: Rosemary Island, Mu: Mundabullangana, and De: Delambre Island) as reported by each observer.

Table 1. Inter-observer difference in the number of new and fresh flatback tracks.night⁻¹ at seven rookeries: Cemetery Beach (Port Hedland), Thevenard Island, Legendre Island, Barrow Island, Rosemary Island, Mundabullangana and Delambre Island. Counts were independently undertaken by two observers (observer 1: S.F. and observer 2: A.V.) and compared to each other in order to estimate inter-observer error. Nd: *Natator depressus* (flatback turtle), Ei: *Eretmochelys imbricata* (hawksbill turtle), and Cm: *Chelonia mydas* (green turtle).

	New tracks.night ⁻¹						Fresh tracks.night ⁻¹					
	Observer 1			Observer 2			Observer 1			Observer 2		
	Nd	Ei	Cm	Nd	Ei	Cm	Nd	Ei	Cm	Nd	Ei	Cm
Cemetery Beach	10	0	0	8	0	0	24	0	0	8	0	0
Thevenard Island	52	0	20	29	0	25	63	0	23	52	0	32
Legendre Island	76	22	44	36	37	48	77	22	44	36	45	52
Barrow Island	96	6	304	95	6	510	147	14	366	274	8	520
Rosemary Island	108	47	26	76	103	13	108	47	26	79	109	13
Mundabullangana	153	0	0	86	0	0	155	0	0	198	0	0
Delambre Island	222	6	2	207	10	3	222	6	2	235	16	3

Intra-observer difference

Images from five rookeries (Barrow Island, Rosemary Island, Legendre Island, Hauy Island, and Cemetery Beach) were analysed twice by the same observer, S.F. The analyses of each set of images occurred more than 6 months apart to be independent.

Overall, there was a significant positive relationship between the first and second counts of new flatback tracks.night⁻¹ for all five rookeries ($R = 0.95$, $p = 0.015$ and $r_s = 0.90$, $p = 0.037$, $n = 5$). There was a 25.6 ± 13.8 % (range = 9.1–50%) difference between the first count of new flatback tracks.night⁻¹ and the second count for all five rookeries. For three of the rookeries, less flatback tracks were found on the second count as some of these tracks were re-attributed to hawksbill turtles. For Cemetery Beach, two new flatback tracks from the first count were considered as “age unsure” during the second count. For Barrow Island, some “age unsure” tracks from the first count were considered as new flatback tracks on the second count.

For all five rookeries, the total number of new tracks from all three species of turtles between the first and second count changed by 6.6 ± 4.8 % (range = 0.0–16.7%).

Table 1. Intra-observer difference in the number of fresh and new flatback tracks.night⁻¹ at five rookeries: Cemetery Beach (Port Hedland), Hauy Island, Legendre Island, Barrow Island and Rosemary Island. Counts were undertaken twice at least 6 months apart by S.F and compared to each other in order to estimate intra-observer error. Nd: *Natator depressus* (flatback turtle), Ei: *Eretmochelys imbricata* (hawksbill turtle), and Cm: *Chelonia mydas* (green turtle).

	New tracks.night ⁻¹						Fresh tracks.night ⁻¹					
	Count 1			Count 2			Count 1			Count 2		
	Nd	Ei	Cm	Nd	Ei	Cm	Nd	Ei	Cm	Nd	Ei	Cm
Cemetery Beach	12	0	0	10	0	0	23	0	0	24	0	0
Hauy Island	52	0	20	29	0	25	63	0	23	52	0	32
Legendre Island	101	3	40	76	22	44	102	3	41	77	22	44
Barrow Island	88	6	304	96	6	304	144	14	366	147	14	366
Rosemary Island	149	14	34	108	47	26	149	14	34	108	47	26