

Supplementary material

Contrasting patterns of residency and space use of coastal sharks within a communal shark nursery

*Beverly Z. L. Oh^{A,B,C,E}, Michele Thums^{B,C}, Russ C. Babcock^D, Jessica J. Meeuwig^A,
Richard D. Pillans^D, Conrad Speed^{B,C} and Mark G. Meekan^{B,C}*

^ACentre for Marine Futures, School of Biological Sciences and Oceans Institute,
The University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia.

^BAustralian Institute of Marine Science, The University of Western Australia, 39 Fairway,
Crawley WA 6009, Australia.

^CIndian Ocean Marine Research Centre, The University of Western Australia, 39 Fairway,
Crawley WA 6009, Australia.

^DCSIRO Oceans and Atmosphere, Ecosciences Precinct, GPO Box 2583,
Brisbane, Qld 4001, Australia.

^ECorresponding author. Email: beverly.oh@gmail.com

Methods

Variables influencing receiver efficiency

To examine environmental effects on monthly patterns of detection efficiency of two acoustic receivers placed 1 and 153 m from a V13–1H sentinel transmitter, we compiled a suite of explanatory variables including water temperature, air pressure, rainfall, tidal height, wind speed and direction, month, sex and total length of shark (Table 1 in the main paper). Water temperature was recorded at Tantabiddi using HOBO Pro V2 data loggers (U22-001; HOBO Data Loggers Australia, Adelaide, South Australia) calibrated at the Australian Institute Marine Science; AIMS and sampling at 30-min intervals, which were periodically downloaded and replaced every 3–12 months. Daily values for air pressure (hPa), rainfall totals (mm), wind speed (m s^{-1}) and direction (degrees) were obtained from a weather station at Milyering (10-m elevation; 22.03°S, 113.92°E) situated 6.8 km south of Mangrove Bay (<http://data.aims.gov.au/>, accessed 7 October 2015). Predicted tidal height data were obtained through the Regional Oceanic Modelling System (<https://www.myroms.org/>, accessed 4 November 2015). Values of monthly mean and range were computed for all variables from November 2013 to January 2015 and chronologically matched with detection data of the sentinel tag across the monitoring period. We used generalized additive mixed models (GAMMs) with binomial error distributions to model detection probability. We modelled month as a random effect in all models and fitted all environmental variables with a cubic regression spline, restricting the basis dimension ‘k’ to < 4 to avoid overfitting. A maximum of one fixed term per model was specified due to fairly small sample sizes ($n = 12$). This resulted in a set of 11 candidate models (Table S2) which were ranked according to the sample-corrected Akaike’s Information Criterion (AIC_C) and relative AIC_C weight (wAIC_C).

Results

Variables influencing receiver efficiency

Atmospheric pressure, water temperature, rainfall, wind speed and direction were not found to be important drivers of receiver performance (Table S2). Therefore, we found no evidence that the monthly patterns in residency and space use of tagged sharks in our study were an artefact of ambient noise from wind or rain or changes in air pressure or water temperature. We found the highest statistical support for model 7 ($\text{wAIC}_C = 1$), which showed a negative influence of tidal height on detection probabilities of the station located 1 m from the sentinel tag, and model 8 ($\text{wAIC}_C = 1$), which showed negative influence of tidal range on detection probabilities of the station located 153 m from the sentinel tag (Table S2; Fig. S2).

Table S1. Summary of the location, habitat type and detections of the acoustic receivers deployed in the Mangrove Bay array

Receiver	Longitude	Latitude	Deployment Start	End	Habitat	MPA zoning	Site zoning	Total detections	Percentage detections
Tantabiddi									
1	-21.899	113.937	01-Mar-14	01-Jun-15	Coral reef		1	1	0.00
2	-21.909	113.944	19-Mar-13	01-Jun-15	Coral reef		1	17	0.00
3	-21.911	113.948	19-Mar-13	01-Jun-15	Coral reef		1	4	0.00
4	-21.915	113.956	01-Mar-14	19-Oct-14	Sandflat		1	0	0.00
5	-21.912	113.952	19-Mar-13	01-Jun-15	Rocky reef		1	1	0.00
6	-21.916	113.959	19-Mar-13	01-Jun-15	Sandflat		1	4	0.00
7	-21.918	113.963	19-Mar-13	01-Jun-15	Rocky reef		1	4	0.00
8	-21.920	113.967	19-Mar-13	01-Jun-15	Rocky reef		1	12	0.00
Mangrove bay									
9	-21.948	113.921	19-Mar-13	01-Jun-15	Coral reef	SZ	2	20	0.00
10	-21.949	113.926	19-Mar-13	01-Jun-15	Rocky reef	SZ	2	0	0.00
11	-21.948	113.933	19-Mar-13	01-Jun-15	Rocky reef	SZ	2	0	0.00
12	-21.948	113.939	19-Mar-13	01-Jun-15	Coral reef	SZ	2	0	0.00
13	-21.950	113.944	19-Mar-13	01-Jun-15	Rocky reef	SZ	2	65	0.01
14	-21.957	113.941	19-Mar-13	01-Jun-15	Rocky reef	SZ	2	970	0.19
15	-21.959	113.944	19-Mar-13	01-Jun-15	Rocky reef	SZ	2	1845	0.36
16	-21.960	113.940	25-Mar-13	01-Jun-15	Algal reef	SZ	2	764	0.15
17	-21.961	113.943	25-Mar-13	31-May-15	Rocky reef	SZ	2	2322	0.46
18	-21.962	113.945	26-Mar-13	31-May-15	Rocky reef	SZ	2	4615	0.91
19	-21.962	113.934	19-Mar-13	01-Jun-15	Rocky reef	SZ	2	231	0.05
20	-21.963	113.940	19-Mar-13	01-Jun-15	Rocky reef	SZ	2	6707	1.33
21	-21.963	113.942	19-Mar-13	01-Jun-15	Rocky reef	SZ	2	30593	6.05
22	-21.964	113.939	19-Mar-13	01-Jun-15	Rocky reef	SZ	2	2018	0.40
23	-21.965	113.941	19-Mar-13	01-Jun-15	Rocky reef	SZ	2	4006	0.79
24	-21.966	113.939	08-Dec-14	31-May-15	Rocky reef	SZ	2	112	0.02
25	-21.967	113.941	19-Mar-13	31-May-15	Rocky reef	SZ	2	5673	1.12
26	-21.967	113.936	19-Mar-13	01-Jun-15	Algal reef	SZ	2	2729	0.54

Receiver	Longitude	Latitude	Deployment Start	End	Habitat	MPA zoning	Site zoning	Total detections	Percentage detections
27	-21.968	113.939	19-Mar-13	01-Jun-15	Sandflat	SZ	2	4407	0.87
28	-21.969	113.941	19-Mar-13	01-Jun-15	Rocky reef	SZ	2	39054	7.72
29	-21.969	113.938	19-Mar-13	31-May-15	Sandflat	SZ	2	135477	26.79
30	-21.974	113.941	19-Mar-13	31-May-15	Sandflat	SZ	2	75768	14.98
31	-21.969	113.925	19-Mar-13	01-Jun-15	Coral reef	SZ	2	1582	0.31
32	-21.969	113.930	19-Mar-13	01-Jun-15	Rocky reef	SZ	2	156	0.03
33	-21.972	113.919	19-Mar-13	01-Jun-15	Coral reef	SZ	2	92	0.02
34	-21.970	113.936	19-Mar-13	01-Jun-15	Sandflat	SZ	2	161182	31.87
35	-21.972	113.939	26-Mar-13	31-May-15	Mangrove	SZ	2	18401	3.64
36	-21.948	113.914	19-Mar-13	01-Jun-15	Coral reef		3	1	0.00
37	-21.956	113.913	19-Mar-13	01-Jun-15	Coral reef		3	0	0.00
38	-21.959	113.912	19-Mar-13	01-Jun-15	Coral reef		3	0	0.00
39	-21.966	113.910	19-Mar-13	01-Jun-15	Coral reef		3	0	0.00
40	-21.971	113.911	19-Mar-13	01-Jun-15	Coral reef		3	2	0.00
41	-21.972	113.902	19-Mar-13	24-May-13	Rocky reef		3	0	0.00
42	-21.973	113.911	19-Mar-13	01-Jun-15	Coral reef		3	1	0.00
43	-21.976	113.907	08-Mar-14	24-Oct-14	Rocky reef		3	0	0.00
44	-21.979	113.912	19-Mar-13	01-Jun-15	Coral reef		3	5	0.00
45	-21.980	113.902	08-Mar-14	01-Jun-15	Rocky reef		3	1	0.00
46	-21.984	113.904	08-Mar-14	24-Oct-14	Rocky reef		3	0	0.00
47	-21.983	113.908	08-Mar-14	01-Jun-15	Coral reef		3	0	0.00
48	-21.983	113.912	19-Mar-13	01-Jun-15	Coral reef		3	0	0.00
49	-21.989	113.902	19-Mar-13	02-Mar-14	Rocky reef		3	26	0.01
50	-21.989	113.909	19-Mar-13	22-Oct-14	Coral reef		3	1	0.00
51	-21.991	113.898	19-Mar-13	19-Oct-14	Rocky reef		3	6	0.00
52	-21.992	113.907	19-Mar-13	01-Jun-15	Coral reef		3	0	0.00
53	-21.998	113.905	19-Mar-13	01-Jun-15	Coral reef		3	0	0.00
54	-22.001	113.903	19-Mar-13	01-Jun-15	Coral reef		3	0	0.00
55	-22.005	113.902	19-Mar-13	01-Jun-15	Coral reef		3	0	0.00

Receiver	Longitude	Latitude	Deployment Start	End	Habitat	MPA zoning	Site zoning	Total detections	Percentage detections
56	-22.013	113.899	19-Mar-13	26-Oct-14	Coral reef		3	0	0.00
57	-21.975	113.924	19-Mar-13	01-Jun-15	Coral reef		4	763	0.15
58	-21.974	113.930	19-Mar-13	01-Jun-15	Algal reef		4	3144	0.62
59	-21.977	113.919	19-Mar-13	01-Jun-15	Coral reef		4	23	0.00
60	-21.980	113.921	19-Mar-13	01-Jun-15	Coral reef		4	13	0.00
61	-21.980	113.929	19-Mar-13	01-Jun-15	Sandflat		4	2119	0.42
62	-21.985	113.932	19-Mar-13	01-Jun-15	Coral reef		4	509	0.10
63	-21.986	113.919	19-Mar-13	01-Jun-15	Coral reef		4	1	0.00
64	-21.987	113.925	19-Mar-13	01-Jun-15	Coral reef		4	12	0.00
65	-21.988	113.923	02-Mar-14	01-Jun-15	Coral reef		4	0	0.00
66	-21.989	113.920	19-Mar-13	01-Jun-15	Coral reef		4	0	0.00
67	-21.989	113.915	19-Mar-13	01-Jun-15	Coral reef		4	2	0.00
68	-21.991	113.922	19-Mar-13	01-Jun-15	Coral reef		4	0	0.00
69	-21.991	113.931	19-Mar-13	01-Jun-15	Algal reef		4	183	0.04
70	-21.992	113.920	19-Mar-13	01-Jun-15	Coral reef		4	0	0.00
71	-21.994	113.925	19-Mar-13	01-Jun-15	Algal reef		4	13	0.00
72	-21.997	113.931	19-Mar-13	01-Jun-15	Rocky reef		4	45	0.01
73	-21.997	113.915	19-Mar-13	01-Jun-15	Coral reef		4	15	0.00
74	-21.999	113.921	19-Mar-13	01-Jun-15	Coral reef		4	6	0.00
75	-22.001	113.926	19-Mar-13	01-Jun-15	Coral reef		4	5	0.00
76	-22.005	113.912	19-Mar-13	01-Jun-15	Coral reef		4	4	0.00
77	-22.006	113.916	19-Mar-13	01-Jun-15	Rocky reef		4	12	0.00
78	-22.006	113.921	19-Mar-13	01-Jun-15	Coral reef		4	0	0.00
Turquoise bay									
79	-22.085	113.871	19-Mar-13	01-Jun-15	Rocky reef		6	0	0.00
80	-22.086	113.874	19-Mar-13	01-Jun-15	Rocky reef		6	0	0.00
81	-22.088	113.877	19-Mar-13	01-Jun-15	Coral reef		6	0	0.00
82	-22.089	113.880	19-Mar-13	01-Jun-15	Coral reef	SZ	5	0	0.00
83	-22.091	113.883	19-Mar-13	01-Jun-15	Coral reef	SZ	5	0	0.00

Receiver	Longitude	Latitude	Deployment Start	End	Habitat	MPA zoning	Site zoning	Total detections	Percentage detections
84	-22.093	113.886	19-Mar-13	01-Jun-15	Coral reef	SZ	5	4	0.00
85	-22.095	113.888	19-Mar-13	01-Jun-15	Coral reef	SZ	5	3	0.00

Table S2. Summary of the effects of environmental variables on detection probabilities recorded on acoustic receivers placed 1 m (receiver #30) and 153 m (receiver #28) from a sentinel transmitter used to monitor detection efficiency in Mangrove bay

Month was treated as a random effect in all models (m1, model 1; etc.); details for each model include the estimated degrees of freedom (d.f._e), the Akaike's Information Criterion for small sample size (AIC_C), relative AICC weight (wAIC_C) and goodness of fit (Adjusted R²). PressAV, mean air pressure; RainAV, mean cumulative rainfall; TempAV, mean water temperature; TempR, water temperature range; TideAV, mean tidal height; TideR, tidal height range; WdireAV, mean wind direction; WspeedAV, mean wind speed; WspeedR, wind speed range

Model number	Model	Receiver #30				Receiver #28			
		d.f. _e	AIC _C	wAIC _C	Adjusted R ²	d.f. _e	AIC _C	wAIC _C	Adjusted R ²
m1	1	0.00	5244.06	0	0	0	3938.69	0	0
m2	days.detected	9.87	4768.45	0	2.6	9.22	3853.48	0	21.4
m3	pressAV	2.76	5065.04	0	7.8	2.83	3892.54	0	5.1
m4	rainAV	1.90	5209.43	0	0.6	2.19	3852.26	0	0
m5	tempAV	2.89	5026.28	0	12.4	2.45	3931.24	0	1.8
m6	tempR	2.91	5189.72	0	0.4	0.43	3940.56	0	0.1
m7	tideAV	2.92	4185.76	0	27.6	2.96	3724.17	1	5.4
m8	tideR	2.92	3860.27	1	31.8	2.7	3770.69	0	2.4
m9	wdireAV	1.95	5186.17	0	0.8	1.74	3934.78	0	5.4
m10	wspeedAV	2.66	5238.57	0	0.4	2.9	3809.00	0	8.6
m11	wspeedR	2.31	5206.21	0	0.7	2.84	3925.91	0	0

Table S3. Summary of the effects of varying sig2 values on estimates of 50 and 95% kernel areas of one *N. acutidens* individual

Monthly tracks of the shark #L1, which had the median value for 50% kernel area, were used to estimate kernel area range

Sig2 value	Detection probability	Kernel area (KA) range	
		50% KA (km ²)	95% KA (km ²)
285.2	0.20	0.24–0.51	0.96–1.84
263.2	0.25	0.22–0.49	0.9–1.75
252.3	0.30	0.21–0.47	0.84–1.67
229.8	0.40	0.18–0.44	0.73–1.51
175.0	0.50	0.12–0.36	0.51–1.56
129.6	0.60	0.08–0.34	0.36–2.77
106.7	0.70	0.07–0.34	0.34–3.85
97.0	0.75	0.07–0.34	0.34–4.33
87.5	0.80	0.06–0.34	0.33–4.8

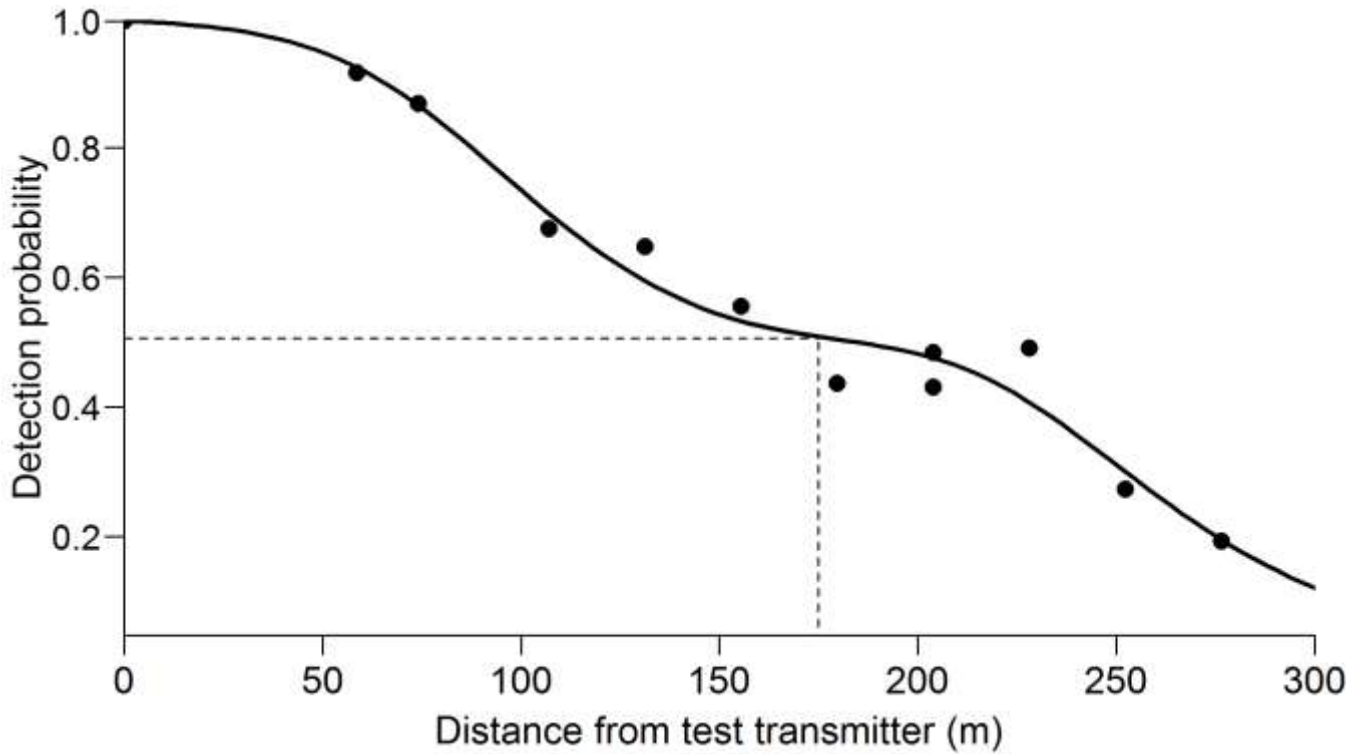


Fig. S1. Detection probabilities recorded on acoustic receivers placed at increasing distances from a test transmitter at Mangrove Bay in March 2013. Data were fitted using a loess smoothing curve and dashed lines represent the effective detection range at which 50% of the transmissions were detected ($D_{50} = 175.0$ m).

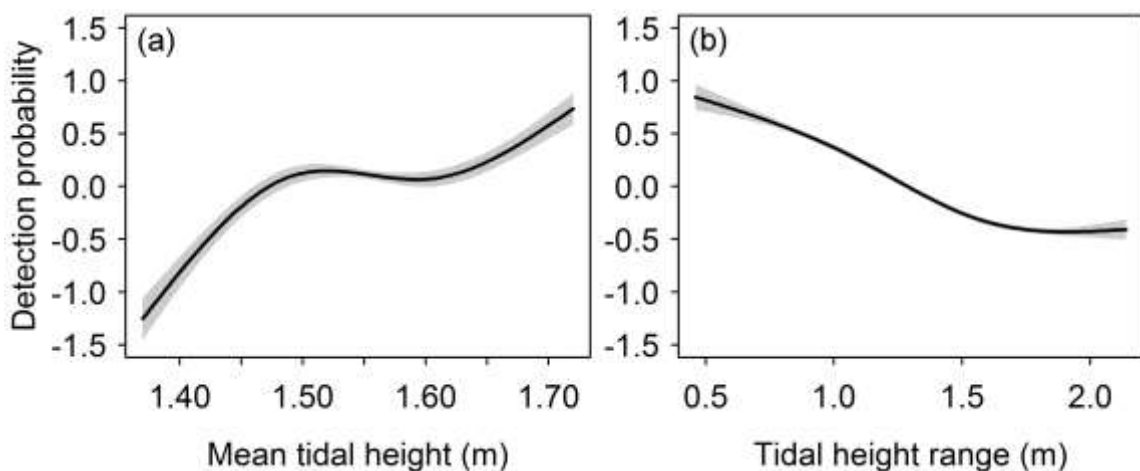


Fig. S2. Summary of the effects of explanatory variables on detection probabilities recorded on acoustic receivers located (a) 1 m and (b) 153 m from a sentinel tag placed within an area with highest shark activity. Dashed lines and error bars represent 95% confidence intervals.