

# Horizontal and vertical movement behaviour of flatback turtles and spatial overlap with industrial development

Michele Thums\*, Jason Rossendell, Mick Guinea, Luciana C Ferreira

\*Corresponding author: m.thums@aims.gov.au

Marine Ecology Progress Series 602: 237–253 (2018)

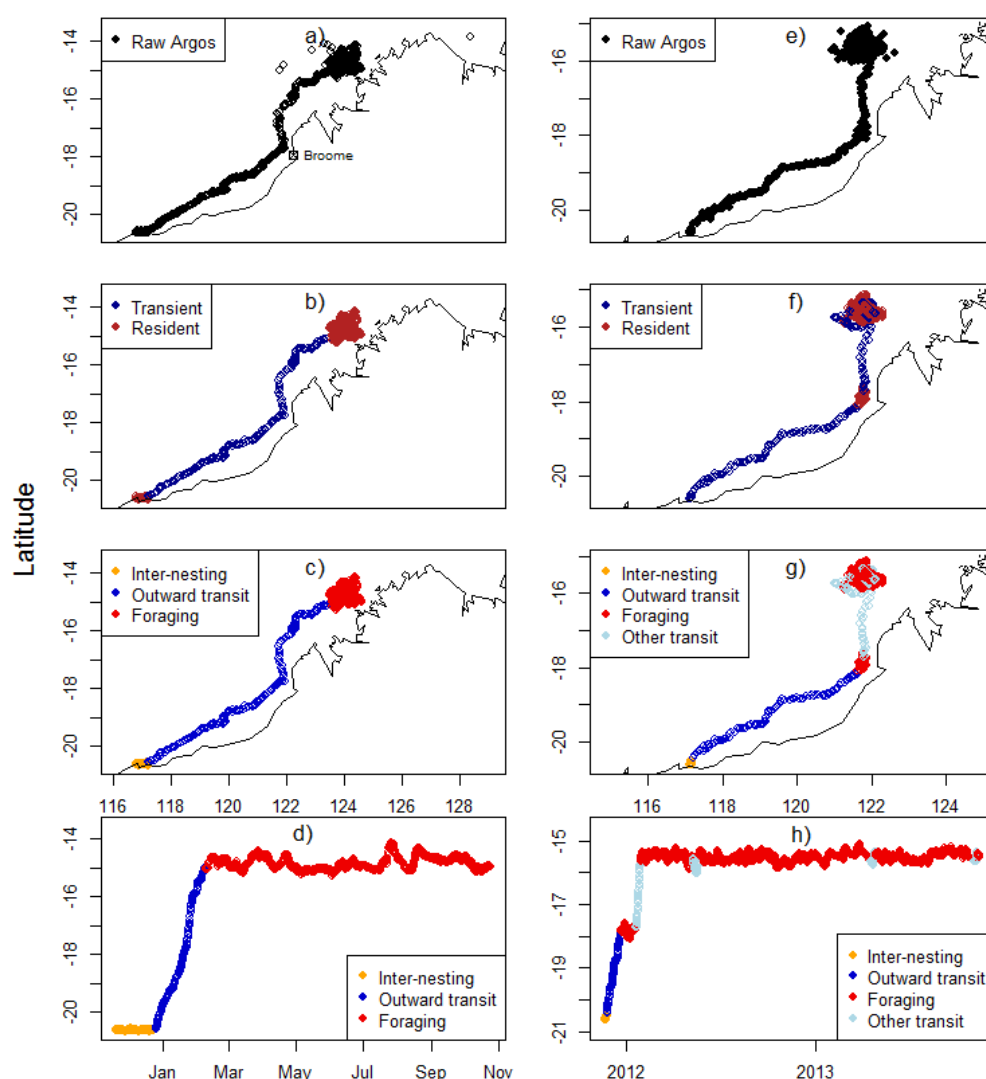


Figure S1. Example tracks of behavioural state determination. Turtle 11640 (left-hand side) with only one foraging area and 11632 (right-hand side) with > 1 foraging area with transient movement between are plotted on maps showing the raw Argos position (a and e), the State Space Model (SSM) position estimates colour coded by the model inferred behaviour (transient or resident) (b & f) and the further delineation of these behaviours into inter-nesting, outward transit, foraging and other transit SSM (c & g). The bottom plots (d & h) show latitude plotted against time to further show this delineation.

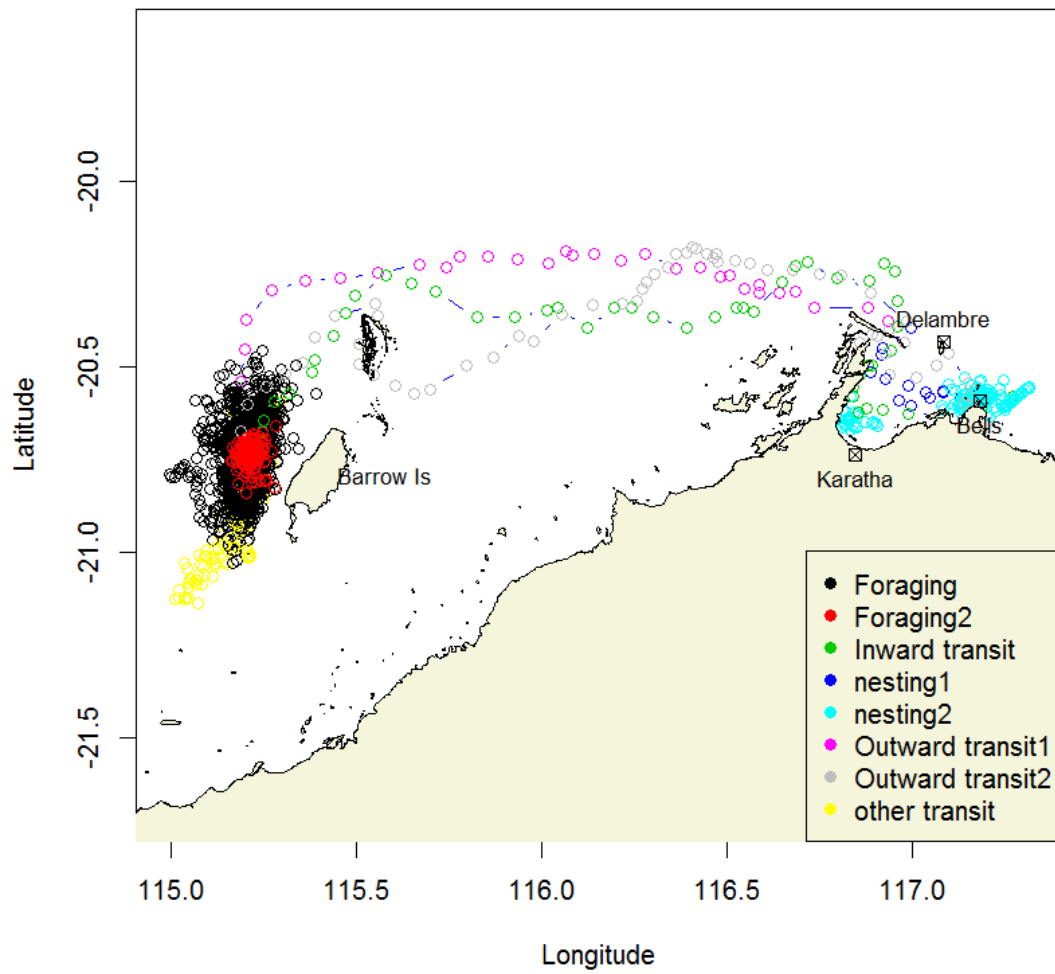


Figure S2. Track of re-migrant turtle; 111633 showing each behaviour colour coded. Numeral 1 refers to the first nesting, transit and foraging and numeral 2 refers to the second nesting (remigration), transit and foraging.

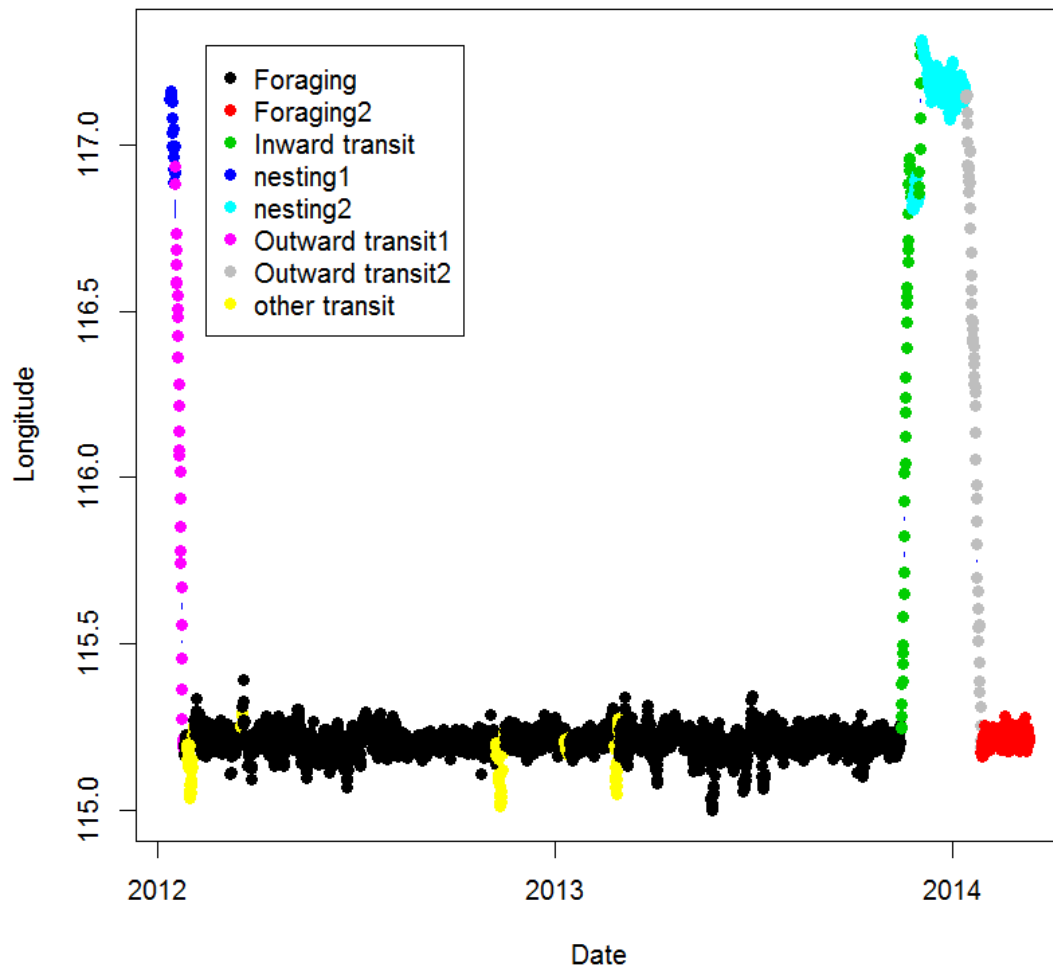


Figure S3. Temporal plot of the track of re-migrant turtle; 111633 showing each behaviour colour coded. Numeral 1 refers to the first nesting, transit and foraging and numeral 2 refers to the second nesting (remigration), transit and foraging.

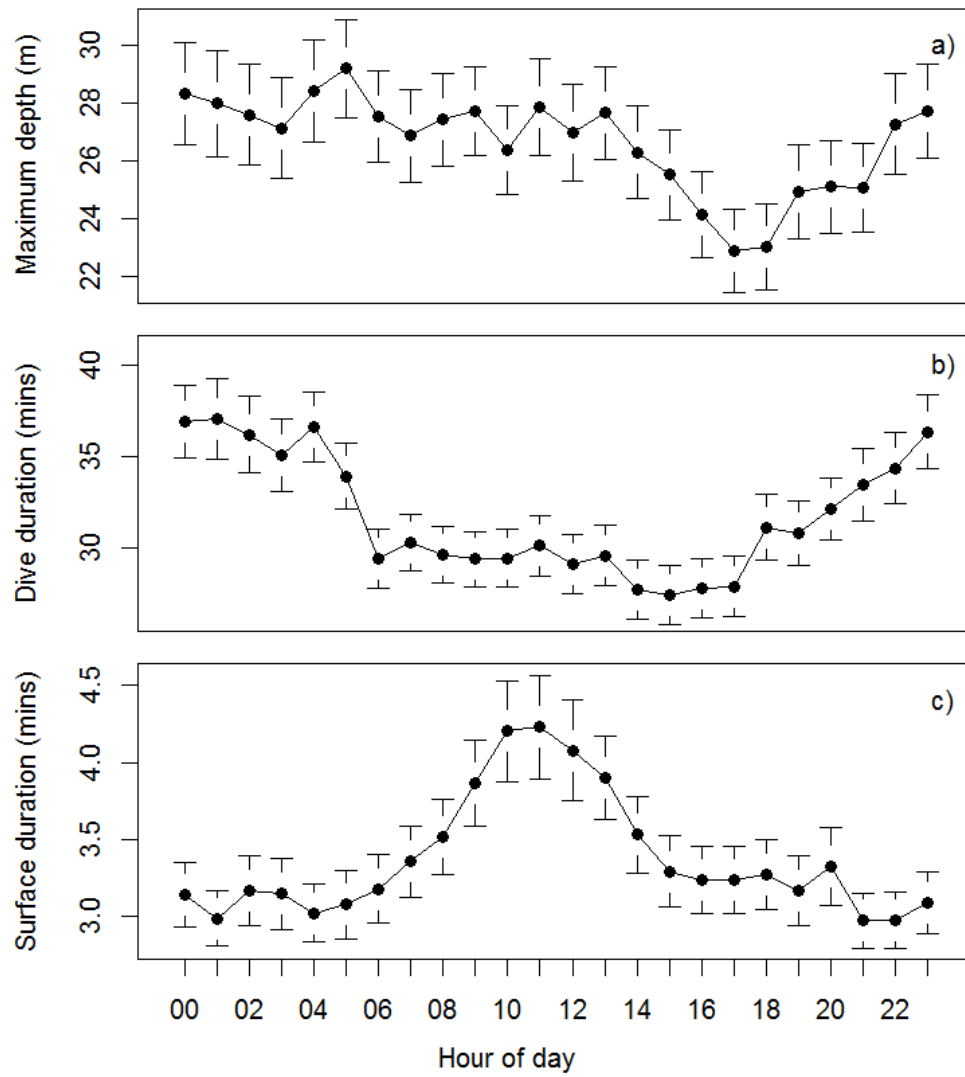


Figure S4. Mean and CI maximum dive depth (a), dive duration (b) and surface duration (c) for each hour of the day (Western standard time).

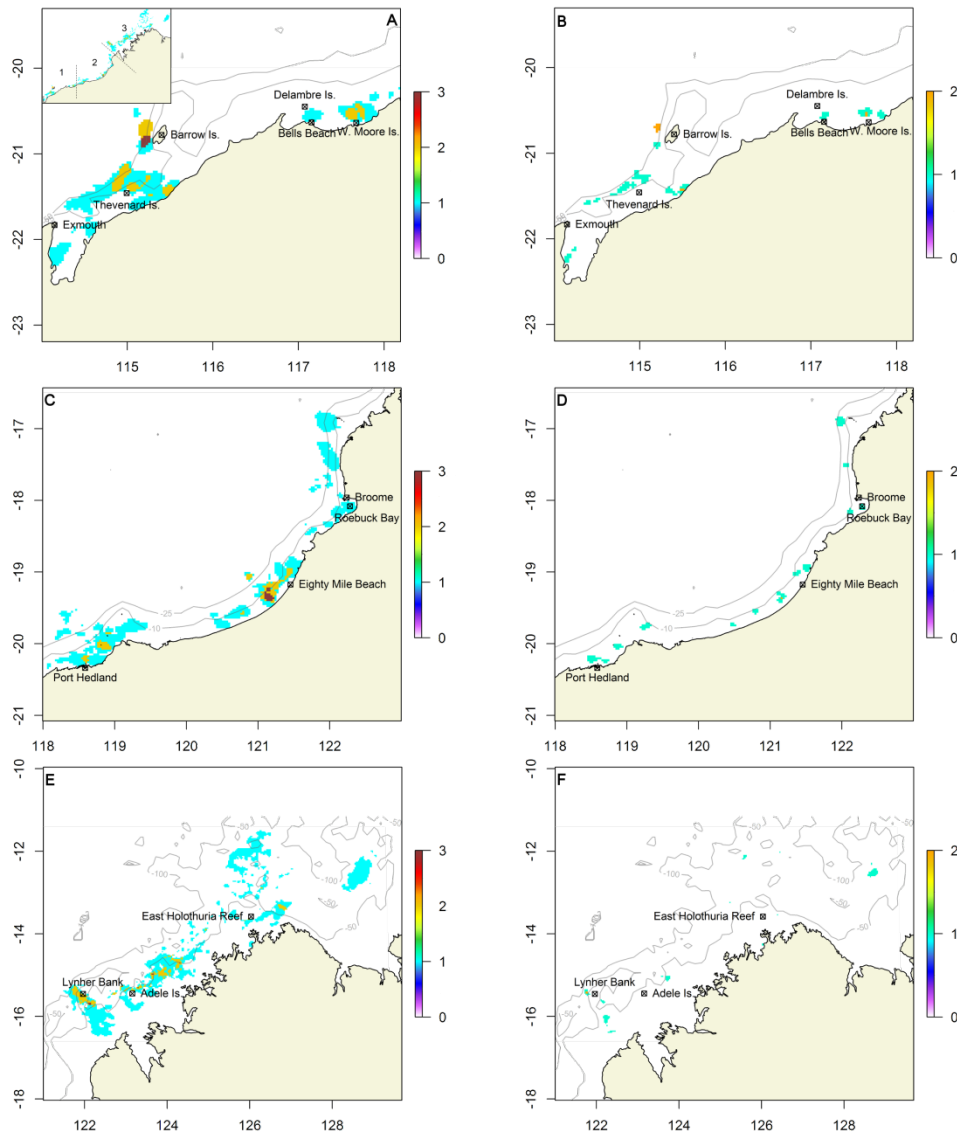


Figure S5. Finer scale resolution of Fig. 2E and F (inset in A) showing the utilisation extent of all flatback sea turtles calculated as the maximum number of individual turtle UD's in each 3 km grid cell during foraging mode in section 1 (A-B) and showing the 25m and 50m depth contours in grey; section 2 (C-D), showing the 10 m and 25 m depth contours in grey and section 3 (E-F) showing the 50 m and 100 m depth contours in grey. 95% utilisation distributions are shown in the left panels and 50% utilisation distributions are shown in the right panels.

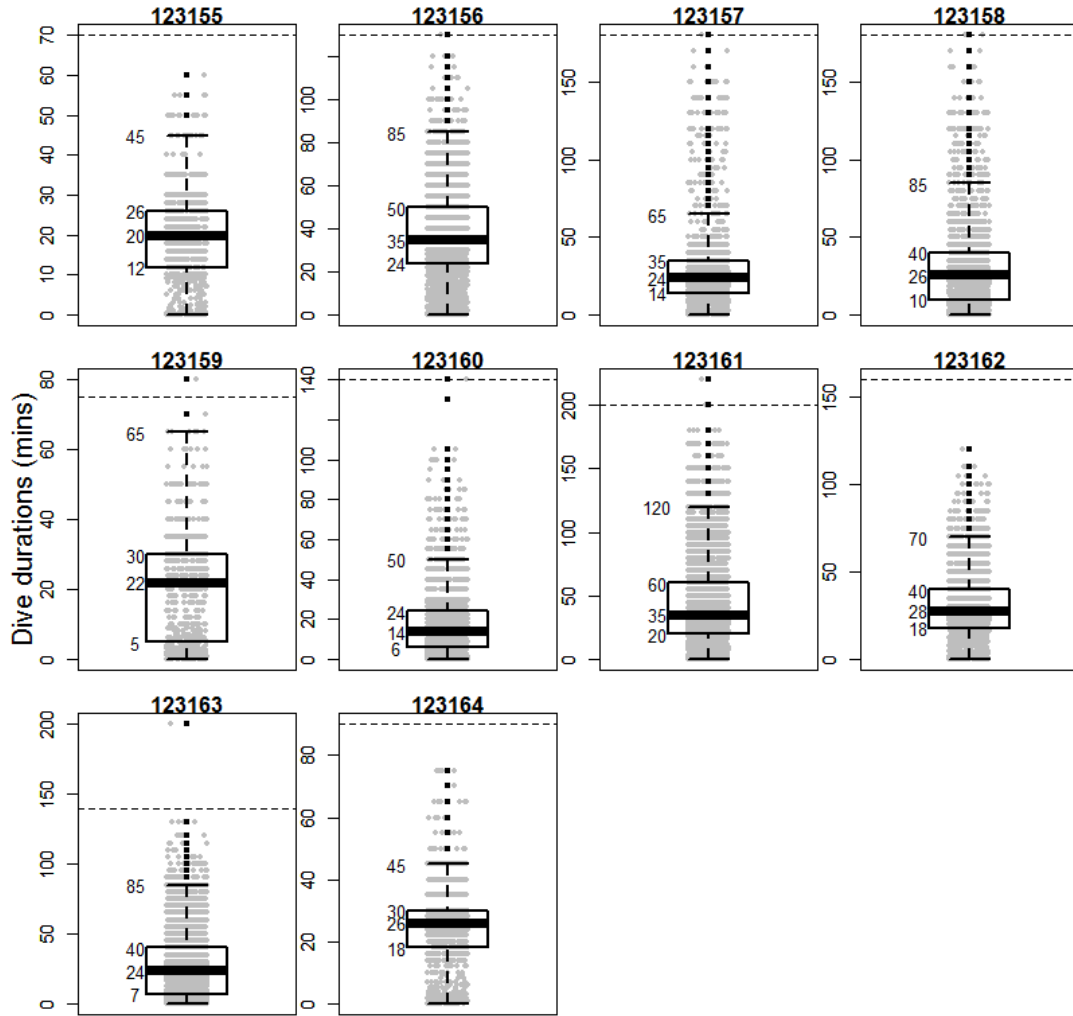


Figure S6. Boxplots of each turtle's dive durations (calculated per dive) with each of the points over-layed in grey and jittered. Dashed line shows the maximum dive duration recorded in the summary statistics of the SRDL.

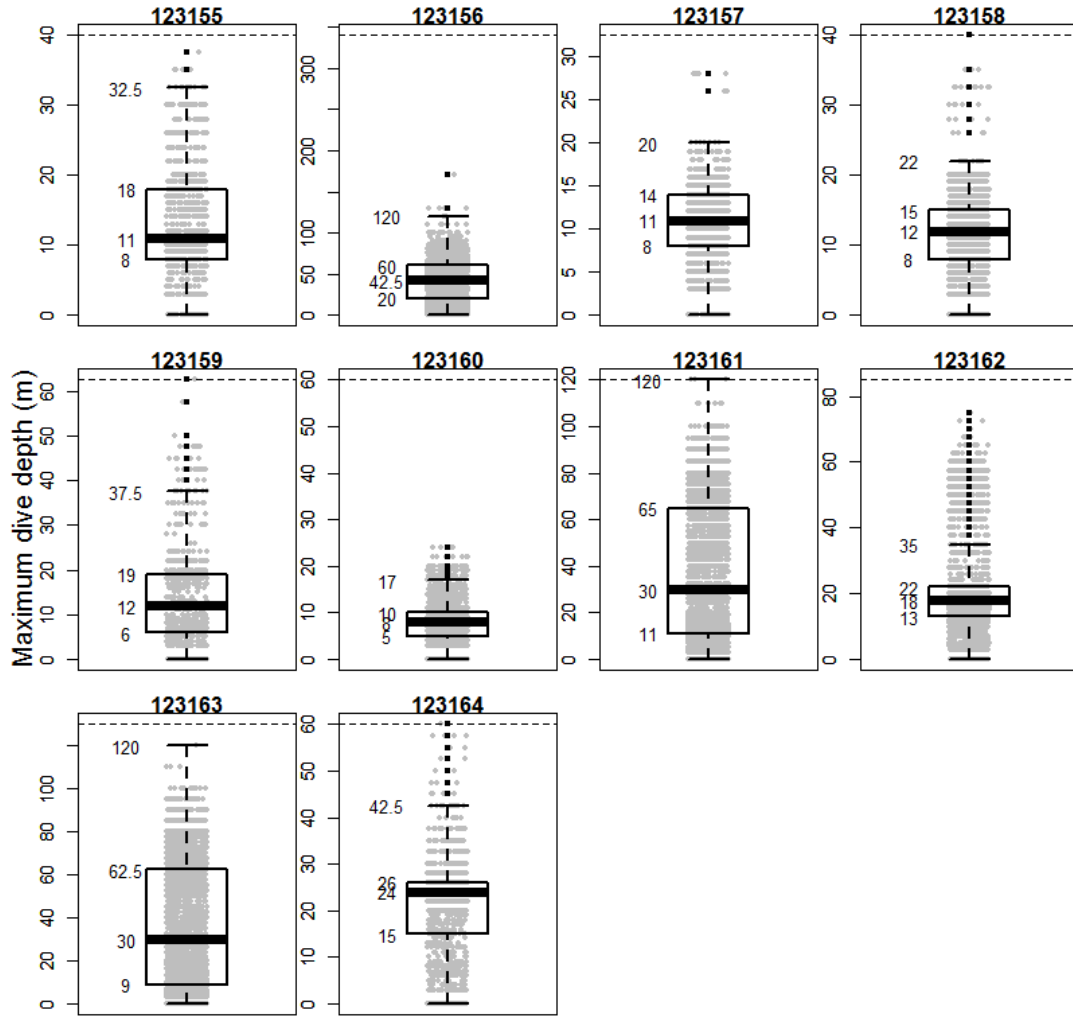


Figure S7. Boxplots of each turtle's maximum dive depths (calculated per dive) with each of the points over-layed in grey and jittered. Dashed line shows the maximum dive duration recorded in the summary statistics of the SRDL.

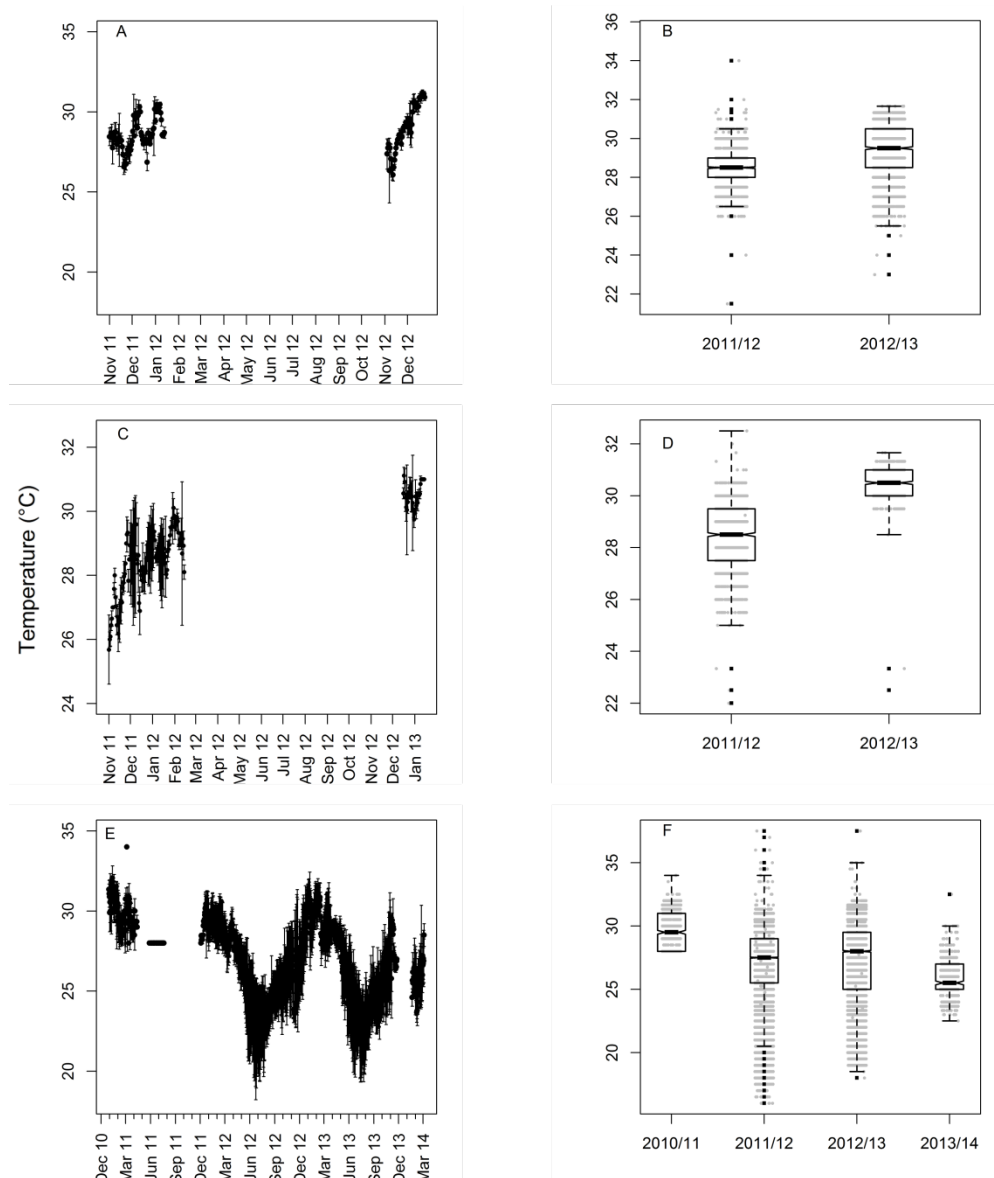


Fig S8. Mean and SD temperature (A,C,E) for each calendar day during tag deployment and boxplot (B,D,F) of temperature for each year during each behaviour mode for all turtles tagged with Kiwisat 101 tags. For outward transit (C, D) data from only one turtle was available for the year 2012/13.



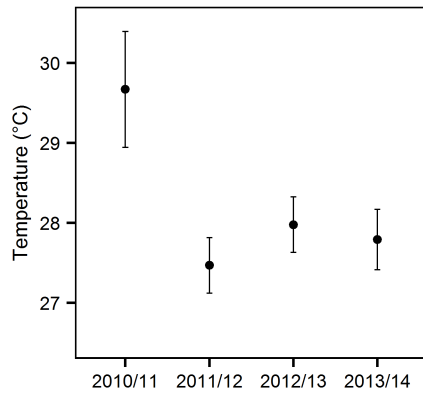


Figure S9. Predicted values and CI from general additive mixed effects models fitted to examine the relationship between temperature and year during foraging.

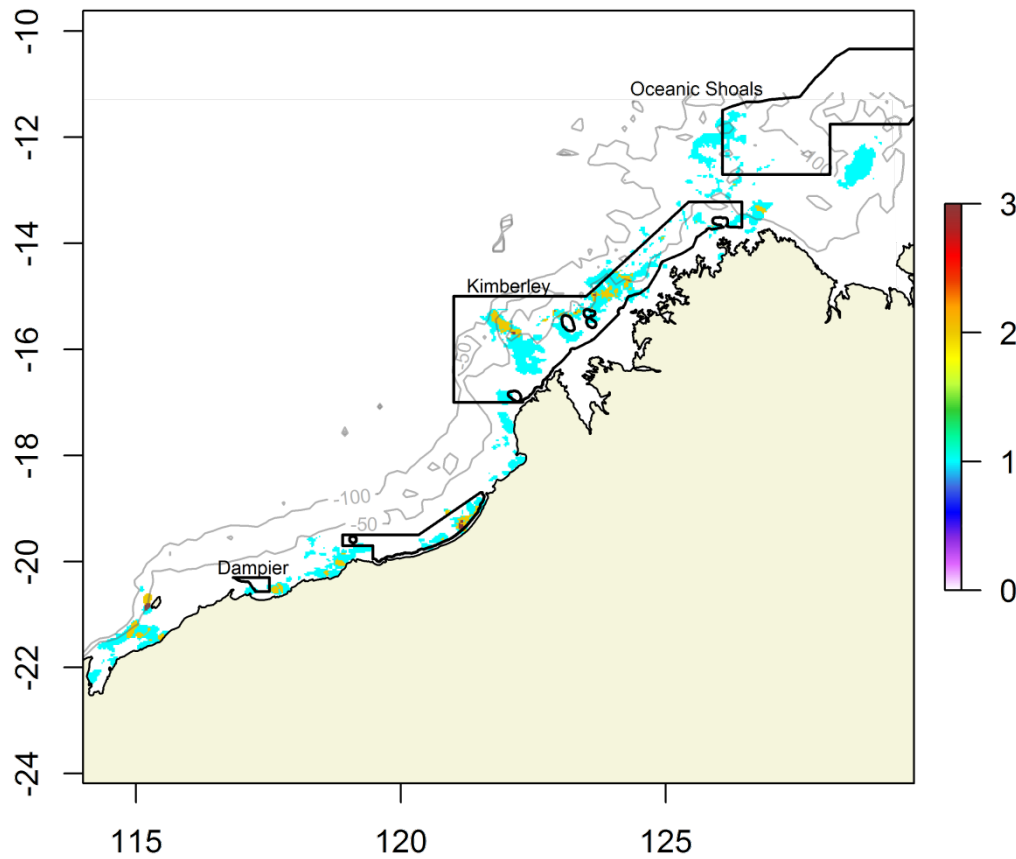


Figure S10. Spatial extent of utilisation by all turtles during foraging and overlap Commonwealth Marine reserves (black contours). The colour scale represents the maximum number of turtles utilising each 3 km grid cell.



Figure S11. Photograph of notches on rear of flatback turtle carapace caused by rubbing of the harness.

Table S1. Details of each turtle's deployment. All transmitters were deployed at Bells Beach except five turtles marked with \* which were deployed at Delambre Island. CCL=curved carapace length in mm, CCW=curved carapace width in mm, days = the number of days for which location data was provided by the transmitter, locs day<sup>-1</sup> = the average number of ARGOS locations received per day and the remaining columns are the percentages of ARGOS locations in each location class (0, 1, 2, 3, A, B, Z). Note that values reported for Fastloc tags includes ARGOS locations only.\* denotes id's for which there were large gaps in the data which likely skewed the calculation of locations per day.

| ID          | Transmitter     | Deployed   | CCL        | CCW        | Days         | Locs day <sup>-1</sup> | 0          | 1          | 2          | 3          | A           | B           | Z          |
|-------------|-----------------|------------|------------|------------|--------------|------------------------|------------|------------|------------|------------|-------------|-------------|------------|
| 99734       | kiwisat101      | 9/12/2010  | 912        | 734        | 133.0        | 4.9 ± 3.1              | 5.7        | 3.1        | 1.4        | 0.8        | 18.9        | 66.8        | 3.4        |
| 99735       | kiwisat101      | 9/12/2010  | 865        | 673        | 86.5         | 6.0 ± 3.0              | 3.4        | 2.7        | 1.3        | 0.6        | 16.8        | 72.1        | 3.1        |
| 99736       | kiwisat101      | 9/12/2010  | 878        | 738        | 233.8        | *3.3 ± 4.1             | 6.7        | 4.4        | 2.4        | 0.9        | 25.5        | 55.6        | 4.5        |
| 103235      | kiwisat101      | 23/11/2011 | 908        | 745        | 540.0        | *1.8 ± 3.6             | 9.4        | 5.2        | 5.7        | 0.5        | 29.7        | 45.8        | 3.7        |
| 103236      | kiwisat101      | 1/12/2011  |            |            | 705.0        | *1.2 ± 2.4             | 4.4        | 4.7        | 5.8        | 0.6        | 23.7        | 58.1        | 2.8        |
| 103237      | kiwisat101      | 22/12/2011 |            |            | 451.1        | 2.9 ± 2.8              | 20.6       | 13.6       | 7.4        | 1.4        | 23.6        | 30          | 3.4        |
| 111631      | kiwisat101      | 1/12/2011  | 903        | 735        | 788.6        | *5.4 ± 5.9             | 2.2        | 2.4        | 1.2        | 0.4        | 14.2        | 79.5        | 0.1        |
| 111632      | kiwisat101      | 19/11/2011 | 929        | 820        | 727.0        | 5.1 ± 4.2              | 13.1       | 11.2       | 6.8        | 2.8        | 17.6        | 48.1        | 0.4        |
| 111633      | kiwisat101      | 12/01/2012 | 889        | 765        | 790.2        | 8.5 ± 4.1              | 12.3       | 13.6       | 7.9        | 4.6        | 18.7        | 42.9        | 0          |
| 111634      | kiwisat101      | 22/12/2011 | 908        | 743        | 665.1        | 5.7 ± 4.2              | 6.2        | 4.7        | 2.7        | 1.1        | 19.1        | 66.1        | 0.1        |
| 111635      | kiwisat101      | 17/01/2012 | 907        |            | 499.6        | 7.9 ± 3.3              | 13         | 14         | 8.1        | 3.2        | 18.1        | 43.5        | 0.1        |
| *111636     | kiwisat101      | 28/11/2012 | 858        | 710        | 249.3        | 6.6 ± 4.7              | 3.6        | 4.3        | 2.3        | 1.1        | 19.5        | 68.9        | 0.2        |
| *111637     | kiwisat101      | 27/11/2012 | 925        | 724        | 279.5        | 6.5 ± 5.2              | 5.1        | 4.2        | 1.7        | 0.8        | 21.1        | 67          | 0          |
| *111638     | kiwisat101      | 28/11/2012 | 883        | 720        | 124.0        | 10.1 ± 6.5             | 3.8        | 4.1        | 1.9        | 1.6        | 19.3        | 69.3        | 0.1        |
| 111639      | kiwisat101      | 4/01/2012  | 936        | 738        | 180.6        | 10.6 ± 5.0             | 3.6        | 2.3        | 0.8        | 0.2        | 20.4        | 72.6        | 0          |
| 111640      | kiwisat101      | 19/11/2011 | 851        | 722        | 339.6        | 7.5 ± 4.1              | 8.3        | 6.8        | 3.5        | 1.8        | 21.8        | 57.6        | 0          |
| <b>Mean</b> |                 |            | <b>897</b> | <b>736</b> | <b>424.6</b> | <b>5.9</b>             | <b>7.6</b> | <b>6.3</b> | <b>3.8</b> | <b>1.4</b> | <b>20.5</b> | <b>59.0</b> | <b>1.6</b> |
| <b>SD</b>   |                 |            | <b>27</b>  | <b>33</b>  | <b>252.8</b> | <b>2.7</b>             | <b>5.0</b> | <b>4.2</b> | <b>2.7</b> | <b>1.2</b> | <b>3.7</b>  | <b>13.7</b> | <b>1.8</b> |
| 122410      | Fastloc F4G291A | 10/11/2012 | 901        | 765        | 18.6         | 3.5 ± 1.9              | 0          | 4.5        | 6.1        | 3          | 10.6        | 75.8        | 0          |
| 122411      | Fastloc F4G291A | 14/11/2012 | 923        | 730        | 329.1        | 1.7 ± 1.5              | 0.7        | 2.3        | 1.3        | 0.4        | 15.5        | 79.7        | 0.2        |
| *122412     | Fastloc F4G291A | 27/11/2012 | 900        | 728        | 158.2        | 2.5 ± 1.6              | 1.2        | 1          | 1.7        | 1.2        | 10.4        | 84          | 0.5        |
| 122413      | Fastloc F4G291A | 23/11/2012 | 892        | 721        | 133.7        | 2.5 ± 1.5              | 1.8        | 1.8        | 1.8        | 1.2        | 18.5        | 74.8        | 0.3        |
| *122415     | Fastloc F4G291A | 27/11/2012 | 865        | 740        | 272.1        | 1.9 ± 1.6              | 5.8        | 6          | 4.3        | 2.3        | 29.8        | 51.6        | 0.2        |
| 122416      | Fastloc F4G291A | 15/11/2012 | 934        | 671        | 14.1         | 3.0 ± 1.8              | 0          | 2.2        | 0          | 4.4        | 8.9         | 84.4        | 0          |

| <b>ID</b>         | <b>Transmitter</b> | <b>Deployed</b> | <b>CCL</b>   | <b>CCW</b>   | <b>Days</b>  | <b>Locs day<sup>-1</sup></b> | <b>0</b>   | <b>1</b>   | <b>2</b>   | <b>3</b>   | <b>A</b>    | <b>B</b>    | <b>Z</b>   |
|-------------------|--------------------|-----------------|--------------|--------------|--------------|------------------------------|------------|------------|------------|------------|-------------|-------------|------------|
| 122417            | Fastloc F4G291A    | 15/11/2012      | 919          | 778          | 139.2        | 2.5 ± 1.6                    | 2.9        | 4.7        | 1.7        | 1.5        | 23.6        | 65.3        | 0.3        |
| 122418            | Fastloc F4G291A    | 14/11/2012      | 935          | 745          | 382.1        | 1.6 ± 1.7                    | 0.6        | 1.9        | 1.4        | 1.6        | 12.9        | 81.3        | 0.2        |
| 122419            | Fastloc F4G291A    | 23/11/2012      | 885          | 766          | 21.7         | 2.5 ± 1.8                    | 1.8        | 3.6        | 1.8        | 3.6        | 10.9        | 78.2        | 0          |
| <b>Mean</b>       |                    |                 | <b>906</b>   | <b>738</b>   | <b>163</b>   | <b>2.4</b>                   | <b>2.1</b> | <b>3.1</b> | <b>2.5</b> | <b>2.1</b> | <b>15.7</b> | <b>75.0</b> | <b>0.3</b> |
| <b>SD</b>         |                    |                 | <b>24</b>    | <b>32</b>    | <b>138</b>   | <b>0.6</b>                   | <b>1.8</b> | <b>1.7</b> | <b>1.7</b> | <b>1.3</b> | <b>7.1</b>  | <b>10.5</b> | <b>0.1</b> |
| 123155            | CTD-SRDL           | 12/01/2013      | 900          | 728          | 93.3         | 9.5 ± 3.2                    | 2.6        | 2.2        | 1.1        | 0.7        | 22.8        | 70.6        | 0          |
| 123156            | CTD-SRDL           | 12/01/2013      | 887          | 719          | 414.5        | 6.6 ± 3.3                    | 12.8       | 9          | 4.6        | 1.6        | 25.1        | 46.8        | 0.1        |
| 123157            | CTD-SRDL           | 26/11/2012      | 865          | 682          | 488.8        | 3.9 ± 3.6                    | 4.6        | 2.9        | 1.2        | 0.5        | 15.5        | 75.2        | 0          |
| 123158            | CTD-SRDL           | 26/11/2012      | 880          | 720          | 288.7        | 6.5 ± 3.6                    | 4.1        | 5.4        | 2.7        | 1.4        | 19.6        | 66.7        | 0.2        |
| 123159            | CTD-SRDL           | 23/11/2012      | 905          | 748          | 171.0        | 5.1 ± 4.2                    | 5.4        | 4          | 1.5        | 0.8        | 16.9        | 71.2        | 0.1        |
| 123160            | CTD-SRDL           | 7/01/2013       | 886          | 737          | 465.6        | 6.1 ± 4.8                    | 0.9        | 0.6        | 0.2        | 0.2        | 10.4        | 87.8        | 0          |
| 123161            | CTD-SRDL           | 26/11/2012      | 880          | 749          | 557.8        | 6.2 ± 3.2                    | 9.6        | 9.6        | 6.1        | 3.6        | 17.7        | 53.5        | 0.1        |
| 123162            | CTD-SRDL           | 8/01/2013       | 881          | 729          | 280.5        | 8.0 ± 2.8                    | 9.5        | 5.9        | 2.4        | 0.7        | 21.5        | 60          | 0.1        |
| 123163            | CTD-SRDL           | 30/11/2012      | 854          | 712          | 516.5        | 6.1 ± 3.8                    | 9.7        | 7.1        | 5.1        | 2.7        | 20.5        | 54.9        | 0          |
| 123164            | CTD-SRDL           | 12/01/2013      | 879          | 759          | 142.3        | 7.9 ± 2.6                    | 10.8       | 5.6        | 2.9        | 0.8        | 27.1        | 52.7        | 0.1        |
| <b>Mean</b>       |                    |                 | <b>882</b>   | <b>728</b>   | <b>342</b>   | <b>6.6</b>                   | <b>7.0</b> | <b>5.2</b> | <b>2.8</b> | <b>1.3</b> | <b>19.7</b> | <b>63.9</b> | <b>0.1</b> |
| <b>SD</b>         |                    |                 | <b>15</b>    | <b>22</b>    | <b>169</b>   | <b>1.6</b>                   | <b>4.0</b> | <b>2.9</b> | <b>1.9</b> | <b>1.1</b> | <b>4.9</b>  | <b>12.6</b> | <b>0.1</b> |
| <b>Grand Mean</b> |                    |                 | <b>894.6</b> | <b>734.2</b> | <b>333.7</b> | <b>5.2</b>                   | <b>6.2</b> | <b>5.2</b> | <b>3.2</b> | <b>1.6</b> | <b>19.0</b> | <b>64.5</b> | <b>0.9</b> |
| <b>Grand SD</b>   |                    |                 | <b>24.1</b>  | <b>29.1</b>  | <b>227.6</b> | <b>2.6</b>                   | <b>4.6</b> | <b>3.5</b> | <b>2.3</b> | <b>1.2</b> | <b>5.3</b>  | <b>13.9</b> | <b>1.4</b> |

Table S2. Turtle haulouts recorded by the SRDL tags that might have been related to nesting behaviour.

| ID     | Duration<br>(mins) | Deployment<br>date | Datetime         | Time<br>elapsed<br>(days) | Distance<br>(km) |
|--------|--------------------|--------------------|------------------|---------------------------|------------------|
| 123157 | 65.5               | 26/11/2012         | 11/12/2012 17:16 | 16.1                      | 1.6              |
| 123158 | 84.5               | 26/11/2012         | 18/12/2012 15:28 | 23.0                      | 0.5              |
| 123159 | 58.0               | 23/11/2012         | 13/12/2012 22:45 | 21.3                      | 1.2              |
| 123161 | 73.0               | 26/11/2012         | 12/12/2012 19:33 | 17.2                      | 4.4              |
| 123161 | 58.5               | 26/11/2012         | 23/12/2012 22:31 | 11.1                      | 0.9              |
| 123161 | 58.5               | 26/11/2012         | 6/01/2013 0:48   | 12.2                      | 1.5              |
| 123163 | 87.5               | 30/11/2012         | 13/12/2012 22:19 | 14.3                      | 1.9              |
| 123164 | 83.0               | 12/01/2013         | 28/01/2013 1:09  | 16.4                      | 1.2              |
| Mean   | 71.1±12.6          |                    |                  | 16.4±4.1                  | 1.7±1.2          |

Table S3. Ranked mixed models of each of the response variables explained by the fixed predictor variables and the random effect turtle ID. Shown for each model are the degrees of freedom (df), log likelihood (LL), Akaike's information criterion corrected for small samples (AIC<sub>c</sub>), the difference in AIC<sub>c</sub> for each model from the top-ranked model ( $\Delta$ AIC<sub>c</sub>), the model weight ( $w$ AIC<sub>c</sub>) and R-squared marginal (R<sup>2</sup> marg), representing the proportion of variance explained by fixed factors and R-squared conditional (R<sup>2</sup> cond), representing the proportion of variance explained by both fixed and random factors. All models are linear except those with temperature (Temp) as the response, which are additive models. TMD = time at maximum depth, PBR = proportion of bottom reached and TAD = time allocation at depth.

| Model                   | df | LL        | AIC <sub>c</sub> | $\Delta$ AIC <sub>c</sub> | $w$ AIC <sub>c</sub> | R <sup>2</sup> marg | R <sup>2</sup> cond |
|-------------------------|----|-----------|------------------|---------------------------|----------------------|---------------------|---------------------|
| Depth~Behaviour         | 8  | -30690.60 | 61397.20         | 0.00                      | 1.00                 | 0.11                | 0.55                |
| Depth~1                 | 6  | -30925.08 | 61862.17         | 464.97                    | 0.00                 | 0.11                | 0.55                |
| Duration~Behaviour      | 8  | -71558.63 | 143133.27        | 0.00                      | 1.00                 | 0.10                | 0.18                |
| Duration~1              | 6  | -71737.23 | 143486.47        | 353.20                    | 0.00                 | 0.10                | 0.18                |
| Surf duration~Behaviour | 6  | -55831.82 | 111675.64        | 0.00                      | 1.00                 | 0.02                | 0.07                |
| Surf duration ~1        | 4  | -55891.03 | 111790.07        | 114.43                    | 0.00                 | 0.02                | 0.07                |
| Descent rate~Behaviour  | 6  | 2259.72   | -4507.43         | 0.00                      | 0.92                 | <0.01               | 0.03                |
| Descent rate~1          | 4  | 2255.22   | -4502.44         | 4.99                      | 0.08                 | <0.01               | 0.03                |
| Ascent rate~Behaviour   | 6  | 9492.53   | -18973.05        | 0.00                      | 1.00                 | 0.01                | 0.03                |
| Ascent rate~1           | 4  | 9457.53   | -18907.07        | 65.98                     | 0.00                 | 0.01                | 0.03                |
| TMD~Beh                 | 6  | -92220.86 | 184453.72        | 0.00                      | 1.00                 | <0.01               | 0.03                |
| TMD~1                   | 4  | -92233.08 | 184474.17        | 20.46                     | 0.00                 | 0.00                | 0.03                |
| PBR~Beh                 | 6  | 1034.22   | -2056.44         | 0.00                      | 1.00                 | 0.02                | 0.11                |
| PBR~1                   | 4  | 979.52    | -1951.04         | 105.40                    | 0.00                 | 0.02                | 0.11                |
| TAD~Beh                 | 6  | 5121.54   | -10231.08        | 0.00                      | 1.00                 | 0.01                | 0.07                |
| TAD~1                   | 4  | 5080.58   | -10153.15        | 77.93                     | 0.00                 | 0.01                | 0.07                |
| Temp~ s(jday)+ s(depth) | 8  | -1114.08  | 2244.20          | 0.00                      | 1.00                 | 0.46                | 0.98                |
| Temp~ s(jday)           | 6  | -1176.78  | 2365.59          | 121.39                    | 0.00                 | 0.45                | 0.98                |

Table S4. Ranked generalised additive mixed models of each of the response variables explained by the fixed predictor and the random effect turtle ID. Shown for each model are the degrees of freedom (df), log likelihood (LL), Akaike's information criterion corrected for small samples ( $AIC_c$ ), the difference in  $AIC_c$  for each model from the top-ranked model ( $\Delta AIC_c$ ), the model weight ( $wAIC_c$ ) and R-squared marginal ( $R^2_{\text{marg}}$ ), representing the proportion of variance explained by fixed factors and R-squared conditional ( $R^2_{\text{cond}}$ ), representing the proportion of variance explained by both fixed and random factors.

| Model                 | df | LL        | $AIC_c$  | $\Delta AIC_c$ | $wAIC_c$ | $R^2_{\text{marg}}$ | $R^2_{\text{cond}}$ |
|-----------------------|----|-----------|----------|----------------|----------|---------------------|---------------------|
| Nesting               |    |           |          |                |          |                     |                     |
| Temp ~ s(jday)        | 6  | -2306.06  | 4624.15  | 1.67           | 1        | 0.16                | -                   |
| Temp ~ year + s(jday) | 7  | -2305.89  | 4625.83  | 0              | 0        | 0.12                | -                   |
| Foraging              |    |           |          |                |          |                     |                     |
| Temp ~ year + s(jday) | 9  | -37001.22 | 74020.45 | 0              | 1        | 0.60                | -                   |
| Temp ~ s(jday)        | 6  | -37195.62 | 74403.24 | 382.79         | 0        | 0.02                | -                   |