

**The spatial ecology of marine turtles**

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**Matthew J. Witt**

## **Abstract**

Gaining an understanding of the spatial ecology of marine turtles is essential for elucidating aspects of their life history ecology and for effective conservation management. This thesis presents a collection of chapters seeking to investigate the spatial ecology of this taxon. An array of technologies and methodologies are employed to ask both ecological and spatial management questions. Work focuses on foraging and thermal ecology, spatial appropriateness of Marine Protected Areas, movement models to describe habitat utilisation, analysis of data from sightings and strandings schemes and the use of a large synoptic fisheries dataset to describe fisheries patterns and putative risks to marine megavertebrates.

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### Chapter I

Prey landscapes help identify potential foraging habitats for leatherback turtles in the northeast Atlantic

Figure 1. (a) Spatial and temporal distribution of reports of live leatherback turtles (1954 to 2003) on the European continental shelf. Dashed lines: 5th and 95th percentiles of this monthly spatial distribution; (o) records outside the defined range. Records between January and April are outside of the core seasonal distribution and represent 5 records in 50 years; the individual latitudes of these records are shown. Number of records for each month is shown above x-axis. (b) Sea surface temperature for records of leatherback turtles (alive  $n = 1514$ , dead  $n = 474$ ). (c) Minimum curved carapace length, CCL observed at each degree of latitude from records with carapace measurements ( $n = 268$ ). Solid line indicates regression ( $R^2 = 0.4$ ,  $F_{1,17} = 10.4$ ,  $p < 0.001$ ).

Figure 2. Leatherback turtles and gelatinous organisms in the northeast Atlantic. Long-term monthly mean (1954–2003) gelatinous organism distribution with records of live leatherback turtles (empty circles) for May to October (1954–2003).  $n$ : number of records within each monthly image. White zones: CPR data deficient regions. Solid white lines: long-term monthly mean position of the 10 and 12°C sea surface isotherms (Hadley ISST, 1954–2003). A: Rockall Bank. B: Porcupine Bank and Porcupine Bight. Dashed black lines: UK declared fishing zone and the Exclusive Economic Zone (EEZ) of Ireland (overlap of UK Fishing Zone and Irish EEZ is disputed territory). Grey coastal zone: territorial waters (12 nautical miles from coastal baseline). Proportion positive: proportion of CPR samples at each location positive for gelatinous organisms.

Figure 3. Gelatinous organisms in the North Atlantic. Long-term seasonal mean (1954–2003) gelatinous organism distribution for (a) summer and (b) autumn. White zones: CPR data deficient regions. Solid white lines: long-term seasonal mean position of the 10 and 12°C sea surface isotherms (Hadley ISST, 1954–2003). Boxes A and B describe leatherback turtle occupation zones recorded from satellite tracking by Ferraroli et al. (2004) (2 turtles), and Hays et al. (2004) (5 turtles) respectively, and circumscribe the minimum and maximum spatial extents of movement within the displayed images. Box C highlights a gelatinous prey 'hotspot' that could support foraging individuals during thermally accessible periods. Insets: frequency distributions of mean gelatinous organism relative abundance calculated from randomised block re-sampling (bootstrapping) using dimensions of box A (solid line) and box B (dotted line) for (a) summer and (b) autumn. Vertical lines: mean gelatinous organism relative abundance calculated for box A and B prior to the bootstrapping routine.

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## Chapter II

Satellite tracking highlights difficulties in the design of effective protected areas for leatherback turtles during the interesting period

Figure 1. (a) Leatherback turtle nesting sites in Gabon (filled circles) including Mayumba National Park. Labels: (I) Equatorial Guinea territorial sea and exclusive economic zone, (II) Sao Tome & Principe economic zone, (III) Gabon territorial sea, contiguous zone and exclusive economic zone and (IV) Congo territorial sea. Hatched zone represents disputed region. Dashed line polygon depicts spatial extents of Figure 1b and c. Inset map shows the African continent, box (dashed line) indicates the spatial extents of Figure 1a. (b) Argos derived tracks of turtles A-E. Dotted black lines are bathymetric contours. Solid black arrows highlight dominant offshore ocean currents derived from absolute dynamic topography satellite altimetry data. (c) Habitat utilisation by tracked turtles using a single daily position taken at 12-midday for each turtle. Vertical inset colour scale indicates the number of occupation events per cell. Dotted black lines are bathymetric contours.

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Table I. Summary table of leatherback turtle morphometrics and movement metrics for time at liberty.

### Chapter III

How much monitoring is needed for the worlds' largest aggregation of nesting leatherback turtles?

Figure 1. Coastal National Parks and Reserves of Gabon. Empty circles indicate aerial survey ground truthing regions. Labelled regions (Pongara, Iguela, Gamba and Bame) also contributed daily count data of leatherback turtle activities for the construction of seasonal nesting activity curves. Labels: Pongara National Park (PN), Wonga Wongue Reserve (WW), Loango National Park (LO), Sette Cama Reserve (SC), Ouangu Reserve (OU) and Mayumba National Park (MN).

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## Chapter V

Spatio-temporal patterns of juvenile marine turtle occurrence in waters of the European continental shelf

Figure 1. Temporal incidence of records of loggerhead, Kemp's ridley and leatherback turtles. Decadal distribution in the British Isles, 1910–2003: (a) loggerhead turtles  $n = 123$ , (b) Kemp's ridley turtles  $n = 28$  and (c) leatherback turtles  $n = 650$ . Annual distribution in the British Isles (filled bars) and France (open bars) 1990–2003: (d) loggerhead turtles. British Isles  $n = 74$  turtles and France  $n = 194$ . (e) Kemp's ridley turtles. British Isles  $n = 6$  and France  $n = 16$ . (f) leatherback turtles. British Isles  $n = 398$  and France  $n = 1018$ .

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Figure 7. Schematic of predominant ocean currents of the North Atlantic

## Chapter VI

A step towards seascape scale conservation: using VMS to map fishing activity

Figure 1. (a) Mean annual spatial distribution of fisheries activity derived from VMS records using a simple speed filter. The colour scale indicates the mean annual number of VMS derived data points within 9 km<sup>2</sup> pixels, solid line circumscribes the UK declared fishing zone, broken line is 200 m depth contour. Regional labels: Western Channel (WA), Goban Spur (GS), Rockall (RK) and Northern North Sea (NI). (b) Tonnes of fish (demersal and pelagic) landed by UK registered vessels from the shown ICES statistical reporting boxes. Total number of vessels registered at main UK fishing ports greater than 17 metres in overall length (filled circles). All vessels for Northern Ireland have been mapped to Belfast. (c) Coefficient of variation of the mean annual distribution of fisheries activity, lighter colours indicate areas of greatest variability in space-use, darker areas indicate regions of consistent space-use on annual time-scales. (d) Coefficient of variation of the mean monthly distribution of fisheries activity, lighter colours indicate areas of greatest variability in space-use, darker areas indicate regions of consistent space-use on monthly time-scales.

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Figure S4. Mean monthly maps of fishing activity (vessels moving  $\geq 3$  and  $\leq 10$  km h<sup>-1</sup>) for the period 2000-2004. Maps show the mean number of data points at each pixel, where darker colour indicates greater number of visits by vessels travelling at speeds most likely to indicate fisheries activity.