Breeding loggerhead marine turtles *Caretta caretta* in Dry Tortugas National Park, USA, show high fidelity to diverse habitats near nesting beaches

KRISTEN M. HART, DAVID G. ZAWADA, AUTUMN R. SARTAIN and IKUKO FUJISAKI

Abstract We used satellite telemetry to identify in-water habitat used by individuals in the smallest North-west Atlantic subpopulation of adult nesting loggerhead turtles *Caretta caretta* during the breeding season. During 2010, 2011 and 2012 breeding periods, a total of 20 adult females used habitats proximal to nesting beaches with various levels of protection within Dry Tortugas National Park. We then used a rapid, high-resolution, digital imaging system to map habitat adjacent to nesting beaches, revealing the diversity and distribution of available benthic cover. Turtle behaviour showing measurable site-fidelity to these diverse habitats has implications for managing protected areas and human activities within them. Protecting diverse benthic areas adjacent to loggerhead turtle nesting beaches here and elsewhere could provide benefits for overall biodiversity conservation.

Keywords ATRIS, *Caretta caretta*, habitat mapping, kernel density estimation, marine protected area, marine spatial planning, satellite-telemetry, site-fidelity

This paper contains supplementary material that can be found online at http://journals.cambridge.org

Introduction

Globally, loggerhead marine turtle *Caretta caretta* populations are declining (Witherington et al., 2009). Within the Western Atlantic five subpopulations have been defined, based on genetic analyses: (1) Northern, (2) Peninsular Florida, (3) Dry Tortugas, (4) Northern Gulf of Mexico, and (5) Greater Caribbean (Shamblin et al., 2011, 2012). The threatened Dry Tortugas subpopulation is estimated to be the smallest, with 258–496 adult females (Richards et al., 2011). The small population and remoteness of the nesting beaches make Dry Tortugas turtles ideal for studying habitat requirements of nesting loggerhead turtles. To provide adequate protection for marine turtles from in-water threats throughout their nesting phase and inter-nesting period, knowledge of both large- and fine-scale habitat-use patterns is required (Hamann et al., 2010).

Dry Tortugas National Park encompasses a cluster of islands c. 100 km west of Key West, Florida (Fig. 1), where loggerhead turtles regularly nest on the sandy beaches (Reardon, 2000). Of the seven islands in the Park, the smallest is East Key (c. 400 m long × c. 100 m wide) and the largest is Loggerhead Key (c. 1.5 km long × c. 250 m wide); the majority of turtle-nesting activity occurs on these two islands (Fig. 1). The Park is subdivided into a Natural Cultural Zone, where Park rules apply but where human uses are permitted, and a Research Natural Area, in which most human activities (e.g. anchoring, fishing) are restricted. The Research Natural Area contains an exclusion zone, the Historic Adaptive Use Zone (Fig. 1), within which anchoring and hook-and-line fishing are permitted.

Hart et al. (2010) described the first in-water habitat-use patterns for seven Dry Tortugas loggerhead turtles nesting on East Key. They used satellite telemetry to identify core habitat zones, and mapped their benthic composition using the U.S. Geological Survey's Along-Track Reef Imaging System (ATRIS; Zawada et al., 2008). As Dry Tortugas contains another significant nesting site (Loggerhead Key), an expanded study was warranted to understand fully the behaviours and needs of this subpopulation during critical inter-nesting periods.

Methods

We analysed satellite tracks of an additional 20 loggerhead turtles, of which 10 nested on East and 10 on Loggerhead Key. We tested the hypothesis that loggerhead turtles used in-water habitat in close proximity to nesting beaches, and characterized the core-use benthic habitat selected by turtles. To track turtles we followed the methods described in Hart et al. (2010): tagging and sampling were carried out after we intercepted turtles following nesting events or false crawls (Table 1). Satellite positions were determined by Argos, with six location classes of varying accuracies: < 250 m for location class 3; 250–$<$ 500 m for 2; 500–$<$ 1,500

KRISTEN M. HART (Corresponding author) U.S. Geological Survey, Southeast Ecological Science Center, 3205 College Avenue, Davie, Florida, USA
E-mail kristen_hart@usgs.gov

DAVID G. ZAWADA U.S. Geological Survey, St. Petersburg Coastal and Marine Science Center, St. Petersburg, Florida, USA

AUTUMN R. SARTAIN CNMC, contracted to U.S. Geological Survey, Southeast Ecological Science Center, Davie, Florida, USA

IKUKO FUJISAKI University of Florida, Fort Lauderdale Research and Education Center, Davie, Florida, USA

Received 2 February 2014. Revision requested 1 May 2014.
Accepted 25 September 2014. First published online 29 December 2014.

doi:10.1017/S0030605314000854

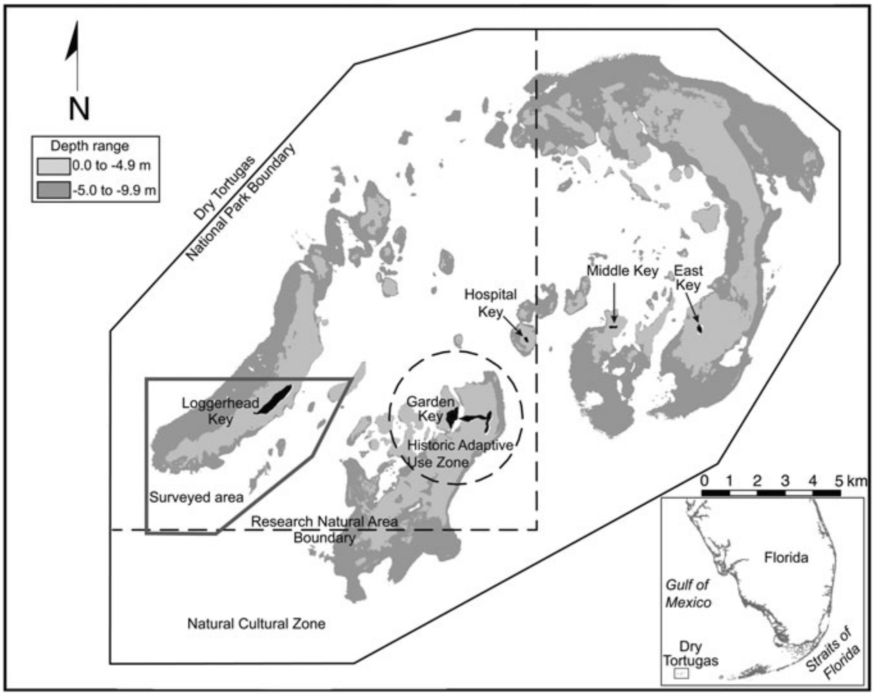

FIG. 1 The location of the study area in Dry Tortugas National Park, Florida, USA. The major shoals within the Park are shaded in grey. ATRIS imagery was collected within the designated survey area (thick grey polygon). The rectangle on the inset shows the location of the main map off the coast of Florida.

TABLE 1 Summary of satellite-tracking details for adult nesting loggerhead turtles *Caretta caretta* in Dry Tortugas National Park during 2010–2012, with tag number, turtle size, tagging date, duration of inter-nesting tracking period, mean daily locations, results of site-fidelity test, and kernel density estimates. A blank cell indicates kernel density estimate was not calculated because mean daily locations was < 20 or the turtle failed the site-fidelity test.

Turtle ID	Turtle size (straight carapace length, cm)	Tagging date	Inter-nesting tracking period (days)	Mean daily locations	Site fidelity test*	50% kernel density estimate area, km^2
Loggerhead Key						
A	99.5	18 May 2011	19 May–19 June 2011 (32)	29	Passed	88.0
B	100.5	23 May 2011	24 May–21 July 2011 (59)	50	Passed	448.4
C	106.5	23 May 2011	24 May–30 June 2011 (38)	31	Passed	243.8
D	82.6	23 May 2011	24 May–25 June 2011 (33)	32	Passed	152.0
E	93.0	24 May 2011	25 May–12 July 2011 (49)	47	Passed	188.6
F	92.5	15 July 2011	16–28 July 2011 (13)			
G	86.0	16 July 2011	17 July–6 Aug. 2011 (21)	21	Failed	
H	92.0	18 July 2011	19 July–5 Aug. 2011 (18)			
I	89.5	13 May 2012	14 May–24 July 2012 (72)	71	Passed	129.8
J	87.0	14 May 2012	17 May–16 July 2012 (61)	60	Passed	32.0
East Key						
K	90.1	29 May 2010	30 May–19 Aug. 2010 (82)	61	Passed	329.7
L	90.0	29 May 2010	30 May–18 July 2010 (50)	26	Passed	166.9
M	91.0	29 May 2010	30 May–20 July 2010 (52)	50	Passed	213.2
N	89.3	30 May 2010	31 May–20 Aug. 2010 (82)	31	Passed	39.0
O	88.8	2 June 2010	3 June–9 July 2010 (37)	24	Passed	73.9
P	91.5	2 June 2010	6 July–11 Aug. 2010 (37)	36	Passed	120.7
Q	74.2	9 May 2012	10 May–16 July 2012 (68)	63	Passed	30.8
R	76.0	11 May 2012	12 May–6 July 2012 (56)	52	Passed	18807.2
S	99.5	11 May 2012	13 May–15 July 2012 (64)	42	Passed	101.8
T	83.8	11 May 2012	12 May–2 July 2012 (52)	51	Passed	24.1
Mean ± SD	90.2 ± 7.8		47.8 ± 20.0			141.7 ± 117.2

*Site-fidelity tests were run to determine if movements within inter-nesting areas were random. Passed indicates rejection of the null hypothesis that the movements were random. The proportion of the random movement paths with higher mean square distance values than the observed path was > 0.99 for all turtles except turtle G, which had a proportion > 0.88.

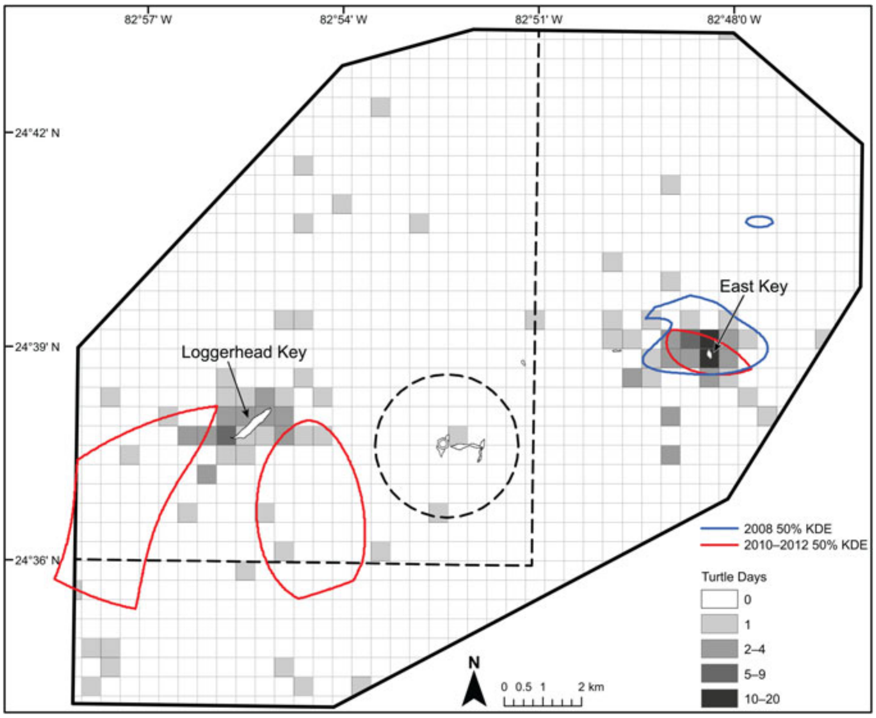

FIG. 2 Inter-nesting locations of loggerhead turtles *Caretta caretta* in Dry Tortugas National Park. The colour of each 0.5 × 0.5 km cell indicates the number of high-quality turtle-tracking days for nesting loggerhead turtles (n = 20). Core-use area overlaps (50% kernel density estimate, KDE) are indicated for turtles nesting on East Key or Loggerhead Key (delineated in red). The blue line delineates the 50% KDE overlap area for the seven turtles tagged in 2008 and 2009 (Hart et al., 2010).

m for 1; and > 1,500 m for 0. For a satellite pass with three or two messages the accuracy was unknown and locations were tagged as location classes A and B, respectively (CLS, 2011, but see also Witt et al., 2010, for on-animal location accuracy estimates). Argos provided Kalman-filtered (Kalman, 1960) data and we manually removed obviously erroneous points (e.g. on land or very distant) and location class Z, as well as points that required straight-line swimming speeds > 5 km per hour, were deeper than 150 m (Hawkes et al., 2011, found that adult female loggerhead turtles in the south-eastern USA did not generally leave the waters of the continental shelf (< 200 m), and the depths throughout Dry Tortugas are ≤ 100 m), occurred on the capture date, and were considered to be outside the inter-nesting time period (i.e. after obvious migration away from the study site, such as the last point within 25 km of Dry Tortugas or after 31 August, the end of the breeding period for Dry Tortugas loggerhead turtles). For filtered locations with at least 20 days of data we generated the mean number of daily locations, to minimize autocorrelation, and used them in the kernel density estimation, a non-parametric method for identifying one or more core areas within a home-range boundary (White & Garrott, 1990), with appropriate weighting of outlying observations. We used *ArcGIS v. 9.3* (ESRI, Redlands, USA) to calculate the in-water area within 50% kernel density estimates to represent the core area of activity during inter-nesting (Hooge et al., 2001; Supplementary Material 1), and overlaid each turtle's core area to determine an overlap area where turtles co-occurred. Turtle site-fidelity to inter-nesting areas was determined with Monte Carlo Random Walk simulations (100 replicates), using the *Animal Movement Analysis* extension for *ArcView v. 3.2* (Supplementary Material 2). We also calculated the number of days within each grid cell (0.5 × 0.5 km) for individual turtles (Fig. 2), using only filtered locations with location classes 3, 2 and 1, as these accuracy estimates matched the spatial scale of the selected grid.

To assess habitat diversity around Loggerhead Key we conducted benthic surveys in July 2011 using ATRIS, which simultaneously acquired geo-referenced, colour digital images and measurements of water depth (Fig. 3a). We assigned ATRIS images to one of five categories based on the predominant substrate type: rubble, sand, seagrass, senile coral reef, or unclassifiable. We grouped categorized images into a 0.5 × 0.5 km grid (Fig. 3a) and computed the inverse of Simpson's index, a measure of habitat diversity (Fig. 3b; see equation in Hart et al., 2010). Cells containing < 50 images were excluded from analyses. To investigate turtle–habitat associations we calculated the total number of turtle tracking days per cell (high-quality locations only), and overlaid this on the habitat-index plot (Fig. 3b).

Results

Our turtle-tracking data revealed that 17 of 18 turtles (94%) showed site-fidelity to core inter-nesting habitats (50% kernel density estimates; Table 1). Distance to the nearest land from the centroids of these 50% kernel density estimates was 0.5–10.5 km (Supplementary Material 1), which supports

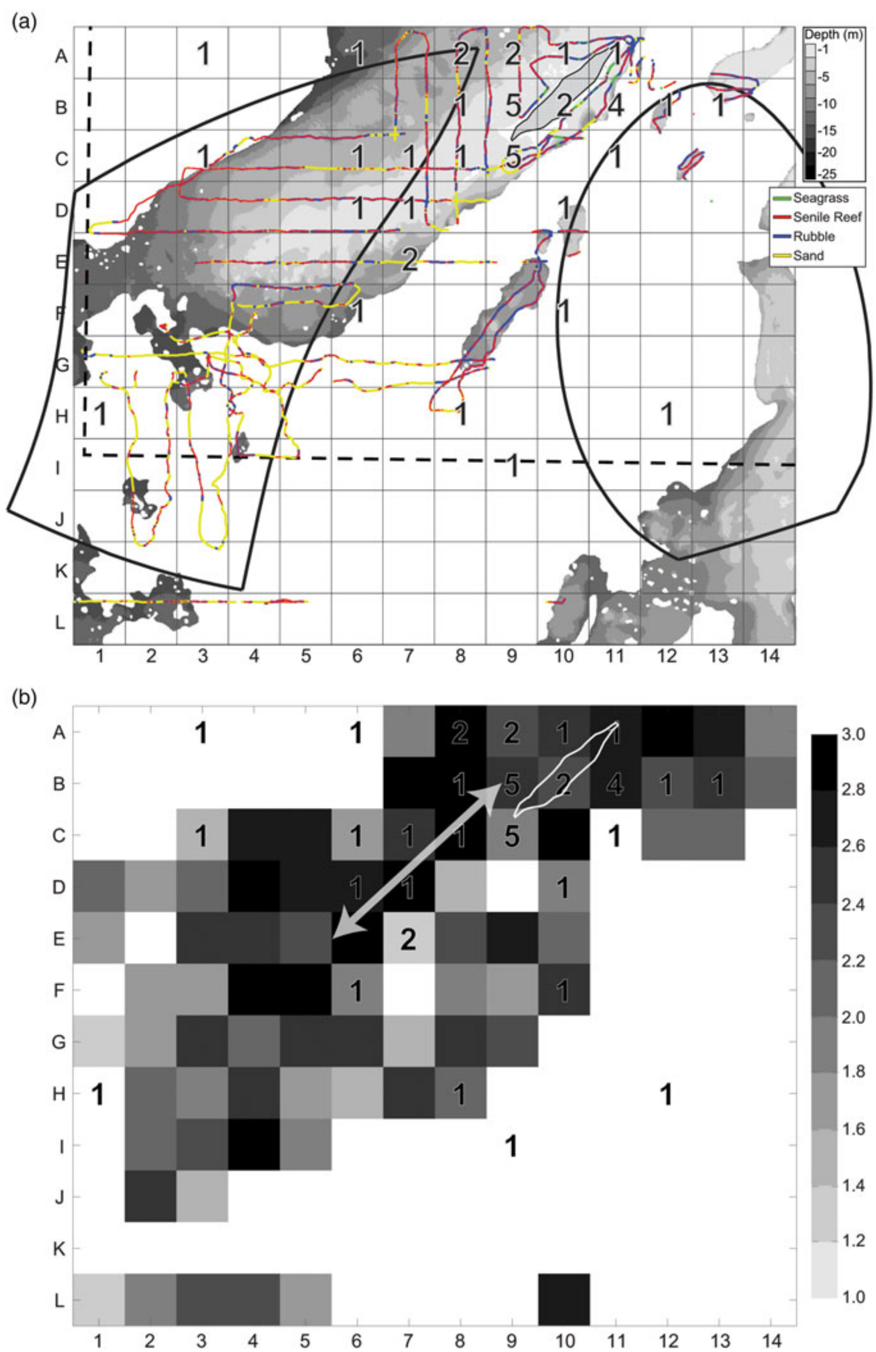

FIG. 3 (a) ATRIS transect lines (103 km surveyed during 13–19 July 2011), coloured according to benthic habitat type; note offshore diversion of track line to avoid a medium-profile patch reef (Little Africa; row A, column 10). The 0.5 × 0.5 km cells were used to compute habitat diversity based on the categorized ATRIS images. The numbers in the cells are the total number of location class 3, 2, and 1 turtle observations obtained via satellite tracking for each cell. The 50% kernel density estimate overlap areas and the Research Natural Area boundary are delineated by solid and dashed black lines, respectively. (b) The inverse Simpson diversity index was computed for the grid cells, excluding cells with < 50 classified ATRIS images. The spatial variability of the index reflects changes in habitat diversity at the 0.5-km scale throughout the study site. Loggerhead Key is delineated in white. Arrows depict a corridor between inter-nesting areas. Higher scale values equate to higher biodiversity index values.

previous findings (Miller, 1997; Schroeder et al., 2003; Hart et al., 2010). The 10 East Key loggerhead turtles used an area almost identical to that reported in Hart et al. (2010; Fig. 2), demonstrating consistency of inter-nesting habitat-use across years and turtles.

The ATRIS surveys (Fig. 3a) yielded 264,100 permanently archived colour digital images; every fifth image (47,312 images) was used for analysis because of extensive overlap. Carbonate sand was the dominant cover type (32.3%) and seagrass was the least represented (3.6%). Senile coral reef was present throughout the surveyed area but was most prevalent and dominant in the western half (Fig. 3a, rows A–E, columns 1–9). Patches of rubble were found all around Loggerhead Key and represented the predominant cover type on the shoals west and south of the island (Fig. 3a, blue area).

The spatial distribution of the inverse of Simpson's index revealed that regions of highest habitat diversity (≥ 2.4) were situated in close proximity to the beach (Fig. 3b, rows A–C, columns 7–13) and to its south-west (rows C–F, columns 4–8). Turtle observations per cell (20 of 37, 54%) showed turtles that nested on Loggerhead Key were most often located within areas of high habitat-diversity. All cells with turtle counts represented various combinations of our tagged turtles, with the exception of the two cells with five counts (Fig. 3, rows B–C, column 9), where turtle I was detected twice in each cell, and the one cell with four counts (Fig. 3, row B, column 11), where turtle J was detected four times. For the duration of the study three turtles (D, E and G) only registered sufficiently high-quality location data within the grid boundary west of Loggerhead Key.

Discussion

As in the previous study of loggerhead turtles around East Key (Hart et al., 2010) the highest-quality turtle-location data occurred within areas of highest habitat-diversity (Fig. 3b). The kernel density estimates exhibit a similar orientation to the south of Loggerhead Key, suggesting these tagged turtles are primarily accessing the nesting beaches from the south and leaving them along similar paths. Previously we observed a westward bias among the core-areas of East Key nesters (Hart et al., 2010); these areas were adjacent to a deep-water channel, with low habitat diversity and dominated by sand and rubble, but they were interspersed between regions of high diversity. At Loggerhead Key the east side offers the most direct access to deep water but is essentially devoid of suitable structure for hiding or resting. Loggerhead Key's west side offers more diverse habitat, including a medium-profile patch reef (Little Africa; Fig. 3a, row A, column 10) and numerous shallow ledges oriented parallel to the island and extending south (row B, columns 8–9 to row E, columns 5–6). Isolated clusters of living coral heads occur on top of and to the west of the ledges. For our tagged turtles nesting on Loggerhead Key, greater habitat diversity and a more topographically complex benthos seem to be more important than proximity to deep water.

Our group of 27 loggerhead turtles (20 in this study, seven in Hart et al., 2010) represents c. 10% of the estimated nesting population in Dry Tortugas, a genetically distinct subpopulation. Tracking data revealed high site-fidelity to the chosen nesting beach and nearby waters during inter-nesting, and preferred corridors between them. Benthic mapping (here and in Hart et al., 2010) showed both nesting beaches are adjacent to diverse habitat, which may contribute to the turtles remaining within c. 10 km of their nesting beach during breeding periods. This behaviour has implications for evaluating current protected-area boundaries as well as regulating human activities in areas near loggerhead turtle nesting beaches at Dry Tortugas. Protecting diverse benthic areas that are located adjacent to loggerhead turtle nesting beaches here and elsewhere could provide benefits for overall biodiversity conservation.

Acknowledgements

We thank National Park Service (NPS) staff at Dry Tortugas National Park, and U.S. Geological Survey (USGS) staff, for field and laboratory assistance. The USGS Coastal and Marine Geology, Priority Ecosystem Studies, and Ecosystems Programs provided funding. We acknowledge the use of STAT at www.seaturtle.org. All research on loggerhead turtles was conducted according to institutional and animal-care protocols (USGS/SESC 2011-05), NPS permits DRTO-2008-SCI-0008, DRTO-2009-SCI-0005, DRTO-2011-SCI-0012, DRTO-2012-SCI-0008, and Florida Marine Turtle Permit 176. Any use of trade, product or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

References

CLS (Collection, Location, Satellites) (2011) *Argos User's Manual: Worldwide Tracking and Environmental Monitoring by Satellite*. 19 August 2011 update. CLS, Toulouse, France. http://www.argos-system.org/web/en/76-user-s-manual.php[accessed 20 October 2011].

Hamann, M., Godfrey, M.H., Seminoff, J.A., Arthur, K., Barata, P.C.R., Bjorndal, K.A. et al. (2010) Global research priorities for sea turtles: informing management and conservation in the 21st century. *Endangered Species Research*, 11, 245–269.

Hart, K.M., Zawada, D.G., Fujisaki, I. & Lidz, B.H. (2010) Inter-nesting habitat-use patterns of loggerhead sea turtles: enhancing satellite tracking with benthic mapping. *Aquatic Biology*, 11, 77–90.

Hawkes, L.A., Witt, M.J., Broderick, A.C., Coker, J.W., Coyne, M.S., Dodd, M. et al. (2011) Home on the range: spatial ecology of loggerhead turtles in Atlantic waters of the USA. *Diversity and Distributions*, 17, 624–640.

Hooge, P.N., Eichenlaub, W. & Hooge, E.R. (2001) *Animal Movement Extension to ArcView, version 2.5*. U.S. Geological Survey, Alaska Biological Science Center–Biological Science Office, Anchorage, USA.

Kalman, R.E. (1960) A new approach to linear filtering and prediction problems. *Journal of Basic Engineering*, 82D, 35–45.

Laver, P.N. & Kelly, M.J. (2008) A critical review of home range studies. *The Journal of Wildlife* Management, 72, 290–298.

Miller, J.D. (1997) Reproduction in sea turtles. In *The Biology of Sea Turtles* (eds P.L. Lutz & J.A. Musick), pp. 51–80. CRC Press, Boca Raton, USA.

Reardon, R.T. (2000) *Annual Report–2000 Season. Dry Tortugas National Park Sea Turtle Monitoring Program*. Dry Tortugas, Florida, USA, p. 49.

Richards, P.M., Epperly, S.P., Heppell, S.S., King, R.T., Sasso, C.R., Moncada, F. et al. (2011) Sea turtle population estimates incorporating uncertainty: a new approach applied to western North Atlantic loggerheads *Caretta caretta*. *Endangered Species Research*, 15, 151–158.

Rodgers, A.R., Carr, A.P., Smith, L. & Kie, J.G. (2005) *HRT: Home Range Tools for ArcGIS*. Ontario Ministry of Natural Resources, Centre for Northern Forest Ecosystem Research, Thunder Bay, Canada.

Schroeder, B.A., Foley, A.M. & Bagley, D.A. (2003) Nesting patterns, reproductive migrations, and adult foraging areas of loggerhead turtles. In *Loggerhead Sea Turtles* (eds A.B. Bolten & B.E. Witherington), pp. 114–124. Smithsonian Institution Press, Washington, DC, USA.

Seaman, D.E. & Powell, R.A. (1996) An evaluation of the accuracy of kernel density estimators for home range analysis. *Ecology*, 77, 2075–2085.

Shamblin, B.M., Bolten, A.B., Bjorndal, K.A., Dutton, P.H., Nielsen, J.T., Abreu-Grobois, F.A. et al. (2012) Expanded mitochondrial control region sequences increase resolution of stock structure among North Atlantic loggerhead turtle rookeries. *Marine Ecology Progress Series*, 469, 145–160.

Shamblin, B.M., Dodd, M.G., Bagley, D.A., Ehrhart, L.M., Tucker, A.D., Johnson, C. et al. (2011) Genetic structure of the southeastern United States loggerhead turtle nesting aggregation: evidence of additional structure within the peninsular Florida recovery unit. *Marine Biology*, 158, 571–587.

White, G.C. & Garrott, R.A. (1990) *Analysis of Wildlife Radiotracking Data*. Academic Press, New York, USA.

Witherington, B., Kubilis, P., Brost, B. & Meylan, A. (2009) Decreasing annual nest counts in a globally important loggerhead sea turtle population. *Ecological Applications*, 19, 30–54.

Witt, M.J., Åkesson, S., Broderick, A.C., Coyne, M.S., Ellick, J., Formia, A. et al. (2010) Assessing accuracy and utility of satellite-tracking data using Argos-linked Fastloc-GPS. *Animal Behaviour*, 80, 571–581.

Worton, B.J. (1995) Using Monte Carlo simulation to evaluate kernel-based home range estimators. *The Journal of Wildlife Management*, 59, 794–800.

Zawada, D.G., Thompson, P.R. & Butcher, J. (2008) A new towed platform for the unobtrusive surveying of benthic habitats and organisms. *Revista de Biologia Tropical*, 56, 51–63.

Biographical sketches

Kristen Hart's research focuses on the population biology of rare and threatened reptiles, including several species of marine turtles, to promote their conservation. David Zawada's research interests include underwater imaging systems, image-processing algorithms, and the optical properties of marine organisms, especially corals. Autumn Sartain has been involved in various research concerning wildlife ecology and conservation, with a particular focus on animal movement patterns. Ikuko Fujisaki's research interests include population ecology, spatial ecology and quantitative ecology, focusing on marine and wetland species.