Geographical and temporal patterns of green turtle occurrence along the Southwestern Atlantic coast

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Figure 1. Juvenile green turtle (*Chelonia mydas*) in Brazil. Photo: Projeto TAMAR.

The green turtle (*Chelonia mydas*) (Figure 1) is commonly found along the eastern coast of South America. Globally listed as Endangered by the International Union for Conservation of Nature (IUCN), it is currently classified as Vulnerable in Brazil, Vulnerable in Uruguay and Threatened in Argentina. The main regional threats currently faced by the species are incidental captures in fisheries and marine debris ingestion. To accomplish effective and coordinated conservation actions among the countries, an understanding of the wider green turtle distribution is needed. Here we use a large-scale data set (N = 20,938) to investigate the spatial and temporal distribution of green turtles recorded in the coastal regions of Brazil, Uruguay and Argentina from June 2005 to May 2011 (six years of observations).

Methods

Data were provided by the following conservation and research groups: in Brazil, (1) Projeto TAMAR–ICMBio (the national sea turtle conservation program), (2) Projeto Tartarugas Urbanas, Associação Guajiru (Paraíba), (3) Projeto Tartarugas, Instituto de Pesquisas Cananéia – IPeC (São Paulo), (4) Laboratório de Ecologia e Conservação – Mamíferos e Tartarugas Marinhas, Centro de Estudos do Mar, Universidade Federal do Paraná (Paraná), (5) Núcleo de Educação e Monitoramento Ambiental – NEMA (Rio Grande do Sul); in Uruguay, (6) Karumbé; and in Argentina, (7) Programa Regional de Investigación y Conservación de Tortugas Marinas (PRICTMA).

The turtles were recorded in the coastal area between latitudes 2.93 and 42.57 degrees South (from Ceará, northern Brazil to northern Patagonia, Argentina), a region comprising about 6,800 km of coastline (Figure 2). The records were obtained by the sea turtle conservation organizations in the three countries during their regular activities, rather than through dedicated sampling.

Green turtles were observed either alive or dead in the natural environment in four different modes: (1) stranded on beaches; (2) floating along the coast; (3) incidentally captured in coastal fisheries; or (4) intentionally captured in coastal waters by sea turtle researchers. Green turtle observations in one of the following categories were not included in this research: (1) turtles found either nesting or stranded or in the water on the oceanic islands Trindade, Atol das Rocas and Fernando de Noronha in Brazil; (2) turtles nesting on the mainland Brazilian coast (there is no green turtle nesting in either Uruguay or Argentina); (3) incidental captures in oceanic fisheries (longlines and drift nets); (4) any records of turtles under veterinary treatment. For turtles that were flipper-tagged for mark-recapture studies, recaptures were disregarded; only the first record of each tagged individual was included in the analyses. Only turtles for which the curved carapace length (CCL, from the anterior point at midline (nuchal scute) to the posterior tip of the supracaudal scutes) was measured were included in the analyses. As a way of avoiding sampling bias, some analyses (indicated in the figure legends) were only carried out for turtles found stranded on beaches regularly monitored for strandings in the six years, where the sampling effort was uniform over the years. In the data analyses, turtles found floating in the water (N = 813) were included in the "Stranded" group, and turtles intentionally captured in coastal waters by sea turtle researchers (N = 126) were included in the "Fisheries" group.

Sea surface temperatures were obtained from the NOAA Optimum Interpolation 1/4 Degree Daily Sea Surface Temperature Analysis, Version 2, Research Data Archive, National Center for Atmospheric Research, USA (http://rda.ucar.edu/datasets/ds277.7; Reynolds et al. 2007). Statistical analyses were performed with the software R 3.2.3 (R Core Team 2015) and its packages *quantreg* (Koenker 2005) and *coin* (Hothorn et al. 2006). The base map in Figure 2 was generated by the software Maptool (http://www.seaturtle.org).

Results and Discussion

Green turtles were observed with CCL in the range of 8–130 cm (N = 20,938). Figure 3 shows the annual number of turtles according to the mode of observation. Specific analyses are presented in subsequent figures. Discussions will be presented in a forthcoming article.
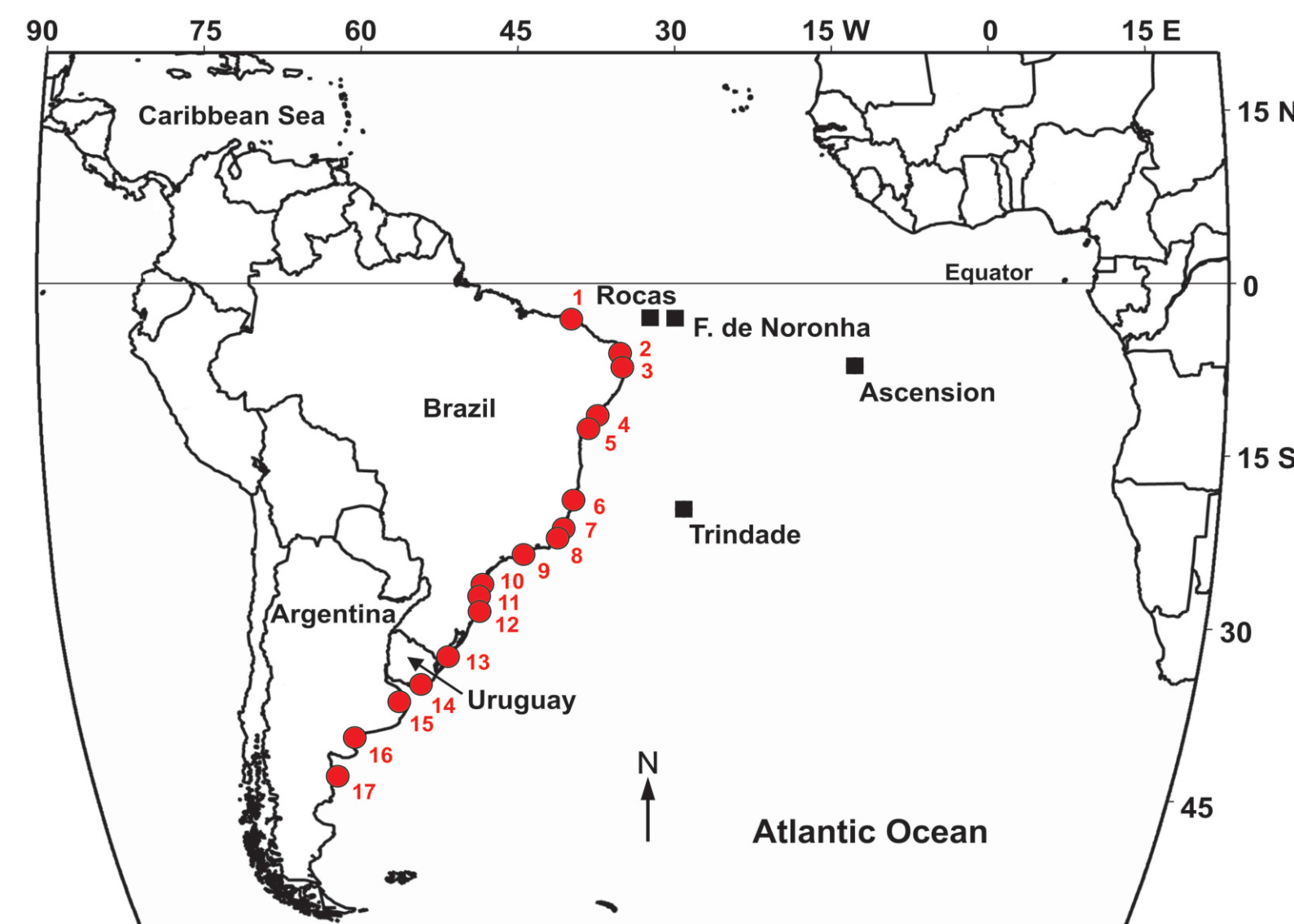

Figure 2. Map of South America and the neighbouring Atlantic Ocean. The numbered red circles indicate the sampling sites. In Brazil: 1 = western Ceará, 2 = Rio Grande do Norte, 3 = Paraíba, 4 = Sergipe, 5 = northern Bahia, 6 = northern Espírito Santo, 7 = southern Espírito Santo, 8 = northern Rio de Janeiro, 9 = northern São Paulo, 10 = southern São Paulo, 11 = Paraná, 12 = Santa Catarina, 13 = southern Rio Grande do Sul. Uruguay = 14. In Argentina: 15 = northern Buenos Aires province, 16 = southern Buenos Aires province, 17 = northern Patagonia. Some regional oceanic islands with significant green turtle nesting are shown symbolized by black squares.
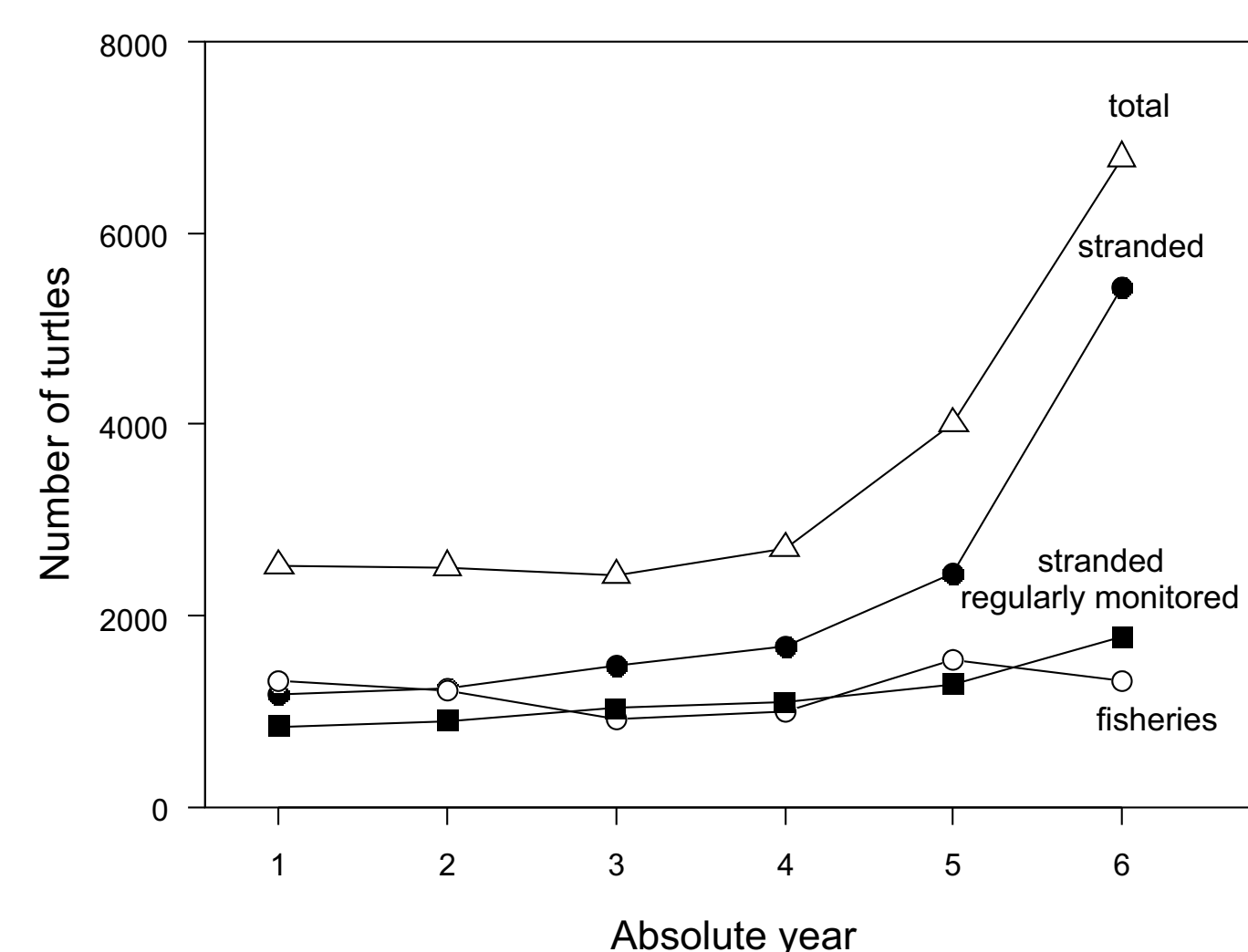

Figure 3. Number of turtles by absolute year (each year starts on 1 June) and mode of observation (either stranded or incidentally captured in fisheries). Total records (N = 20938), turtles incidentally captured in fisheries (N = 7309), turtles found stranded (N = 13465) and turtles found stranded in regularly monitored areas (N = 6929). For 164 turtles, the mode of observation was not recorded; these turtles are included in the "total" graph, but neither in the "stranded" nor in the "fisheries" nor in the "stranded regularly monitored" graphs. The "stranded regularly monitored" data (black squares) are a subset of the "stranded" data, and represent the number of turtles stranded in areas that were regularly monitored for strandings in the six years (see Methods).

For turtles stranded in the regularly monitored areas, an exponential curve fitted to the five initial years of data (N = 5153) produces a better fit than one fitted to the six years of data, as the rate of increase between years 5 and 6 is much higher than the average annual rate of increase between years 1 and 5. For the five initial years, the estimated annual increase is of 11.2%, with 0.95 confidence interval = (7.9, 14.7).
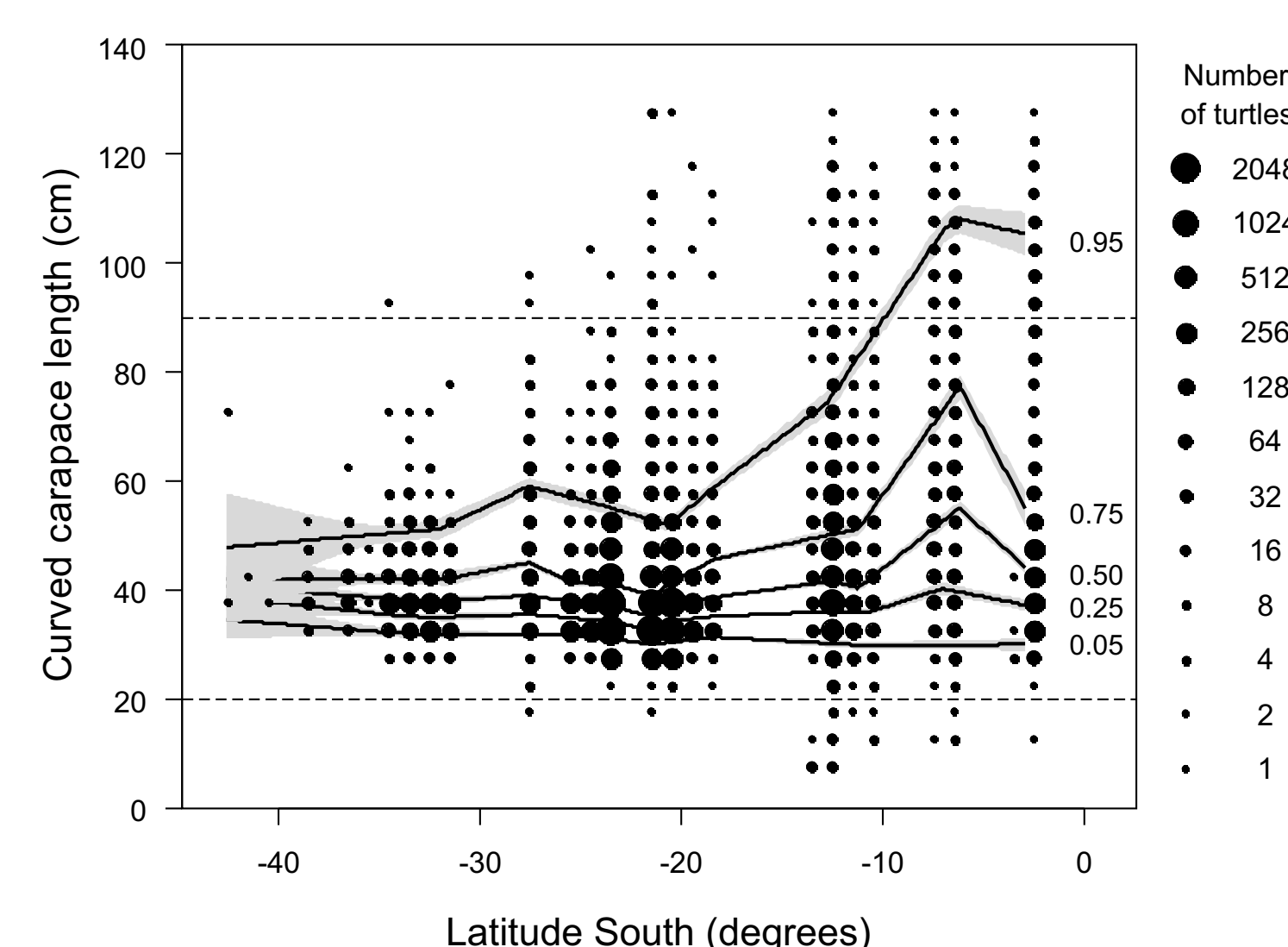

Figure 4. Curved carapace length (CCL) by latitude (N = 20938). Latitude was grouped in 1 degree intervals, and CCL was grouped in 5 cm intervals. The size of the points indicate [legend continued in the next column]

the number of turtles in each group, according to the scale on the right. The curves are nonparametric quantile regressions; the regressions were calculated with the actual individual data points; the number placed just to the right of each curve indicates the quantile relative to the curve. The shaded area around each regression curve indicates a 0.95 uniform confidence band. The horizontal lines indicate CCLs of 20 and 90 cm (this CCL, taken as a reference to the minimum CCL of adult-sized green turtles, is the mean size of green turtles nesting on Trindade Island, Brazil; but note that genetic analyses show that not all green turtles found on the eastern South American coast originate from Brazil).

Among the large turtles (CCL ≥ 90 cm; N = 400), 93.3% (N = 373) were found north of latitude 15°S (Bahia, Brazil). Turtles with CCL ≤ 20 cm (N = 55) were generally (N = 53) found to the north of latitude 15°S (Bahia, Brazil).
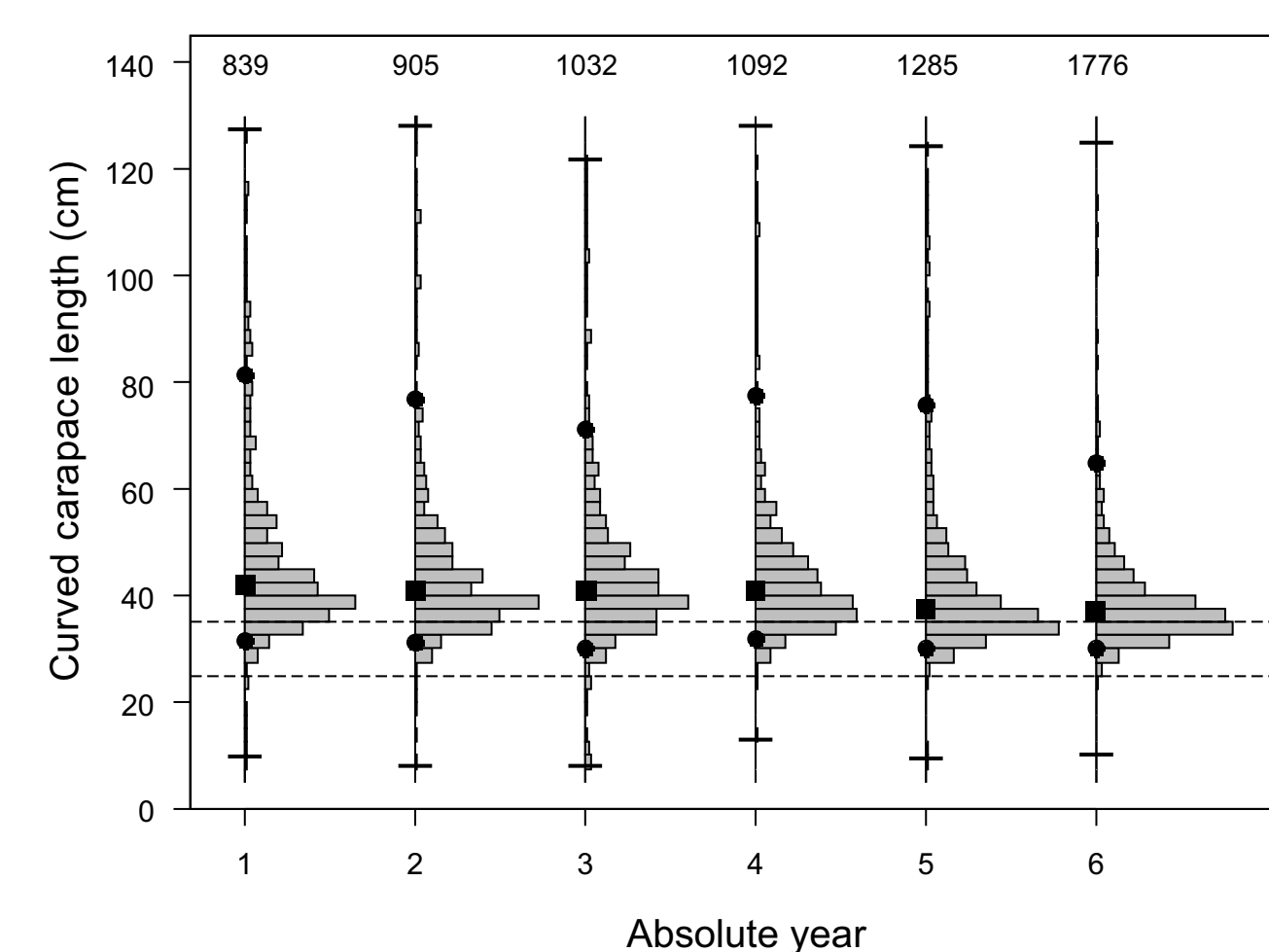

Figure 5. Curved carapace length (CCL) distribution by absolute year (each year starts on 1 June), turtles stranded in regularly monitored areas (N = 6929). CCL was grouped in 2.5 cm intervals. In each histogram, the short horizontal lines indicate the minimum and maximum CCL for the year, the black circles indicate the quantiles 0.05 and 0.95 of the distribution, and the black square indicates the median. Horizontal dashed lines were placed at CCL = 25 and 35 cm, as an aid to the visualization of the changing distribution of CCL along the years (in the six years, 24.9% of the turtles stranded in regularly monitored areas had the CCL in that range).

There was a statistically significant decrease in median CCL along the years, as seen through a nonparametric Jonckheere-Terpstra test (Hollander and Wolfe 1999) implemented by means of the *coin* package (permutation tests) of the R software, with 50,000 permutations (Z = -17.446, P < 0.0001). The median CCL decreased over the six years from 42.0 to 37.0 cm, and the proportion of turtles with CCL in the range of 25-35 cm increased from 14.2% to 35.2%.
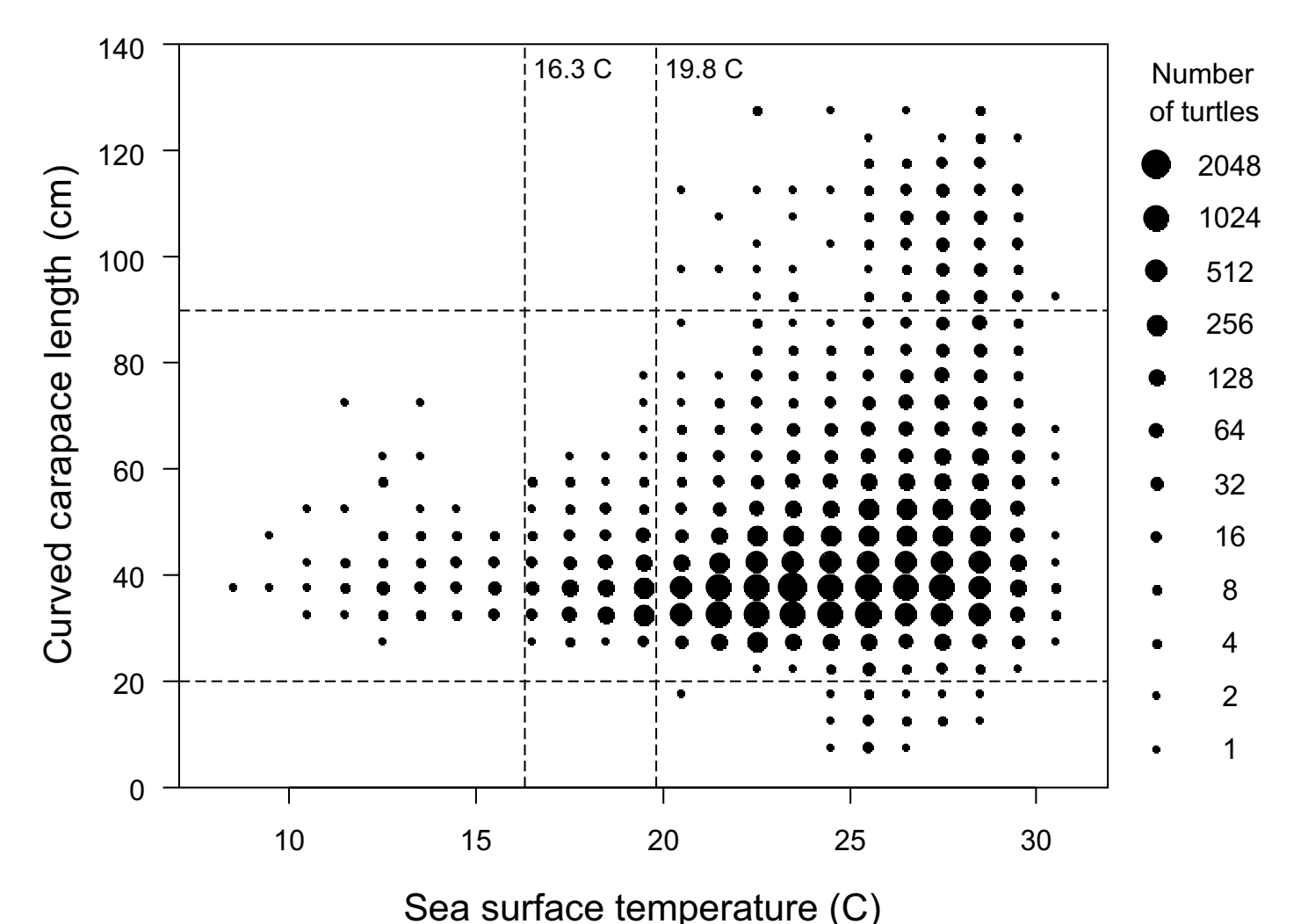

Figure 6. Curved carapace length (CCL) by sea surface temperature (SST) (N = 20938). CCL was grouped in 5 cm intervals, and SST was grouped in 1 °C intervals. The vertical lines indicate the quantiles 0.01 (16.3 °C) and 0.05 (19.8 °C) of the SST distribution. The horizontal lines indicate CCLs of 20 and 90 cm (see the legend of Figure 4). SST was in the range of range of 8.74–30.50 °C.

There is of course an association between temperature and latitude. SSTs below 16.3 °C (the quantile 0.01 of SST) were only found to the south of latitude 25.57°S (Paraná, Brazil).
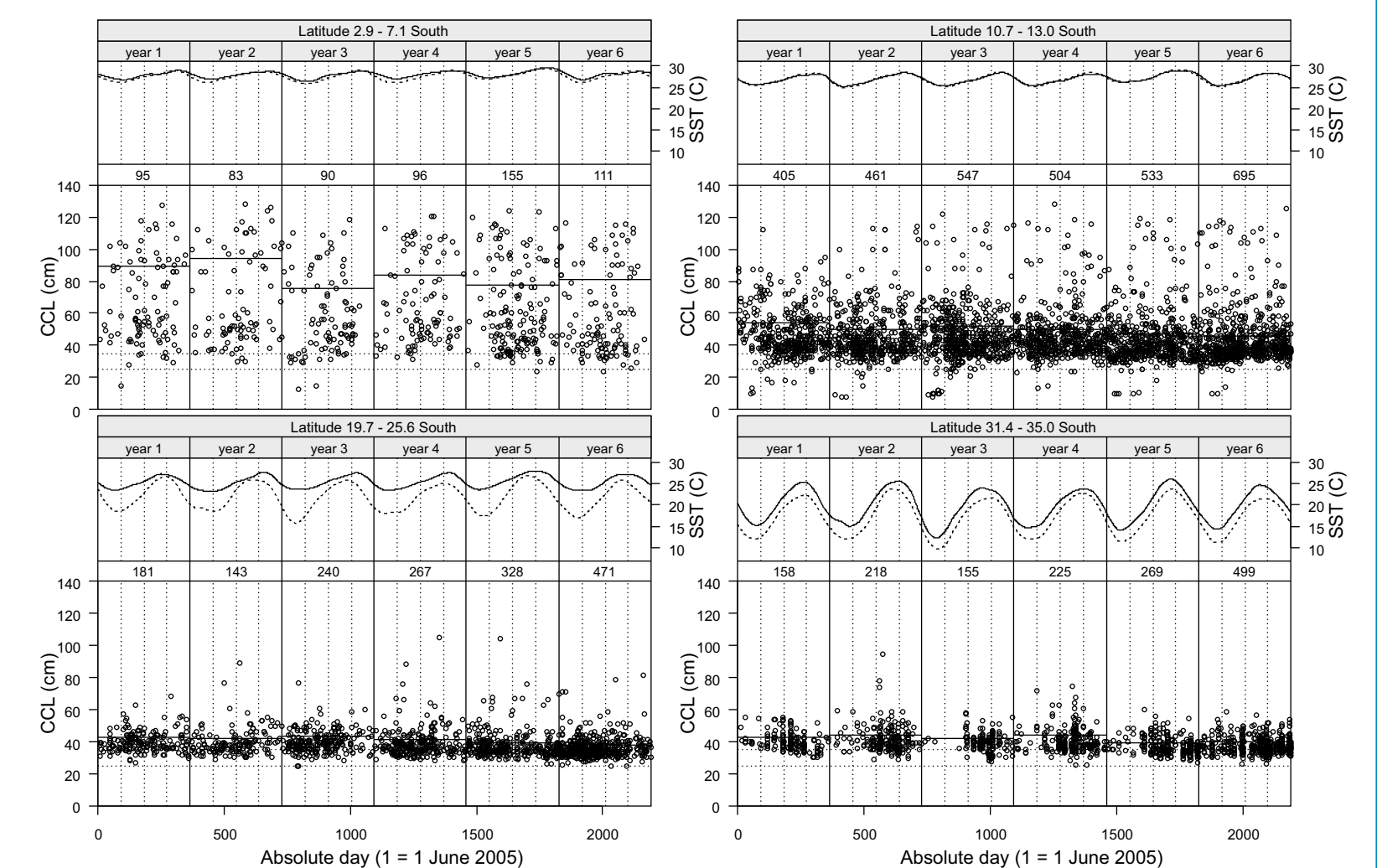

Figure 7. Seasonal patterns for turtles stranded in regularly monitored areas: curved carapace length (CCL) and sea surface temperature (SST) by absolute day, by grouped latitude (N = 6929). In each grouped latitude panel: (1) the horizontal row of numbers indicates the annual sample sizes; (2) the solid vertical lines separate the years (each year starts on 1 June). (3) the dotted vertical lines, corresponding to 1 September, 1 December and 1 March, divide the years into three-month intervals; (4) two SST curves are presented: the solid one shows daily SST at the coastal position with the northernmost latitude within the panel latitude range; the dashed curve shows daily SST at the coastal position with the southernmost latitude within the panel latitude range (note that in each of the two upper latitude panels the two SST curves are nearly superimposed); (5) dotted horizontal lines were placed at CCL = 25 and 35 cm (see Figure 5); (6) for each year the solid horizontal line in the CCL graph indicates the quantile 0.75 of the CCL distribution for the year in the given latitude range.
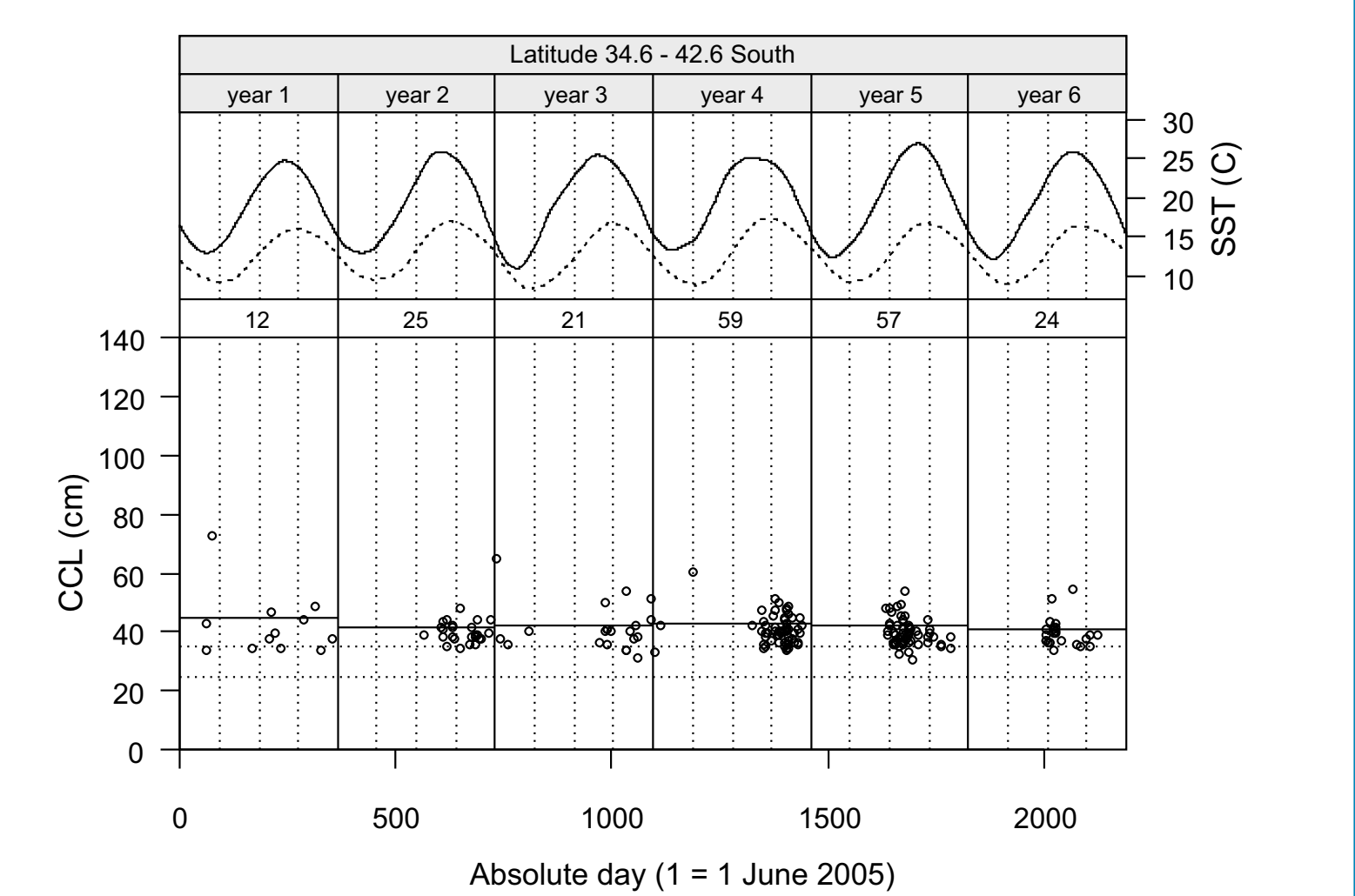

Figure 8. Seasonal patterns exclusively for Argentina, where there was no regular monitoring during the winter (there was essentially no fieldwork during the winter): curved carapace length (CCL) and sea surface temperature (SST) by absolute day (N = 198). In the graph (1) the horizontal row of numbers indicates the annual sample sizes; (2) the solid vertical lines separate the years (each year starts on 1 June). (3) the dotted vertical lines, corresponding to 1 September, 1 December and 1 March, divide the years into three-month intervals; (4) two SST curves are presented: the solid one shows daily SST at the coastal position with the northernmost latitude within the panel latitude range; the dashed curve shows daily SST at the coastal position with the southernmost latitude within the panel latitude range; (5) dotted horizontal lines were placed at CCL equal to 25 and 35 cm (see Figure 5); and (6) for each year, the solid horizontal line indicates the quantile 0.75 of the CCL distribution for the year.

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