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

Matthew J. Witt · Rod Penrose · Brendan J. Godley

Abstract We present data spanning approximately 100 years regarding the spatial and temporal occurrence of marine turtle sightings and strandings in the northeast Atlantic from two public recording schemes and demonstrate potential signals of changing population status. Records of loggerhead ($n = 317$) and Kemp's ridley ($n = 44$) turtles occurring on the European continental shelf were most prevalent during the autumn and winter, when waters were coolest. In contrast, endothermic leatherback turtles ($n = 1,668$) were most common during the summer. Analysis of the spatial distribution of hard-shell marine turtle sightings and strandings highlights a pattern of decreasing records with increasing latitude. The spatial distribution of sighting and stranding records indicates that arrival in waters of the European continental shelf is most likely driven by North Atlantic current systems. Future patterns of spatial-temporal distribution, gathered from the periphery of juvenile marine turtles habitat range, may allow for a broader assessment of the future impacts of global climate change on species range and population size.

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Introduction

For hard-shell marine turtles, the development to mature adult involves a progression through several life phases and spatially discrete habitats (Musick and Limpus 1997). Of these life history phases, the juvenile oceanic stage remains the most elusive in terms of monitoring animal movement and identifying patterns in distribution and abundance. For loggerhead turtle (*Caretta caretta*) hatchlings that emerge from northwest Atlantic beaches oceanic dispersal is thought to involve the North Atlantic gyre (Carr 1987; Bolten 2003). Similarly, Kemp's ridley (*Lepidochelys kempii*) post-hatchling turtles from the Gulf of Mexico can also use the North Atlantic gyre as a developmental habitat prior to returning to neritic environments (Collard and Ogren 1990). Observations on the movements of post-hatchling juvenile turtles in ocean currents often report a spatial association with sargassum aggregations (Carr 1986; Carr 1987), particularly those forming at downwelling systems (Witherington 2002). The duration of this oceanic phase is thought to be highly variable. For loggerhead turtles, growth models suggest the oceanic phase from hatching to recruitment to neritic habitats may range between 6.5 and 11.5 years, with individuals attaining curved carapace lengths of 46–64 cm (Bjorndal et al. 2000).

The presence of loggerhead and Kemp's ridley turtles in the Azores archipelago has implicated the North Atlantic gyre as a feature that drives oceanic dispersal

of post-hatchling marine turtles (Brongersma 1972; Eckert 1989; Bolten and Martins 1990; Bolten et al. 1990, 1993; Brongersma 1995; Bjorndal et al. 2000). The island group is positioned within the northeast traversing arm of North Atlantic gyre, and it would appear that the gyre currents provide a copious source of oceanic recruits. Reports of juvenile loggerhead turtles in Madeira and the Canary Islands, which border the periphery of the North Atlantic gyre, and are upstream of nesting beaches on the West African Atlantic coast (Fretey 1998), lend further support to this gyre-mediated dispersal mechanism. Further indication of basin wide movement has come from mtDNA analysis of juvenile loggerhead turtles from the Azores, Madeira and the Mediterranean (Bolten et al. 1998; Laurent et al. 1998). Many sampled individuals expressed genetic markers suggesting their origin as from the Americas.

In recent decades there has been an increasing number of reports that demonstrate transatlantic passage from the USA to the European continental shelf (Brongersma 1972; Wibbels 1983; Penhallurick 1990; Bolten et al. 1992) with the period of transatlantic drift from the coast of the USA to the British Isles having been estimated at 1.8–3.75 years (Hays and Marsh 1997). Originally, such incidents were thought to represent nonviable derelict individuals from northwest Atlantic coast populations (Carr 1987). However, the establishment of reporting schemes in Europe has shown the magnitude of marine turtle sightings and strandings to be appreciable.

Without careful consideration, analysis of data taken from reporting schemes can be problematic, most notably because it is not possible to make rigorous effort related correction. Nonetheless, spatio-temporal trends that may arise from several thousand validated records, collected over nine decades, are likely to be instructive and offer insights into a life history phase and part of their geographic range for which there is a paucity of published literature. Data on marine turtle sightings and strandings from the northeast Atlantic has not been subject to detailed analysis since the seminal work of Brongersma (1972). This region of the Atlantic Ocean may serve as a location from which to measure changes in population structure, and provide information that contributes to a greater understanding of the physiological and oceanographic factors that define the range of these species.

We set out to determine the spatial and temporal trends for sightings, strandings and captures of hard-shell marine turtles in the northeast Atlantic from two recording schemes. To understand how the physical structuring and seasonality of environmental conditions in the North Atlantic might affect the presence of hard-shell marine turtles, we also analysed public sightings records for the endothermic leatherback turtle (*Dermochelys coriacea*), a species that seasonally frequents British coastal waters during the boreal summer and autumn (Godley et al. 1998).

Methods

Records of sightings and strandings of marine turtles in the British Isles were obtained from the TURTLE database operated by Marine Environmental Monitoring (Penrose 2005). TURTLE is multi-agency project that commenced in 2001 to act as a repository for records of marine turtle sightings, strandings and captures. Reports of such events are received from members of the public, governmental agencies or marine environmental organisations. Regularly, these groups collect morphometric and pertinent ancillary data (e.g. geographic location) from stranded individuals and arrange for either rehabilitation or necropsy. Appropriate data is then passed to the TURTLE coordinator and it is validated and subsequently added to the project database, which also contains historic records of marine turtle sightings, strandings and capture since c.1758. Historic records were sourced from published literature (Brongersma 1972; Penhallurick 1990), unpublished data and governmental reports (e.g. English Nature, Scottish Natural Heritage). Such records were stringently validated and subsequently added to TURTLE. We chose to extract TURTLE records from 1910 to 2003. Prior to 1910 records became increasingly sparse in the data they contained. For records of at-sea sightings we used those records where the turtle was subsequently landed and species confirmed. We are therefore confident that species identification was robust.

Records of marine turtle sightings, strandings and captures occurring in French waters originated from annual sightings and strandings publications of Duguy and colleagues (Duguy 1990, 1992, 1993, 1994, 1995, 1996, 2004; Duguy et al. 1997a, b, 1999, 2000, 2001, 2002, 2003). Records presented in Duguy publications prior to 2001 contained location descriptions, providing no geographic coordinates with error estimates. Longitude and latitude positions for these events were estimated to be the closest coastal point to the descriptive location. Duguy publications, 2001 onwards, were accompanied by maps displaying the approximate location of sightings and strandings events. These maps were digitised and georeferenced and coordinate positions determined for all appropriate records.

Sea surface temperatures (SST) were determined for records of sightings and strandings from a monthly 1° spatial resolution SST product—Hadley Ice and Sea Surface Temperature (Rayner et al. 2003). Due to the positional accuracy of some records it was not possible to extract sea surface temperature from the Hadley SST product; these records were subsequently excluded from statistical analysis involving sea surface temperature.

Results

For the period 1910–2003 (British Isles 1910–2003 and France 1990–2003) we identified 2,042 records of marine turtle sightings, strandings and captures. This dataset contained 1,668 leatherback turtle records (British Isles $n = 650$ and France $n = 1,018$) and 374 hard-shell turtle records. Of these records, 317 were of the loggerhead turtle (British Isles $n = 123$, France $n = 194$) and 44 of Kemp's ridley turtles (British Isles $n = 28$, France $n = 16$). Both regions recorded events of green turtle (*Chelonia mydas*) strandings (British Isles $n = 5$, France $n = 7$). There was a single stranding event of a hawksbill turtle (*Eretmochelys imbricata*) near Cork, Ireland in 1983. The British Isles reported 6 capture events (loggerhead $n = 4$, Kemp's ridley $n = 2$) while France reported 11 capture events (loggerhead $n = 10$, Kemp's ridley $n = 1$). Combined, these captures represented 4.5% of hard-shell turtle records; for the purposes of statistical analysis we combined records of capture with those of live sightings and strandings.

Decadal and annual patterns

The decadal patterns of sightings and strandings recorded for loggerhead, Kemp's ridley and leatherback turtles are shown in Fig. 1. Records of loggerhead turtles in the British Isles (Fig. 1a) increased from 1910s until the 1950s, declining to minima during the 1970s. Since the 1980s records have increased to unparalleled levels. Figure 1b displays the decadal trend for Kemp's ridley records; this demonstrates an increase in records from the 1910s to 1930s/1940s. Following this period, both the 1950s and 1980s experienced no records of sightings or strandings and there is an evident decline in the number of records. For hard-shell turtles recorded in the British Isles, we found no significant correlation in the decadal total of records occurring in the period 1910 to 2003 (Spearman Rank Correlation —loggerhead $r_s = 0.6$, $P > 0.05$ Fig. 1a; Kemp's ridley $r_s = -0.3$, $P > 0.05$ Fig. 1b). When comparing the decadal patterns of records for loggerhead and Kemp's ridley turtles we observed no correlation

in the frequency of records over time (Spearman Rank Correlation $r_s = 0.05$, $P > 0.05$). Leatherback turtle records occurring in the British Isles (Fig. 1c) demonstrated a consistent decadal increase, with the exception of the 2000s that contain only 4 years data, 2000–2003 (Spearman Rank Correlation $r_s = 0.95$, $P < 0.001$). We found no significant trends in the annual number of records occurring in the French dataset (1990–2003, Spearman Rank Correlation - loggerhead $r_s = 0.13$, $P > 0.05$, Kemp's ridley $r_s = -0.07$, $P > 0.05$, leatherback $r_s = 0.35$, $P > 0.05$). However, when comparing the annual incidence of records from the British Isles and France for the period 1990–2003 (Fig. 1d–f) we found statistically significant correlations for all species (Spearman Rank Correlation —loggerhead $r_s = 0.56$, $P < 0.05$, Kemp's ridley $r_s = 0.6$, $P < 0.05$ and leatherbacks $r_s = 0.55$, $P < 0.05$).

Spatial distribution

Figure 2 displays the position of records for loggerhead (Fig. 2a British Isles $n = 124$, France $n = 175$) and Kemp's ridley turtles (Fig. 2b British Isles $n = 25$, France $n = 15$). For the majority, sightings and strandings occurred on the western aspect of the British Isles and France, and on adjacent shores of the English Channel. For loggerhead and Kemp's ridley turtles in the British Isles we found a significant negative correlation between the number of records and increasing latitude (loggerhead—Pearson $r = -0.78$, $P < 0.05$, Kemp's ridley—Pearson $r = -0.76$, $P < 0.05$). A significant pattern of decreasing incidence of loggerhead turtle records with increasing latitude was also identified on the French coast (Pearson $r = -0.97$, $P < 0.05$) but not for Kemp's ridley turtle records (Pearson $r = -0.53$, $P > 0.05$). When combining records from the British Isles and France for the period 1990–2003, we found the number of loggerhead turtle records to decrease with increasing latitude (Pearson $r = -0.8$, $P < 0.001$). Repeating this exercise for Kemp's ridley turtles yielded a broadly similar, but not statistically significant, pattern (Pearson $r = -0.4$, $P > 0.05$). We calculated the proportion of loggerhead and Kemp's ridley turtles recorded as dead at each latitudinal band, but proportion dead did not correlate with latitude (loggerhead—Pearson $r = 0.39$, $P > 0.05$, Kemp's ridley—Pearson $r = 0.21$, $P > 0.05$).

Seasonal patterns

The cumulative monthly frequencies of sighting and stranding records for loggerhead, Kemp's ridley and leatherback turtles for Britain and France are
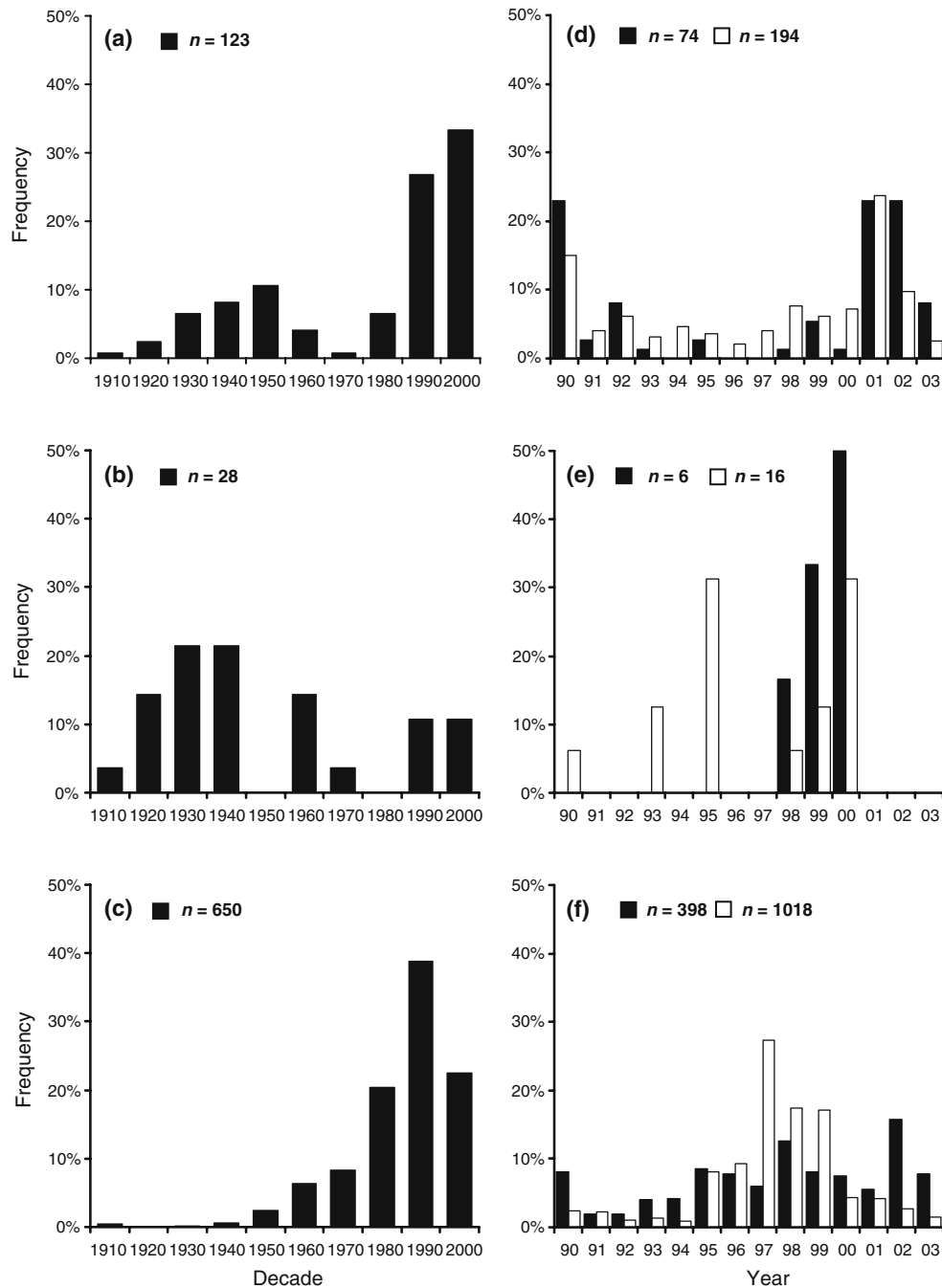
Fig. 1 Temporal incidence of records of loggerhead, Kemp's ridley and leatherback turtles. Decadal distribution in the British Isles, 1910–2003: **a** loggerhead turtles, **b** Kemp's ridley turtles and

c leatherback turtles. Annual distribution, in the British Isles (*filled bar*) and France (*open bar*) 1990–2003: **d** loggerhead turtles, **e** Kemp's ridley turtles and **f** leatherback turtles

displayed in Fig. 3. Loggerhead turtle records (Fig. 3a, b) occurred year-round. For the British Isles (Fig. 3a) the core distribution occurred between November and March, while in France (Fig. 3b) it was between January and April. Restricting statistical analysis to records of loggerhead turtles reported alive we found that the monthly patterns experienced by each regional dataset differed significantly (Mann–Whitney $U = 2540.5$,

$P_{81,148} < 0.001$, British Isles—median December, France—median March). We adopted this approach as data were not available on the state of decomposition for many of the turtles reported dead; hence, these individuals may have been floating for an undetermined time prior to being discovered. In the British Isles the seasonal distribution of Kemp's ridley turtle records (Fig. 3c) occurred between October and
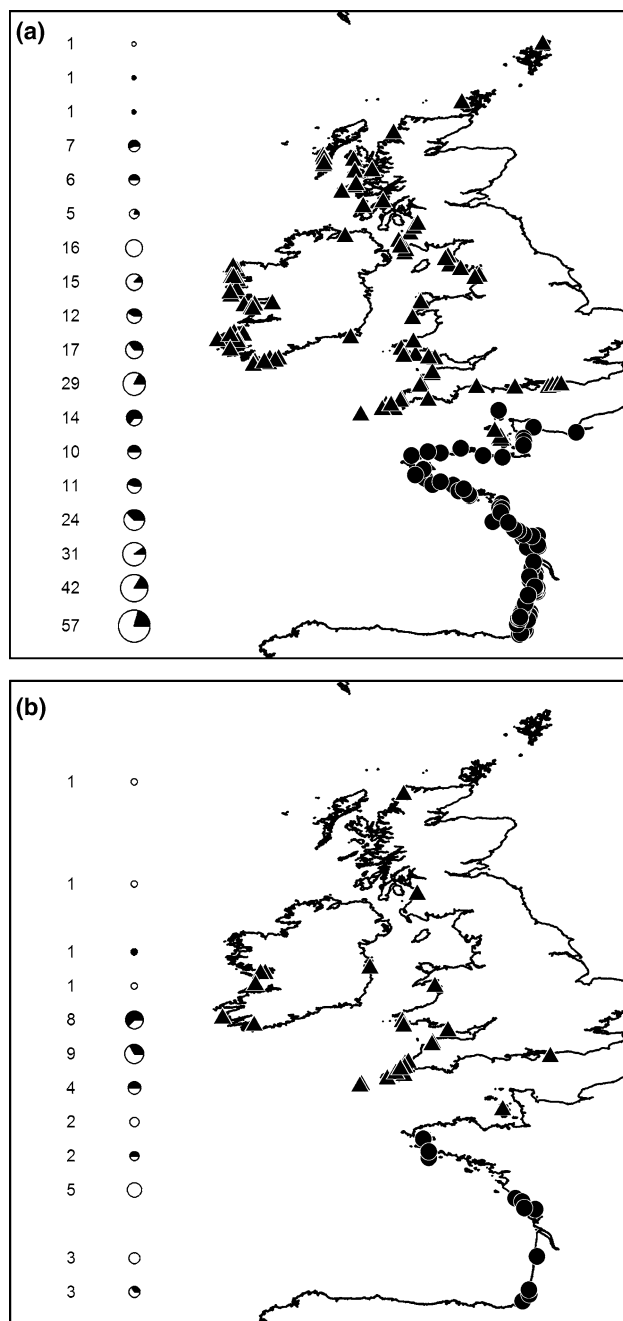
Fig. 2 Latitudinal distribution of sightings and strandings records for **a** loggerhead turtles and **b** Kemp's ridley turtles. Pie chart size is proportional to the total number of records in each 1° latitudinal band. Number beside pie chart is the total number of records for that latitude. *Filled* and *open sectors* represent proportion of turtles recorded dead/alive, respectively. Records for the British Isles (*filled triangles*), 1910–2003, and records for the French Atlantic coast (*filled circles*), 1990–2003

February, and for the France between October and April (Fig. 3d). The monthly pattern of Kemp's ridley turtles reported as alive differed significantly between regions (Mann Whitney $U = 32$, $P_{13,14} < 0.05$, British Isles: median December, France: median January).

Leatherback turtle record distribution was most pronounced during the summer and then declined during the late autumn and winter (Fig. 3e, f). The monthly distributions of records for leatherback turtles from the British Isles and France did not differ significantly (Mann Whitney $U = 271742$, $P_{562,1018} > 0.05$, British Isles and France: median August).

Distribution versus sea surface temperature

Mean monthly sea surface temperature was successfully extracted for 322 hard-shell turtle records (British Isles—loggerhead $n = 102$, Kemp's ridley $n = 21$; France—loggerhead $n = 183$, Kemp's ridley $n = 16$). When comparing the SST estimates for loggerhead turtle records (Fig. 4a) to the thermal threshold reported to induce floatation (9.5°C, Schwartz (1978)) we found 276 records (97% of records) exceeded this threshold (95% of dead records, 98% of live records). For Kemp's ridley turtles (Fig. 4b), 34 records (92% of records) exceed the 10°C floatation threshold reported by Schwartz (1978) (90% of dead records, 93% of live records). When combining records from the British Isles and France we found the sea surface temperature distribution for loggerhead turtles reported as dead was significantly lower than the distribution of those reported as alive (Mann Whitney $U = 6171$, $P_{77,208} < 0.05$, dead: mean 12.7°C ± 2.9 SD, range 8.5–20.5°C; live: mean 13.1°C ± 2.3 SD, range 8.5–22°C). This trend was similarly evident for Kemp's ridley records, where the sea surface temperature determined for turtles recorded dead differed significantly from those recorded alive (Mann–Whitney $U = 73.5$, $P_{10,27} < 0.05$, dead: mean 11.2°C ± 1 SD, range 9.9–12.9°C; live: mean 12.1°C ± 1.2 SD, range 9.5–15.6°C). Figure 4c and d show the monthly mean sea surface temperature (SST) profiles for the period of 1910–2003 (49°N−60°N,12°W–5°E) and 1990–2003 (43°N–49°N, 12°W–5°E) respectively. Winter-time temperatures for the British Isles commonly fall below the thermal threshold reported to induce floatation; whereas, temperatures experienced in French waters do not.

Body size

A total of 258 records contained data on straight carapace length (SCL) (Fig. 5), 217 of which were measurements for loggerhead turtles (British Isles $n = 56$, mean 29.4 cm ± 17.8 SD, range 13.5–110 cm and France $n = 161$, mean 24.1 cm ± 11.0 SD, range 12.5–97 cm). Although the vast majority of hard-shell turtles are juvenile, the size distributions appear to encompass at least some individuals of adult size [age at first maturity
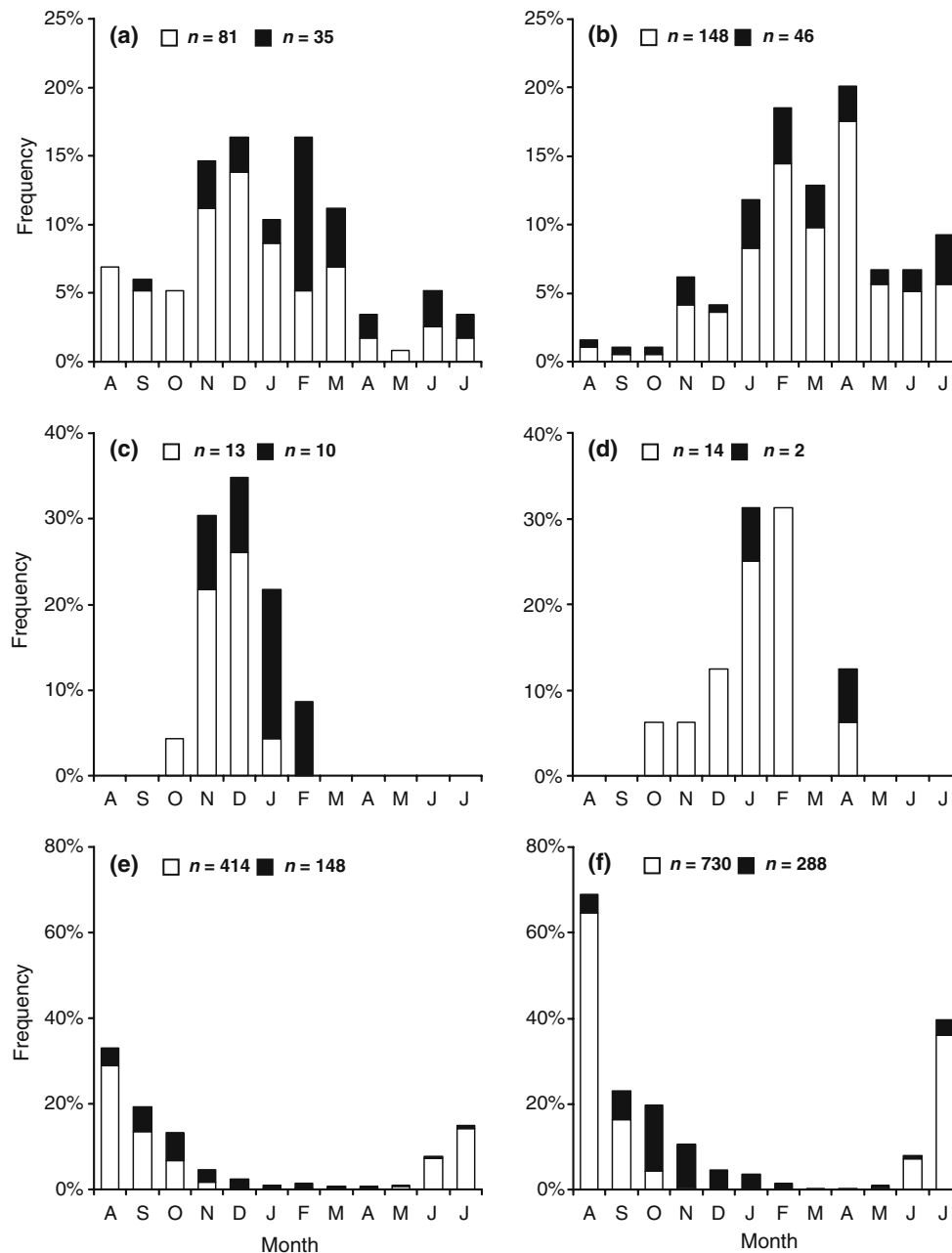
Fig. 3 Cumulative monthly frequency of sightings and stranding records, records of living turtles (*open bars*), and records of dead turtles (*filled bars*). British Isles, 1910–2003: **a** loggerhead turtles, **c** Kemp's ridley turtles and **e** leatherback turtles. France, 1990–2003: **b** loggerhead turtles, **d** Kemp's ridley turtles and **f** leatherback turtles

>74 cm SCL (Márquez 1990)]. The modal SCL size class for loggerheads turtles from the British Isles was 15–19.9 cm and for the France 20–24.9 cm, but median SCL (British Isles vs. France) was not statistically different (Mann Whitney $U = 3862.5$, $P_{56,161} > 0.05$). Both the British Isles and France shared the same modal SCL for Kemp's ridley turtles (20–24.9 cm), median SCL from these two regions did not differ significantly (Mann Whitney $U = 160.5$, $P_{25,15} > 0.05$). Of the 217 loggerhead records with straight carapace length, 215 also contained

the reported status of the turtle (48 dead,167 alive). For Kemp's ridley turtles, 36 records contained both status and SCL (10 dead, 26 alive). Median SCL of loggerhead turtles recorded as dead differed significantly from those recorded as alive (Mann Whitney $U = 2,882$, $P_{48,167} < 0.05$, median: dead 20.8 cm, alive 23.8 cm). In contrast, for Kemp's ridley turtles there was no significant difference in the median SCL between reports of dead and living records (Mann Whitney $U = 124.5$, $P_{26,10} > 0.05$, median: dead 25.2 cm, alive 25.6 cm).
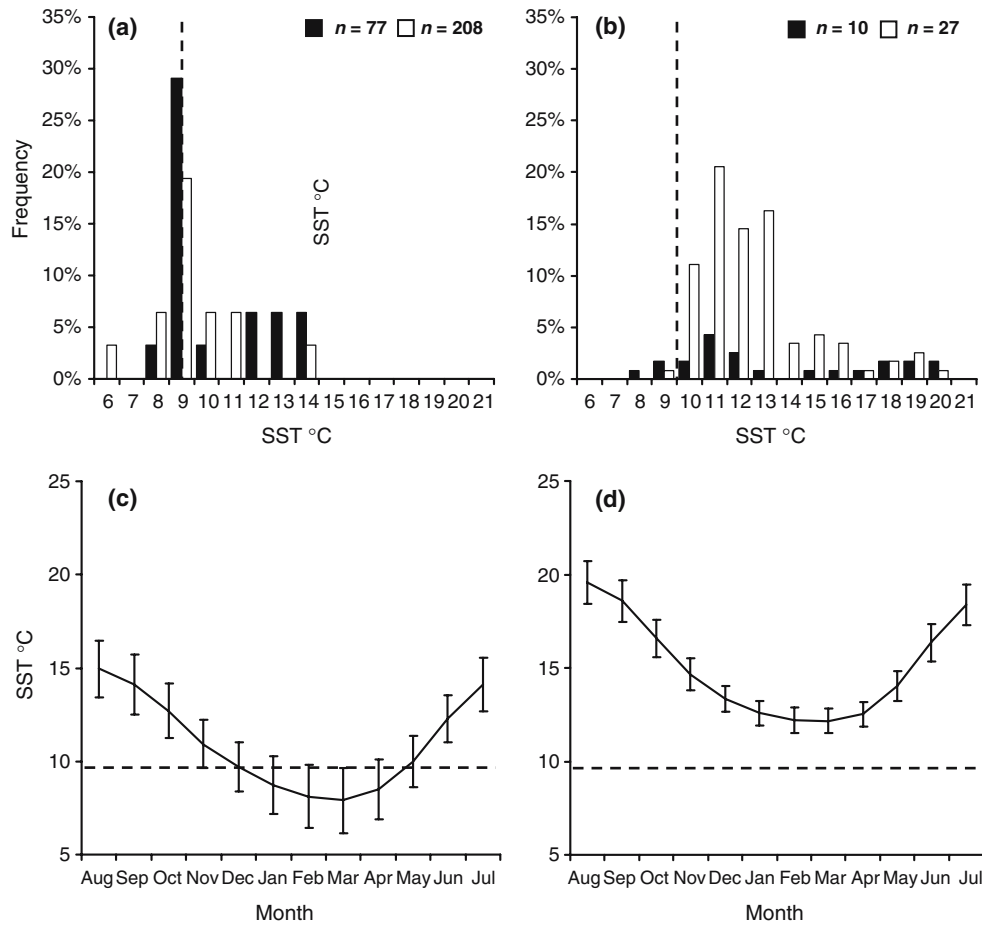
Fig. 4 Sea surface temperature (°C) for records of loggerhead and Kemp's turtles in the British Isles (1910–2003) and France (1990–2003): **a** loggerhead turtles, *open bar* (alive) and *filled bar* (dead), and **b** Kemp's ridley turtles, *open bar* (alive) and *filled bar* (dead). *Vertical dashed line* indicates the temperature at which forced surfacing and floatation has been observed in each species (Schwartz 1978). Mean (±SD) monthly sea surface temperature profile from Hadley ISST dataset: **c** Britain Isles, 1910–2003, 49°N–60°N, 12°W–5°E and **d** France, 1990–2003, 43°N–49°N, 12°W–5°E. *Horizontal dashed line* is the thermal threshold reported to induce floatation (10°C Kemp's ridley turtles, 9.5°C loggerhead turtles (Schwartz 1978))
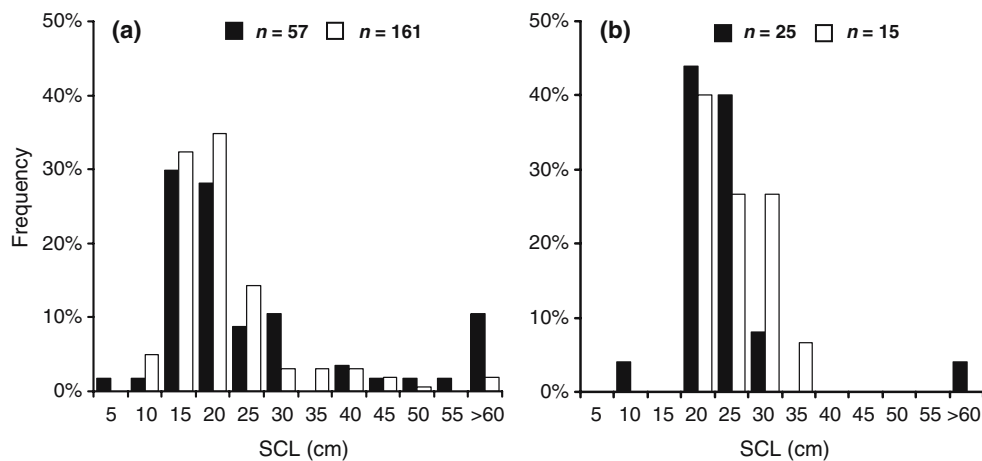

Fig. 5 Straight carapace length (SCL) distribution from loggerhead and Kemp's ridley turtle records. **a** loggerhead turtles in the British Isles (1910–2003, *filled bar*) and France (1990–2003, *open bar*) and **b** Kemp's ridley turtles in the Britain Isles (1910–2003, *filled bar*) and France (1990–2003, *open bar*)

Straight carapace length versus weight

Figure 6 displays the straight carapace length (SCL) to weight relationship for 125 loggerheads (Fig. 6a) and 14 Kemp's ridley turtles (Fig. 6b). Included in Fig. 6a is a SCL versus weight relationship derived from 375 loggerhead turtles sampled from the Atlantic coast of the USA (Braun-McNeill and Avens, unpublished data). With one exception, records of turtles sighted or stranded in the British Isles and France, with an SCL greater than 42 cm (minimum size upon which the USA relationship was derived), lay below this relationship. For Kemp's ridley turtles (Fig. 5b) two additional SCL vs. weight relationships were obtained, one from the Atlantic coast of the USA (Braun-McNeill and Avens, unpublished data) and one from the Gulf of Mexico (Coyne 2000).

Discussion

One response to the growing concern for the status of marine vertebrates has been the establishment of public recording schemes for sightings and strandings. In contrast to effort-corrected scientific surveys, data from such schemes are potentially biased at several levels (e.g. seasonal and spatial variation in recording, interannual variation in surveying). Notwithstanding, we have rigorously filtered and analysed such data and have identified possible seasonal, inter-annual and decadal trends that provide additional insight into a life history phase of hard-shell marine turtles that is little

understood. Moreover, we identify potential long-term integrative signals of changing population status of marine turtles in habitats far removed from their natal beaches.

For the British Isles we see three distinct species specific patterns in the incidence of marine turtle records. The decadal pattern of loggerhead and Kemp's ridley records appear to reflect the historical events that have affected the number of nesting females, the resulting magnitude of nests laid and the subsequent number of hatchlings recruiting to oceanic habitats. For the Kemp's ridley turtle the decadal pattern of records appears to reflect the decline and tentative recovery of this species. Prior to 1966, Kemp's ridley eggs were subject to intense harvest at Rancho Nuevo in Mexico (Hildebrand 1963), the main nesting beach for this species, where the population was found to be in precipitous decline. We associate this population decline with the absence of juveniles from the British Isles from the period 1950 to 1967. Of the four records of sightings and strandings for the 1960s, three occurred in the latter part of the decade subsequent to the beach protection programme and following commencement of work at Padre Island, Texas in 1964 to assist in restocking the species (Zwinenberg 1977). The lowest recorded nesting years at Rancho Nuevo occurred between 1985 and 1987, a decade during which there were no reports of sightings or strandings in the British Isles. A combination of turtle excluder devices in shrimp nets within the USA and beach protection of nests and hatchlings is thought to have culminated in increased nesting during the 1990s (Márquez
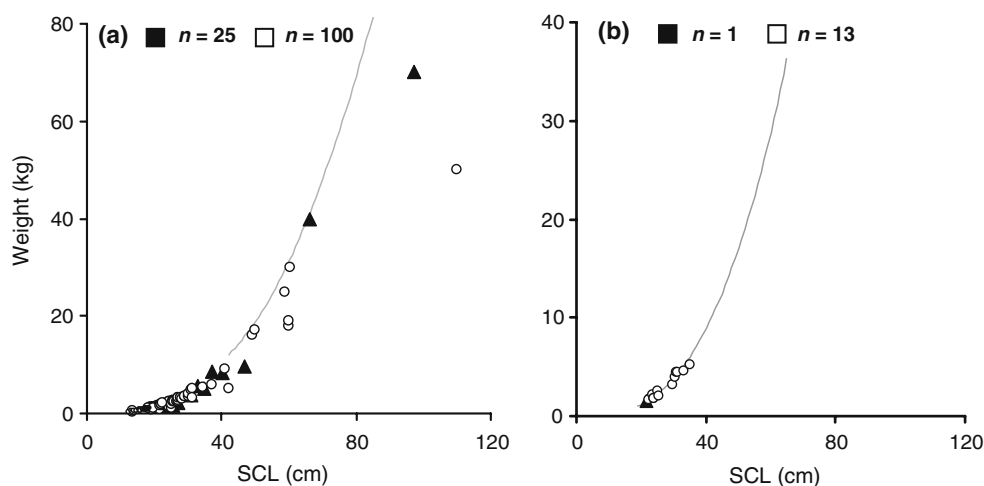

Fig. 6 Plot of straight carapace length (SCL) vs. weight (kg) from records of sightings and strandings of **a** loggerhead (*n* = 125) and **b** Kemp's ridley (*n* = 14) turtles. Records of living turtles (*open circle*) and dead turtles (*filled circle*). Continuous line (Fig. 5a) is the SCL/weight relationship (r^2 = 0.9) derived from 375 logger-head turtles (SCL range 42.3–98.9 cm) from northwest USA coast (Braun–McNeill and Avens, unpublished data). *Dashed line* (Fig. 5b) is the SCL/weight relationship (r^2 = 0.98) derived from 377 Kemp's ridley turtles (SCL range 19.6–65.8) caught at sea from southwest USA Atlantic (Coyne 2000)

et al. 1999; TWEG 2000) and return of juveniles to the British Isles during the late 1990s (1998 $n = 1$, 1999 $n = 2$). During the 1990s, 11 events of sightings and strandings were recorded in France (Fig. 1e) with a further five events since 2000. For loggerhead turtles the observed decline in records for the 1960s to 1980s coincides with a period prior to the classification of the loggerhead turtle as an endangered species in the USA (1978) and the concomitant sharp rise in conservation management. We tentatively suggest the increase in records observed may be the result of increased hatchling recruitment since the 1980s.

In contrast to hard-shell turtles, the decadal trend for leatherback turtle records in British waters demonstrated a consistent decadal increase. This trend is likely to reflect increasing awareness and promotion of public reporting schemes for marine vertebrates, but may, in part, reflect an increasing number of leatherbacks in the North Atlantic, a possible response to the changing distribution and abundance of gelatinous prey (Mills 2001). Equally, more favourable water temperatures arising from regional warming may have expanded the thermal niche for this species (McMahon and Hays 2006, Witt et al. 2006, in press). The overall population status of Atlantic leatherback turtles is difficult to determine. Some sub-populations are thought to be increasing [British Virgin Islands, (Hasting 2003); Florida USA, B. Witherington, personal communication Florida Fish and Wildlife Conservation Commission; US Virgin Islands, (Boulon et al. 1996)] while others remain stable or are potentially declining (Costa Rica, (Troeng et al. 2004)). Important to this study is the observed trend of leatherback records over circa. 90 years in that it provides context with which to interpret the decadal pattern of hard-shell turtle records. If the number of records in any decade reflects only changing public awareness then we may expect the number of loggerhead and Kemp's ridley records to have exponentially increased as observed with leatherback turtle records. We make a conservative assumption that conservation awareness within Europe has monotonically increased during the last century, manifest by the increase in environmental organisations and legislation. The trends for hard-shell turtles indicate the likely involvement of other biological, environmental or anthropogenic factors acting upon their distribution and abundance in the northeast Atlantic.

It does however remain that the presented temporal and spatial trends, and their ability to convey indicative signals of changing population structure, are hindered by the lack of effort correction. This inability to correct rates of sightings and strandings based on survey effort increases the uncertainty when assessing extraneous factors that contribute to observed changes in trends of distribution. The strength of the signals presented here suggest that taking a decadal approach dampens much of the interannual noise generated by variation in the number of recruited hatchling, regional climate systems (e.g. North Atlantic Oscillation, see Hurrell (1995)) and changes in survey effort. Interestingly, the significant correlations in the annual number of records experienced by the British Isles and France for loggerhead, Kemp's ridley and leatherback turtles, at least in part corroborates that generalised patterns of changing incidence can be determined from independently operated public recording schemes.

Analysis of the spatial distribution of records for Britain and France highlight that the incidence of sightings and strandings occurred generally on western facing aspects and that the number of records decreased with increasing latitude. Factors that drive this observed spatial pattern most likely include regional wind patterns and surface currents, water temperature and coastal morphology (i.e. coastline tortuosity and bathymetry). Such factors have been identified as important for predicting cold-stunning and stranding events in Cape Cod Bay, Massachusetts. Here individuals that fail to migrate south during the North American autumn become cold-stunned in embayments as temperatures decline quickly; moreover, wind direction played an important role influencing the location of beach stranding (Still et al. 2005). Regional wind-influenced surface currents operating in the northeast Atlantic undoubtedly play an important role in influencing the spatial distribution of marine turtles that occupy the epipelagic realm. The aggregation of records on western aspects suggests arrival on the European continental shelf and adjacent coasts is most likely mediated by one of several routes, including the Azores current for southern latitudes (France, Spain and Portugal) and the North Atlantic current (see Fig. 7) that flows adjacent to the continental shelf of Europe for more northern latitudes (England, Wales, Ireland and Scotland).

For juvenile loggerhead and Kemp's ridley turtles it is unlikely that arrival in the northeast Atlantic reflects the annual cycling of hatchling recruitment in the Americas. Kemp's ridley nesting occurs between April and July in Mexico (Zwinenberg 1977) with periodic nesting along the USA Gulf of Mexico coast (Shaver et al. 2005). By contrast, loggerhead nesting occurs over a much greater latitudinal and temporal range (North Carolina to Colombia) (Ehrhart et al. 2003) resulting in a more diffuse pulse of hatchlings entering the North Atlantic. For both species it would be expected that the seasonal pulse of juveniles would be

Fig. 7 Schematic of predominant ocean currents of the North Atlantic
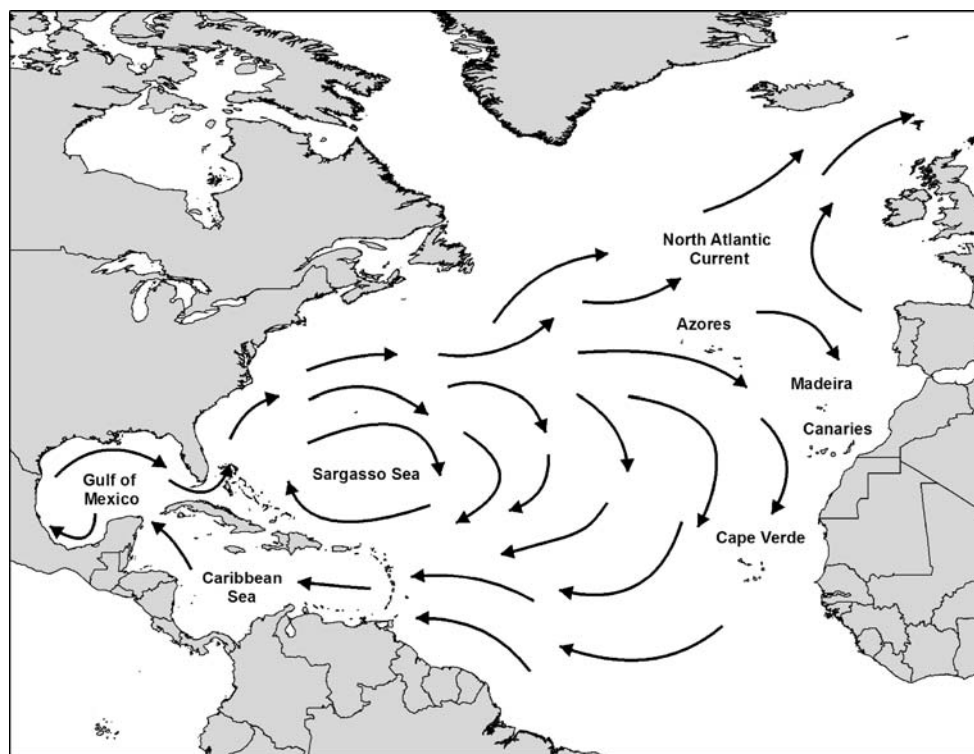
considerably dampened, both spatially and temporally, as their journey across the North Atlantic proceeds. This dampening is potentially reflected in the broad, year-round, distribution of loggerhead turtle records observed. A seasonal peak is however evident, occurring in the winter and early spring for both species, a pattern potentially driven by the ocean environment. In addition to hatchlings emerging from northwest Atlantic shores, hatchlings from the West African coast (Fretey 1998), including Cape Verde, may also contribute to the observed year-round distribution of records.

Sea surface temperature is likely to be the factor determining the incidence of hard-shell turtles in the British Isles and France. For the majority, sightings and strandings of loggerhead and Kemp's ridley turtles in the northeast Atlantic increase during seasonally inclement water temperature (winter and spring). During this period sea surface temperatures around the British Isles are within the range reported to induce floatation (Schwartz 1978). Presence of juvenile turtles in the northeast Atlantic when conditions are physiologically challenging suggests the occupation of this habitat is not the result of active choice - supporting a view that juvenile movement in the North Atlantic gyre can be both active and passive but profoundly influenced by surface currents (Bolten 2003). That hard-shell turtles can be reported as dead on the French coast, where temperatures rarely fall below the

critical thermal threshold for induced floatation indicates that death in this region is the result of a combination of factors, including nutritional status, disease state and anthropogenic influence (e.g. incidental capture in fisheries) and is not solely a response to water temperature. In contrast, leatherback turtles appear to be most abundant during the summer when gelatinous prey is plentiful; this pattern most likely indicates active habitat selection by these large, endothermic marine turtles (Davenport 1998, Witt et al. 2006, in press).

Analysis of size class distribution of loggerhead and Kemp's ridley turtles demonstrates several interesting features. The modal size for Kemp's ridley turtles was slightly larger than loggerheads. This may indicate the longer transit time and distance that this species typically undergoes prior to reaching the European continental shelf. For loggerhead turtles, the presence of some individuals with SCL greater than the core distribution is suggestive of behavioural plasticity. Individuals therefore might exert some choice on when they depart and/or return to oceanic habitats. The return to oceanic habitats by juvenile loggerhead turtles of neritic size has been recorded by satellite telemetry in the northwest Atlantic (C. McLellen, personal communication). These larger individuals may also represent juvenile turtles that have been entrained into mesoscale features of the North Atlantic gyre and experienced extended transit times. Alternatively, these larger turtles may originate from the West African

coast and are nearing the end of their juvenile oceanic phase, have already completed a circuit of the gyre or are carrying out adult pelagic behaviour (Hawkes et al. 2006). It is however evident from the data that the majority of individuals recorded in European continental waters are 'first-passage' turtles, having dispersed from nesting beaches in the Americas and the Gulf of Mexico (Ehrhart et al. 2003) and the Caribbean (Bell et al. 2006, in press). Morphometric relationships of SCL versus weight obtained from northwest Atlantic populations highlighted that some loggerheads in the northeast Atlantic were underweight for their length when compared to individuals in the neritic juvenile phase. This is likely to reflect the nutritional status of these juvenile turtles in temperate waters, experiencing conditions that induce lethargy and subsequent reduced feeding. In contrast, Kemp's ridley turtles appeared to conform well to the comparative morphometric relationship.

Green and hawksbill turtles were conspicuous by their relative absence from the public recording schemes, especially given that both species are more abundant than Kemp's ridley turtles. Similarly to loggerhead and Kemp's ridley turtles, green and hawksbill turtles are thought to recruit to the open ocean as hatchlings and have been previously recorded in such habitats (Carr 1987). For hawksbill turtles, oceanic residency is considered to be shorter than loggerhead turtles. Juvenile hawksbill turtles generally appear in neritic environments at sizes over 20 cm SCL (Márquez 1990), and this recruitment is thought to occur between the ages of 1 and 3 years (Musick and Limpus 1997). Their relative absence from northeast Atlantic records might suggest inter-species variability in dispersal mechanisms that leads this species to occupy ocean current systems of the Caribbean, Gulf of Mexico or Sargasso Sea rather than entrainment in currents that lead to the outer reaches of the North Atlantic gyre. Alternatively, the relative absence of hawksbill and green turtles from the European continental shelf may be artefact of a greater physiological intolerance to cooling. Should these species reach their critical thermal threshold at temperatures higher then either loggerheads and Kemp's ridley turtles it would place them at risk of death in more distant waters, reducing their chance of reaching European shores.

There are numerous caveats to be considered before interpreting data from public recordings schemes; however, with careful interpretation valuable patterns of distribution can be gathered. Over longer timescales, data gathered at the periphery of the range distribution for hard-shell turtle species may allow for a broader assessment of the impacts of global climate change on species range extension. Analysis of sightings and strandings data would appear to provide early warning signals of population declines and subsequent recoveries. With more extensive effort-corrected surveys of European continental shelf, integrated with surveying for other marine mega fauna, it may be possible to provide robust data on changing abundance and distribution of juvenile turtles. These surveys may help to forewarn conservation managers of the current status of juvenile turtle cohorts in their passage through North Atlantic waters.

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