Age at size and growth rates of early juvenile loggerhead sea turtles (*Caretta caretta*) in the Mediterranean based on length frequency analysis

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Growth rate is a fundamental parameter in understanding sea turtle population dynamics and is also important for the conservation of these threatened species. It can be influenced by both environmental and genetic factors, and thus it can vary according to the area. Growth rates and age at size of loggerhead turtles (*Caretta caretta*) are estimated for the first time in the Mediterranean sea and in particular for the elusive first period of life, through length frequency data from 88 turtles ranging from 6.4 to 30 cm curved carapace length found in Italian waters. A visual examination of the length distribution of small turtles found in pelagic habitats suggests a preliminary growth curve for early juveniles in the Mediterranean. Results indicate that this size range includes turtles in the first four years of life. Growth rates ranged from 11.8 cm/yr in the first six months of life to 3.6 cm/yr at the age of 2.5–3.5 years and are similar to those estimated from the Atlantic. Results also suggest a secondary increase in growth rates in larger turtles recruiting to neritic habitats, supporting a polyphasic growth pattern proposed for other populations and other sea turtle species.

Key words: growth pattern, Italy, Mediterranean sea, population dynamics

INTRODUCTION

Many aspects of sea turtle population dynamics are still poorly known, and this makes it difficult to understand how the populations of these threatened species respond to human impacts. To plan adequate conservation strategies, assessment of growth rates is fundamental to estimate the duration of the different life history stages as well as age at maturity (e.g. Heppell et al., 2003).

Sea turtles show great variability in growth rates, even within the same population, which may be caused by genetic, sexual and/or environmental factors (see Heppell et al., 2003). For instance, Bjorndal & Bolten (1988) reported that growth rates obtained through capture–mark–recapture of loggerhead turtles in the Bahamas were much higher than those from the same size class in the north Atlantic estimated through length frequency analysis (Bjorndal et al., 2000). This difference was particularly striking in specimens of 40–50 cm straight carapace length (SCL; Bahamas: 15.7 cm/yr, n=3; N. Atlantic: 4.0 cm/yr, n=2), suggesting that an environmental effect (food availability, temperature, etc.) was acting mainly on the small size classes (Bjorndal & Bolten, 1988). Observations in captivity have revealed that loggerhead turtles in the first years of life are capable of extraordinary growth rates (one individual grew to 56.5 cm SCL in 1.65 years, i.e. 34 cm/yr; Swingle et al., 1993). In the wild they show compensatory growth, probably an adaptation to a variable environment when they have limited movement capacity (Bjorndal et al., 2003).

For this reason, growth rates of a certain population or of animals in a particular area cannot be assumed to be representative, and it is necessary to obtain specific estimates and variances for different populations and even for different foraging grounds of the same population.

Unfortunately, estimating growth rates is not a simple task, requiring large samples and approaches such as capture–mark–recapture, skeletochronology or length–frequency analyses. Growth rates in the first years of life are particularly difficult to obtain, due to the intrinsic low availability of very small turtles (see Bjorndal, 2003 for a review), with very few estimates available for loggerhead turtles in the north Pacific (Zug et al., 1995) and the north Atlantic (Bjorndal et al., 2000, 2003). However, since the highest growth rates are expected for the smallest turtles (e.g. Bjorndal et al., 2000), the greatest difference in size among different cohorts is expected in the first years of life, making this age class theoretically easier to investigate.

In the Mediterranean, loggerhead turtles represent the most common species, widespread all over the basin (Margaritoulis et al., 2003), and are relatively isolated from the Atlantic populations (Carreras et al., 2006a). Unfortunately, growth rates are not available for the Mediterranean so far, and this study aims to estimate this parameter using a visual examination of modes exhibited by the length–frequency distribution, for the smallest size class of loggerhead turtles in the first period of life, when they feed mainly on epipelagic prey in contrast to later stages when they feed mainly on benthic prey (Bolten, 2003; Casale et al., 2008).

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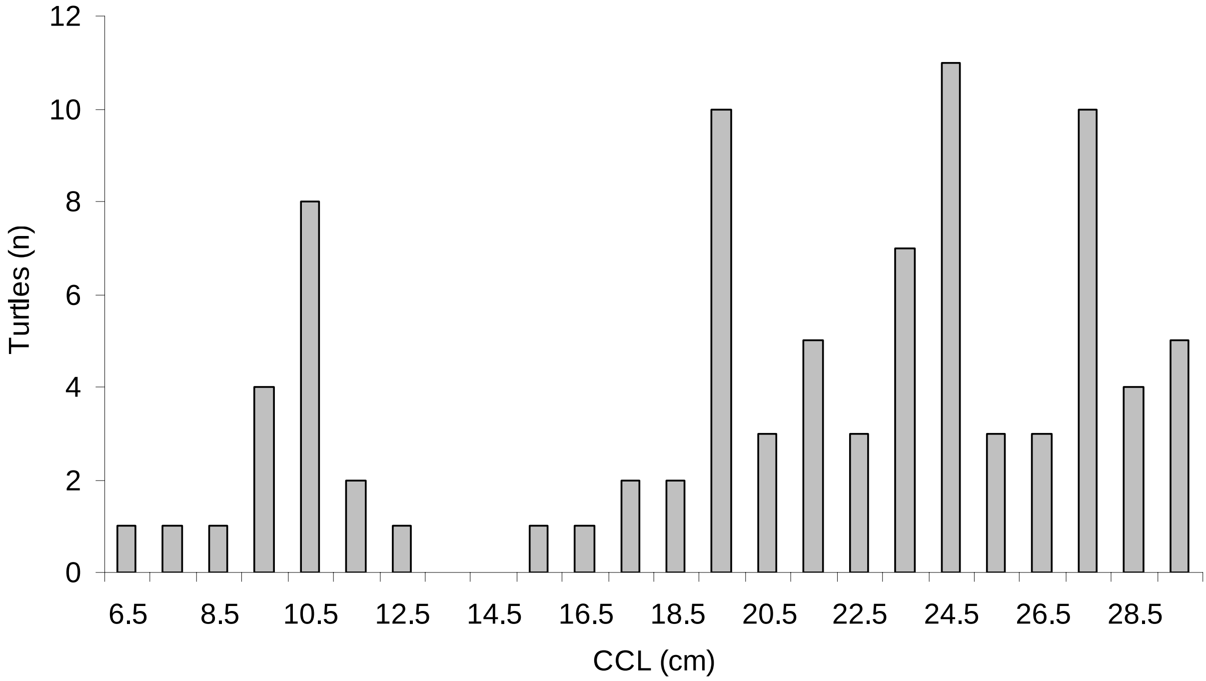

Fig. 1. Size frequency distribution of 88 loggerhead turtles ≤30 cm curved carapace length (CCL) found in February and March in the period 1987–2008 along Italian coasts (mainly south Adriatic Sea).

METHODS

In order to investigate growth in individuals in the first few years of life, we studied only turtles of ≤30 cm curved carapace length (CCL, notch to tip; Bolten, 1999). Turtles in this range usually prey on pelagic animals, although in special circumstances, such as on shallow continental shelves, some may prey upon benthic animals too (Casale et al., 2008). Since food type may affect growth, only turtles found in areas other than large continental shelves, which are more likely to have a typical epipelagic feeding pattern, were included. Finally, only those turtles found in February and March were considered, because 1) restricting the analysis to a limited sampling period per year facilitates the identification of cohorts, 2) these two months had the highest number of records and 3) they are characterized by low sea temperatures and, probably, consequently slow growth; so it is assumed that size differences among individuals of the same cohort within these two months are minimal in comparison to other periods of the year.

In this way 88 turtles were selected, which represents a relatively large sample size for this elusive size class. Turtles were basically found stranded or floating at sea in the period 1987–2008, in areas around Italy not on the continental shelf: south Adriatic Sea (n=80), north Ionian (n=2); Strait of Sicily (n=3), Tyrrhenian (n=3). Although is some cases, especially in large specimens, an advanced state of decomposition might affect measurements, this was unlikely to be a problem in the study sample because most turtles were found alive (75%) and only a part of the dead ones were in an advanced state of decomposition.

In the frequency distribution of 1-cm size classes, modes were assumed to represent the average size of turtles of the same age, and consecutive modes were considered to represent age classes with one-year differences. Modes identified by eye were used as initial values for estimating means and SD of each mode through the NORMSEP method for modal progression analysis in the programme FiSAT II (Gayanilo et al., 2005). Since the hatching period is basically August–September (e.g.

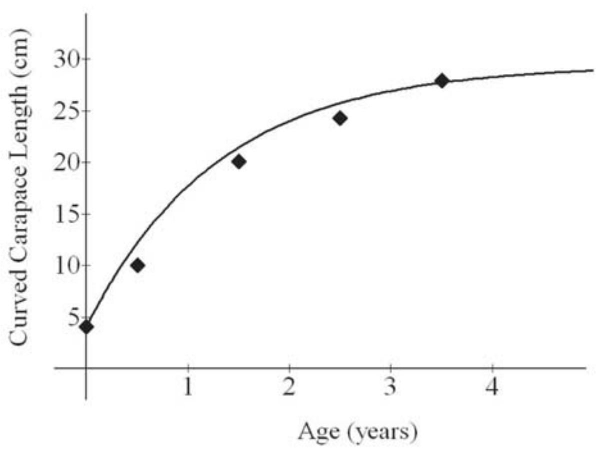

Fig. 2. Von Bertalanffy growth function for loggerhead turtles ≤30 cm curved carapace length (CCL). Size at birth and modal values at corresponding assumed ages are also shown.

Table 1. Size modes (mean and SD), corresponding ages and growth rates in the intervals between them of loggerhead turtles ≤30 cm.

Mean CCL (cm)	SD (cm)	Age (years)	Growth rate in the last interval (cm/yr)
4.10		0	–
10.00	1.387	0.5	11.8
20.08	1.976	1.5	10.08
24.28	0.674	2.5	4.20
27.92	1.072	3.5	3.64

Margaritoulis, 2005), for convenience it was assumed that turtles were born on 1 September, so that the period February–March (for convenience considered as 1 March) corresponded to Age (years) = m–0.5, where m is the mode (1 to *n*). The size difference between contiguous modal values was used to calculate growth rates (cm/yr) for each interval (one of 6 months and the other of 12 months). For the first interval of 6 months size at birth is needed. For practical reasons hatchling size is commonly measured as straight and not curved carapace length and although a curved measurement is by definition longer than a straight one, in hatchlings the difference is minimal. The mean size of hatchlings from Zakynthos, Greece, is 4.04 cm straight carapace length (Margaritoulis, 1982) and it is here assumed to correspond to 4.1 cm CCL. The linking of means method in the programme FiSAT II (Gayanilo et al., 2005) was used to estimate the von Bertalanffy (1938) growth function parameters L_∞ (the mean asymptotic carapace length) and k (growth coefficient), assuming that this function can describe the growth in the observed size range.

RESULTS

Turtles ranged from 6.4 to 30 cm curved carapace length. Size distribution (Fig. 1) shows four evident modes (at 10.5, 19.5, 24.5 and 27.5 cm), and this suggests that, in the Mediterranean, loggerhead turtles of ≤30 cm CCL are within the first four years of life. The estimated modal values and corresponding ages and growth rates are shown in Table 1. The von Bertalanffy growth parameters were estimated as k=0.769/yr and L_∞=29.45 cm CCL. Naturally, these values are totally unrealistic for the species and the von Bertalanffy growth rate function described by them (Fig. 2) should be considered as an approximation of growth in the observed size range only. In the observed size range, growth rates decrease with increasing size, ranging from 11.8 cm/yr in the first six months of life to 3.6 cm/yr at the age of 2.5–3.5 years.

DISCUSSION

Loggerheads in the Mediterranean appear to take four years to grow to 30 cm CCL, on average. Very few studies on the growth rate of small loggerhead turtles are available for comparison. From the Atlantic, Bjorndal et al. (2000) reported on six turtles with an average size of 9.9 cm CCL found in February and one of 10.4 cm CCL in January, indicating a growth rate of 12 cm/yr in the first six months of life assuming they were born on 1 September, which is pretty close to the present findings (Table 1). For the size class 20–30 cm they estimated growth rates of 5–6 cm/yr, but this was based on a linear growth function estimated from a sample including larger turtles (Bjorndal et al., 2000). However, ages at size similar to the present results (e.g. four years old at 30 cm CCL) were estimated by another study on Atlantic loggerhead turtles based on skeletochronology (Bjorndal et al., 2003). On the other hand, in the north Pacific loggerhead turtles seem to have a slower growth rate, since age at 25 cm CCL was estimated to be 3–3.9 years by skeletochronology (Zug et al., 1995). Hence, our results indicate that Mediterranean loggerhead turtles in the first four years of life display growth rates very similar to Atlantic turtles.

We believe that our growth rate estimate applies to loggerheads of Mediterranean origin. Although Atlantic turtles in the oceanic/pelagic stage are known to enter the Mediterranean in large numbers (Carreras et al., 2006b), five considerations make it likely that none or very few of them are included in the present sample:. 1) Genetic markers revealed that Atlantic turtles frequent the western basin more, and are much rarer in the eastern one, especially in eastern Italy (Carreras et al., 2006b), where 91% of the turtles in the present sample were found (south Adriatic). 2) The south Adriatic/north Ionian area is rather close to one of the most important nesting sites of the Mediterranean, Zakynthos island, Greece, and is likely to be an important development area for this population (Casale et al., 2005). These considerations strongly suggest that even if Atlantic turtles arrive in the study area, they would be expected to be larger than the size range investigated in this study. 3) The modal size of 71 loggerhead turtles found on the Atlantic coast of northern Europe is about 23 cm CCL (20.5 cm SCL, converted according to Bjorndal et al., 2000) (Hays & Marsh, 1997), indicating that Atlantic turtles enter the Mediterranean at this size and when they reach the study area, far away from the Gibraltar Strait, they would be much larger. 4) The smallest turtle found in the western Mediterranean and carrying an mtDNA haplotype endemic to the west Atlantic was in the size range 26–30 cm CCL, while for the eastern Mediterranean the smallest turtle was in the size range 30–34 cm CCL (Laurent et al., 1998); however, these genetic studies did not consider other Atlantic populations, e.g. Cape Verde. 5) Turtles tagged and released from Texas and the Azores were re-encountered in the Strait of Sicily (Bolten et al., 1992) and in the north Ionian (Manzella et al., 1988) at 43.5 and 42 cm CCL respectively.

Our results probably concern Mediterranean loggerhead turtles mostly feeding on pelagic prey. Turtles were selected to reduce the probability of benthic feeding (see Methods), and in any case, even in the two continental shelves close to the study area, most turtles in the size range ≤30 cm appear to feed on pelagic prey: the smallest turtles caught by bottom trawlers in the neritic areas of the north Adriatic and the central Mediterranean were 29.5 and 22 cm CCL respectively (Casale et al., 2004, 2007), and the smallest turtles with evidence of benthic feeding in these two areas were 30 and 26 cm CCL respectively (Lazar et al., 2008; Casale et al., 2008).

Obviously, the growth curve estimated for the observed size range (<30 cm CCL; Fig. 2) is unrealistic for the whole size range. However, it would be compatible with the polyphasic growth pattern that has been proposed for pelagic loggerhead turtles in the north Pacific (Chaloupka, 1998) and also for Kemp's ridley turtles (*Lepidochelys kempii*; Chaloupka & Zug, 1997), where a secondary increase in growth rates would occur at sizes larger than the range investigated in this study.

Growth rates are among the most difficult biological parameters of sea turtles to assess, and multiple approaches (e.g. length frequency analysis, capture–mark–recapture, skeletochronology) are desirable.

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