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Morphological Variations in the Green Turtle (*Chelonia mydas*): A Field Study on an Eastern Mediterranean Nesting Population

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Morphological studies in marine turtles might be used to obtain information about changes in developmental habitats. Information regarding mortality and growth rates can be obtained by collecting data on the size of nesting females on the nesting beach. Morphometric and meristic traits of female green turtles (*Chelonia mydas*) were recorded on Samandağ Beach, Turkey, during the 2006-2016 nesting seasons. The study aimed to determine the mean and minimum curved carapace length (CCL) of the nesting green turtle and the differences in body size and scute pattern over the years. The relationship between the body size of nesting green turtles and latitude was also analysed. CCL and curved carapace width (CCW) were recorded for 365 individuals and meristic measures were recorded for 292 individuals. The mean CCL and CCW were recorded as 86.9 (± 6.14) and 77.9 (± 5.95) cm, respectively. The minimum CCL of nesting green turtles was also recorded as 72 cm. The CCL and CCW showed differences over the years and they tended to become smaller from 2006 to 2016. However, this trend was not significant according to the Mann-Kendall trend test. The CCL value was negatively correlated with the latitude and rejected Bergmann's rule. There was no relationship between year and carapace scute deviation. The Samandağ green turtle population had the smallest nesting green turtle based on CCL. In addition to environmental factors, recruitment of females, and growth and mortality rates, and the nesting shift between nesting beaches may be some of the reasons behind a smaller value over the years.

Key words: *Chelonia mydas*, Morphology, Meristics, Bergmann's rule, Samandağ.

BACKGROUND

Morphological studies have a long history and are an integral dynamic part of paleontology and biology. Morphological studies also provide us with basic information about animal development, evolution, biodiversity, biomechanics, behaviour, ecology, and physiology (van Dam and Diez 1998). Marine turtles offer good opportunities to investigate morphological variation because of their global distribution. Marine turtles are also ideal model organisms for comparative studies of life history variation because they have a complex life cycle and they move across very different ecological zones (Tiwari and Bjorndal 2000). Furthermore, morphological analyses play an important role in characterising populations and analysing similarities between populations (Figueroa and Alvarado 1990; van Dam and Diez 1998).

Morphological variations in factors such as body size are well studied in animal biology, and there are many theoretical frameworks to interpret size differentiation models (Gardner et al. 2011). The best-known ecogeographic rule in biology is Bergmann's rule. Bergmann's rule proposes that a positive relationship exists between mean body size and latitude, smaller individuals being found at lower

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latitudes (Ashton and Feldman 2003; Gardner et al. 2011; Angielczyk et al. 2015). However; support for Bergmann's rule has only been shown for endothermic animals (Ashton and Feldman 2003). Regarding the ectotherms reptiles group, the effectiveness of the Bergmann's rule has been discussed for each group in many studies (Ashton and Feldman 2003; Angielczyk et al. 2015; Werner et al. 2016). In those studies where the effectiveness of the Bergmann's rule in the ectotherms has been tested, marine turtles were excluded, and there is therefore no available information on this issue.

Morphology can be used not only to detect inter-regional variation (Figueroa and Alvarado 1990; Kamezaki and Matsui 1995; Wyneken et al. 1999), but also the effect of biotic and abiotic factors in turtles. For instance, the marine turtle morphology (carapace size and tail length) is used to analyse sexual dimorphism in adults (Godley et al. 2002), as well as growth rate (*i.e.*, straight or curved carapace size) (Limpus and Chaloupka 1997; Bjorndal et al. 2000; Omeyer et al. 2018). Morphological analyses help us to understand the swimming performance of hatchlings and their survival rate (Ischer et al. 2009). Morphometrics can be used to test the effect of incubation temperature on hatchling morphology (Stokes et al. 2006) and carapace scute pattern (Kobayashi et al. 2017) and understand how nest relocation can have an effect on hatchling phenotype (Mast and Carr 1989; Suganuma et al. 1994; Sönmez et al. 2011). Detailed data on adult nesting carapace size of Mediterranean populations of green turtles (*Chelonia mydas*) is limited, and these data originate from studies on nesting ecology and conservation biology (Coley and Smart 1992; Geroso et al. 1995; Broderick and Godley 1996; Stokes et al. 2014). However, there are a few studies on the effect of biotic and abiotic factors on the morphology of the green turtles using morphological data in Mediterranean green turtle populations. For example, Broderick et al. (2003) reported variation in the reproductive output of marine turtle using morphology in Cyprus. Regional differences on flipper and body size of green turtle hatchlings between Cyprus and South Atlantic populations were also studied (Glen et al. 2003). Information on body size and carapace scute variations was reported in the relocated nests in Cyprus (Özdemir and Türkozan 2006). Similarly, the effect of nest relocation on the scute pattern and body size on Samandağ Beach was examined (Sönmez et al. 2011). Moreover, Ergene et al. (2011) tested the relationship between scute patterns and the mortality rate of hatchlings. Gender identification was tested using the morphological differences between genders (Sönmez et al. 2016).

Body size is commonly measured in field studies with wild animals, but a lack of size data causes an important gap, especially in Mediterranean green turtle populations (Casale et al. 2018). One of the most of commonly studied body size traits in marine turtles is the curved carapace length (CCL). CCL can, for instance, be compared between populations for regional differences, and latitudinal trends can be evaluated across nesting populations (Tiwari and Bjorndal 2000). Growth rate and clutch size can be estimated using CCL size in marine turtles (Broderick et al. 2003) and CCL variations can provide clues about changes in the developmental habitats (Casale et al. 2018). Moreover, the minimum and maximum CCL values of nesting females during long-term field studies can be obtained and used to categorize strandings as potentially adult females or subadults depending on their CCL value. However, this information is scarcely available for green turtle rookeries in the Mediterranean region. Given the lack of morphological data on the Mediterranean green turtle, this study will fill knowledge gaps by determining: a) the carapace size of the nesting green turtle (*i.e.*, CCL and CCW), b) variation in the body size and scute pattern of the green turtle over time, c) variation in CCL of the nesting green turtle across latitudes.

MATERIALS AND METHODS

Study field

Morphometric and meristic data were collected on Samandağ Beach (36°07'N, 35°55'E), located on the Eastern Mediterranean coast of Turkey, during 2006–2016 nesting seasons (Fig. 1). Samandağ Beach is approximately 14 km in length and can be divided into three subsections: (1) Cevlik Beach, 5.5 km; (2) Şeyh-Hızır Beach, 4 km and (3) Meydan Beach, 4.5 km. The Şeyh-Hızır and Çevlik segments have the highest nesting activity (Yalçın Özdilek 2007).

Measurements

Five people patrolled the beach at nights to observe female nesting turtles. Turtles were tagged and measured after they laid their eggs. Two types of tags (plastic and metal) were used. The plastic tags were used during the 2006–2009 nesting seasons (Tag code TR31SD-0). The metal tags were used during the 2010–2016 nesting seasons (Tag code: TRY-9). The tags were placed on the trailing edge of the left fore flipper, as recommended by Balazs (1999). Moreover, it was checked whether the turtles were tagged or not from previous years. If the turtle was tagged from previous years, it was re-tagged on another fore flipper to prevent pseudo replication. However, measurements of recaptured turtles were not included in the analysis. Similarly, straight carapace sizes were not included in the analysis due to use of different calipers among years. A flexible tape measure (accurate to the nearest mm) was used to obtain the curved measurements of the carapace. Measurements were taken as described by Bolten (1999). Measured characters were curved carapace length (CCL) and width (CCW). Meristic traits included carapace scute patterns such as vertebrals, left and right costals, left and right marginals (Özdemir and Türkozan 2006; Sönmez et al. 2011).

To test the variation in the nesting green turtle's CCL depending on the latitudinal gradient, published studies from assorted nesting beaches in different regions were used (see Table 1 for detailed information). However, some studies have given only straight carapace length (SCL) size, and therefore the equation CCL = (SCL + 0.0515)/0.9426 (Goshe et al. 2010) was used to convert SCL to CCL. The CCL size values in all published studies represent the average CCL value of nesting females.

Statistical analyses

The homogeneity of CCL and CCW size measurements over the years was tested using the Box's M test. Multivariate analysis of variance (MANOVA)

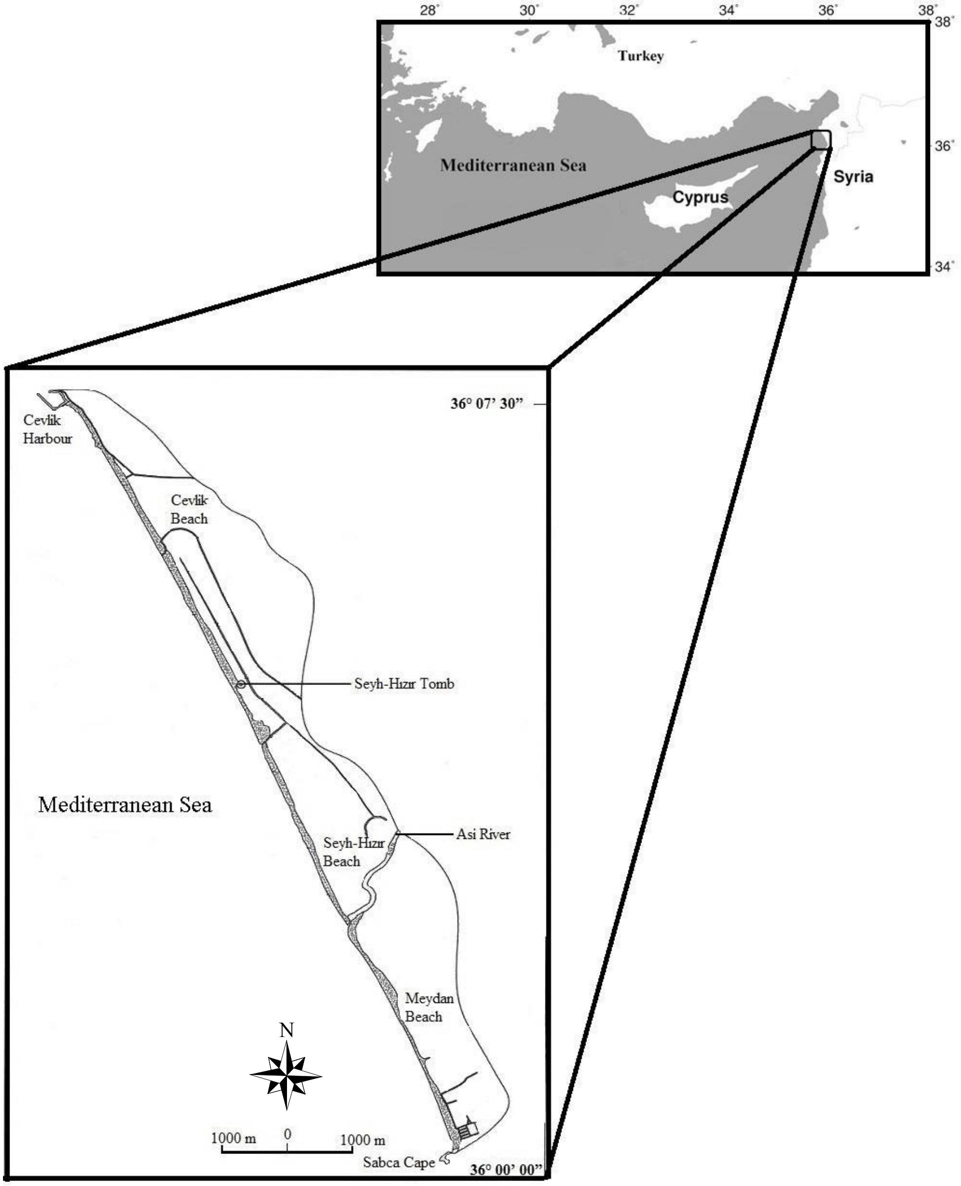

Fig. 1. Map of the study area (highlight shows survey area).

was carried out to test the significance of differences in morphometric characters (CCL and CCW) among the years. The comparison of CCL values between nesting populations in the Mediterranean was performed with the Independent Samples *T*-Test, and also the comparison of CCL values of each nesting beach between each other was performed by One-Sample *T*-test. These tests were conducted with SPSS v. 17.0 (SPSS Inc., Chicago, United States).

Tests for trend in the CCL and CCW values over the years were performed using the nonparametric and non-seasonal Mann-Kendall Trend test (Hipel and McLeod 1994). It was stated that this test can be used for all distributions (*i.e.*, data do not have to meet the assumption of normality) and the data do not have to fit a linear trend (Gilbert 1987; Hipel and McLeod 1994). It can even be used in data sets containing missing (or deficient) as long as there are at least 8 to 10 measurements (Gilbert 1987; Hipel and McLeod 1994). The Mann-Kendall trend test has been used in the long-term examination of marine turtles (da Silva et al. 2007; Marcovaldi et al. 2007; Sönmez 2018). In the trend analysis, the Theil-Sen regression and 95% confidence intervals were used to predict the regression constants based on the Kendall correlation coefficient (Sen 1968). Moreover, the Theil-Sen trend line was generated to visualize if there are any trends in the data. The null hypothesis in the Mann-Kendall test is that the data are independent and randomly ordered, that is, there is no trend. However, the presence of positive autocorrelation in the data increases the probability of detecting trends, when actually none exist or vice versa. The Durbin-Watson statistic was used to test for the presence of autocorrelation in the residuals of a regression model in trend. The null hypothesis of the test is that there is no autocorrelation. The trend test was performed using XLSTAT 2018.4 software (Addinsoft, NY, United States).

The normality of CCL size regarding the latitude gradient was performed with a Kolmogorov-Smirnov test because of the low sample size. The relationship between CCL size and latitude gradient was tested with the Pearson correlation coefficient (Angielczyk et al. 2015; Werner et al. 2016) using SPSS v. 17.0 (SPSS Inc., Chicago, United States).

Scute deviations were determined by observing each individual's normal scute patterns. Depending on the presence or absence of scute deviations, the trait was classified as either 1 or 0, respectively. The number of each scute on carapace is considered a countable variable (Mast and Carr 1989) and therefore, countable data models such as Poisson and Negative Binomial are often used to analyse those data in marine turtles studies (Pradhan and Leung 2006; Gardner et al. 2008). In a standard Poisson model, the variance is assumed to be equal to the mean, but the real data often violate this assumption by having greater variances than the mean (*i.e.*, over-dispersed). The Negative Binomial Model

Table 1. The CCL size data reported in the various published reports from assorted nesting beaches in different regions (*indicates conversion from CCL from SCL) (CCL: curved carapace length, SCL: straight carapace length)

Region	Nesting Beach	Latitude	CCL	*n*	Range	Reference
Southwest Pasific	Heron Island, GBR, Australia	-23°	107	1942	91-124	Limpus 2008
South Atlantic	Trindade Island, Brazil	-20°	115.2	3010	90-143.5	Almeida et al. 2011
Southwest Indian	Mohéli, Comoros Islands	-12°	108.1	742	90-129	Innocenzi et al. 2010
Southwest Pasific	Raine Island (Australia)	-11°	105.9	20947	86-130.1	Limpus et al. 2013
Southwest Indian	Aldabra, Seychelles Islands	-9°	109.6*	54	95-114	Frazier 1971
South Atlantic	Ascension Island (UK)	-7°	116.8	738	101.6-131.5	Hirth 1997
South Atlantic	Atol das Rocas, Brazil	-3°	114.5	1850	96-132	Bellini et al. 2013
South Atlantic	Galibi Reserve (Suriname)	5°	116*	291	97-125	Schulz 1975
East Indian	Turtles Island (Philippines)	6°	99.5	?	?	Trono 1991
North Indian	Kosgoda (Sri Lanka)	6°	105	418	85.9-120.2	Ekanayake et al. 2016
North Atlantic	Tortuguero (Casta Rica)	10°	106.6*	2017	?	Bjorndal and Carr 1989
South Atlantic	Aves Island (Venezuella)	15°	112.4	450	?	Vera 2008
North Indian	Ras al Hadd (Omman)	22°	102.7	36	89-116	Mendonça et al. 2010
North Pasific	Orchid Island (Taiwan)	22°	103.9	66	93-116	Cheng et al. 2009
North Indian	Ras Baridi (Saudi Arabia)	24°	105.2	15	92-114	Hirth 1997
North Atlantic	Cape Canaveral, Florida (USA)	28°	108*	90	83.2-116.7	Witherington and Ehrhart 1989
Mediterranean	Alagadi (Cyprus)	35°	91.5	92	77 -106	Broderick et al. 2003
Mediterranean	Kazanlı (Turkey)	36°	89.5	43	76 – 104	Elmaz and Kalay 2006
Mediterranean	Akyatan (Turkey)	36°	91.9	39	82.5-102.5	Türkecan 2010
Mediterranean	Samandağ (Turkey)	36°	86.9	365	72-106	This study

allows for variance that differs from the mean, and it is often used to model countable data when the data are over-dispersed (Hilbe 2007). Scute patterns were over-dispersed and better described by the Negative Binomial Model. Therefore, the Negative Binomial Model (with the function log link) was used to test whether there is a regression in meristic characters throughout the years. For each carapace scute models, a fixed value was selected for the scale parameter method, and the Fisher method was used for the parameter estimation. Moreover, the likelihood ratio chi-square test was used to detect a model effect. This test allows for selecting the best explanatory model by retaining explanatory variables that significantly improved the model fit. The difference in the scute deviation of frequency distribution was analysed with the chi-square Fisher's exact test because the expected count was less than 5. These analyses were conducted using SPSS v. 17.0. (SPSS Inc., Chicago, United States). All means are presented with ± SD and min-max.

RESULTS

Morphometrics

In total, 365 green turtles were measured for CCL and CCW, and the resulting descriptive statistics are shown in table 2. The mean CCL and CCW were 86.9 ± 6.14 cm (range = 72–106) and 77.9 ± 5.95 cm (range = 63–95), respectively. The smallest nesting female size was 72 cm.

Twelve samples in total were excluded from all statistical analyses due to low sample sizes in 2008, 2013, and 2015. Multivariate statistic (MANOVA) identified overall significant differences in variables and confirmed that the CCL and CCW showed variations over the years (Wilks's Lambda = 0.825, F = 4.953, *d.f.*1 = 14, *d.f.*2 = 688, $p = 0.001$). The Durbin Watson test showed no autocorrelation for CCL and CCW in residuals ($P > 0.05$). The mean CCL and CCW values tended to become smaller over the years, but this trend was not significant for both measured traits ($P > 0.05$) (Fig. 2).

CCL values were negatively correlated with the latitudinal gradient ($r = -0.760$, $p = 0.001$, $n = 20$, two-tailed) (Fig. 3). The size of nesting marine turtles is larger on average at low latitudes. Moreover, the minimum CCL value of nesting female was also negatively correlated with the latitudinal gradient ($r = -0.804$, $p = 0.001$, $n = 17$, two-tailed). When the latitudinal gradient was divided into the Southern hemisphere and Northern hemisphere, CCL size was not correlated with latitude in Southern hemisphere ($r = 0.374$, $p = 0.409$, $n = 7$, two-tailed), whereas it was negatively correlated in the Northern hemisphere ($r = -0.753$, $p = 0.003$, $n = 13$, two-tailed).

Meristics

In total, 292 green turtles were examined for carapacial scute patterns. The most common carapace scute patterns were 5 vertebral scutes (95.5%), 4 right and left costal scutes (95.5% and 94.8%, respectively), and 11 right and left marginal scutes (93.8% and 96.2%, respectively). The carapace scute deviation rates over the years are shown in table 3. Carapacial scute patterns were not examined in 2014. Also, the scute patterns in 2008, 2009, 2013 and 2015 (in total 12 samples) were not included in the analysis due to their low sample size. The negative binomial regression model was used because of over-dispersion in all scute patterns, and no relationship was found between year and carapace scute deviation (Table 4). Although the right part of the carapace (right costal and marginal) indicated very weak negative relationships, the left part and center of the carapace indicated very weak positive relationships with years. However, each model for each scute deviation explained only a very small part of this relationship (Table 4).

When the frequency distribution difference of scute deviations was compared over the years, there were statistically significant differences in left marginal (Fisher's Exact = 29.172, $p = 0.0001$) and right marginal scutes (Fisher's Exact = 52.673, $p = 0.0001$). However, there were no significant differences in vertebral (Fisher's Exact = 15.297, $p = 0.129$), left costal (Fisher's Exact = 12.966, $p = 0.090$), and right costal (Fisher's Exact = 12.934, $p = 0.105$) over the years.

DISCUSSION

The mean CCL and CCW values over 11 years on Samandağ Beach were 86.9 and 77.9 cm, respectively while the minimum CCL of nesting green turtles was 72 cm. Many previous studies recorded higher mean and minimum CCL values in different regions than that of the Samandağ nesting population (see Table 1 for details). The mean CCL value of nesting green turtles in different nesting beaches ranges between 89.5 (Kazanlı, Mediterranean) and 116.8 cm (Ascension Island, South Atlantic). The mean CCL value of the nesting green turtle population on Samandağ Beach has the smallest reported mean CCL so far for any population (see Table 1).

In previous studies, it was reported that the Mediterranean green turtle population was smaller than

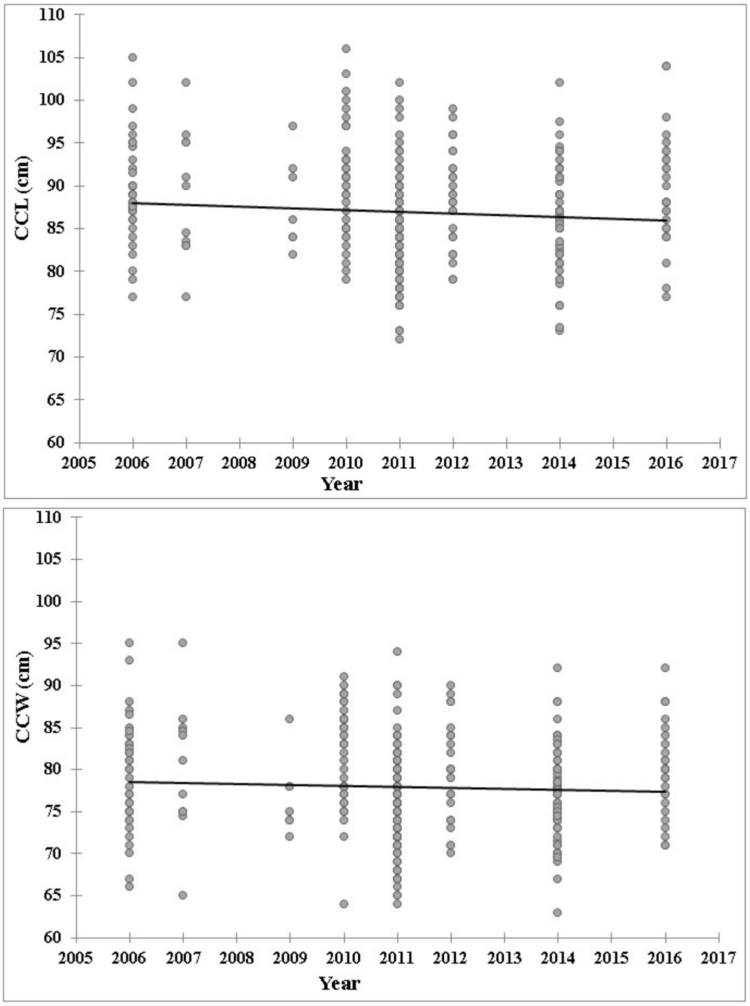

Fig. 2. The temporal change in the CCL (curved carapace length) and CCW (curved carapace width) values over the years (Black lines are Theil-Sen trend lines).

Table 2. The descriptive statistics of the morphometrics characters over years (CCL: curved carapace lenght, CCW: curved carapace width) (*indicates the years that were eliminated from the statistical analysis owing to the small sample sizes)

Years		CCL (cm)			CCW (cm)		
	N	Mean	± SD	Min-Max	Mean	± SD	Min-Max
2006	38	89.39	5.8	77-105	79.38	6.46	66-95
2007	11	89.09	7.49	77-102	80.18	7.98	65-95
2008*	2	83.50	2.12	82-85	77.50	2.12	76-79
2009	7	88.0	5.44	82-97	76.71	4.64	72-86
2010	43	90.51	6.25	79-106	81.93	5.77	64-91
2011	134	84.44	5.35	72-102	75.61	5.37	64-94
2012	26	88.42	5.77	79-99	79.76	5.64	70-90
2013*	5	86.60	5.12	81-93	76.20	4.65	71-82
2014	65	86.06	5.82	73-102	77.35	5.38	63-92
2015*	5	88.0	1.41	86-90	77.80	1.30	76-79
2016	29	89.44	6.47	77-104	80.0	5.35	71-92
Total	365	86.92	6.14	72-106	77.91	5.95	63-95

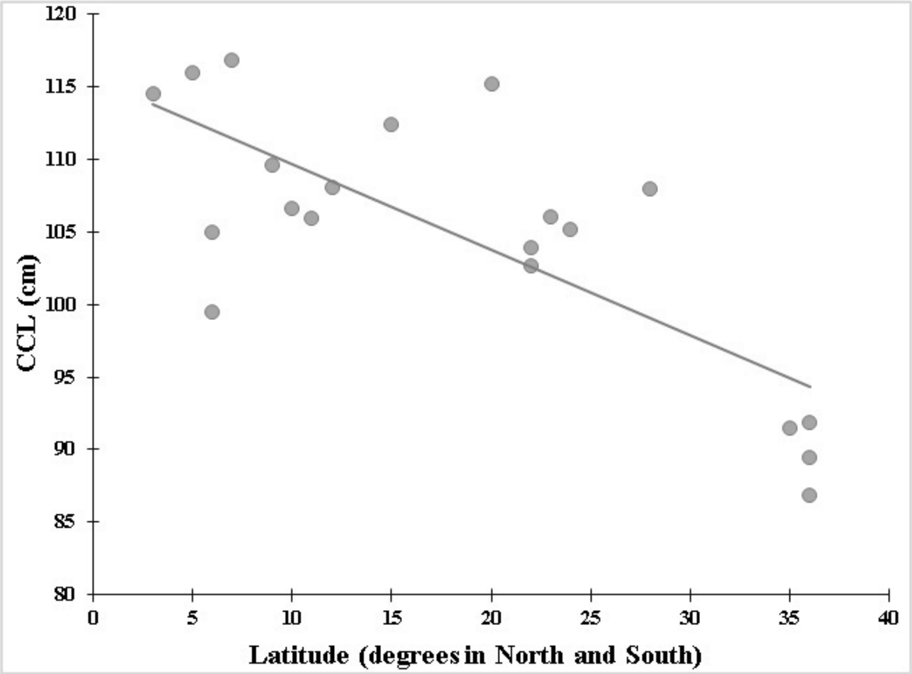

Fig. 3. The relationship between nesting CCL (curved carapace lenght) size and latitude in marine turtles across different regions.

Table 3. The descriptive statistics of the carapacial scute deviations within years (0 = no scute deviations; 1 = scute deviations) (*indicate the years that were eliminated from the statistical analysis owing to the small sample sizes)

Scute Pattern	Deviation	%/n	2006	2007	2008*	2009*	2010	2011	2012	2013*	2015*	2016	Total
Marginal (left)	0	(%)	94.8	91	100	100	100	100	100	40	100	82.2	96.2
		n	36	10	1	2	43	134	26	2	4	23	281
	1	(%)	5.2	9	0	0	0	0	0	60	0	17.8	3.8
		n	2	1	0	0	0	0	0	3	0	5	11
Marginal (right)	0	(%)	94.8	91	100	100	100	100	100	60	100	57.2	93.8
		n	36	10	1	2	43	134	26	2	4	16	274
	1	(%)	5.2	9	0	0	0	0	0	40	0	42.8	6.2
		n	2	1	0	0	0	0	0	3	0	12	18
Vertebral	0	(%)	97.4	91	100	100	100	97.7	84.6	100	100	85.7	95.5
		n	37	10	1	2	43	131	22	5	4	24	279
	1	(%)	2.6	9	0	0	0	2.3	15.4	0	0	14.3	4.5
		n	1	1	0	0	0	3	4	0	0	4	13
Costal (left)	0	(%)	94.8	100	100	100	97.7	95.5	92.3	100	100	85.7	94.8
		n	36	11	1	2	42	128	24	5	4	24	277
	1	(%)	5.2	0	0	0	2.3	4.5	7.7	0	0	14.3	5.2
		n	2	0	0	0	1	6	2	0	0	4	15
Costal (right)	0	(%)	94.8	100	100	100	100	97.7	96.2	100	75	78.6	95.5
		n	36	11	1	2	43	131	25	5	3	22	279
	1	(%)	5.2	0	0	0	0	2.3	3.8	0	25	21.4	4.5
		n	2	0	0	0	0	3	1	0	1	6	13

other populations (*i.e.*, Atlantic and Pacific) (Erhart 1982). These differences may be due to a recent genetic separation between populations and/or different growth rates of these populations. It was stated that the Atlantic green turtles colonized the Mediterranean Sea after the last glacial period based on non-Bayesian methods (Naro-Maciel et al. 2014). The same result was obtained by several authors using different methods (*e.g.*, Bowen et al. 1992; Enclada et al. 1996; Bağda et al. 2012). Therefore, many rookeries can now be considered as individual management units (Naro Maciel et al. 2014) and separated as source populations (Carreras et al. 2014). Along with genetic factors, environmental conditions of the Mediterranean might affect body size. Tiwari and Bjorndal (2000) claimed that environmental conditions and geological history of the Mediterranean Sea can explain why the Mediterranean population of loggerhead turtles (*Caretta caretta*) is smaller than the Atlantic population. The Atlantic system has a richer nutrients level than the Mediterranean system (Tiwari and Bjorndal 2000). The isolating barriers as a result of the tectonic events and land mass movements have contributed to oligotrophic conditions, particularly in the eastern basin where adult green turtles reside (Sara 1985). It was stated that low levels of nutrients could have important effects on marine turtle populations (Tiwari and Bjorndal 2000). Therefore, resource availability could have effects on the growth rate, and hence the size of the turtles (Bjorndal 1985). Mediterranean turtles can respond to the constraints of limited resources by maturing early, directing the energy needed for growth to reproduction and maximizing the conversion efficiency of the resources (Tiwari and Bjorndal 2000). There are many differences in size among different regions based on the nutrient contents or environmental conditions of those regions. The growth rate of the marine turtle is related to the carapace size (*i.e.*, SCL or CCL), and the green turtles can have different growth rates in different regions (*i.e.*, in the Atlantic and the Pacific Oceans) (Limpus and Chaloupka 1997; Bjorndal et al. 2000; Omeyer et al. 2018).

The mean CCL value of nesting green turtles on Samandağ Beach is also smaller than those of Mediterranean populations, but this difference is not statistically significant (*T*-test, $p > 0.05$, see Table 1). When the mean CCL value of the Samandağ nesting population was compared to the mean CCL value of each nesting populations of Mediterranean, significant differences were detected (One Sample *T*-test, $t = 37.208$, $p = 0.017$ for Alagadi, $t = 95.316$, $p = 0.007$ for Kazanlı, $t = 72.680$, $p = 0.009$ for Akyatan). Why is the Samandağ population smaller than the others even though they share a common ancestor? This difference in CCL could be possibly due to local environmental conditions rather than genetic factors. Chaloupka et al. (2004) stated that the rate of growth among green turtle populations with the same mtDNA haplotype may vary depending on environmental conditions such as food availability and nutrient uptake rates. Also, it should be not forgotten that the Mediterranean green turtle populations showed a low level of mtDNA variation (Bağda et al. 2012). It is known that marine turtles use different habitat types during their life history, and nutrient richness in these different habitats also effect the growth of marine turtles (Bjorndal 1985). Food stock dynamics subject to local environmental stochasticity, which may lead to differences in food availability and nutrient uptake rates, may lead to differences in CCL size of green turtles (Chaloupka et al. 2004). The trophic status and growth rate of green turtles in the Mediterranean should be investigated for better conservation management in the future. Moreover, shorter migrations due to a lower growth rate with a similar age at maturity can cause smaller size in turtles (Casale et al. 2011). Based on the stranded green turtle data, Yalçın Özdilek and Aureggi (2006) and Sönmez (2018) noted that the Samandağ coastal area is a possible feeding ground for green turtles, indicating that this population may have a short migration route. Does the fact that the Samandağ population has a smaller CCL size than the other female green turtle populations both in and out the Mediterranean have any disadvantages? It may have a negative impact on clutch

Table 4. The test results of carapacial scute deviation using negative binomial regression with log link

	Negative Binomial Regression with log link					95% Confidence Interval for Exp (B)	
Variable	Likelihood Ratio Chi-Square	*d.f.*	*p*	Slope	Exp (B)	Lower	Upper
Marginal (left)	0.013	1	0.910	0.0001	0.999	0.984	1.015
Marginal (right)	0.094	1	0.759	-0.0002	0.998	0.987	1.010
Vertebral	0.019	1	0.892	0.0001	0.999	0.985	1.013
Costal (left)	0.012	1	0.914	0.0001	0.999	0.985	1.013
Costal (right)	0.029	1	0.865	-0.0001	0.999	0.986	1.012

size, *i.e.*, the number of hatchlings, because the smaller size (*i.e.*, smaller CCL) of the green turtle produces smaller clutch sizes in the Mediterranean populations (Broderick et al. 2003). Moreover, it can have a negative impact on genetic diversity and population size in future populations. Large female marine turtle size could be effective in mating with more than one male (this phenomenon is called "multiple paternity"), and smaller female turtle could tend to mate with fewer males (Zbinden et al. 2007; Sarı et al. 2017). It was stated that the high frequency of multiple paternity (or polyandry) implies a possible high genetic diversity and population size within a population, *i.e.* indirect genetic benefits (Zbinden et al. 2007; Alfaro-Nunez et al. 2015; Sarı et al. 2017). Although multiple paternity has been documented in the green turtle (Lee and Hays 2004; Wright et al. 2013; Alfaro-Nunez et al. 2015), there is no relationship between multiple mating and body size (Lee and Hays 2004; Wright et al. 2013). However; Wright et al. (2013) reported that polyandry was significantly more common in re-migrant females compared with first-time nesters (potential new recruits), even if recruits females are smaller than re-migrants. When considering that one of the reasons for the downward tendency in body size in the Samandağ population could be a recruitment of new females (discussed below), this situation may provide a disadvantage to future populations in terms of genetic diversity or indirect genetic benefits.

The morphometric characters (CCL and CCW) of turtles on the Samandağ nesting beach showed significant differences among the years. Similarly, it was reported that there was a significant difference in nesting size of green turtles over the years on Raine Island, Australia (Limpus et al. 2003). The same result was reported by Bellini et al. (2013) for the Atol das Rocas, Brazil. In contrast, Limpus et al. (1984) found no significant differences between seasonal variations on nesting size of the green turtle over 8 years on Heron Island, Australia. The differences in CCL value over time may be due to the change in selective forces caused by changes in density-related maturation mechanisms or mortality patterns (Bellini et al. 2013). There may be different mortality rates among subgroups of adult turtles living in different feeding areas because they may be exposed to different death risks in different areas (Hatese et al. 2002). It was reported that the mean CCL size of the stranded green turtles, which was recorded on the nesting beaches near Samandağ Beach, ranged between 33 and 86 cm (Türkozan et al. 2013). Sönmez (2018) stated that CCL size of the stranded green turtles showed increases on Samandağ Beach over the 2002-2017 nesting seasons. This situation may be caused by CCL value inter-seasonal differences over the years.

The CCL and CCW values tended to decrease from 2006 to 2016 in the present study, but this trend was not significant. Perhaps the reason for the lack of a significant difference in the trend may be that the trend begins towards the end of the study period. It was stated that the CCL value of stranded green turtles at Samandağ Beach increased significantly after the 2012 nesting season (Sönmez 2018). The separation of larger turtles from the population by the stranding suggests that the smaller turtles are nesting. Significant downward trends in the mean CCL value of nesting green turtle females on Raine Island over 26 nesting seasons were reported by Limpus et al. (2003). Similarly, the mean CCL values of the green turtles nesting on the Atol das Rocas (Rocas Atoll) significantly decreased during the 1990–2008 nesting seasons (Bellini et al. 2013). A similar result was also found for the olive ridley turtle (*Lepidochelys olivacea*) in the States of Sergipe and Bahia, North-Eastern Brazil (da Silva et al. 2007). The causes of the downward trend in CCL and CCW values can be explained in three different ways. Firstly, this downward trend could be seen as an indication that, in addition to the present nesting population, new females were also recruited. Probably younger and smaller female turtles participated, as in the case of the Atol das Rocas nesting beach for the green turtle (Bellini et al. 2013) and North-Eastern Brazil for the olive ridley turtle (da Silva et al. 2007). Moreover, it was reported that the mean CCL size of the nesting green turtle in Cyprus is decreasing over time due to recruitment of neophytes (Stokes et al. 2014). Secondly, the decrease in CCL may be related to a mortality rate of nesting adults because the mortality rate of adults can explain the CCL decrease (da Silva et al. 2007). However; Türkozan et al. (2013) showed that the stranding green turtles are mainly sub-adults on Samandağ Beach. Sönmez (2018) also stated that the CCL value of the stranded green turtles after 2012 nesting season has increased on Samandağ Beach. Thirdly, the downward trend could be a result of nesting shifts among the nesting beaches. Yılmaz et al. (2015), suggested that a nesting shift may exist among Akyatan, Kazanlı and Samandağ Beaches, which are important nesting beaches for green turtles in the Mediterranean. It has been reported that two green turtles nested in four different nesting beaches during the same nesting season based on tagging (Sönmez et al. 2017). Similarly, 73% of the loggerhead turtles in the Northern Recovery Unit, USA laid egg at more than one nest within a distance of 20 km based on microsatellite genotypes, whereas 54% nested elsewhere based on tagging (Shamblin et al. 2017). The value of CCL may be affected as a result of the exchange of nesting females among the beaches in the Mediterranean region. However, the loggerhead turtles are a different species, known to have low nest site fidelity, and the green turtles in the Mediterranean are thought to have very high nest site fidelity (Broderick et al. 2002 2007; Snape et al. 2018).

The CCL value of nesting green turtles showed a negative correlation with latitude. This result rejected Bergmann's rule which suggests a positive relationship between latitude and body size (Gardner et al. 2011). Tiwari and Bjorndal (2000) also found a negative relationship between body size and latitude in loggerhead turtle nesting populations (Brazil, Florida, and Greece). The effectiveness of Bergmann's rule has been discussed for all reptile groups, such as the chelonians (Lindsey 1966; Ashton and Feldman 2003; Angielczyk et al. 2015). Ashton and Feldman (2003) found that data from some chelonians support Bergmann's rule, whereas data from others reject it. Furthermore, Werner et al. (2016) found that the carapace length of *Testudo graeca* was correlated with latitudes, both globally and locally, following Bergmann's rule. Angielczyk et al. (2015) also indicated that the body sizes (CCL) of 336 species except marine and island turtles were not consistent with Bergmann's rule. Concordantly, they found a significant negative correlation between the latitude and body size. As a result of warmer and more consistent temperatures at lower latitudes, reptiles can grow throughout the year and become larger. On the other hand, at higher latitudes, the climates are less stable and fluctuate daily and seasonally, which may lead to less growth throughout the year and therefore smaller individuals (Lindsey 1966; Ashton and Feldman 2003; Angielczyk et al. 2015). As marine turtles occupy temperate and tropical climates, Lindsey (1966) did not assess the body size across latitudes. Similarly, Angielczyk et al. (2015) did not include marine turtles in their analysis to represent a phylogenetically distinct group and variations between ocean basins. As marine turtles migrate between feeding and breeding grounds, spending the majority of their lives at the former, it may be more appropriate to test the latitude variation across feeding areas instead of nesting beaches.

Scute deviation in marine turtles is a common morphological variation (Mast and Carr 1989; Suganuma et al. 1994; Özdemir and Türkozan 2006; Ergene et al. 2011; Sönmez et al. 2011). The observed scute deviation was not as high in adults as in hatchlings (Suganuma et al. 1994; Türkozan et al. 2001), because the hatchlings with deviant scute likely die before they reach the adult stage (Özdemir and Türkozan 2006; Sönmez et al. 2011). Sönmez (2018) reported that stranded oceanic and sub-adult green turtles showed higher carapace scute deviation rates than their adults. The size of the deviation in adult green turtle on Samandağ Beach was larger than the Alata nesting populations in Turkey (Ergene et al. 2011). For 13 adult green turtles on the Alata nesting beach, the frequency of scute deviation was shown as 7.7% for vertebral and 15.2% for left costal; and both marginal scutes and right costal did not show any deviations (Ergene et al. 2011). Scute deviations can be related to DNA methylation levels during embryonic development, which is an epigenetic mechanism (Caracappa et al. 2016). DNA methylation levels correlate with environmental conditions (Varriale 2014), because environmental parameters can affect the DNA methylation and, consequently, the activation or suppression of certain genes (Caracappa et al. 2016). Scute deviations may be due to genetic and maternal characteristics (Glen et al. 2003) as well as environmental factors including temperature during incubation (Kamezaki 1989). Moreover, scute deviations may be caused by high temperatures during incubation (Kobayashi et al. 2017) or by the relocation of nests (the transfer of eggs to a safer area). For example, scute deviations in the green turtle hatchlings in relocated nests were higher than *in situ* nests in Japan (Suganuma et al. 1994). A similar result was also observed for the green turtle hatchlings on Samandağ Beach (Sönmez et al. 2011).

CONCLUSIONS

In conclusion, the mean CCL of the nesting green turtle population on Samandağ Beach is the smallest recorded in the Mediterranean (see Table 1 for further information), and the smallest size of nesting females is 72 cm. Both morphometric (*i.e.*, CCL and CCW) and meristic characters showed differences across the years, except for both costal and vertebral scutes. Samandağ's green turtle population showed a decreasing temporal trend in body size. CCL of nesting green turtle showed a negative correlation with the latitudinal gradient, rejecting Bergmann's rule. Along with the information provided by this present study, further research on the diversity of nutrition in feeding areas, growth rates, and understanding of how the growth rate and food availability are affected by ongoing global climate change will contribute to the conservation biology of Mediterranean green turtle populations.

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