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Dichotomy in morphology of the same genetic lineage of green turtles

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Morphological studies of marine turtles are important to provide insight into changes in their developmental environment. This study aimed to determine green turtles' *Chelonia mydas* morphological differences within the same genetic lineage in the eastern Mediterranean MED3 management unit and to find the best conversion equations between carapace size. A total of 106 adult green turtles (curved carapace length [CCL] range 79–105 cm) were measured on the five major nesting beaches of the eastern Mediterranean during 2020 and 2021. Morphological differences were tested with PERMANOVA and the relationship among body sizes was tested by linear regression. In the eastern Mediterranean green turtles, the mean CCL and SCL (straight carapace length) were 88.5 cm and 83.5 cm, respectively. There were no statistically significant differences in any of the examined morphological characteristics of green turtles collected from five nesting beaches. In the clustering analysis, however, it was found that all the turtles fell into two distinct groups: larger (> 95.2 cm) and smaller (< 85.2 cm) turtles. As well, the conversion equations between CCL and SCL showed a high coefficient of determination ($R^2 = 0.938$). We suggest that the conversion equations may be applied to all green turtles belonging to this population and nesting in the eastern Mediterranean.

Keywords: Chelonia mydas, morphology, conversion equation, K-means, eastern Mediterranean

INTRODUCTION

Through morphological studies (van Dam & Diez, 1998), it is possible to obtain basic information on topics such as animal development, evolution, biomechanics, behaviour, ecology, and physiology. Marine turtles provide great opportunities to study morphological variations because of their global distribution and because they move across very different ecological zones (Tiwari & Bjorndal, 2000). For instance, local conditions such as food availability and nutrient uptake rates affect food stock dynamics. This could affect the growth rate and hence the carapace length of marine turtles (Chaloupka et al., 2004). Further, the phenotypic variation of a species can be used to characterise the populations (Glen et al., 2003). For example, the relationship between size and weight of the body form can be used to describe the degree of differentiation of different populations of marine turtles (Figueroa & Alvarado, 1990; van Dam & Diez, 1998). Many researchers have indicated that green turtles differ between regions in carapace size (Figueroa & Alvarado, 1990), skull morphology (Kamezaki & Matsui, 1995), and flipper size (Wyneken et al., 1999). Similarly, it was stated that morphometric scaling varies among life stages of the loggerhead turtle in the western north Atlantic (Marn et al., 2015). In addition to these, inter-regional variation in carapace shape of the green turtle between Atlantic, eastern Pacific, and western Pacific genetic lineages was investigated (Álvarez-Varas et al., 2019), and at least three distinct morphotypes are proposed. Similar research was also conducted on foraging grounds (Álvarez-Varas et al., 2021), and all body traits (carapace, plastron, head and flipper) of south-central/western Pacific genetic lineage turtles showed variations between foraging grounds (south-west Atlantic and eastern Pacific).

In addition to determining inter-regional variations, carapace size and tail length are used to distinguish between sexes in both adults (Godley et al., 2002) and hatchlings (Sönmez et al., 2016). Also, carapace sizes help us determine growth rates in adult turtles (Omeyer et al., 2018). Hatchlings' morphology can give us clues about their locomotor performance and their survival, as larger hatchlings are associated with faster crawling and swimming speeds (Ischer et al., 2009). Growth and proportional increases in carapace width versus length in post-hatchlings may provide clues about higher morphological defenses and the ability to escape from predators (Salmon et al., 2016). Also, we can use morphology to understand how nest relocation affects the hatchling phenotype, e.g. nest relocation may cause scute abnormalities (Sönmez et al., 2011; Sönmez, 2018). Morphology can be used to estimate the reproductive output or clutch size of nesting turtles, as larger females

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are associated with larger clutch size (Broderick et al., 2003), and assess longitudinal and temporal trends in nesting populations (Tiwari & Bjorndal, 2000; Sönmez, 2019).

Carapace size is measured at nesting beaches to determine the minimum size at sexual maturity, reveal the body size relationship with reproductive output, and monitoring nesting female size for a certain nesting beach (Bolten, 1999). It is also measured on foraging grounds to determine the frequency of turtle size classes and monitor their growth rate (Bolten, 1999). Thus, information on habitat quality and physiological conditions of marine turtles could be obtained by analysing the growth rates (Bolten, 1999) hence the carapace size. There are two types of linear measurements for carapace size, which are straight line measurements (taken with calipers) and curved measurements (taken with a flexible tape measure). Straight line measurements are more reliable because curved measurements tend to be less accurate and precise due to irregularities in the surface of the carapace and epibionts (Bjorndal & Bolten, 1988; Bolten, 1999). During field studies, carapace sizes are commonly measured, but the lack of size data in both foraging and nesting populations causes a significant gap, particularly in Mediterranean green turtle populations (Casale et al., 2018). Moreover, there are no equations to convert between the carapace size of the green turtle for the Mediterranean population. This equation can be useful for finding the missing measurement when one of the measurements is unavailable. It may therefore be helpful for comparative studies with other populations.Furthermore, the minimum carapace sizes to help categorise stranding green turtles as adults or sub-adults (Türkozan et al., 2013; Casale et al., 2018) are limited for the Mediterranean. In a recent study on the Samandağ beach, it was reported that the carapace size of the nesting green turtles decreased over the years and the minimum curved carapace length (CCL) was 72 cm (Sönmez, 2019). There is no study in which nesting beaches are represented separately, and a common evaluation is carried out for the eastern Mediterranean population.

The green turtle, which has a global distribution in tropical and subtropical waters, has genetically differentiated groups in the Mediterranean due to strong natal homing (Bowen & Karl, 2007). According to the International Union for Conservation of Nature (IUCN) (Seminoff, 2004), the population of green turtles in the Mediterranean is Endangered (EN). It is also one of the 17 most important management units (MUs) (Wallace et al., 2010) because of the strength of the threats in the area and the risk of extinction. Based on a study of mitochondrial short tandem repeats (mtSTR), Tikochinski et al. (2018) suggest that the Mediterranean green turtle population consists of at least 4 MUs. These MUs are Akamas, Alagadi, Israel, and Turkey. A recent study, Karaman et al. (2022) extended the above-mentioned study and proposed a minimum of 3 MUs for the Mediterranean population. The MUs are MED1 (Akamas and Akdeniz), MED2 (Alagadi), and MED3 (North and South Karpaz, Israel, Samandağ, Akyatan, Sugözü, Kazanlı, Alata, and Davultepe). The nesting beaches of Alata, Kazanlı, Akyatan, Sugözü, and Samandağ, which are the main focus of this study, are located in MED3, with these beaches accounting for about 78 % of all nests in the Mediterranean (Casale et al., 2018). Therefore, this study will fill the following knowledge gaps by determining in MED3 MU: a) carapace size ranges of nesting green turtles and morphological similarities and differences between nesting beaches, b) obtaining the best conversion equations between carapace dimensions and c) identification of the presence of polymorphy.

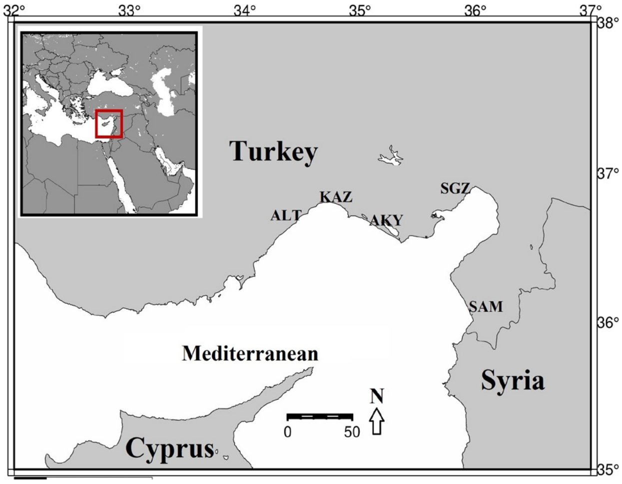

Figure 1. Map depicting the nesting beaches of *Chelonia mydas* in the eastern Mediterranean where carapace sizes were measured (ALT: Alata, KAZ: Kazanlı, AKY: Akyatan, SGZ: Sugözü, SAM: Samandağ)

METHODS

The study area includes Alata, Kazanlı, Akyatan, Sugözü, and Samandağ beaches (Fig. 1), which are major nesting beaches for *C. mydas* in the MED3 MU (Karaman et al., 2022). The average number of nests for the recent five years on these beaches ranges between 125 and 365 (Casale et al., 2018). Night patrols collected samples from each nesting beach during the conservation studies 2020 and 2021 nesting seasons. Samples were collected from the last week of June to the second week of July, and each beach was visited a total of six times during the two years. Five people patrolled the beach at night to observe female nesting turtles. Turtles were tagged and measured after they laid their eggs. The metal tags were placed on the trailing edge of the left fore flipper, as recommended by Balazs (1999). In each turtle, curved carapace length (CCL) and width (CCW) and straight carapace length (SCL) and width (SCW) were measured according to Bolten (1999) and Sönmez (2019). Three carapace measurements were carried out by an observer at each nesting event for each female, and a mean was calculated. A flexible tape measure and a mechanical caliper (Haglöf Mantax Blue, accurate to the nearest mm) were used to obtain the CCL and SCL, respectively.

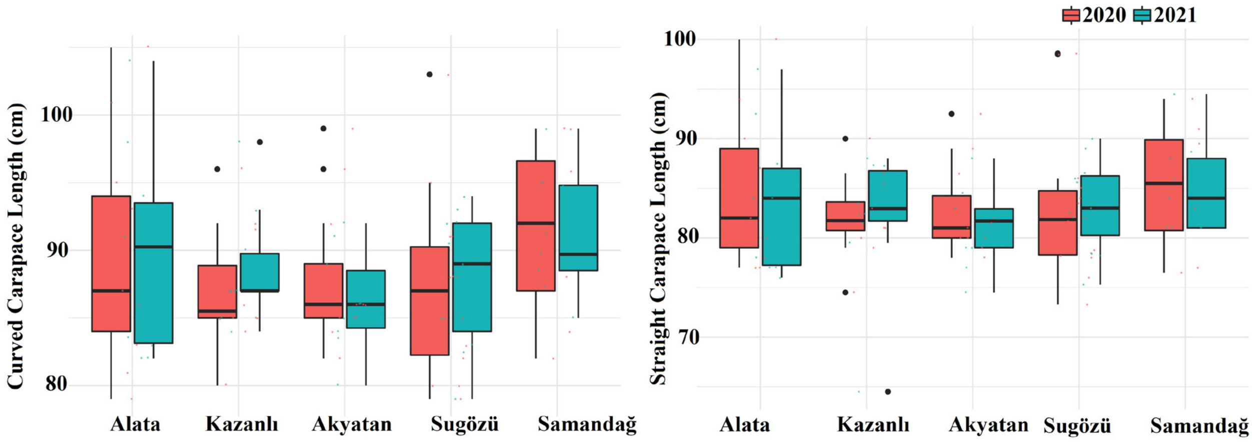

Figure 2. Boxplot of CCL and SCL by year and nesting beach, with standard deviation, median and data points. Whiskers showing highest and lowest observations. Black dots show statistical outlier value.

Data analyses

The study's methodology and models are designed around three primary topics: (i) modelling the relationships between morphological traits and nesting beaches, (ii) identifying the linear relationship between body measurements, and (iii) multivariate estimation of morphological fit using a morphological trait data set. Before evaluating the data set, exploratory data analysis was performed using descriptive statistics to examine its structure. A boxplot was then drawn to visually evaluate how CCL and SCL changed over the years and in relation to nesting beaches. The independent t-test was carried out to examine how the four body measurements changed by year (for 2020 and 2021) on each nesting beach, and along the entire beach.

Then, The Permutational Multivariate Difference-based ANOVA (PERMANOVA), the main test (and pairwise comparisons) were used to determine whether morphological traits differed substantially between nesting beaches (Anderson & Walsh, 2013). The pairwise PERMANOVA was utilised to compare beaches that showed significant differences in PERMANOVA (p-value 0.05).

In the study, we utilised linear regression analysis to estimate the relationship between body sizes, which was specified in the equation:

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i$$

where, Y is vector of dependent variable, *X* is vector of independent variable, β_0, β_1 are model parameters, and ε_i is error term.

The analysis was based on a model that transformed the dependent variable's variation into a linear function of the independent variable. The β_1 term is the regression coefficient, which describes the empirical relationship between dependent and independent variable, whereas ε denotes the random error of, which encompasses environmental variation (Khadivi-Khub, 2014).

The non-hierarchical K-means clustering algorithm was employed in this study to determine whether or not subjects have a polymorphic structure in terms of dimensions and to group them into appropriate clusters (Wagstaff, 2012). The silhouette coefficient was calculated to determine the efficacy of the K-Means algorithm's cluster separation (Kodinariya & Makwana, 2013). The aim here is to reduce the variation within the group, if there is a variation on the basis of size, and to decompose it so that each group has homogeneous variance within itself.

The statistical analyses were performed with R version 4.1.0 (R Core Team 2021) using the R packages of ade4 (Dray & Dufour, 2007), pairwiseAdonis (Arbizu, 2019), vegan (Oksanen et al., 2020), AppliedPredictiveModeling (Khun & Johnson, 2018), and summarytools (Comtois, 2021).

RESULTS

A total of 106 green turtles were measured in four body dimensions. The resulting descriptive statistics in terms of each nesting beach are shown in Table 1. The mean CCL and CCW were 88.5 ± 5.8 cm (79–105) and 79.1 ± 5.5 cm (70–102), respectively. The mean SCL and SCW were 83.5 ± 5.5 cm (73.3–100) and 64.6 ± 4 cm (57.6–77.2), respectively. The boxplot that was drawn to visually evaluate CCL and SCL changed over the years in terms of nesting beaches is shown in Figure 2.

The independent samples t-test showed that there was no statistical difference between years in terms of the four body dimensions on each nesting beach, and in total ($p > 0.05$). Multivariate statistics (PERMANOVA) identified no significant differences in variables between nesting beaches ($p > 0.05$). Also, it confirmed that the four body dimensions showed no variation between the years according to the nesting beaches ($p > 0.05$). The PERMANOVA pairwise test showed no significant differences for all body sizes in the pairwise comparison of nesting beaches ($p > 0.05$).

Through linear regression the CCL and SCL dimensions showed significant relationships ($R^2 = 0.938$, df = 102, $p = 0.0002$). The conversion equation between them:

$$CCL = 1.03 + 1.04 * SCL \quad \text{(Fig. 3a).}$$

Table 1. The descriptive statistic of morphological data on each nesting beach (CCL: Curved carapace length, CCW: Curved carapace width, SCL: Straight carapace length, SCW: Straight carapace width)

		CCL		CCW		SCL		SCW	
Nesting beach	**n**	**Mean (Sd)**	**Min-Max**	**Mean (Sd)**	**Min-Max**	**Mean (Sd)**	**Min-Max**	**Mean (Sd)**	**Min-Max**
Alata	22	87.8 (4.2)	80–98	78.5 (3.6)	73–87	83.1 (3.5)	74.5–90	64.4 (2.8)	59.5–70
Kazanlı	21	87.1 (4.5)	80–99	77.2 (4.5)	72–90	81.9 (4.2)	74.5–92.5	63.1 (3.9)	58–72
Akyatan	21	89.8 (7.7)	79–105	80.8 (8.1)	70.5–102	84.4 (7.1)	76–100	65.2 (4.5)	58.7–73.5
Sugözü	17	91.2 (5.4)	82–99	80.6 (5.1)	73–89	85.1 (5.4)	76.5–94.5	64.5 (3.4)	60–71
Samandağ	25	87.3 (5.8)	79–103	78.3 (4.7)	70–92	83.1 (6.2)	73.3–98.6	65.3 (4.7)	57.6–77.2
Total	**106**	**88.5 (5.8)**	**79–105**	**79.1 (5.5)**	**70–102**	**83.5 (5.5)**	**73.3–100**	**64.6 (4)**	**57.6–77.2**

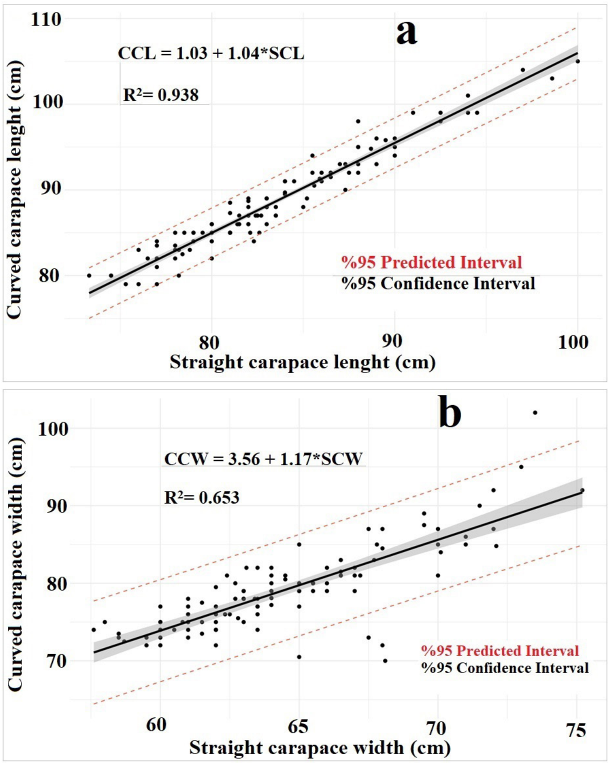

Figure 3. The significant relationships between CCL and SCL, CCW and SCW. The red dots represent the 95 % predicted interval and the grey dots represent the 95 % confidence interval. Conversion equation with the coefficient of determination in each relation is shown on the left of Figure.

According to these conversion equations, there is a 1.04 cm increase in CCL for every 1 cm increase in SCL. The CCW and SCW dimensions showed significant relationships (R^2 = 0.653, df = 102, p = 0.0002). The conversion equation between them:

CCW = 3.56 + 1.17 * SCW (Fig. 3b).

According to these conversion equations, there is a 1.17 cm increase in CCW for every 1 cm increase in SCW.

Two clusters were found based on four body dimensions for all nesting beaches (Fig. 4). The within-cluster sum of squares by the cluster was 60.8 %. The first cluster (69.1 %) included individuals with smaller (< 85.2 cm) body dimensions, and the second cluster (33.1 %) had larger (> 95.2 cm) body dimensions (see Table 2 for details).

DISCUSSION

Our results showed that the mean CCL and SCL on the nesting beaches of the eastern Mediterranean were 88.5 cm and 83.5 cm, respectively. The minimum CCL was 79 cm and the SCL was 73.3 cm, both of which were recorded for turtles nesting on Samandağ beach. The PERMANOVA tests showed no clear difference between nesting beaches, and they overlapped each other. The nesting beaches in the present study are included in the same MU (MED3) with the Israel, north and south Karpaz, and Davultepe beaches. There is limited study on the morphological data for the other MUs. Only one study has reported the green turtle CCL size of 91.5 cm for Alagadi (MED2) (Broderick et al., 2003). The CCL data for nesting beaches within the same MU (MED3) presented in this study is shown in Supplementary Table S1.

The smallest nesting turtle was recorded on the Samandağ beach as 72 cm in previous years (Sönmez, 2019). In the present study, the lowest CCL recorded on the Samandağ beach is also the lowest CCL recorded in the same MU and around the world (see Supplementary Table S1 for details). Why is the Samandağ population smaller than other populations in the same MU? This may be due to the fact that the CCL size of the Samandağ population tends to decrease over the years (Sönmez, 2019). Also, the size of the Samandağ population may be affected by the recruitment of new females. The CCL size of the green turtle nesting in Cyprus decreases over time due to the recruitment of neophytes (Stokes et al., 2014). Another reason may be the high mortality rate of nesting turtles as a result of anthropogenic or natural effects. Sönmez (2018) reported that the CCL size of the stranded green turtle on the Samandağ beach increased after 2012. It is recommended to investigate the long-term morphological tendency or differences of other nesting beaches within MED3 MU.

The size data reported in several reports from various nesting beaches in different regions or oceans recorded larger mean CCL and SCL values than that of the

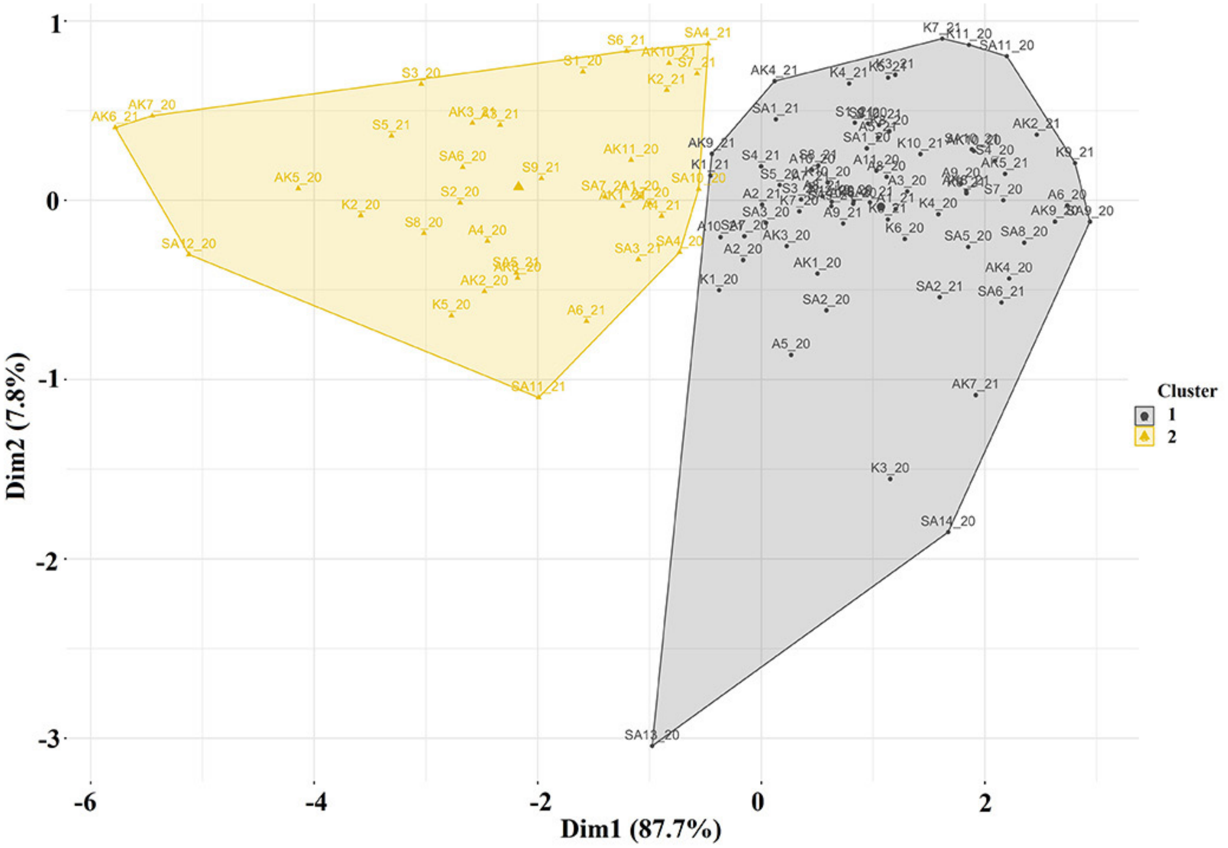

Figure 4. Two clusters based on morphological data for five nesting beaches. The grey cluster indicates first (smaller, <85.2 cm) and the yellow cluster indicates second (larger, > 95.2 cm). Figure includes nest numbers and nesting beach short names of each specimen. Paying attention to the nesting beach of each sample, it can be seen that each nesting beach is represented in both clusters.

Table 2. Descriptive statistics of each morphological dimension represented under two clusters as a result of non-hierarchical K-means clustering algorithm (CCL: Curved carapace length, CCW: Curved carapace width, SCL: Straight carapace length, SCW: Straight carapace width)

	Cluster 1			Cluster 2		
	n	**mean (±sd)**	**min-max**	**n**	**mean (±sd)**	**min-max**
CCL	71	85.2 (±3.01)	79–92	35	95.2 (±3.94)	90–105
CCW	71	76.0 (±2.69)	81–76	35	85.0 (±4.74)	79–102
SCL	71	80.3 (±2.85)	73.3–86.5	35	89.6 (±4.13)	84–100
SCW	71	62.7 (±2.92)	57.6–77.2	35	68.3 (±3.16)	62.4–75.2

Mediterranean nesting population (see Supplementary Table S1 for details). Previously, it was stated that the Mediterranean population of green turtles was smaller than the Atlantic and Pacific populations (Erhart, 1982). Mediterranean green turtles probably colonised from North Atlantic green turtles at the Younger Dryas Event, a global cooling event 10,000 years ago (Encalada et al., 1996). The observed size differences may be due to a number of factors in addition to genetic differentiation, as follows:

(i) Food abundance; the Atlantic system has a richer nutrient level than the Mediterranean system (Tiwari & Bjorndal, 2000). Even within the same population, females experiencing higher food availability are larger (Marn et al., 2017). It has been stated that Atlantic loggerhead turtles have better feeding conditions and are larger than Mediterranean loggerhead turtles (Marn et al., 2019). Therefore, it may be considered that low food availability may have a size-reducing effect on the Mediterranean green turtle.

(ii) growth rate and maturation; marine turtle growth rate is connected with size (i.e. SCL or CCL), and green turtles may have different growth rates in different regions (i.e. the Atlantic and Pacific Oceans) (Bjorndal et al., 2000; Omeyer et al., 2018). The rate of growth among green turtle populations with the same mtDNA haplotype may vary depending on environmental conditions (Chaloupka et al., 2004). Marn et al. (2019) noted that Mediterranean loggerhead turtles grow and mature faster than their Atlantic counterparts due to faster assimilation, but reach a smaller ultimate size due to lower food availability and higher somatic maintenance. Also, it was stated that Mediterranean loggerheads are sexually mature at a smaller size due to the lower cumulative investment to maturation (Marn et al., 2019). Depending on environmental conditions such as food availability and nutrient uptake rates, green turtles may have a smaller ultimate size due to faster maturity and growth.

The conversion equations for green turtles in the eastern Mediterranean were first reported by this study. Although there is a conversion equation between CCL and SCL for the loggerhead turtle in the Mediterranean (Casale et al., 2017), its absence has been noted as a deficiency for the green turtle in the Mediterranean (Casale et al., 2018). There are not many conversion equations for green turtles globally. (Supplementary Table S2). Moreover, the existing conversion equations are specific to a type of feeding ground or are made of stranded individuals, that is, to research such as the relationship between age and size or sexual dimorphism. Moreover, some of them also cover different life stages (Supplementary Table S2). In contrast, our analysis is based on nesting female data. The coefficient of determination (R^2) in our study is similar to that of other studies, only higher than the value found by the authors in Ascension Island (Supplementary Table S2). Because growth rate decreases as carapace size increases (Bjorndal & Bolten, 1988; Patricio et al., 2014; Colman et al., 2015; Omeyer et al., 2018), conversion equations incorporating different life stages may potentially increase data scatter and model uncertainty. In addition, we should not forget the morphological scale between life stages. There are no morphological scaling studies on green turtles. However, it was stated that although morphometric scaling in loggerhead turtles differs between life stages, a common model can be used for all life stages (Marn et al., 2015). Considering a conversion equation that will cover the entire Mediterranean and all life stages, the effect of different growth rates in different regions (Bjorndal et al., 2000; Omeyer et al., 2018) and different life stages (Bjorndal & Bolten, 1988; Patrício et al., 2014; Colman et al., 2015) should not be ignored. Therefore, we suggest that our conversion equations can be applied to just all green turtles belonging to this MED3 population and nesting in the eastern Mediterranean.

MED3 management unit, including the five beaches analysed in this study, is important for genetic variability because it contains a set of partially connected populations (especially the Samandağ and Alata hubs of connectivity) (Karaman et al., 2022). Samandağ nesting beach connects Alata, north Karpaz, and Israel to the nesting beaches of Akyatan, Kazanlı, Sugözü, and Davultepe (Karaman et al., 2022). The fact that these five beaches have connection hubs for genetic diversity as well as display morphological compatibility, reveals the need for special conservation and management plans.In this context, future body sizes may decrease due to the effects of temperature on the developmental and physiological processes of marine turtles as a result of global climate change (Ohlberger, 2013; Marshall et al., 2020). Currently, some populations exhibit decreases in body size (Sönmez, 2019; Le Gouvello et al., 2020; Mortimer et al., 2022). Considering the relationship between reproductive output and morphology, which is that larger females have greater reproductive output (Broderick et al., 2003), changes in annual nesting activities with the body size may help contribute to better estimates of the population size structure and abundance (i.e. hatchling recruitment) (Wu et al., 2022). Therefore, it is recommended that macro-ecological models (Wu et al., 2022) of size dependent reproductive output should be "reveal" for the MED3 population, which will play a role in revealing the future conservation and management plan.

Although the five nesting beaches are not separated in terms of morphological characteristics and are clustered together, they are divided into two clusters that correspond to the sizes of turtles (smaller and larger). Therefore, if a morphological study is designed in the future, sampling from any beach might be sufficient. However, because of the dichotomy, it could be necessary to sample both size groups, because there are individuals representing each nesting beach in each cluster (see Fig. 4). So, why are they separated into two different clusters even though they are in the same MU and overlap in clusters?

First, this MED3 MU population may have size-dependent habitat use, i.e. a polymorphic foraging strategy. Polymorphic foraging strategies in green turtles have been studied using different methods such as satellite transmitters (Richardson et al., 2013), stable isotope analysis (Hatase et al., 2006), and stomach content (Jiménez et al., 2017). Also, size-dependent post-nesting habitat use for the green turtle has been reported in the Galapagos using satellite tracking data (Seminoff et al., 2008), and it has been suggested that smaller turtles may prefer neritic waters. Similar polymorphic foraging strategies have been reported for loggerhead turtles in Japan (Hatase et al., 2002). Larger females (> 95.2 cm) may benefit from offshore ocean habitats, and smaller females (< 85.2 cm) may benefit from neritic habitats in this MED3 MU population. In MED3 MU the unpublished data indicates that two foraging strategies depend on size, smaller and larger size females prefer neritic and pelagic feeding strategies, respectively (Yalçın Özdilek, unpublished data).

Second, the migration routes of the two clusters may differ. Shorter migrations may result in smaller sizes in turtles due to a similar maturity age and lower growth rate (Casale et al., 2011). Cluster 1, with a smaller body, may use different foraging habitats as a neritic area, with shorter migration routes.

Lastly, the growth rates of the two clusters may differ. The growth rate among populations of green turtles with the same mtDNA haplotype may vary depending on environmental conditions such as food availability and nutrient uptake rates in the foraging ground (Chaloupka et al., 2004). In juvenile loggerhead turtles, the neritic feeding strategy would have a greater growth advantage, while the oceanic feeding strategy provides slower growth but a safer life cycle (Peckham et al., 2011). It is known that nutrient richness in different habitats affects the growth of marine turtles (Bjorndal, 1985) and when food availability increases, turtles grow larger (Stubbs et al., 2020). Food stock dynamics subject to local environmental stochasticity can lead to differences in the CCL size of green turtles (Chaloupka et al., 2004).

In a mechanistic model based on Dynamic Energy Budget (DEB), it was found that the allocation of energy to the growth of green turtles occurs more slowly at lower temperatures (Stubbs et al., 2020). It was also stated in this modelling that CCL length was mostly affected by the presence of food, whereas the effect of temperature would not be discernible (Stubbs et al., 2020). Similarly, the growth rate of loggerhead turtles was primarily affected by temperature and also positively correlated with available food (Marn et al., 2017).

In conclusion, the adult females nesting on the five major nesting beaches of the eastern Mediterranean have a mean CCL of 88.5 cm and a mean SCL of 83.5 cm. The minimum recorded CCL and SCL are 79 cm and 73 cm, respectively. Nesting populations were not morphologically separated and clustered. Also, the conversion equations that can be used between CCL and SCL were first obtained in the Mediterranean. These are the first published conversion equations for carapace size for eastern Mediterranean green turtles. Adult females from the five nesting beaches were divided into two clusters, larger and smaller. Presumably, although these two clusters are the same MU (Karaman et al., 2022), they may use different foraging grounds. The fact that these five beaches are hubs of genetic diversity connections (Karaman et al., 2022) and that they are morphologically similar shows how important it is to find special ways to protect and manage them.

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REFERENCES

Álvarez-Varas, R., Heidemeyer, M., Riginos, C., Benítez, H.A., Reséndiz, E., Lara-Uc, M., ... & Véliz, D. (2021). Integrating morphological and genetic data at different spatial scales in a cosmopolitan marine turtle species: challenges for management and conservation. *Zoological Journal of the Linnean Society*, 191(2), 434–453. https://doi.org/10.1093/zoolinnean/zlaa066.

Álvarez-Varas, R., Véliz, D., Vélez-Rubio, G.M., Fallabrino, A., Zárate, P., Heidemeyer, M., ... & Benítez, H.A. (2019). Identifying genetic lineages through shape: An example in a cosmopolitan marine turtle species using geometric morphometrics. *PLoS ONE*, 14(10), e0223587. https://doi.org/10.1371/journal.pone.0223587.

Anderson, M.J. & Walsh, D.C.I. (2013). PERMANOVA, ANOSIM, and the Mantel test in the face of heterogeneous dispersions: What null hypothesis are you testing? *Ecological Monographs*, 83(4), 557–574. https://doi.org/10.1890/12-2010.1.

Arbizu, P.M. (2019). pairwiseAdonis: Pairwise multilevel comparison using adonis R package version 0.3. https://github.com/pmartinezarbizu/pairwiseAdonis.

Balazs, G.H. (1999). Factors to consider in the tagging of sea turtles. In *Research and management techniques for the conservation of sea turtles*. Eckert, K.L., Bjorndal, K.A., Abreu-Grobois, F.A. & Donnelly, M. (Eds.). IUCN/SSC Marine Turtle Specialist Group, Publication no. 4, Washington DC, USA. 101–109 pp.

Bjorndal, K.A. & Bolten, A.B. (1988). Growth rates of immature green turtles, *Chelonia mydas*, on feeding grounds in the southern Bahamas. *Copeia*, 1988, 555–564.

Bjorndal, K.A. (1985). Nutritional ecology of sea turtles. *Copeia*, 1985, 736–751.

Bjorndal, K.A., Bolten, A.B. & Martins, H.R. (2000). Somatic growth model of juvenile loggerhead sea turtles *Caretta caretta*: duration of pelagic stage. *Marine Ecology Progress Series*, 202, 265–272. https://doi.org/10.3354/meps202265.

Bolten, A.B. (1999) Techniques for measuring sea turtles. In *Research and management techniques for the conservation of sea turtles*. Eckert, K.L., Bjorndal, K.A., Abreu-Grobois, F.A. & Donnelly, M. (Eds.). IUCN/SSC Marine Turtle Specialist Group, Publication no. 4, Washington DC, USA. 110–114 pp.

Bowen, B.W. & Karl, S.A. (2007). Population genetics and phylogeography of sea turtles. *Molecular Ecology*, 16(23), 4886–4907. https://doi.org/10.1111/j.1365-294X.2007.03542.x.

Broderick, A.C., Glen, F., Godley, B.J. & Hays, G.C. (2003). Variation in reproductive output of marine turtles. *Journal of Experimental Marine Biology and Ecology*, 288(1), 95–109. https://doi.org/10.1016/S0022-0981(03)00003-0.

Casale, P., Broderick, A.C., Camiñas, J.A., Cardona, L., Carreras, C., Demetropoulos, A., ... & Türkozan, O. (2018). Mediterranean sea turtles: current knowledge and priorities for conservation and research. *Endangered Species Research*, 36, 229–267. https://doi.org/10.3354/esr00901.

Casale, P., Freggi, D., Rigoli, A., Ciccocioppo, A. & Luschi, P. (2017). Geometric morphometrics, scute patterns and biometrics of loggerhead turtles (*Caretta caretta*) in the central Mediterranean. *Amphibia-Reptilia*, 38(2), 145–156.

Casale, P., Mazaris, A.D. & Freggi, D. (2011). Estimation of age at maturity of loggerhead sea turtles *Caretta caretta* in the Mediterranean using length-frequency data. *Endangered Species Research*, 13(2), 123–129. https://doi.org/10.3354/esr00319.

Chaloupka, M., Limpus, C. & Miller, J. (2004). Green turtle somatic growth dynamics in a spatially disjunct Great Barrier Reef metapopulation. *Coral Reefs*, 23(3), 325–335. https://doi.org/10.1007/s00338-004-0387-9.

Colman, L.P., Patrício, A.R.C., McGowan, A., Santos, A.J., Marcovaldi, M.Â., Bellini, C. & Godley, B.J. (2015). Long-term growth and survival dynamics of green turtles (*Chelonia mydas*) at an isolated tropical archipelago in Brazil. *Marine Biology*, 162(1), 111–122.

Comtois, D. (2021) summarytools: Tools to Quickly and Neatly Summarize Data. R package version 1.0.0.

Dray, S. & Dufour, A.B. (2007). The ade4 package: implementing the duality diagram for ecologists. *Journal of Statistical Software*, 22, 1–20.

Encalada, S.E., Lahanas, P.N., Bjorndal, K.A., Bolten, A.B., Miyamoto, M.M. & Bowen, B.W. (1996). Phylogeography and population structure of the Atlantic and Mediterranean green turtle *Chelonia mydas*: a mitochondrial DNA control region sequence assessment. *Molecular Ecology*, 5(4), 473–483. https://doi.org/10.1111/j.1365-294X.1996.tb00340.x.

Erhart, L.M. (1982) A review of sea turtle reproduction. In *Biology and conservation of sea turtles*. Bjorndal, K.A. (Ed.). Washington DC, USA. 29–38 pp.

Figueroa, A. & Alvarado, J. (1990). Morphometric comparison of the Chelonia populations of Michoacan, Mexico and Tortuguero, Costa Rica. In *Proceedings of the seventeenth annual workshop on sea turtle biology and conservation.* Epperly, S.P. & Braun, J. (Eds.). NOAA Technical Memorandum NMFS^ SEFSC, Vol. 415. 294 pp.

Glen, F., Broderick, A.C., Godley, B.J. & Hays, G.C. (2003). Incubation environment affects phenotype of naturally incubated green turtle hatchlings. *Journal of the Marine Biological Association of the United Kingdom*, 83(5), 1183–1186. https://doi.org/10.1017/S0025315403008464h.

Godley, B.J., Broderick, A.C., Frauenstein, R., Glen, F. & Hays, G.C. (2002). Reproductive seasonality and sexual dimorphism in green turtles. *Marine Ecology Progress Series*, 226, 125–133. https://doi.org/10.3354/meps226125.

Hatase, H., Sato, K., Yamaguchi, M., Takahashi, K. & Tsukamoto, K. (2006). Individual variation in feeding habitat use by adult female green sea turtles (*Chelonia mydas*): Are they obligately neritic herbivores? *Oecologia*, 149, 52–64.

Hatase, H., Takai, N. & Kinne, O. (2002). Size-related differences in feeding habitat use of adult female loggerhead turtles *Caretta caretta* around Japan determined by stable isotope analyses and satellite telemetry. *Marine Ecology Progress Series*, 233, 20–21.

Ischer, T., Ireland, K. & Booth, D.T. (2009). Locomotion performance of green turtle hatchlings from the Heron Island Rookery, Great Barrier Reef. *Marine Biology*, 156(7), 1399–1409. https://doi.org/10.1007/s00227-009-1180-7.

Jiménez, A., Pingo, S., Alfaro-Shigueto, J., Mangel, J.C. & Hooker, Y. (2017). Feeding ecology of the green turtle *Chelonia mydas* in northern Peru. *Latin American Journal of Aquatic Research*, 45, 585–596.

Kamezaki, N. & Matsui, M. (1995). Geographic variation in skull morphology of the green turtle, *Chelonia mydas*, with a taxonomic discussion. *Journal of Herpetology*, 51–60. https://doi.org/10.2307/1565085.

Karaman, S., Turkozan, O., Carreras, C., Yılmaz, C., Sönmez, B., Candan, O., ... & Ulger, C. (2022). Population genetic diversity of green turtles, *Chelonia mydas*, in the Mediterranean revisited. *Marine Biology*, 169(6), 1–10. https://doi.org/10.1007/s00227-022-04068-1.

Khadivi-Khub, A. (2014). Regression association analysis of fruit traits with molecular markers in cherries. *Plant Systematics and Evolution*, 300(5), 1163–1173.

Kuhn, M. & Johnson, K. (2018) AppliedPredictiveModeling: Functions and data sets for 'Applied Predictive Modeling'. R package version 1.1-7.

Kodinariya, T.M. & Makwana, P.R. (2013). Review on determining of cluster in K-means. *International Journal of Advance Research in Computer Science and Management Studies*, 1(6), 90–95. https://www.researchgate.net/publication/313554124.

Le Gouvello, D.Z., Girondot, M., Bachoo, S. & Nel, R. (2020). The good and bad news of long-term monitoring: An increase in abundance but decreased body size suggests reduced potential fitness in nesting sea turtles. *Marine Biology*, 167(8), 1–12. https://doi.org/10.1007/s00227-020-03736-4.

Marn, N., Klanjscek, T., Stokes, L. & Jusup, M. (2015). Size scaling in Western North Atlantic Loggerhead turtles permits extrapolation between regions, but not life stages. *PLoS ONE*, 10(12), e0143747. https://doi.org/10.1371/journal.pone.0143747.

Marn, N., Jusup, M., Catteau, S., Kooijman, S.A.L.M. & Klanjšček, T. (2019). Comparative physiological energetics of Mediterranean and North Atlantic loggerhead turtles. *Journal of Sea Research*, 143, 100–118.

Marn, N., Jusup, M., Legović, T., Kooijman, S.A.L.M. & Klanjšček, T. (2017). Environmental effects on growth, reproduction, and life-history traits of loggerhead turtles. *Ecological Modelling*, 360, 163–178.

Marshall, D.J., Pettersen, A.K., Bode, M. & White, C.R. (2020). Developmental cost theory predicts thermal environment and vulnerability to global warming. *Nature Ecology & Evolution*, 4(3), 406–411. https://doi.org/10.1038/s41559-020-1114-9.

Mortimer, J.A., Appoo, J., Bautil, B., Betts, M., Burt, A.J., Chapman, R., ... & Hays, G.C. (2022). Long-term changes in adult size of green turtles at Aldabra Atoll and implications for clutch size, sexual dimorphism and growth rates. *Marine Biology*, 169(10), 1–10.

Ohlberger, J. (2013). Climate warming and ectotherm body size - from individual physiology to community ecology. *Functional Ecology*, 27(4), 991–1001. https://doi.org/10.1111/1365-2435.12098.

Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P.R., O'Hara, R.B., Simpson, G.L., ... & Wagner, H. (2020). vegan: Community Ecology Package. R package version 2.5-7.

Omeyer, L.C., Fuller, W.J., Godley, B.J., Snape, R.T. & Broderick, A.C. (2018). Determinate or indeterminate growth? Revisiting the growth strategy of sea turtles. *Marine Ecology Progress Series*, 596, 199–211. https://doi.org/10.3354/meps12570.

Patricio, R., Diez, C.E. & van Dam, R.P. (2014). Spatial and temporal variability of immature green turtle abundance and somatic growth in Puerto Rico. *Endanger Species Research,* 23, 51–62. https://doi.org/10.3354/esr00554.

Peckham, S.H., Maldonado-Diaz, D., Tremblay, Y., Ochoa, R., … & Nichols, W.J. (2011). Demographic implications of alternative foraging strategies in juvenile loggerhead turtles *Caretta caretta* of the North Pacific Ocean. *Marine Ecology Progress Series*, 425, 269−280.

Richardson, P.B., Broderick, A.C., Coyne, M.S., Ekanayake, L., Kapurusinghe, T., … & Godley, B.J. (2013). Satellite telemetry reveals behavioural plasticity in a green turtle population nesting in Sri Lanka. *Marine Biology*, 160, 1415–1426.

Salmon, M., Wyneken, J., Hamann, M. & Whiting, S. (2016).

Early growth and development of morphological defenses in post-hatchling flatbacks (*Natator depressus*) and green turtles (*Chelonia mydas*). *Marine and Freshwater Behaviour and Physiology*, 49(6), 421–435.

Seminoff, J.A. (2004). *Chelonia mydas*. The IUCN Red List of Threatened Species 2004, e.T4615A11037468.

Seminoff, J.A., Zárate, P., Coyne, M., Foley, D.G., Parker, D., Lyon, B.N. & Dutton, P.H. (2008). Post-nesting migrations of Galápagos green turtles *Chelonia mydas* in relation to oceanographic conditions: integrating satellite telemetry with remotely sensed ocean data. *Endangered Species Research*, 4(1–2), 57–72.

Sönmez, B. (2019). Morphological variations in the green turtle (*Chelonia mydas*): A field study on an eastern Mediterranean nesting population. *Zoological Studies*, 58, 16. https://doi.org/10.6620/ZS.2019.58-16.

Sönmez, B. (2018). Sixteen year (2002–2017) record of sea turtle strandings on Samandağ Beach, the eastern Mediterranean coast of Turkey. *Zoological Studies*, 57, 53. https://doi.org/10.6620/ZS.2018.57-53.

Sönmez, B., Turan, C. & Özdilek, Ş.Y. (2011). The effect of relocation on the morphology of Green Turtle, *Chelonia mydas* (Linnaeus, 1758), hatchlings on Samandağ beach, Turkey: (Reptilia: Cheloniidae). *Zoology in the Middle East*, 52(1), 29–38. https://doi.org/10.1080/09397140.2011.10638476.

Sönmez, B., Turan, C., Yalçın Özdilek, Ş. & Turan, F. (2016). A research on morphological differences for sex description of green sea turtle hatchlings. *J Black Sea/Mediterranean Environment*, 22(1), 93–102.

Stokes, K.L., Fuller, W.J., Glen, F., Godley, B.J., Hodgson, D.J., Rhodes, K.A., Snape, R.T.E. & Broderick, A.C. (2014). Detecting green shoots of recovery: the importance of long-term individual-based monitoring of marine turtles. *Animal Conservation*, 17, 593–602.

Stubbs, J.L., Marn, N., Vanderklift, M.A., Fossette, S. & Mitchell, N.J. (2020). Simulated growth and reproduction of green turtles (*Chelonia mydas*) under climate change and marine heatwave scenarios. *Ecological Modelling*, 431, 109185.

Tikochinski, Y., Bradshaw, P., Mastrogiacomo, A., Broderick, A., Daya, A., Demetropoulos, A., ... & Carreras, C. (2018). Mitochondrial DNA short tandem repeats unveil hidden population structuring and migration routes of an endangered marine turtle. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 28(4), 788–797. https://doi.org/10.1002/aqc.2908.

Tiwari, M. & Bjorndal, K.A. (2000). Variation in morphology and reproduction in loggerheads, *Caretta caretta*, nesting in the United States, Brazil, and Greece. *Herpetologica*, 56(3), 343–356.

Türkozan, O., Özdilek, Ş.Y., Ergene, S., Uçar, A.H., Sönmez, B., Yılmaz, C., ... & Aymak, C. (2013). Strandings of loggerhead (*Caretta caretta*) and green (*Chelonia mydas*) sea turtles along the eastern Mediterranean coast of Turkey. *The Herpetological Journal*, 23(1), 11–15.

van Dam, R.P. & Diez, C.E. (1998). Caribbean hawksbill turtle morphometrics. *Bulletin of Marine Science*, 62(1), 145–155.

Wagstaff, K.L. (2012). Data Clustering. Advances in Machine Learning and Data Mining for Astronomy, 31(3), 543–561. https://doi.org/10.1201/b11822-19.

Wallace, B.P., DiMatteo, A.D., Hurley, B.J., Finkbeiner, E.M., Bolten, A.B., Chaloupka, M.Y., ... & Mast, R.B. (2010). Regional management units for marine turtles: a novel framework for prioritizing conservation and research across multiple scales. *Plos ONE*, 5(12), e15465. https://doi.org/10.1371/journal.pone.0015465.

Wu, N.C., Rusli, M.U., Broderick, A.C. & Barneche, D.R. (2022). Size scaling of sea turtle reproduction may reconcile fundamental ecology and conservation strategies at the global scale. *Global Ecology and Biogeography*, 31, 1277–1289. https://doi.org/10.1111/geb.13502.

Wyneken, J., Balazs, G.H., Murakawa, S. & Anderson, Y. (1999). Size differences in hind limbs and carapaces of hatchling green turtles (*Chelonia mydas*) from Hawaii and Florida, USA. *Chelonian Conservation and Biology*, 3(3), 491–495.

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