Nest temperatures and sex-ratio estimates of loggerhead turtles at Patara beach on the southwestern coast of Turkey

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Abstract: During the nesting period in 2000 and 2001 on Patara beach, total emergence and non-nesting emergence of loggerhead turtles (Caretta caretta), nest distribution, and nest distance from the sea were recorded. The main nesting seasons for sea turtles (family Cheloniidae) were during June and July. Loggerhead turtles comprised the majority of sea turtle emergence records; only two green turtle (Chelonia mydas) emergences were recorded. The small nesting population (52 and 53 nests in 2000 and 2001, respectively) of sea turtles on Patara beach was due to low hatching success resulting from a rise in seawater levels, owing to beach erosion, and the subsequent inundation of most nests. The temperatures of four nests and sand at different distances from the sea were measured with electronic temperature loggers, which recorded mean nest temperatures of 28.8–30.7 °C, with the mean temperature in the middle third of the incubation period from 28.5 to 31.0 °C. The mean temperatures, incubation periods, temperature during the middle third of the incubation period, and percentage of hatching sexes were evaluated with respect to sand and nest temperatures. The results showed a female-dominated sex ratio, which was probably the result of predation of nests far from the sea and the seawater inundation of nests close to the sea, as the sand temperature was different at sites close and far from the sea.

Résumé : Durant la période de nidification en 2000 et en 2001 sur la plage de Patara, nous avons déterminé les émergences totales des caouanes (Caretta caretta), les émergences des tortues loin des nids, la répartition des nids sur la plage, ainsi que les distances des nids à la mer. Les périodes principales de nidification des tortues marines (Cheloniidae) ont lieu en juin et en juillet. La majorité des tortues qui ont émergé étaient des caouanes; seules deux émergences de tortues vertes (Chelonia mydas) ont été observées. La petite taille de la population nidificatrice (52 et 53 nids respectivement en 2000 et 2001) de tortues marines sur la plage de Patara semble s’expliquer par le faible succès de l’éclosion à cause de la montée du niveau de la mer provoquée par l’érosion de la plage et à cause de l’inondation subséquente de la plupart des nids. La température moyenne du sable et celle de quatre nids situés à des distances différentes de la mer, mesurées à l’aide de thermomètres électroniques enregistreurs, varient de 28,8 à 30,7 °C et la température moyenne du tiers médian de la période d’incubation, de 28,5 à 31,0 °C. Les températures moyennes, la durée des périodes d’incubation, les températures durant le tiers médian de la période d’incubation et la proportion des mâles et des femelles chez les nouveau-nés ont été évaluées en fonction des températures du sable et des nids. Les rapports mâles:femelles sont dominés par les femelles. Ces rapports sont sans doute affectés par la prédation des nids aux sites éloignés de la mer et par l’inondation des nids par l’eau de mer aux sites proches de la mer, puisque les températures du sable différent selon que les sites sont proches ou éloignés de la mer.

[Intégration de la rédaction]

Introduction

Sea turtles (family Cheloniidae) are an example of a species that is diminishing in numbers as a result of the degradation of the living and nesting habitats, incidental catches, and pollution. Two species of marine turtles, Chelonia mydas (green turtle) and Caretta caretta (loggerhead turtle), are known to nest in the Mediterranean (Groombridge 1990). The nesting sites of sea turtles are heavily used by people, resulting in their destruction, especially during the last 25–30 years. The major nesting beaches identified for loggerhead turtles were in Greece and Turkey, with smaller numbers recorded in Cyprus, Libya, Egypt, Syria, Tunisia, Israel, and Italy (Broderick et al. 2002). The distribution of nesting green turtles was more localized; the only substantial nesting areas were in Turkey and Cyprus, and a few nests were also recorded in Israel.

For sea turtles, population survival is dependent on the occurrence of a sufficient range of incubation temperatures to produce offspring of both sexes. Estimates of the sex ratio have been obtained by combining the nesting distribution...
with the sexing of samples of hatchlings from different times during the season by Mrosovsky (1994) or from pivotal incubation durations (Marcovaldi et al. 1997; Godley et al. 2001a, 2001b). Freedberg and Wade (2001) reviewed sex-ratio estimates, and only few studies were present in the Mediterranean (Kaska et al. 1998; Broderick et al. 2000; Casale et al. 2000; Godley et al. 2001a, 2001b; Houghton and Hays 2001).

Temperature-dependent sex determination has been the subject of a number of studies (i.e., Morreale et al. 1982; Mrosovsky and Pieau 1991; Mrosovsky 1994; Freedberg and Wade 2001). Fisher (1930) claimed that population sex ratios should be 1:1 at birth. In sea turtles, the sex ratio is skewed towards females (Mrosovsky and Provancha 1992; Marcovaldi et al. 1997; Hanson et al. 1998). Analysis of mitochondrial DNA suggests that loggerhead turtles nesting in different parts of the world are genetically distinct (Encalada et al. 1996; Laurent et al. 1998). However, males from one site can mate with females from a distant site as determined by male-mediated gene flow, which was found by nuclear DNA analysis of sea turtle populations among some Turkish beaches (Schroth et al. 1996). Therefore, it may be interesting to determine the sex ratio of hatching loggerhead turtles in populations nesting in other geographic areas.

There were 13 main and 4 minor nesting beaches along the southern coast of Turkey (Baran and Kasparek 1989). Intensive studies were carried out on major nesting beaches such as Dalyan, Fethiye, Patara, and Kizilot. The general outline of these beaches and some local problems were mentioned in Baran and Kasparek (1989). They reported a high proportion of false crawls and low hatching success on Patara beach. More recent studies on Patara beach have reported between 52 and 85 nests in one season (Kaska 1993; Erdoğan et al. 2001; Taşkin and Baran 2001; Öz et al. 2002).

Of the female-dominated sex ratios (81.6%) on Turkish beaches that have been reported (Kaska et al. 1998), 71% were for only one nest on Patara beach. The low hatching success, due to inundation of the nests by seawater, was also highlighted (Kaska 1993; Erdoğan et al. 2001; Taşkin and Baran 2001). In the present study, we examined seasonal changes in sand temperature, incubation period, hatching success, and percent emergence in loggerhead turtle nests on one major nesting ground in Turkey to estimate the sex ratio of the hatchlings produced.

**Materials and methods**

Patara beach is bisected by the Eşen River. The western beach (in Muğla Province) is 5000 m long and the eastern beach (in Antalya Province) is 6915 m long; the combined beach length is 12 km. (Fig. 1). The beaches lie between 36°14’931″N, 29°18’988″E and 36°19’724″N, 29°13’523″E.

The study was conducted from the last week of May to mid-September in 2000 and 2001. The beaches were measured with a tape measure and marked with numbered wooden posts at 500-m intervals running parallel to the beach. This was to allow for the accurate positioning of turtle activity and egg chamber by measuring to the nearest post. A nest was recorded when a track led to an area of disturbed sand where digging and covering had occurred. All the nests were left in situ. False crawls were recorded in one of two ways: (1) when some digging in the sand, if only slight, occurred but no covering was apparent (i.e., an attempt to dig a body pit and (or) egg chamber by the female) or (2) when a sea turtle made no nesting or digging attempts but simply crawled on the beach and then crawled back to the sea. Species identification was possible using the criteria of track and nest-pit morphology (Groombridge 1990). The
beaches were patrolled from 2100 to 0200 and early in the morning from 0600 to 1100 to record any loggerhead turtle activity. All the activities from the previous night were accepted and evaluated as the next day’s activity. Nest positions were also recorded by the global-positioning system.

Electronic continuous temperature recorders, launched and offloaded via computer, were placed into the middle of nests during oviposition or in the night or morning of ovipositing in the case of relocation. Temperatures at three levels (top, middle, and bottom) in one nest were also recorded. Temperature was measured using “tiny talk” temperature recorders (Orion Components (Chichester) Ltd., Chichester, UK), which fitted into 35-mm film cases. The accuracy of the device was tested under laboratory conditions against a standard mercury thermometer and had a mean resolution of 0.35 °C (minimum 0.3 °C, maximum 0.4 °C) for temperatures between 4 and 50 °C. Temperature data were downloaded off the temperature recorders to a computer and the temperature data analyzed. Although emergence occurred over more than one night and the middle third of the incubation period was calculated from the total incubation period (i.e., from the night of ovipositing to the day of first hatching), incubation durations were calculated as the number of days between the night of ovipositing and the night the first group of hatchlings emerged. Nest contents were excavated, nest chamber depth measured, and data loggers retrieved. Through a count of unhatched eggs and hatched shell fragments, the total number of eggs and hatching success were calculated. Besides the nests that had their internal temperatures recorded, other nests were also examined for predation.

The sex ratios of hatching loggerhead turtles were estimated using the method from a previously published study on loggerhead turtle nests in the Mediterranean (Kaska et al. 1998), and using the empirical relationship among temperature, incubation durations, and sex ratio used by other researchers (i.e., Houghton and Hays 2001; Godley et al. 2001a, 2001b). Examples of different estimation methods have been reported previously (Marcovaldi et al. 1997; Godfrey et al. 1999; Mrosovsky et al. 1999; Godley et al. 2001a, 2001b).

Results

Activities of 163 loggerhead turtles and two green turtles were recorded during the summer of 2000. Data from the two green turtle nests were excluded from the figures and statistical analyses. A total of 85 loggerhead nests were investigated. The temporal distribution of all loggerhead turtle activities recorded on Patara beach during both nesting seasons showed that the majority of recorded nests were laid during June and July (weeks 2 and 8, respectively, in Figs. 2a, 2b). This pattern was almost the same in both years. Only three non-nesting loggerhead turtle emergences were recorded even though no nests were recorded during May and August 2000. The proportion of emergences leading to nests on the two parts of Patara beach was statistically significant ($\chi^2$ test, $\chi^2 = 9.24$, df = 1, $P < 0.002$). The proportion of emergences producing nests in the different months on both parts of the beach was also significant ($\chi^2 = 10.061$, df = 3, $P < 0.01$). The emergence density on the beaches was also significantly different (Mann–Whitney $U$ test, $U = 181.5$, $P < 0.05$). Only 147 loggerhead turtle emergences were recorded during the summer of 2001, of which only 53 (36%) resulted in nests.

Nests were not distributed regularly on Patara beaches. Nesting density was high on a stretch of beach approximately 1 km east and west of the mouth of the Esen River (beach zones 6 and 7) and the east end of the beach (beach zone 1) in both years (Figs. 3a, 3b). There was a non-uniform spatial distribution of nests perpendicular to the sea in both years (Figs. 4a, 4b). The spatial distribution of nests at 5-m intervals from the water’s edge in the morning to a distance inland were statistically different (Mann–Whitney $U$ test, $U = 404$, $P < 0.05$). Loggerhead turtle activities resulted in nests mainly at 10–50 m from the sea.

The mean incubation period was 55.1 ($n = 19$) days (minimum 46, maximum 66) for the year 2000 and 53.2 ($n = 40$) days (minimum 46, maximum 66) for the year 2001. The frequencies of the incubation periods and comparison of the mean incubation periods of both years are shown (Figs. 5a, 5b, and 5c). Hatching occurred only in 40 (75.4%) of 53 nests in 2001 and only in 19 of 85 nests (23%) in 2000. It is suggested that this low hatching success is mainly due to the inundation of the nests by seawater within the first 20-m section of beach. There were 11 nests in this beach zone in 2000, none of which hatched; similarly, there were 18 nests in this beach zone in 2001, 2 of which hatched. Nest farther inland also had low hatching success, which was due to predation especially in 2000. Nests were protected against pre-

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The rate of predation was 63% in 2000, which decreased to 32% in 2001 when the screens were added. The main predators were red foxes (*Vulpes vulpes*) and ghost crabs (*Ocypode quadrata*). The hatching percentages of the beach zones between the first 20 m and 20–50 m and between 50 m and farther inland were statistically different ($\chi^2 = 10.92$, df = 2, $P < 0.05$). The main reason for this very low hatching success in the first 20-m beach zone was the inundation of the nests within this beach zone by seawater during the entire incubation period.

The mean temperature of the whole incubation period for four nests was 28.8–30.7 °C, whereas the mean temperature in the middle third of the incubation period was 28.5–31.0 °C. The maximum temperature increase during the incubation period for loggerhead turtle nests was 4.5 °C (minimum 27.7 °C, maximum 32.2 °C). A typical nest temperature is shown (Fig. 6).

We were able to compare sand temperatures with the temperature of a nest at the same depth. We observed decreasing temperature with increasing depth. There were also remarkable differences in the temperature at the same depth at different distances from the sea on the same beach. The temperatures at depths of 40, 50, and 60 cm were cooler close to the sea and almost the same in the first 30 m of beach, becoming warmer inland until 60 m from the sea and almost the same farther inland (Fig. 7a). The daily temperature fluctuations were higher at a depth of 40 cm, lower at a depth of 50 cm, and nearly constant at a depth of 60 cm. By analyzing these data, the maximum temperature differences were recorded up to 1.7 °C at a depth of 40 cm, up to 0.9 °C at a depth of 50 cm, and up to 0.5 °C at a depth of 60 cm. We compared sand temperatures with nest temperatures at the same depth, but recorded at shorter periods. The mean sand temperature was lower than the mean loggerhead turtle nest temperature at the same depth. In general, the daily mean temperature of sand was 0.9–1.6 °C lower than the daily mean temperature of a loggerhead turtle nest for the same period of time at the same depth. This difference was higher during the middle third of the incubation period.

The mean incubation temperatures were used to estimate the incubation period. The pivotal temperature for sea turtles in the Mediterranean was just below 29 °C and the pivotal incubation duration was 59.9 days (Kaska et al. 1998). There was a positive correlation between the mean temperature of the middle third of the incubation period ($r^2 = 0.97$) and sex ratio (percent female) (Fig. 8a), but an inverse correlation ($r^2 = 0.98$) between the mean temperature of a nest and the entire incubation period (Fig. 8b). This inverse correlation was still significant between the mean temperatures during the middle third incubation period and the total incubation period ($r^2 = 0.92$; Fig. 8c). The mean incubation temperatures can be use to estimate the incubation period. In general, a 1 °C decrease in the mean incubation temperature translated to a 4- to 5-day increase in incubation period (Table 1 and Fig 8b). From these and previous results (Kaska et al. 1998), the pivotal temperature for sea turtles in the Mediterranean was determined to be 28.8 °C. The pivotal incubation
temperature was estimated as 28.6 °C and the pivotal incubation duration was 57.5 days (Figs. 8a, 8b). The mean incubation period was 55.1 and 53.2 days for 2000 and 2001, respectively.

Fig. 5. Frequencies of incubation periods of hatched nests during 2000 (a) and 2001 (b) and a comparison of incubation periods during both years (c). The horizontal line marks the pivotal incubation period.

Fig. 6. Typical temperature profile of a loggerhead turtle nest on Patara beach (nest No. 4 in Table 1). The two vertical lines mark the middle third incubation period, whereas the horizontal line marks the pivotal temperature.

Fig. 7. Comparison of temperatures at a depth of 60 cm recorded between 3 and 12 June 2000 at three distances from the sea on Patara beach.

Fig. 8. (a) Correlation between mean temperatures during the middle third of the incubation period and estimated sex ratios. (b) Correlation between mean incubation temperatures during the entire incubation period and total incubation period. (c) Correlation between mean incubation temperatures during the middle third of the incubation period and total incubation period. data from Kaska et al. 1998; data from this study combined with unpublished 2001 data from Y. Kaska.
respectively. By analyzing the data from Fig. 8 and accepting the fact that a 1 °C change results in about a 4.8-day change in incubation period, we conclude that these mean incubations represent mean temperatures of 29.9 °C (67% females) and 30.4 °C (74% females) for 2000 and 2001, respectively. These values were obtained by calculating the mean incubation duration of every 2-week period during the entire hatching season and the corresponding sex ratios. The means of these half-month incubation durations, and the corresponding sex ratio from Kaska et al. (1998), resulted in a 70.5% female-dominated sex-ratio estimate. The mean annual female-dominated sex ratio for 2000 was 67% and for 2001 was 74%; however, as seen in Fig. 5, the mean incubation duration in 2001 was shorter than in 2000, leading to the expectation that there would be more female-skewed sex ratios in 2001.

Discussion

There may be 50–100 loggerhead turtle nests annually on Patara beach (Geldiay et al. 1982; Baran and Kaspurek 1989; Baran et al. 1992; Kaska 1993; Öz et al. 2002), since it is estimated that one in three emergences can result in a nest and that each female (nesting every 2–3 years) lays, on average, three nests in any season (Groombridge 1990). Although factors influencing nest site selection of sea turtles in the Mediterranean are still unknown, Geldiay et al. (1982) suggested that nest site selection is related to water temperature. For example, the eastern Mediterranean coast is warmer than the western Mediterranean coast (i.e., water temperature at Alanya is 28 °C compared with 25 °C at Dalyan); however, some beaches were used by both species in the cooler western Mediterranean coast (e.g., Goksu Delta and many beaches on northern Cyprus). Nest placement by loggerhead turtles in the Mediterranean were also investigated previously (Hays and Speakman 1993). Nests were concentrated on the beach zones closest to rivers; therefore, freshwater sources may be another factor used by sea turtles in nest site selection. The distribution of nests on Patara beach is also concentrated on the beach zone closest to the Esen River. The temperatures at nest depths closest to sea and closest to rivers (may be due to the high moisture content) were cooler than those farther inland. Therefore, the spatial distribution of nests along the beach and perpendicular to the sea should be considered one of the factors that affect the potential sex ratios produced from one beach.

Reported sex ratio for loggerhead turtles and green turtles is generally female dominated (Mrosovsky 1994; Kaska et al. 1998; Broderick et al. 2000; Casale et al. 2000; Godley et al. 2001a, 2001b; Houghton and Hays 2001; Freedberg and Wade 2001). Although female-dominated sex ratios (81.6%) on Turkish beaches have been reported (Kaska et al. 1998), certain beaches such as Fethiye beach have been documented as the most male-producing (37%) beach owing to specific sand characters. In Brazil where most sites are largely female producing, some key sites may have conditions that are biased towards the production of male hatchlings (Baptistotte et al. 1999). Marcovaldi et al. (1997) estimated the sex ratios of loggerhead turtles in Brazil from pivotal incubation durations and found that 82.5% of the loggerhead turtle hatchlings produced were female. Godley

| Table 1. Nest data during the entire and middle third incubation periods of loggerhead turtles, *Caretta caretta*, on Patara beach, southwestern Turkey. |
|---|---|
| Nest No. | Oviposition date | Clutch size* | Hatching success | Distance (m) from the sea | Incubation period (d) | Incubation success | Sex ratio (♀) |
| 1 | 4 July 2000 | 72 | 60.2 | 69 | 35 | 28.6±1.6 | 27.1-30.2 | 48 |
| 2 | 4 July 2000 | 82 | 69.1 | 63 | 35 | 28.6±1.6 | 27.1-30.2 | 48 |
| 3 | 1 July 2001 | 60 | 90 | 27 | 55 | 30.7±1.2 | 29.1-32.4 | 77 |
| 4 | 1 July 2001 | 76 | 93.4 | 71 | 34 | 30.7±1.2 | 29.1-32.4 | 83 |

*Number of eggs per nest. 
† Number of loggerhead turtle hatchlings per nest.
et al. (2001a) also estimated sex ratios from pivotal incubation durations in Cyprus. They used the Brazil incubation durations to estimate sex ratios and found that 89%–99% of the hatchlings produced were females. The bias in sex ratio could be decreased by differentially higher mortality of smaller, less fit turtles (mostly females) from rapidly developed nests; sex- and emergence-related mortalities have been suggested in sea turtles (Kaska 2000). Here, in Patara beach, the inundations of nests close to the sea by seawater and predation of nests farther inland both affect the hatching success, and therefore the natural sex ratio. Discussion of the effects of global warming on sea turtle populations have focused on the loss of nesting beach habitat as a result of an increase in sea level and on the changes in sex ratios (Davenport 1997; Nicholls et al. 1999). The largest environmental changes will take place around the Mediterranean and Baltic coasts and to a lesser extent on the Atlantic coast of Central and North America and the smaller islands of the Caribbean (Nicholls et al. 1999). Therefore, sea turtle populations in the Mediterranean may be the first affected by climatic changes compared with other populations in the world. Hence, the survival of this species in the Mediterranean is dependent on the protection of beaches that produce almost equal numbers of male and female sea turtles. The mean sex ratio for 2 years of estimates on Patara beach was 70.5%, which was similar to previous studies (reviewed in Freedberg and Wade 2001). We did not consider the seasonal variation in sex ratio, which according to Godfrey and Mrosovsky (1999) should be taken into account along with significant spatial differences in mortality or clutch size to avoid substantial errors in the sex-ratio estimates. Therefore, the temperatures of more nests from both early and late season and the work on actual histology of a number of sea turtle hatchlings would be more appropriate in estimating more precisely the sex ratio.

Percent hatch is greatest at 25% moisture and significantly less at higher and lower levels of moisture. According to Mcgehee (1990), the average moisture content of the sand in natural nests of loggerhead turtles is 18% on Merritt Island, Florida. Higher levels of salinity in the sand reduce the ability of eggs to absorb water and reduce the humidity in the nest chamber (Bustard and Greenham 1968). Embryonic sea turtles exposed to wet conditions during development had longer incubation periods and grew larger than those incubated in drier settings (Hendrickson 1958; Mcgehee 1990). Lengthening the incubation period increases the chances that a predator will find the nest. Under natal beach conditions, the sea turtle eggs incubate at temperatures between 24 and 33 °C (Hendrickson 1958; Bustard 1972). The hydric environment of the nest may influence temperature and subsequent sex determination of the embryos. The low number of nests detected on Patara beach may be due to the low hatching success of nests as a result of the hydric environment of the nests. Different ideas about the conservation of sea turtles have been reviewed by Pritchard (1980). In the absence of data on temperature-dependent sex determination and a thermal transect of a beach, the relocation of nests may affect the natural sex ratio. The temperatures of nests close to the sea may be cooler, which potentially will result in more males hatching; nests farther inland may be exposed to warmer temperatures, which potentially will result in more females hatching. The relocation (or hatchery) of nests to safer areas may increase the hatching success, but the natural sex ratio and the sex ratio after the relocation may be different. According to our research, there is a female-skewed hatching sex ratio under natural conditions on Patara beach, which confirms the previous work on sex ratio in Turkey (Kaska et al. 1998).

Acknowledgements

We are grateful to Gemma Hall and Tony Holmes for their suggestions that improved the manuscript and to two anonymous reviewers for their comments on an earlier version of the manuscript. This study was supported by The Authority For The Protection of Special Areas, The Ministry of Environment of Turkey (project No. B.19.1.ÖÇK.07.00.A07040-109).

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