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Abundance Trends and Nesting Biology of Green Turtles *Chelonia mydas* (Testudines: Cheloniidae) During Ten Consecutive Breeding Seasons at Akyatan Beach, Turkey

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Data obtained from long-term survey studies are valuable for assessing the population status and trends in critical populations of threatened species, like sea turtles. Akyatan beach is one of the most important green turtle nesting beaches in the Mediterranean and has been monitored since 2006 without interruption. The beach is 22 km long and more than 100 m wide at some points, and both loggerhead and green turtles nests on the beach. However, the loggerhead nesting is very limited in comparison to green turtles. A total of 3866 *C. mydas* nests were recorded during ten consecutive years at Akyatan beach, with a mean of 387 ± 127 nests (range = 201–559). The average nesting density was 17.6 nests km^{-1} (range = 9.1–25.4 nests km^{-1}). In the 3309 nests, a total of 355,259 eggs were counted. The overall mean clutch size was 112 ± 26.10 eggs. Of these eggs, 50.80% hatched (depredated nests included), and 78.07% of them were able to reach the sea. The overall mean hatching success was 73.07 ± 26.20%. The overall mean incubation duration was 51.4 ± 3.5 days. The clutch sizes and hatching success differed between years, and there was a significant trend in mean incubation duration to decrease over ten years of study. A total of 1585 green turtle nests (41.02% of nests) were totally or partially depredated by golden jackals and wild boar, while other predators depredated 20.5% of hatchlings. The nesting data obtained since 2006 showed strong annual fluctuations ranging from 170 (in 2007) to 562 (in 2006) with a slightly increasing but statistically insignificant trend ($r = 0.94$, $p > 0.05$). The main threats to the population were depredation by jackals and wild boars.

Key words: Endangered species, Conservation, Sea turtles.

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BACKGROUND

Sea turtles are migratory species with a complex life history that spend most of their lives in the sea, and only females come to beaches to reproduce. They have different habitats during these complex life cycles. The creation of practical action plans to protect endangered sea turtles will be possible by obtaining detailed information about these different habitats and revealing the connections between these habitats.

In this respect, the Mediterranean is an area containing essential habitats for two species: the green turtle (*Chelonia mydas*) and the loggerhead turtle (*Caretta caretta*). It was defined as a regional management unit for both species. A total of 17 regional management units (RMUs) were identified for green turtles worldwide, and one of them is the Mediterranean region with the high threats category (Wallace et al. 2010 2011). Recent studies reveal that the populations of these two species have increased both globally (Mazaris et al. 2017) and regionally (Casale et al. 2018).

The loggerhead and green turtles nesting in the Mediterranean prefer Turkey, Greece, Libya, Egypt, and Tunisia coasts as foraging and wintering grounds (Broderick et al. 2007; Casale and Margaritoulis 2010; Godley et al. 2003; Rees et al. 2008; Snape et al. 2016; Stokes et al. 2015). The nesting of green turtles in the Mediterranean is confined to Turkey, Northern Cyprus, Lebanon, Israel, and Egypt (Türkozan and Kaska 2010; Casale et al. 2018), and the average number of documented nests is 1500 nests/year in the Mediterranean (Casale and Margaritoulis 2010). Of the nesting grounds in the Mediterranean, Turkey, and Cyprus comprise almost 99% of the overall nesting activity (Kasparek et al. 2001; Türkozan and Kaska 2010; Casale et al. 2018). Recent studies using mtSTR described 3 to 4 management units for green turtle stocks in the Mediterranean (Tikochinski et al. 2018; Karaman et al. 2022).

Of the 13 major green turtle rookeries in the Mediterranean, six are located on Turkish coasts (Casale et al. 2018), and a total of 452–2051 green turtle nests are estimated annually in Turkey (Türkozan and Kaska 2010). The Akyatan beach has been monitored since 2006 regularly, and a -1.2% change was reported in the nest numbers before 1999 and after 2000 monitoring programs (Casale et al. 2018). This decrease is noticeable since other crucial green turtle nesting beaches (Kazanlı and Samandağ, Turkey) provided a 71.4–279.1% increase in nest numbers (Casale et al. 2018). Since Akyatan beach is a part of a strictly protected area and far from the anthropogenic effects, we focused on the long term population parameters to identify possible causes of this decrease. The population size and nest density estimate not based on yearly long-term monitoring studies on nesting beaches may provide misleading results due to biased calculations caused by fluctuations in the number of nests (Sönmez et al. 2021). We, therefore, offered long-term data and ongoing nesting activities on the beach, which hosts about 20% of the total number of green turtle nests recorded in the Mediterranean.

MATERIALS AND METHODS

Study site

Akyatan beach is located on the eastern Mediterranean coast of Turkey and within the Wildlife Development Area of 15,304 ha under protection status by the Ministry of Forest and Agriculture since 1987. Akyatan Beach is between Akyatan Lagoon and the Mediterranean and is 22 km long (Fig. 1). Both green and loggerhead turtles nest on Akyatan beach, but green turtle nesting is denser. Conservation studies of sea turtles in Akyatan beach were carried out according to the protocol signed by the Ministry of Agriculture and Forestry, 7th Regional Directorate of Nature Conservation and National Parks, and WWF-Turkey since 2006 and continue.

Fig. 1. Akyatan Beach on the Turkish coast.

Nesting data

The nesting data for *C. mydas* were collected over ten nesting seasons (2012–2021) between June 1 and September 15 each year (except for the 2014 and 2015 nesting seasons when the survey started on May 15th). About 14 km of the 22 km beach was monitored daily on foot, and the remaining 8 km was monitored once in every three days (Fig. 1).

Adult emergence

The location of clutches within a nest and non-nesting emergences were determined by carefully using a metal rod. The distance of nests and the apex of non-nesting emergences from the sea were measured using a flexible tape measure in cm. All clutch locations that were individually marked and recorded with GPS (Garmin Etrex 20) and non-depredated nests were caged with a wire mesh screen (72 × 72 cm, mesh size 9 cm) to prevent nest depredation by mammals. Depredated eggs were counted in the nests, moved to another location on the beach, and reburied. Clutches laid in areas at risk of flooding were relocated to a site at lower risk with the dimensions of the original nest.

Hatchling emergence

The hatchlings reaching the sea were determined daily from hatchling tracks emanating from nests. Counted tracks were obscured by feet to avoid recounting. When the tracks were interrupted by predator tracks, such as golden jackal (*Canis aureus*) or wild boar (*Sus scrofa*), the hatchlings were assumed to be preyed upon before they reached the sea by those predators. Each nest was excavated carefully, by hand, or using a shovel 3 or 5 days after the first emergence of hatchlings. Nest contents were classified as hatched eggs/empty shells (hatchlings emerged), unhatched eggs (unfertilised eggs and eggs without visible embryos or blood formation), and dead embryos (developmentally delayed eggs, early embryo: embryo < 1 cm; middle embryo: embryo 1–2 cm; late embryo: embryo > 2 cm). The hatching success in the nests was calculated as the percentage of hatched empty shells/ total number of eggs in the entire clutch. Predated nests were not considered for the assessment of hatching success. When fragmented eggshells were found, eggshell pieces were reassembled to represent one egg. Also, incubation duration was defined as the number of days from the nesting date to the date of the first hatchling's emergence onto the surface of the sand.

Estimates of population sizes

The total number of nesting females was estimated based on clutch frequency (CF) using the clutch frequency of 2.9 (range = 2.0–3.1) for green turtles in the Mediterranean (Broderick et al. 2002) since this information is not available for Akyatan Beach. We considered the remigration interval (RI) as three years for the green turtle populations in the Mediterranean region (Broderick et al. 2002). The total nesting female numbers were calculated with the following formula:

Total Nesting Female Numbers = Total Nest Number/ CF * (Total years/RI) (Sönmez et al. 2021)

Also, the current female numbers in the last two nesting seasons (2020 and 2021) were calculated with the following formula:

Current Female Numbers = (Mean Nest Number/ CF) * RI (Sönmez et al. 2021)

Statistical analysis

The data were not normally distributed according to Levene and Kolmogorov–Smirnov tests ($p < 0.05$). However, parametric tests could be used based on the central limit theorem regardless of the shape of our data in large sample sizes (Field 2013). We, therefore, used the One-Way ANOVA test to compare mean clutch size, depredated eggs, hatching success, and incubation duration among nesting seasons. The trend analysis for hatching success, incubation durations, and nest numbers across the years was performed by linear regression. All statistical analyses were performed using the IBM SPSS Statistics 20 software. All means are presented with SD (standard deviation).

RESULTS

Nests, eggs, and hatchlings

A total of 10,767 green turtle emergences were recorded, with 3866 (35.91%) clutches being successfully laid during ten consecutive reproduction seasons (2012-2021) on Akyatan beach. The annual mean number of nests was 387 ± 127 (range = 201–559 nests), and the mean nest density was 17.57 nests km^{-1} (range = 9.14–25.41 nests km^{-1}). Due to the risk of inundation of nests by seawater, 42 (1.09%) green turtle nests were relocated.

A total of 355,259 eggs were deposited in 3309 nests (excavated nests), and the mean clutch size excluding predated nests was 112 ± 26.10 eggs (range: 4–222) (Table 1). The clutch sizes were significantly different between the nesting seasons (one-way ANOVA, $F = 3.105$, $p < 0.01$) (Fig. 2a), and 2012, 2016, 2020, and 2021 nesting seasons had larger mean clutch sizes (see Table 1 for details). Of the 355,259 eggs, 180,421 (50.80%) produced hatchlings, and 140,851 (78.07%) of them were able to reach the sea. When depredated nests are not included, the mean hatching success ranged from 66.53 ± 29.87% to 79.87 ± 21.41%, with an overall mean hatching success of 73.07 ± 26.20% (Table 1). The hatching success was significantly different between the nesting seasons (one-way ANOVA, $F = 5.594$, $p < 0.0001$) (Fig. 2b). The nesting seasons of 2019 and 2020 had lower mean hatching success (see Table 1 for details). The mean hatching success in 10 consecutive years showed a significant decreasing trend ($r^2 = 0.006$, *d.f.* = 2164, $p < 0.0001$) (Fig. 3a). A total of 54,878 dead embryos were counted in 2227 nests, and of these dead embryos, 69.54% (38.162) were early-stage embryos, 7.84% (4.300) were mid-stage embryos and 22.62% (12.416) were late-stage embryos.

Table 1. Biological data about *Chelonia mydas* at Akyatan Beach. Unhatched eggs = eggs without visible embryos or blood formation; developmentally delayed eggs, early embryo = embryo < 1 cm; middle embryo = 1 < embryo < 2 cm; late embryo = embryo >2 cm)

Nesting Seasons	2012	2013	2014	2015	2016	2017
Total number of nests	444	249	433	201	559	349
No. of nests depredated	110	82	159	97	270	159
No. of nests with eggs uncountable due to depredation	64	39	80	29	70	50
No. of nests left on the beach	15	14	15	10	28	12
No. of nests excavated	319	153	259	94	261	178
No. of nests excavated and eggs countable	365	196	338	162	461	287
Total number of eggs	40758	20401	35559	16448	48474	29396
• Unhatched eggs	671	589	884	396	1702	869
• Early embryo	5430	1807	4016	1327	4608	3221
• Middle embryo	479	193	612	113	589	289
• Late embryo	2052	431	999	247	1485	1215
• Depredated eggs	5150	4104	7438	6435	18914	10401
• Total number of hatchlings (hatched eggs)	26976	13277	21610	7930	21176	13402
• • Hatchlings depredated	7526	3594	3300	2067	3538	2180
• • Dead hatchlings in nests	305	91	178	103	193	146
• • Hatchlings reached the sea	19145	9592	18132	5760	17445	11076
Mean clutch size (no. of eggs/nest) *	116.04 ± 26.06	108.42 ± 24.71	109.05 ± 25.42	107.64 ± 22.56	113.74 ± 22.92	107.60 ± 22.47
Mean Hatching success (%)*	74.09 ± 27.26	79.87 ± 21.41	76.00 ± 25.50	79.41 ± 21.50	72.48 ± 26.21	71.34 ± 25.65
Mean incubation duration (days)	51.39 ± 2.92	51.25 ± 2.38	52.19 ± 3.12	53.27 ± 2.09	50.39 ± 2.75	52.38 ± 3.54

Nesting Seasons	2018	2019	2020	2021	Overall	
Total number of nests	341	348	532	410	3866	
No. of nests depredated	130	210	198	131	1546	
No. of nests with eggs uncountable due to depredation	3	27	90	2	454	
No. of nests left on the beach	9	-	-	-	103	
No. of nests excavated	202	148	334	279	2227	
No. of nests excavated and eggs countable	329	321	442	408	3309	%
Total number of eggs	34925	34234	49982	45082	355259	100
• Unhatched eggs	1191	754	1516	1312	9884	2.78
• Early embryo	2908	2715	7862	4268	38162	10.74
• Middle embryo	568	541	514	402	4300	1.21
• Late embryo	1664	1119	1786	1418	12416	3.49
• Depredated eggs	12581	18188	12974	13890	110075	30.98
• Total number of hatchlings (hatched eggs)	16011	10917	25330	23792	180421	50.80
• • Hatchlings depredated	2169	1292	7026	4357	37049	20.53
• • Dead hatchlings in nests	132	98	916	359	2521	1.40
• • Hatchlings reached the sea	13710	9527	17388	19076	140851	78.07
Mean clutch size (no. of eggs/nest) *	110.13 ± 27.50	110.63 ± 25.19	114.38 ± 32.46	113.98 ± 22.83	111.93 ± 26.10	
Mean Hatching success (%)*	71.34 ± 28.73	66.53 ± 29.87	67.39 ± 28.28	76.36 ± 20.60	73.07 ± 26.20	
Mean incubation duration (days)	51.41 ± 3.98	52.48 ± 3.70	51.52 ± 4.64	49.61 ± 2.77	51.39 ± 3.46	

* Predated nests were not considered for assessment of mean clutch size and hatching success.

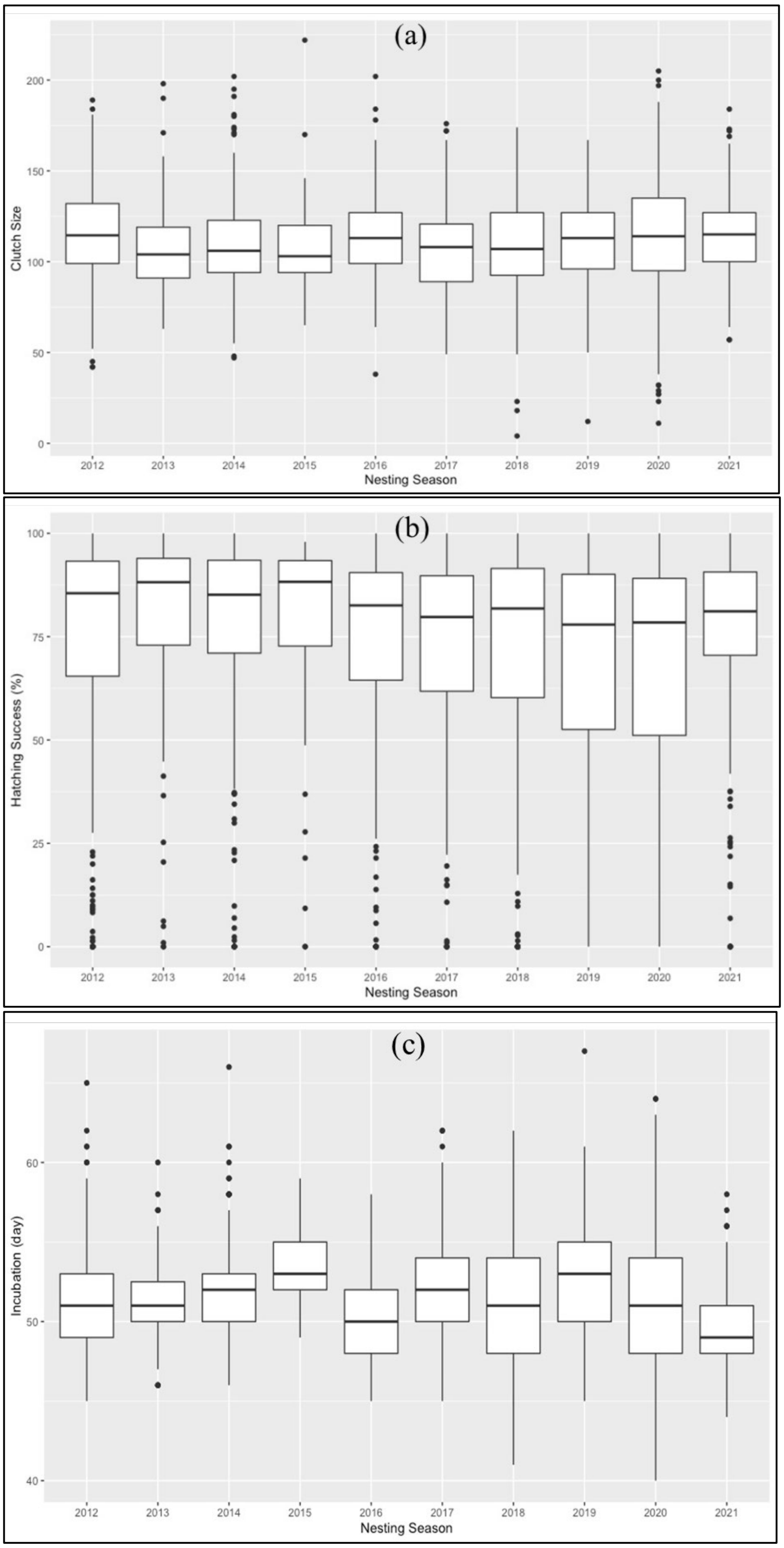

Fig. 2. Interannual variation of green turtle (a) clutch size, (b) hatching success, and (c) incubation duration on Akyatan Beach for 10 years. Shown are medians (horizontal line), interquartile ranges (upper and lower box limits), range (vertical lines), and outliers (circles).

The mean incubation durations ranged from 49.6 ± 2.77 to 53.3 ± 2.09 days, with an overall mean of 51.4 ± 3.46 days (Table 1). The incubation duration was significantly different during the breeding seasons (one-way ANOVA, $F = 12.960$, $p < 0.0001$) (Fig. 2c). The mean incubation durations in 10 consecutive years showed a significant decreasing trend (regression analysis, $r^2 = 0.007$, $d.f. = 1528$, $p < 0.001$) (Fig. 3b).

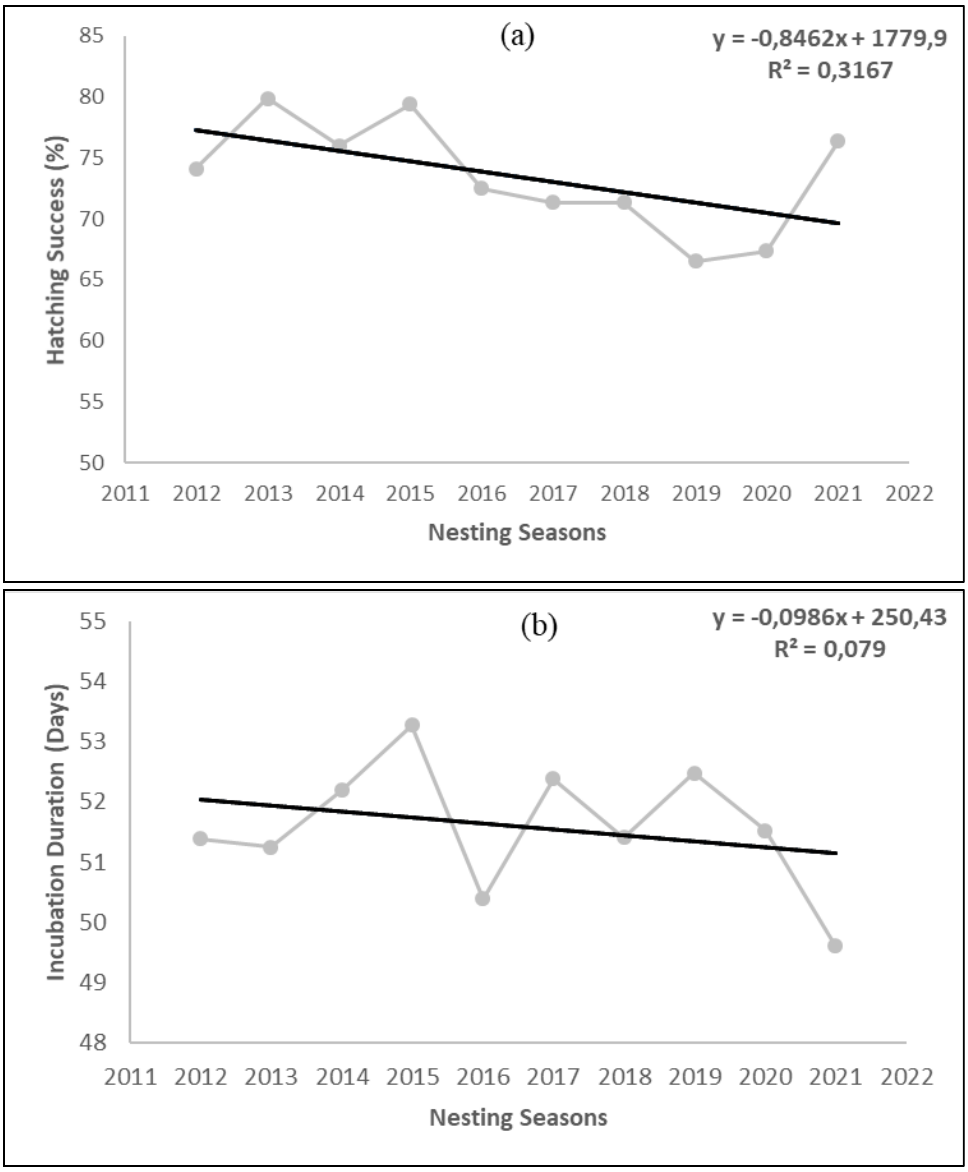

Fig. 3. Temporal trend in hatching success (a) and incubation durations (b) of green turtle nests over 10 consecutive years on Akyatan Beach.

Three peak nesting periods were recorded according to the temporal distribution of green turtle nests between nesting seasons (Table 2). The first nest was recorded on the 19th of May, while the last nest was recorded on the 23rd of August (Table 2). However, based on ten nesting seasons, the mean peak-nesting season on Akyatan beach was between 29th June and 8th July (Fig. 4). Hatching starts during the third week of July (except in 2018, in the first week of July), and there were two different periods for the peak-hatching season among nesting seasons (Table 2). The overall peak-hatching season was in the period of 10th–19th Aug (Fig. 5). The average distance of green turtle nests from the tide line was 43.17 ± 18.00 m ($n = 3882$, range 5.60–125.4; Fig. 6).

Table 2. Dates for peak-nesting/hatching seasons, nesting and hatching season during 10 nesting seasons for green turtle in Akyatan Beach

Season	Nesting	Peak-nesting season	Hatching	Peak-hatching season
2012	May – 5th Aug	29th June – 8th July	1st July – After 15th Sep	10th – 19th Aug
2013	May – 23th Aug	19th – 28th June	19th June – After 15th Sep	20 th – 29 th Aug
2014	19th May – 5th Aug	29th June – 8th July	25th June – After 15th Sep	10th – 19th Aug
2015	28th May – 13th Aug	9th – 18th July	29th June – After 15th Sep	20th – 29 th Aug
2016	May – 20th Aug	29th June – 8th July	18th June – After 15th Sep	10th – 19th Aug
2017	May – 17th Aug	29th June – 8th July	23rd June – After 15th Sep	20th – 29th Aug
2018	May – 8th Aug	19th – 28th June	19th June – After 15th Sep	10th – 19th Aug
2019	May – 11th Aug	19th – 28th June	24th June – 27th Sep	10th – 19th Aug
2020	May – 18th Aug	29th June-8th July	30th June – 5th Oct	20th – 29th Aug
2021	May – 26th July	19th – 28th June	20th July – 9th Sep	10th – 19th Aug

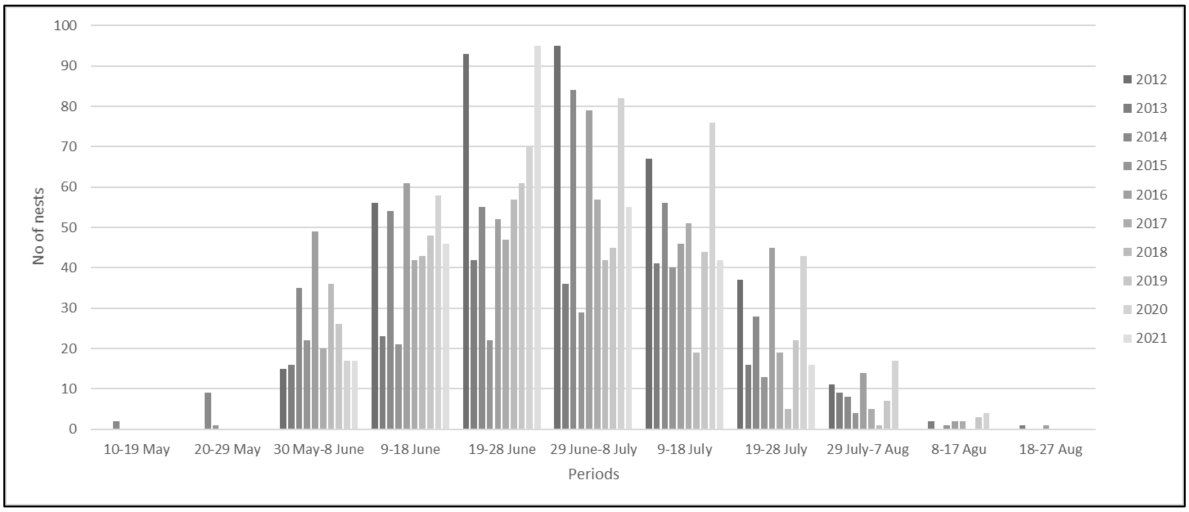

Fig. 4. Temporal distribution of green turtle nests on Akyatan beach, Turkey (Data are grouped into 10 day bins).

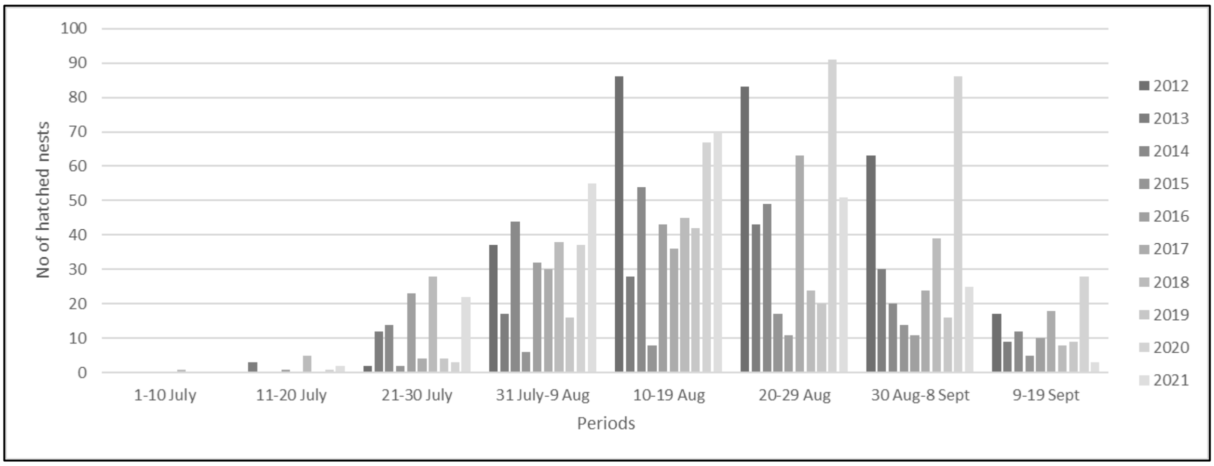

Fig. 5. Temporal distribution of green turtle hatching on Akyatan beach, Turkey (Data are grouped into 10-day bins).

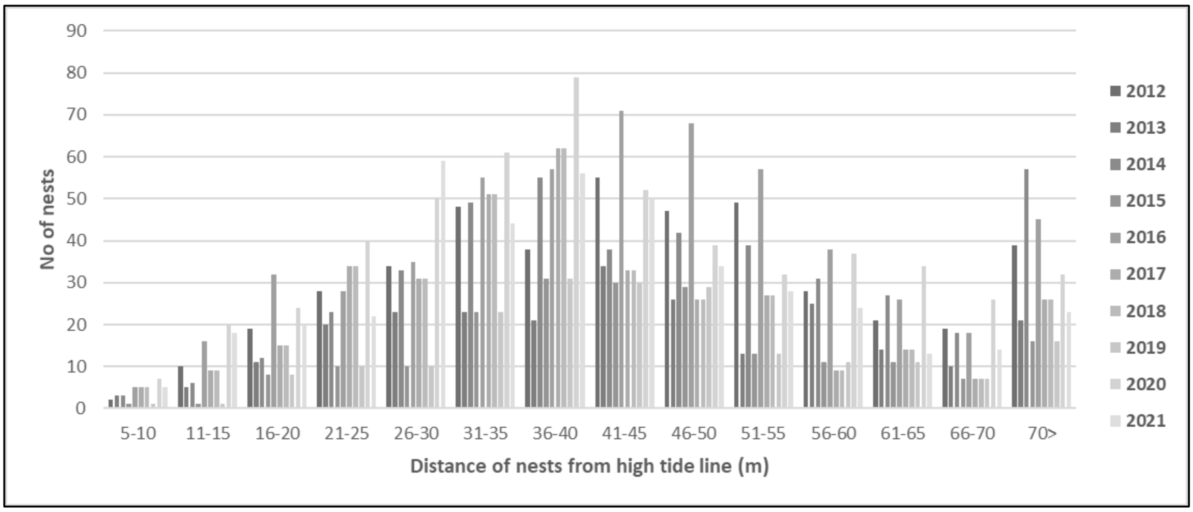

Fig.6. Spatial distribution of green turtle nests on Akyatan beach.

A total of 1585 green turtle nests (41.02% of nests) were completely or partially depredated by golden jackals (*Canis aureus*) and wild boars (*Sus scrofa*). Of the 1585 nests, 1204 (75.96%) were depredated by golden jackals and 381 (24.04%) by wild boar. While the number of eggs depredated by golden jackals was counted in most cases, the number of eggs depredated by wild boar could not be counted. A total of 110,075 eggs were destroyed by golden jackals (Table 1). The number of depredated eggs significantly differed between the nesting seasons (one-way ANOVA, $F = 32.438$, $p < 0.0001$). The depredated eggs in 10 consecutive years showed a significant increasing trend ($r^2 = 0.009$, $d.f. = 1238$, $p < 0.0001$). A total of 37,049 (20.53%) hatchlings were predated on their journey from the nest to the seawater edge (Table 1). Of the predated hatchlings, 36,242 (97.82%) were predated by jackals, 345 (0.93%) by crabs, 45 (0.12%) by seagulls, and 60 (0.16%) by wild boars, and the fate of 357 (0.96%) hatchlings that were disoriented and entered the forest is unknown. Furthermore, 2521 (1.40%) hatchlings were found dead in the nests without predation (Table 1).

Nesting trend and abundance

A total of 6034 green turtle nests were recorded during 16 consecutive years (2006–2021), with a mean of 377 ± 127.2(range = 170–562) nests per year on Akyatan Beach. The number of nests showed a strong annual fluctuation ranging from 170 (in 2007) to 562 nests (in 2006), with a difference of 231% (Table 3). Yearly numbers of nests in 16 consecutive years showed a insignificant but increasing trend (regression analysis, $r^2 = 0.012$, $d.f. = 14$, $p > 0.05$) (Fig. 7).

The total number of females nesting each year was estimated as 2081 (range = 1947-3018) females (Table 3). The total mean number of females nesting on Akyatan Beach was 390 (range = 365–566). The current number of females on Akyatan Beach was 487 (range = 456–707). The mean estimated population size (390 females) of nesting females for all years (2006–2021) was lower than for the current year (487 females) (2020–2021).

Table 3. Number of nests recorded through the years and estimated number of females based on clutch frequency (CF) study in the Mediterranean region according to Broderick et al. (2002) (± SD)

Years	Nest number	Estimated number of nesting females (Number nest/CF)	Max (Number nest/CF)	Min (Number nest/CF)	References
2006	562	193.8	281.0	181.3	Yılmaz et al. (2015)
2007	170	58.6	85.0	54.8	
2008	542	186.9	271.0	174.8	
2009	261	90.0	130.5	84.2	
2010	289	99.7	144.5	93.2	
2011	346	119.3	173.0	111.6	
2012	444	153.1	222.0	143.2	This study
2013	249	85.9	124.5	80.3	
2014	433	149.3	216.5	139.7	
2015	201	69.3	100.5	64.8	
2016	559	192.8	279.5	180.3	
2017	349	120.3	174.5	112.6	
2018	341	117.6	170.5	110.0	
2019	348	120.0	174.0	112.3	
2020	532	183.4	266.0	171.6	
2021	410	141.4	205.0	132.3	
Overall	6036	2081.4	3018	1947	

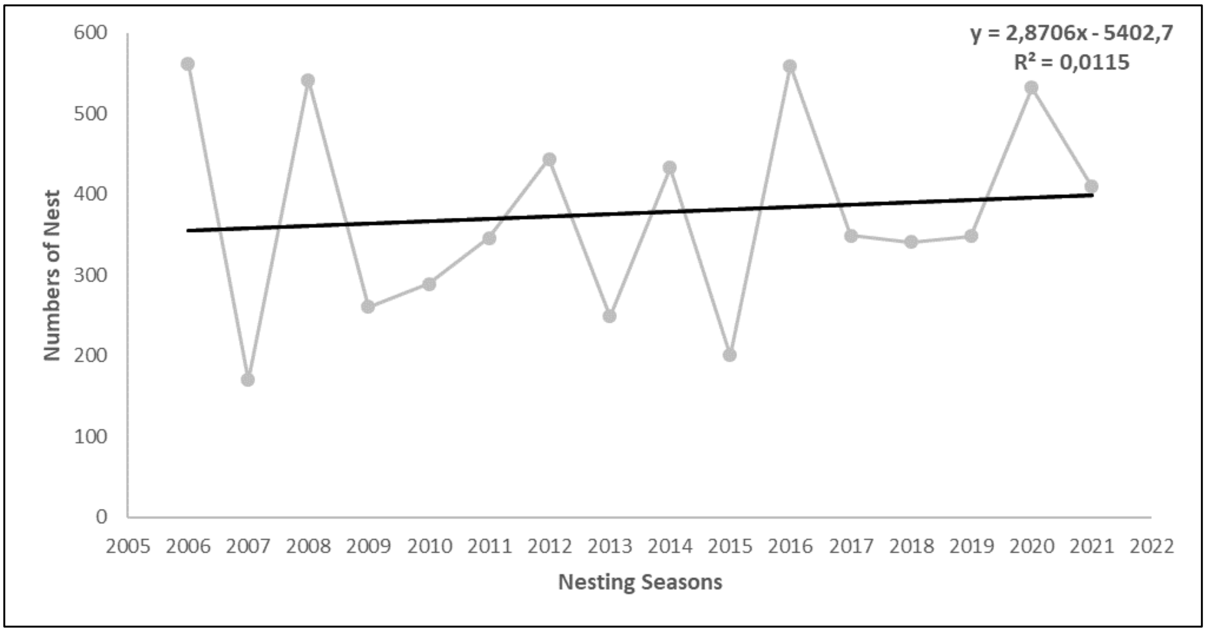

Fig. 7. Temporal trend in the number of green turtle nests over 16 consecutive years on Akyatan Beach.

Threats on the beach

During the research period, 12 green turtles were found stranded on the beach. Furthermore, seven adult green turtles were killed by golden jackals while nesting. Human disturbance on the beach at night was low due to the restriction of entry to Akyatan Beach due to its protected status as a Wildlife Development Area. The main anthropogenic threat was caused by several tractors illegally entering the beach, which compacted the sand affecting hatchling emergence and leaving tracks that trapped hatchlings.

DISCUSSION

Nests, eggs, and hatchlings

Of the 13 major green turtle rookeries in the Mediterranean, six are located in Turkey, and these beaches comprise almost 80% of the overall nesting activity in the Mediterranean (Türkozan and Kaska 2010). The annual mean number of nests on Akyatan beach (387 nests) constitutes almost 17.51–23.39% of the overall nesting in the Mediterranean, while it comprises 27.4–37.6% of the broad green turtle nesting activity along the Turkish coasts. The annual mean nest number of Akyatan is higher than other nesting colonies in the Mediterranean (see table S11 Casale et al. 2018) and therefore, still the most critical site for green turtles. Long-time surveys indicated a 47% increase in the number of nests laid by Mediterranean green turtle populations (Casale et al. 2018). However, the comparison of average nest numbers obtained due to the monitoring studies carried out before 1999 and the average number of nests in the monitoring studies carried out after 2000 provided a 1.2% change on Akyatan beach (Casale et al. 2018). In contrast, Kazanlı and Samandağ nesting beaches (both in Turkey), other essential nesting grounds in the Mediterranean, showed a remarkable increase (71.4–279.1%) during the same period. The decrease is surprising since Akyatan beach is a strictly protected area and far from adverse anthropogenic effects. We believe that this could result from shifting of adult females since the nest site fidelity of green turtles seem to be region specific rather than beach specific (Karaman et al. 2022). The interchange of nesting individuals between Akyatan-Sugözü and Samandağ-Syria was also reported with mark-recapture studies previously (Sönmez et al. 2017). On the other hand, nest numbers showed an increasing trend which is possibly the result of long term conservation efforts in the region.

The overall mean clutch size recorded for Akyatan beach during ten consecutive reproduction seasons (112 eggs) is within the range for green turtle populations in the Mediterranean (Alagadi/North Cyprus: 116 eggs, Egypt: 101 eggs, Latakia/Syria: 108 eggs, Kazanlı/Turkey: 111 eggs, Akyatan/Turkey: 114 eggs, see table S15 Casale et al. 2018). The clutch size in green turtles increases with body size of the female (Broderick et al. 2003). Bjorndal and Carr (1989) indicated that carapace length of females with a small mean clutch size in 1976 nesting season were significantly shorter than all other years.The current study's significantly different mean clutch sizes between the nesting seasons may be due to size differences of nesting females during those breeding seasons. However, since we have no measure of female size, we cannot precisely comment on this topic.

Hatching success in our study (73.07%) was higher than Egypt (53.7%) and lower than Alagadi/North Cyprus (84.2%), Latakia/Syria (80.0%), Kazanlı/Turkey (78.3%), Akyatan/Turkey (75.6%) and Samandağ/Turkey (81.1%) (see table S15 Casale et al. 2018). Also, the mean hatching success among the nesting seasons was determined to have significant differences and showed a crucial decreasing trend over ten consecutive years. Hatching success can be affected by the nest location and its microhabitat (Zárate et al. 2013), temperatures (Godley et al. 2001; Pike 2013; Hays et al. 2017; Türkozan et. al. 2021), fungal infections (Limpus et al. 1983) and moisture (Wood and Bjorndal 2000). The hatching success is reduced when the temperature is higher (Godley et al. 2001; Pike 2013; Hays et al. 2017). Furthermore, Türkozan et al. (2021) reported that hatching success declines after conditions exceed the 33°C thermal thresholds for two-fifths of the incubation period in Akyatan Beach. But the hatching success was increased despite the reduced incubation duration depending on temperature rise in the 2021 nesting season (Fig. 2b, c). The low mean incubation duration in the 2021 nesting season probably resulted from more depredated nests (65.65%) laid until May and June 15th, possibly with a high incubation duration.

Of the recorded embryonic deaths in nests, 69.54% were early-stage, 7.84% were mid-stage, and 22.62% were late-stage embryos. Compared to Yılmaz et al. (2015), while the early-stage embryos in our study were lower, mid-stage and late-stage were higher (early-stage embryos: 76.4%, mid-stage embryos 4.4%, and late-stage embryos: 19.2%). Environmental factors such as precipitation and temperature influence embryonic deaths (Rafferty et al. 2011). Booth and Dunstan (2018) found that the proportion of early embryo death was remarkable in two green turtle nests that experienced the highest nest temperature, lowest oxygen (PO_2), and highest carbon dioxide (PCO_2) during the first week of incubation in green turtle nests. Also, the high temperatures experienced in the early stages of incubation might cause malformations, leading to increased mortality rates (Booth et al. 2020).

The overall mean incubation duration (51.39 ± 3.46) was in the range of values reported for green turtle populations in the Mediterranean (Alagadi/North Cyprus: 51.1 days, Egypt: 46.5 days, Kazanlı/Turkey: 52.2 days, Akyatan/Turkey: 52.9 days, and Samandağ/Turkey: 52.9 days, see table S15; Casale et al. 2018). Also, the incubation duration was determined to be significantly different between the nesting seasons. While variation in incubation durations is related to temperature profiles and sand characteristics on other nesting beaches (Yılmaz et al. 2015), the same nesting beach is affected by the temperature profile in different nesting seasons. Türkozan et al. (2021)

found that incubation temperatures will significantly increase in future years in the Mediterranean region. This situation will further reduce the incubation durations of green turtle nests in the Mediterranean. The significant decrease in mean incubation durations over ten consecutive years found in our study supports this conclusion.

The overall peak-nesting season is between 29th June–8th July on Akyatan beach (Fig. 3), with the first nesting event on 19th May and the last nesting event on 23rd Aug (Table 2). Yılmaz et al. (2015) reported the latest nest records as 7th Aug 2008 for green turtles in Akyatan Beach. Broderick and Godley (1996) reported that the first nest was recorded on 31st May 1994, and the last nest on 25th Aug 1993 for green turtles in Cyprus. For *Caretta caretta*, the earliest and the latest nest records were reported as 19th May 2001 and 14th Sep 1984, respectively, in Greece (Margaritoulis, 2005). Furthermore, Weishampel et al. (2005) reported that earlier nesting of *C. caretta* was correlated with sea surface warming. The peak nesting season for green turtle nests in the Mediterranean is between 19–28 June in Akyatan Beach (Yılmaz et al. 2015) and 12–19 June in Northern Cyprus (Broderick and Godley 1996). The first, last nesting and peak-nesting season of sea turtle nests in the same or different populations may respond to climate change between nesting seasons. Patel et al. (2016) reported the nesting season of the loggerhead turtle could shift to an earlier date by as much as 50 to 74 days in the Mediterranean by the year 2100 because of the rise in air and ocean temperatures.

Although non-depredated nests were caged with wire mesh in the morning survey, the predation rate (41.02% of nests) was high on Akyatan beach. This predation rate is higher than the predation rate (33.4%) from the other study done on Akyatan Beach (Yılmaz et al. 2015). Also, the depredated eggs showed a significant increasing trend for ten consecutive years. This is because the nests were predated by wild boar (*S. scrofa*) despite being caged with wire mesh, especially in the 2012, 2014, 2016, 2017, and 2020 nesting seasons. Although the cages are placed at a depth of about 20 cm from the surface of the nests, the nests were predated by wild boar (*S. scrofa*). Engeman et al. (2016) demonstrated that cages and screens offer little protection against feral swine (*S. scrofa*) depredation. If the nutrient in the diet of the wild boar (*S. scrofa*) is included in Wildlife Development Area during the nesting period, then the nest predation can reduce. While 75.96% of depredated nests were predated by golden jackals (*C. aureus*), 24.04% of departed nests were predated by wild boars (*S. scrofa*). Most of the nests depredated by golden jackals (*C. aureus*) were predated before being caged with wire mesh in the morning survey. Brown and Macdonald (1995) reported that 63.8% of green turtle nests were predated by canids (*C. aureus* and *Vulpes vulpes*) on Akyatan beach. As in the study by Yılmaz et al. (2015), the golden jackal (*C. aureus*) continues to have the highest impact on egg predation at Akyatan Beach.

Nesting trend and abundance

Nest numbers during six consecutive nesting seasons (2006–2011) showed an insignificantly decreasing trend (Yılmaz et al. 2015), while longer-term data (2006–2021) identified an insignificant increasing trend with a mean of 377 nests (Fig. 7). The increasing nesting trend suggests that conservation efforts have been successful. Yılmaz et al. (2015) indicated an increase in green turtle nests in 6 consecutive nesting surveys at Samandağ and Kazanlı beaches. In other studies around the world, while the number of nests over 18 years showed a positive trend for the entire beach at Tortuguero, Costa Rica (Troëng and Rankin 2005), the number of nests over 14 years showed weak negative trends on Misali Island, Pemba (Giorno and Herrmann 2016). Recent studies showed that the Mediterranean and global green turtle populations suggest population increases in some regions (Stokes et al. 2014; Mazaris et al. 2017; Casale et al. 2018). The overall nesting female numbers (2006–2021) are lower than the current season (2020–2021). This discrepancy indicates that the number of turtles nesting on Akyatan Beach has increased over the years or the natality rate is higher than the mortality rate. The five consecutive years survey was carried out in 1994 and 1998 on Akyatan beach for the first time, but nests of green turtles are not caged (Aureggi et al. 2000). In the study carried out in 2002, cages were placed on the nests for the first time (Oruç et al. 2002). A survey has been carried out on Akyatan beach since 2006 (Yılmaz et al. 2015) and nests that do not undergo predation are caged. The reproductive maturation age of green turtles is estimated to be between 15 to 50 years (Limpus and Walter 1980; Limpus and Chaloupka 1997; Chaloupka et al. 2004; Lemm 2006). From recent surveys, we can deduce the hatchlings come to the Akyatan beach after reaching sexual maturity. Despite the increase in the number of nesting females, nest numbers had an insignificantly increasing trend. The insignificant increase in nests means the yield for the 16-year consecutive conservation study despite the intensive predation of eggs and hatchlings by mammals on the Akyatan beach. This shows once again that long-term survey studies are essential.

Threats on the beach

Golden jackals killed seven female green turtles during the 2012 and 2021 nesting seasons. Previous studies recorded the killing of nesting females by golden jackals (Peters and Verhoeven 1992; Akçınar et al. 2006). As in Yılmaz et al. (2015), the main threats were predation of eggs and hatchlings by jackals and eggs by wild boars. Since golden jackals and wild boar are protected as part of the Wildlife Development Area, removal and killing are not an option. In addition to the daytime survey, the night survey can be carried out mainly to prevent adult and nest predation during the nesting period. However, the 22 km long Akyatan beach can complicate this survey very difficult. Providing additional natural nutrients which are included in the diet of golden jackal could reduce the depredation of adults, eggs, and hatchlings.

CONCLUSIONS

In conclusion, Akyatan Beach continues to be essential for the green turtle population in the Mediterranean. The clutch size, hatching success, and incubation duration differed significantly between the nesting seasons. Over ten consecutive years, the mean hatching success and incubation durations showed a significant decreasing trend. The first, last nesting and peak-nesting seasons vary in the same or different populations. The golden jackal (*C. aureus*) predation of eggs continued to have the highest impact. The insignificant increasing trend in the green turtle nests during 16 consecutive surveys showed that conservation efforts are successful despite mammal predation of the nests. As well as the continuation of the surveys for the continuity of the population, studies about how global climate change affects the green turtle will contribute to the conservation biology of Mediterranean turtle populations.

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