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RESEARCH ARTICLE

Sporadic nesting grounds of loggerhead turtle on the Aegean coasts of Türkiye

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Abstract

Loggerhead sea turtles (*Caretta caretta*) are expanding their nesting range in the Mediterranean, likely in response to rising sea surface temperatures. While major nesting grounds are well-documented in southern Türkiye, sporadic nesting in the Central Aegean remains poorly understood. We analysed 14 years (2012–2025) of nesting data from Kuşadası and the surrounding region, evaluating temporal trends, spatial hotspots, and reproductive parameters, including clutch size, hatching success, and incubation duration. Nesting activity exhibited a significant exponential increase ($y=0.070 \cdot e^{0.402x}$), transitioning from an average of 1.3 nests per year (2012–2022) to a record high of 13 nests in 2025. Spatial analysis identified Parlamenterler Sitesi (Didim) and Ayyıldız Cafe (Kuşadası) as emerging hotspots. While clutch size (70.7±15.6) did not correlate with hatching success ($p>0.05$), seasonal declining trend in success was observed, with June nests (75.2%) outperforming August (48.6%) nests. Mean incubation duration (53.2±4.5 days) confirms the thermal suitability of these beaches. The Kuşadası region is transitioning from a sporadic to a regular minor nesting ground. Conservation efforts should prioritize the "early-season success window" and the protection of newly identified hotspots to support this range expansion.

Keywords: *Caretta caretta*, nest, hatchlings, Kuşadası, Türkiye

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Introduction

The loggerhead sea turtle (*Caretta caretta*) is the most common sea turtle species in the Mediterranean Sea, with a nesting range historically concentrated in the eastern basin (Casale *et al.* 2018). Türkiye hosts the second-largest nesting

population in the Mediterranean, after Greece, with nesting activities typically confined to the southern coastline (Turkozan and Kaska 2010). Since the late 1980s, systematic monitoring has revealed over 20 key nesting beaches, including Dalyan, Belek, and Patara, located predominantly along the Mediterranean coast (Turkozan and Kaska 2010). However, in response to rapidly changing environmental conditions, the spatial distribution of nesting activity is becoming increasingly dynamic, characterized by a rise in "sporadic nesting"—rare nesting events in areas with historically low or no recorded activity (Tomás *et al*. 2002; Delaugerre and Cesarini 2004; Bentivegna *et al.* 2008; Sénégas *et al*. 2008; Hochscheid *et al*. 2022; Şirin and Başkale 2024; Margaritoulis *et al*. 2025).

Global climate change significantly threatens sea turtle populations, primarily due to increasing sand temperatures that influence temperature-dependent sex determination (TSD) and hatching success (Patricio *et al*. 2017; Turkozan *et al.* 2021, 2023). High incubation temperatures in traditional rookeries are leading to the feminization of populations (Jensen *et al.* 2018) and reduced hatchling survival (Rivas *et al*. 2024), prompting concerns about the long-term viability of these sites. Consequently, range expansion into cooler, higher latitudes is considered a critical adaptive mechanism for the species (Pike 2013; Santidrián Tomillo and Spotila 2020). This phenomenon, described as a "dormant mechanism" of colonization, involves philopatric females opportunistically nesting near developmental foraging grounds when environmental conditions become favourable (Carreras *et al*. 2006, 2011; Maffucci *et al*. 2006; Clusa *et al*. 2014). While this trend has been extensively documented in the western Mediterranean, where nesting is increasing in Italy and Spain (Hochscheid *et al*. 2022; Cardona *et al*. 2023), similar range shifts are now being observed in the Aegean Sea (Yalçın-Özdilek *et al*. 2020; Margaritoulis *et al*. 2025).

Recent investigations on the Turkish coastline indicate a northward and westward expansion of nesting activity beyond the recognized Mediterranean strongholds (Yalçın-Özdilek *et al*. 2020; Sandık *et al*. 2023; Şirin and Başkale 2024). While the main nesting sites remain between Ekincik and Samandağ (Turkozan and Kaska 2010), sporadic nests have been increasingly recorded along the Aegean coast, including locations such as Marmaris, Kuşadası, and Urla (Sürücü *et al*. 2017). Nesting has notably extended the northernmost Aegean latitudes, with verified nests on the Gelibolu (Gallipoli) Peninsula in 2020 (Yalçın-Özdilek *et al*. 2020) and Gökçeada Island in 2023 (Sandık *et al*. 2023). These records delineate the northern limit of loggerhead nesting in the eastern Mediterranean and support the hypothesis that turtles are seeking alternative nesting sites in response to climate change.

Despite their low density, these sporadic nesting sites may serve as crucial reservoirs for population resilience, potentially providing cooler thermal profiles that promote male hatchling production (Şirin and Başkale 2024). However, these newly identified nesting sites frequently overlap with regions experiencing

significant anthropogenic pressure, such as extensive tourism and coastal development, resulting in potential "ecological traps" where nesting efforts may be compromised by human interference (Pike 2013; Hochscheid *et al*. 2022). Given that minor nesting areas may remain undetected without specific monitoring (Prato *et al*. 2022), it is imperative to identify these sporadic occurrences to enhance national conservation strategies. This paper presents data on sporadic nesting occurrences along the Aegean coast of Türkiye, evaluating the characteristics of these new sites and their potential role in the future distribution of loggerhead turtles in the Mediterranean.

Materials and Methods

The study site, encompassing Kuşadası and its surrounding areas (Figure 1), falls within the monitoring range of Ekosistemi Koruma ve Doğa Sevenler Derneği (Ecosystem Protection and Nature Lovers; EKODOSD), a non-governmental organization (NGO) focusing on environmental problems and marine megavertebrates. The organization has committed members who maintain year-round monitoring efforts, including the documentation of stranded animals. During these surveys, all potential nesting beaches were inspected for sea turtle activity. The beaches were monitored daily by volunteers. Once a nesting attempt was identified, the site was visited by experts to locate the eggs. Nests were located by carefully probing the sand with a metal rod, ensuring no damage to the clutch. The distance of nests to the high tide line was measured by a tape. Nests were enclosed in cages and marked with perimeter tape to safeguard against predation and human interference. As the anticipated hatching dates approached, volunteers monitored the sites in shifts to record the exact timing of hatchling emergence. This allowed for the precise calculation of incubation duration—the time elapsed from oviposition to the first emergence. Furthermore, volunteers kept monitoring nests during the entire hatching period of each nest and recorded and guided hatchlings to ensure they reached the sea. Following the completion of the emergence period, nests were excavated to analyse their contents. Data collected included the number of empty shells (hatched eggs), unhatched eggs, and embryos, which were used to determine the total clutch size. Hatching success was subsequently calculated as the percentage of hatched eggs relative to the total clutch size. All means are expressed as mean ± standard deviation (SD). All statistical analyses were performed using SPSS (V.26) and visualizations using Python (V3.10). Statistical significance for all tests was set at a threshold of $p<0.05$.

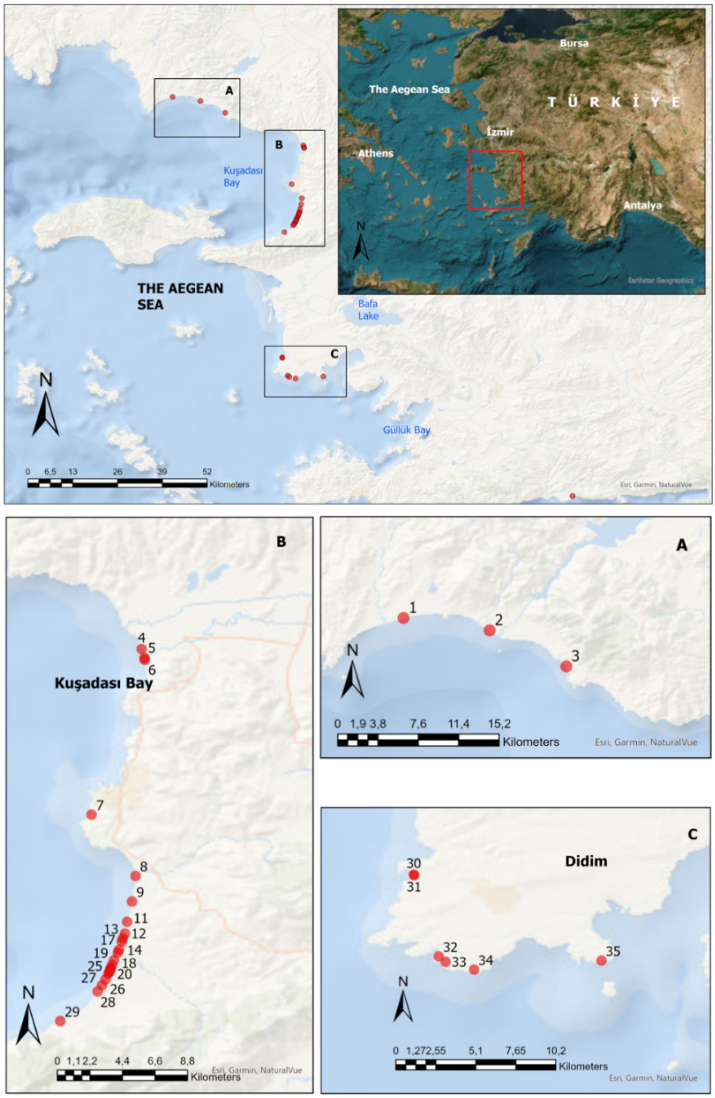

Figure 1. The locations of sporadic nesting events. The nesting occurred in three segments (A, B and C) of the Aegean coasts. 1. Gümüldür Ürkmez Plajı, 2. Gümüldür Cactus, 3. Özdere Merkez Bankası, 4. Pamucak, 5. Efes Selçuk Dereli, 6. Pamucak Dereli, 7. Kadınlar Denizi, 8. Evim Tatil Sitesi, 9. Nazilli Sitesi, 11. Emir Beach, 12. Sökem Sitesi, 13. Orsen Sitesi, 14. SSK Sitesi, 17. Özçelik, 18. Efe Sitesi, 19. Ayday Sitesi, 20. Özsoy Sitesi, 21. Gönül Sitesi, 22. Örnekköy Sitesi, 23. Söke Sahil Kumsalı, 24. Köyüm Sitesi, 26. Sevgi Plajı, 27. Öztarımcılar, 28. Ayyıldız Kafe, 29. Şahika, 30. Didim Anadolu Otel, 31. Didim Sağtur Plajı, 32. Didim Aquasis, 33. Didim Manastır Koyu, 34. Didim Parlementerler Sitesi, 35. Didim Third Bay, 36. Muğla Ören Plajı.

Results

The nesting occurred mainly in three segments of the Aegean coasts (Figure 1). Monitoring efforts between 2012 and 2025 recorded a total of 43 confirmed *C. caretta* nests with a total of 2970 eggs. All hatchlings were confirmed as reaching the sea (Table 1). The first decade of the study period was characterized by low-frequency, sporadic activity (0–2 nests per year). However, a sharp upward trajectory began in 2023, with nesting frequency following an exponential growth model ($y=0.070 \cdot e^{0.402x}$, $p<0.001$) (Figure 2). The highest annual nesting density was recorded in 2025 (n=13), representing a nearly tenfold increase over the historical average.

Table 1. Hatching success on sporadic nesting beaches

	Number of eggs	Percentage (%)
Hatched	1880	63.3
Unhatched	924	31.1
Dead embryos	166	5.6
Total	2970	100

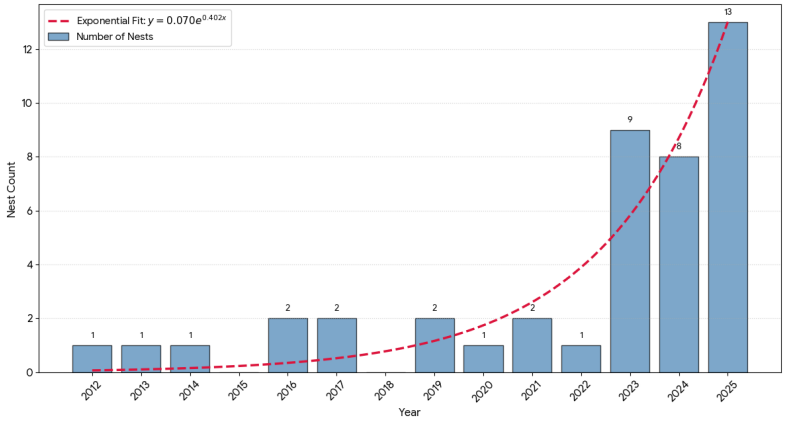

Figure 2. Annual nesting trend of loggerhead turtles (*Caretta caretta*) in the Kuşadası region (2012–2025). The bar chart represents the total observed nests per year (n=43), with the dashed line indicating the exponential growth model ($y=0.070 \cdot e^{0.402x}$).

Nesting was distributed across the Central Aegean coastline, including Kuşadası, Didim, Selçuk, and Gümüldür. Hotspot analysis revealed that certain beaches, such as Parlamenterler Sitesi and Ayyıldız Cafe, supported multiple nesting events over the study period (Figure 1). Turtles placed nests at an average distance of 7.63±3.20 m from the high-tide line. Most loggerhead turtles prefer to nest in a narrow band close to the shoreline. Over 75% of the nests were placed between 4 and 8 meters from the high tide line. While a negative correlation was observed between distance to sea and hatching success, it was not statistically significant

(Spearman rho=−0.249, p>0.05) and nest placement was generally consistent across the region (Figure 3).

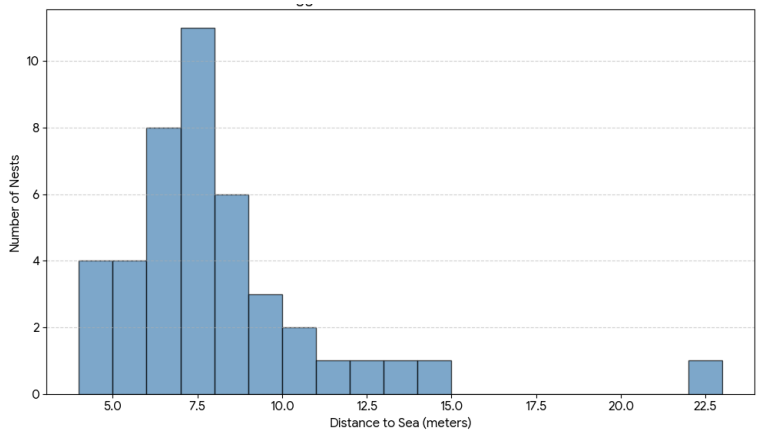

Figure 3. Spatial distribution of nest placement relative to the high-tide line. The histogram displays the frequency of nests at various distances from the sea (meters). Most nesting activity is concentrated within a 4–8 meter zone, highlighting the critical coastal strip used by the emerging population.

The mean clutch size was 70.7±15.6 eggs. No significant correlation was found between the number of eggs (clutch size) and hatching success (Spearman rho=0.084, p>0.05). However, the timing of nesting played a critical role in embryonic survival. The mean hatching success was higher in June (75.2%) than in August (48.6%), this seasonal decline was not statistically significant (Kruskal-Wallis test, H=4.86, p=0.088) (Figure 4).

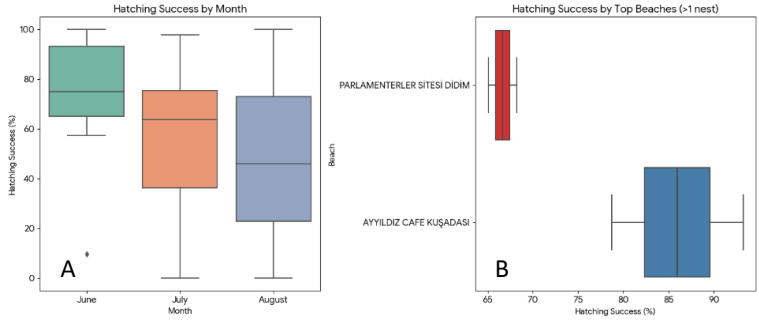

Figure 4. Distribution of hatching success (%) of *Caretta caretta* nests (n=42) categorized by (A) nesting month and (B) high-frequency nesting beaches (n > 1). Boxplots indicate the median (center line), interquartile range (box), and the minimum/maximum values (whiskers), excluding the clutch size outlier (n=2). The data highlights higher median success during the month of June and the site-specific variability in the Central Aegean.

Incubation durations ranged from 45 to 60 days, with a mean of 53.2±4.5 days. These durations are consistent with thermally viable environments capable of producing both sexes. Late-season nests (August) exhibited longer incubation periods (56.3±3.8 days) compared to June nests (53.2±3.9 days), reflecting the cooling of sand temperatures during the late stages of development in September. No significant correlation was found between the incubation duration and hatching success (Spearman rho=-0.158, $p>0.05$).

Discussion

Increasing amounts of sporadic nesting grounds and westward and northward expansion of nesting ranges provide clear evidence of increasing habitat suitability for sea turtles in the Aegean and western Mediterranean (Hochscheid *et al*. 2022; Cardona *et al.* 2023; Margaritoulis *et al*. 2025; Panagopoulou *et al*. 2025). The nesting records from Aegean coasts (2012–2025) provide another clear window into the northward expansion of loggerhead turtles in the Mediterranean. The most striking finding is the exponential growth in nest numbers, particularly the jump to 13 nests in 2025. This trend suggests that the Central Aegean is no longer an "accidental" nesting site but becoming a functional reproductive habitat paralleling recent expansions of loggerheads into the Western Mediterranean and green turtles (*Chelonia mydas*) into the central basin (Erdoğan *et al*. 2001; Hochscheid *et al*. 2022; Cardona *et al*. 2023; Margaritoulis *et al*. 2025; Panagopoulou *et al*. 2025). One possible explanation for these sporadic nesting events is that they are relicts of ancient nesting populations in these locations (Carreras *et al*. 2018), as some sporadic nesting had been reported in the past (Llorente *et al.* 1992). However, another possibility could be that these nests are examples of contemporary long-distance dispersal events from distant nesting populations (Carreras *et al*. 2018). Carreras *et al*. (2018) hypothesized that sporadic nesting within developmental foraging habitats may serve as an adaptive strategy to bypass the constraints of philopatry, thereby enhancing both the dispersal potential and the resilience of the species in flux.

The confirmed incubation range of 45 to 60 days is biologically significant. In sea turtles, incubation duration is a proxy for nest temperature (Mrosovski *et al*. 2009). A 45-day period is exceptionally short for this latitude and suggests that "heat windows" in the Central Aegean are adequate for successful hatching. Recent studies reported that the prevailing climatic conditions in the western Mediterranean, both terrestrial and marine, seem conducive to loggerhead turtle nesting during summer months (Cardona *et al*. 2023; Santidrián Tomillo *et al*. 2024). Models predict that climate change will further increase the suitability of the Northern and Western Mediterranean for nesting and foraging, potentially facilitating the establishment of new populations (Mancino *et al*. 2022; Arslan *et al*. 2023; Mazaris *et al*. 2023).

As incubation temperatures in major eastern rookeries increasingly exceed the pivotal temperature for balanced sex ratios, driving feminization (Kaska *et al*. 2006; Candan and Kolonkaya 2016; Turkozan *et al*. 2023), northern sites like Gökçeada may act as critical thermal refugia producing male hatchlings. The cooler thermal profiles of these higher-latitude beaches could provide resilience against the extreme temperatures that jeopardize reproductive output in southern Türkiye. The westward and northward expansion of nesting beaches likely serves as an adaptive response to rising sea surface temperatures and sand temperatures at traditional rookeries (Mazaris *et al*. 2013; Mancino *et al*. 2022; Türkozan and Tonay 2024).

The lack of correlation between distance to sea and success suggests that the turtles are successfully identifying suitable nesting zones across the available beach width. The decline in hatching success from June (75.2%) to August (48.6%) has critical management implications. Despite being the most productive, we often overlook early-season nests because monitoring typically peaks in late summer. Conservation efforts should prioritize the protection of June nests to maximize the reproductive output of this emerging population.

Effective management requires a shift from focusing solely on high-density aggregations to a broader "dynamic management" approach that includes potential colonization zones. This includes regulating beach usage in newly identified sporadic areas like Phaselis and Kazanova (Şirin and Başkale 2024) to maintain their high hatching success and implementing predator control and habitat restoration at high-density sites like Yakacık (Sözbilen 2024). Future research must prioritize genetic profiling of these colonizers to determine if they represent range expansions of specific Regional Management Units (RMUs) or the establishment of genetically distinct subpopulations.

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Author contributions: O.T. and B.S. planned the study. B.S. carried out the fieldwork and collected the data. O.T. analysed the data and prepared the first draft. Both authors reviewed and confirmed the final draft of the paper.

İri başlı deniz kaplumbağasının Ege kıyılarındaki rastgele yuvalama alanları

Öz

İribaşlı deniz kaplumbağaları (*Caretta caretta*), muhtemelen artan deniz yüzeyi sıcaklıklarına yanıt olarak Akdeniz'deki yuvalama alanlarını genişletmektedir. Ana yuvalama alanları Türkiye'nin güneyinde iyi keydedilmiş olsa da, Orta Ege'deki seyrek yuvalama faaliyetleri henüz yeterince anlaşılamamıştır. Bu çalışmada; Kuşadası ve çevre bölgesinden elde edilen 14 yıllık (2012-2025) yuvalama verileri analiz edilerek; zamansal eğilimler, mekansal yoğunluk alanları (hotspots) ve kuluçka büyüklüğü, yavru çıkış başarısı ile kuluçka süresi gibi üreme parametreleri değerlendirilmiştir.

Yuvalama faaliyeti, 2012-2022 yılları arasında yıllık ortalama 1,3 yuvadan 2025 yılında 13 yuva ile rekor bir seviyeye ulaşarak anlamlı bir üstel artış ($y=0.070 \cdot e^{0.402x}$) göstermiştir. Mekansal analizler, Parlamenterler Sitesi (Didim) ve Ayyıldız Kafe (Kuşadası) bölgelerini yeni gelişen sıcak noktalar olarak belirlemiştir. Yuva büyüklüğü (70.7±15.6) ile yavru çıkış başarısı arasında anlamlı bir ilişki saptanmazken ($p>0.05$), başarı oranında sezonsal olarak bir düşüş eğilimi gözlemlenmiştir; Haziran ayı yuvaları (%75,2), Ağustos ayı yuvalarına (%48,6) göre daha yüksek performans göstermiştir. Ortalama kuluçka süresi (53.2±4.5 gün), bu kumsalların termal uygunluğunu doğrulamaktadır.

Kuşadası bölgesi, "seyrek yuvalama alanı" statüsünden "düzenli küçük yuvalama alanı" statüsüne geçiş yapmaktadır. Koruma çalışmaları, bu alan genişlemesini desteklemek amacıyla "erken sezon başarı penceresine" ve yeni tanımlanan yoğunluk alanlarının korunmasına öncelik vermelidir.

Anahtar kelimeler: *Caretta caretta*, yuva, yavrular, Kuşadası, Türkiye

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