The population status of loggerhead sea turtles (*Caretta caretta*) in Kefalonia, Greece.

Abstract

Understanding the status of a population by measuring factors including population size, age structure and reproductive output is important in developing conservation measures that aid in the recovery of a threatened species. However, there is a lack of this information in sea turtle populations due to the difficulty in researching them. I study the status of a population of loggerhead sea turtle using the temporal dynamics of nesting activity and size turtle, and how this is associated with the reproductive output and nesting behaviour. We find there was an overall increase in the nest count, from 36 in 1984 to 365 in 2024, and a decreasing mean in size of turtle (width of plastron drag track), from 14.85 cm in 2017 to 12.87 cm in 2024. This can be explained by an increasing number of younger individuals into the population. The turtle size was positively correlated with clutch size, due to larger turtles having a greater egg carrying capacity. The size of turtle was also associated with the location of nest. We conclude that the population has recovered, which may be due to the conservation measures applied at the nest beach, with protection of nests and hatchlings, and therefore we recommend this to be continued.

Introduction

Research suggests we are currently entering or are within a sixth world mass extinction (Barnosky et al., 2011; Wake & Vredenburg., 2008). There has been an unprecedented loss of biodiversity worldwide (Gumbs et al., 2020), with over 200 vertebrate species going extinct in the last century (Ceballos et al., 2017). Anthropogenic impacts to species have accelerated these extinction events, causing major declines in population numbers, through climate change, direct-killing, habitat degradation and pollution (Barnosky et al., 2011; Rodríguez-Caro et al., 2023). Therefore, conservation is essential in order to mitigate these impacts from human activity and return the state of these threatened species to stable populations (Robinson et al., 2018; Rodríguez-Caro et al., 2023; Shackelford et al., 2018).

Improving the knowledge on the demography of populations, including the abundance, age structure and birth rate is essential in measuring their population status, viability and extinction risk (Broderick et al., 2003; Conde et al., 2019; Palmero et al., 2021; Pas-Vinas et al., 2013; Rushing et al., 2016). This can be used to determine whether a population is threatened, and therefore justify whether active conservation management is required to protect the species (Ceriani et al., 2019; Finkelstein et al., 2010). Further, providing a time series of these demographic variables supplies information of the predicted population trajectory and the life stages which may at threat (Pas-Vinas et al., 2013; Volis & Deng., 2020). Thus, can be used to apply suitable conservation intervention, as well as evaluating whether previous conservation measures have been effective (Ceriani et al., 2019; Hu et al., 2019; Palmero et al., 2021; Robinson et al., 2018).

The loggerhead sea turtle (*Caretta caretta*) is listed globally as vulnerable on the IUCN Red List (Casale and Tucker., 2017), although the Mediterranean subpopulation is categorized as least concern (Casale., 2015). Loggerhead sea turtles are sensitive to anthropogenic disturbance to their environment, predation, and the accelerated rate of global warming (Almpanidou et al., 2018; Sousa-Guedes et al., 2025). Habitat degradation, human disturbance and pollution affects sea turtles nesting grounds (Casale et al., 2015; Pietroluongo et al., 2023), boat strikes and by-catch can cause direct death to sea turtles (Casale., 2011; Casale et al., 2015), and predators eat eggs in nests and hatchlings (Leighton et al., 2011). Global warming may cause phenological shifts (Almpanidou et al., 2018), changes in the distributional range of sea turtles (Hays et al., 2014), and impacts foraging grounds (Goudarzi et al., 2024; Patel et al., 2016) and hatchlings due to their temperature dependent sex determination (Almpanidou et al., 2018; Hays et al., 2017). Consequently, conservation efforts are currently running worldwide to protect the loggerhead sea turtle (Kornaraki et al., 2006), and there has been an extensive input of research on sea turtles to guide this, which primarily involves the monitoring of populations at nesting beaches (Robinson et al., 2023). However, there is still a gap in knowledge of sea turtle population estimates and temporal dynamics, as sea turtles are difficult to study due to them being aquatic (Robinson et al., 2023), their long and complex life history (Maurer et al., 2021), and being highly migratory (Girard et al., 2009).

Here, I study the status of a population of loggerhead sea turtles on Kamina and Potamakia beach, Kefalonia, Greece. The first aim was to determine the population trajectory and why this was happening. First, I test whether the nest count varies annually, and predict that the nest count will increase with year due to protection from the NGO which increases the number of breeding individuals into the population. Second, I test if the size of turtle tracks varies with year and predict that the mean size of turtle will remain the same, as new, smaller individuals will enter the population, and re-migrant individuals will continue to grow and nest. The second aim was to determine how the size of turtle was associated with the reproductive output and nesting behaviour. First, I test if the clutch size varies with the size of turtle. I predict that the clutch size will increase with size of turtle, as larger turtles have a greater capacity to carry more eggs. Then, I test the location of nest laid in relation to the size of turtle. I predict that there will be locations that are favoured by different sized turtles, as these regions will have beach features that are more suitbale to them and their size. Next, I test whether the distance of nest up the gradient of the beach varies with the size of turtle. I predict that nests laid by larger sized of turtle will be a further distance up the beach from the tide, as smaller turtles will have a greater ability to carry themselves further distances. Finally, I test if the size of turtle is associated with the date the nest is laid in the season and predict that there is no significant difference in the date the nest is laid with the size of turtle. This information can be used to provide a better understanding of the population, the status, and its future (Ceriani et al., 2019; Hanscom et al., 2020; Mazaris et al., 2005; Palmero et al., 2021; Rushing et al., 2016).

Methodology and Materials

Study species

The loggerhead sea turtle is a marine reptile (Fuentes et al., 2012) distributed around the world in sub-tropical and temperate oceans (DiMatteo et al., 2022; Margaritoulis et al., 2023). This includes the Mediterranean Sea, where they are the most abundant sea turtle species (DiMatteo et al., 2022), with the majority of rookeries concentrated in the eastern basin, such as Greece (Casale et al., 2015; Margaritoulis et al., 2023). Juvenile sea turtles disperse into open ocean, with hatchlings from the Ionian region distributing across the Ionian, Adriatic and south-central Mediterranean areas (Luschi & Casale., 2014). They live within pelagic areas before moving to neritic and benthic foraging sites (Snover et al., 2010), feeding on organisms that live within sea grass (Patel et al., 2016). The energy gained is allocated towards growth in juveniles, until a few years prior to sexual maturity where there is a shift and energy is allocated towards vitellogenesis (production of egg-yolk) for reproduction (Omeyer et al., 2017; Patel et al., 2016; Smelker et al., 2014). Loggerhead sea turtles are indeterminate growers, whereby they continue to grow throughout their whole life (Morales-Mérida et al., 2024; Omeyer et al., 2018). Therefore, the turtle size increases with age (Casale., 2011; Frazer., 1983; Turner Tomaszewicz et al., 2022; Van Houtan & Halley., 2011). Upon reaching sexual maturity, estimated at 25 years old (Casale et al., 2018; Casale & Heppell., 2016), female loggerhead sea turtle adults migrate to breeding areas and nesting beaches from foraging sites (Nagelkerken et al., 2003; Rees et al., 2013). This occurs on average every 2 to 3 years (Bjorndal et al., 1983; Casale et al., 2018), usually depending on the foraging conditions (Neeman et al., 2015). Sea turtles exhibit natal philopatry, whereby females return to the same beach each time they nest (Baltazar-Soares et al., 2020; Carreras et al., 2018). This has arisen due to the increased certainty of finding a mate, and that the area is a suitbale site for their offspring (Stiebens et al., 2013). This also creates an isolated population (Stiebens et al., 2013; Lasala et al., 2018), and so can assume that the nesters on a beach belong to the same population. The loggerhead sea turtle nesting season in the Mediterranean occurs between May and September (Girard et al., 2021). The nesting sequence occurs at night (Salmon et al., 1995), and involves the female sea turtle emerging from the sea and crawling up the beach, digging the nest, laying the eggs (oviposition), refilling the nest and camouflaging it with sand, and returning to the sea (Ilgaz et al., 2011; Marco et al., 2015). Loggerhead sea turtles lay on average 3 - 5 nests (clutches) per season (Luna-Ortiz et al., 2024; Rees et al., 2020), and deposit 50 - 150 eggs per nest (clutch), with a mean of 110 eggs (Le Gouvello et al., 2020; Margaritoulis et al., 2003). The hatchlings exhibit temperature-dependent sex determination, in which females are produced under warmer temperatures, whilst males are produced at cooler temperatures, with a pivotal temperature of around 29 °C where there is a 50:50 sex ratio (Hays et al., 2017). These nests are laid in selected places on the beach relevant to increasing the turtle's reproductive success (Serafini et al., 2009; Siqueira-Silva et al., 2020) and maintaining the sex-ratio of hatchlings (Marco et al., 2018). The potential factors which may affect the nest placement includes vegetation cover, sand composition, sand moisture, distance of nest from the water, temperature, beach elevation, beach width and anthropogenic disturbance (Martins et al., 2022; Mazaris et al., 2006; Siqueira-Silva et al., 2020; Weishampel et al., 2003). The eggs incubate for approximately 2 months (Ilgaz et al., 2011), before hatching at night and returning to the ocean (Martins et al., 2021).

Study site

Data were collected on Kaminia and Potamakia beaches on the southern coastline of Kefalonia island, Ionian Sea, Greece (Figure 1). From 1984 onwards, the Non-Governmental Organisation (NGO) 'The Katelios Group' have protected and monitored the loggerhead sea turtles on Kaminia and Potamakia beaches. Fieldwork was carried out during the nesting season of female loggerhead sea turtles in 2024 (July – August), and data collected in previous years of 2017, 2018 and 2019, as well as the nest counts from 1984, will also be used as part of this research to measure temporal dynamics.

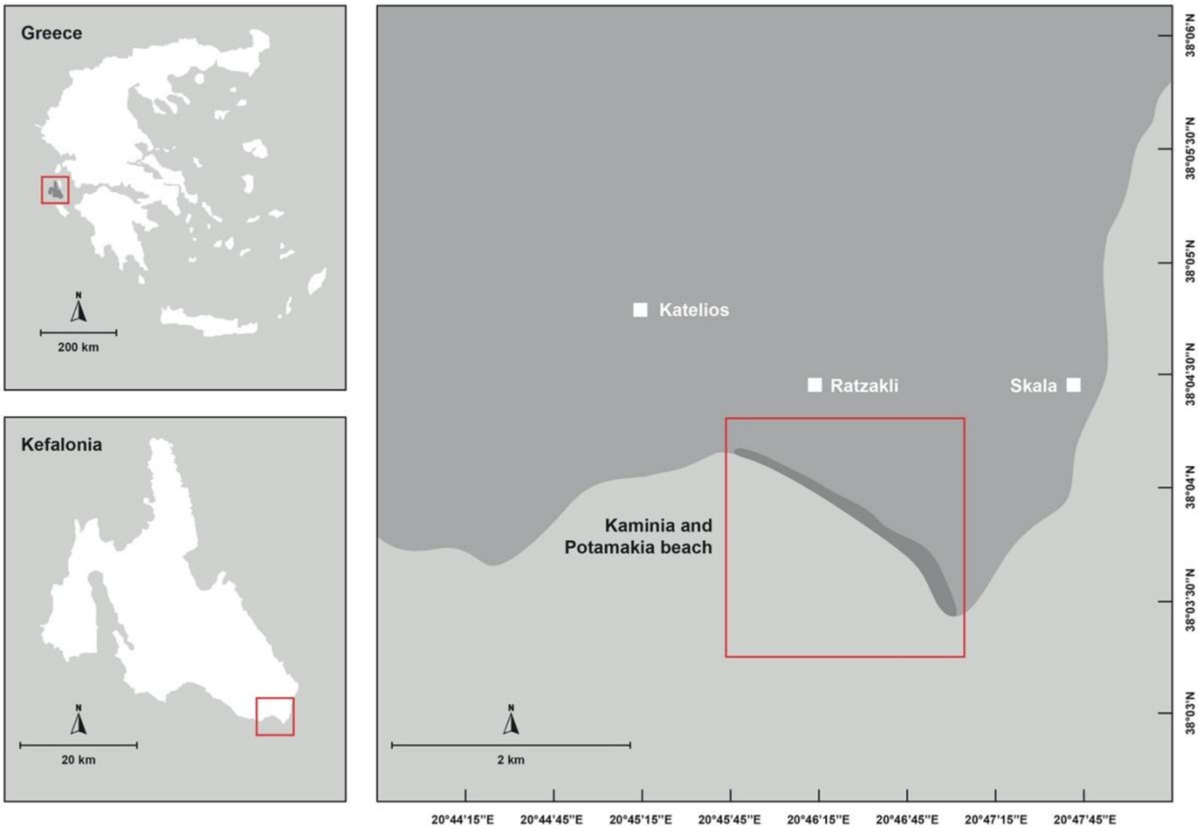

Figure 1. Maps of Greece, Kefalonia and the study area of Kaminia and Potamakia beaches on the southern coastline of the island.

Data collection

The beaches were surveyed on foot from one end to the other (west to east) (Figure 1). This was completed at sunrise so nesting turtles were not disturbed when nesting at night, and whilst the turtle tracks and nests are still fresh, as surveying earlier minimises the effects of human activity (which occurs later in the day by locals and tourists), and environmental factors such as wind and the tide that may disrupt the sea turtle tracks and nests and cause them to become less noticeable. Any female turtle tracks detected were classified into three categories: investigations, false crawl and nests. Investigations are tracks with no pits dug, and less than 10 meters from tide (Figure 2). False crawls are tracks more than 10 meters from tide and may have pits, but have not completed the nest (Figure 3). Nests are also more than 10 meters from tide, and contain pits, as well as a raised area of sand where the female has 'camouflaged' the nest (Figure 4). The tracks are marked with an X, using a stick on the sand so that they are not repeated.

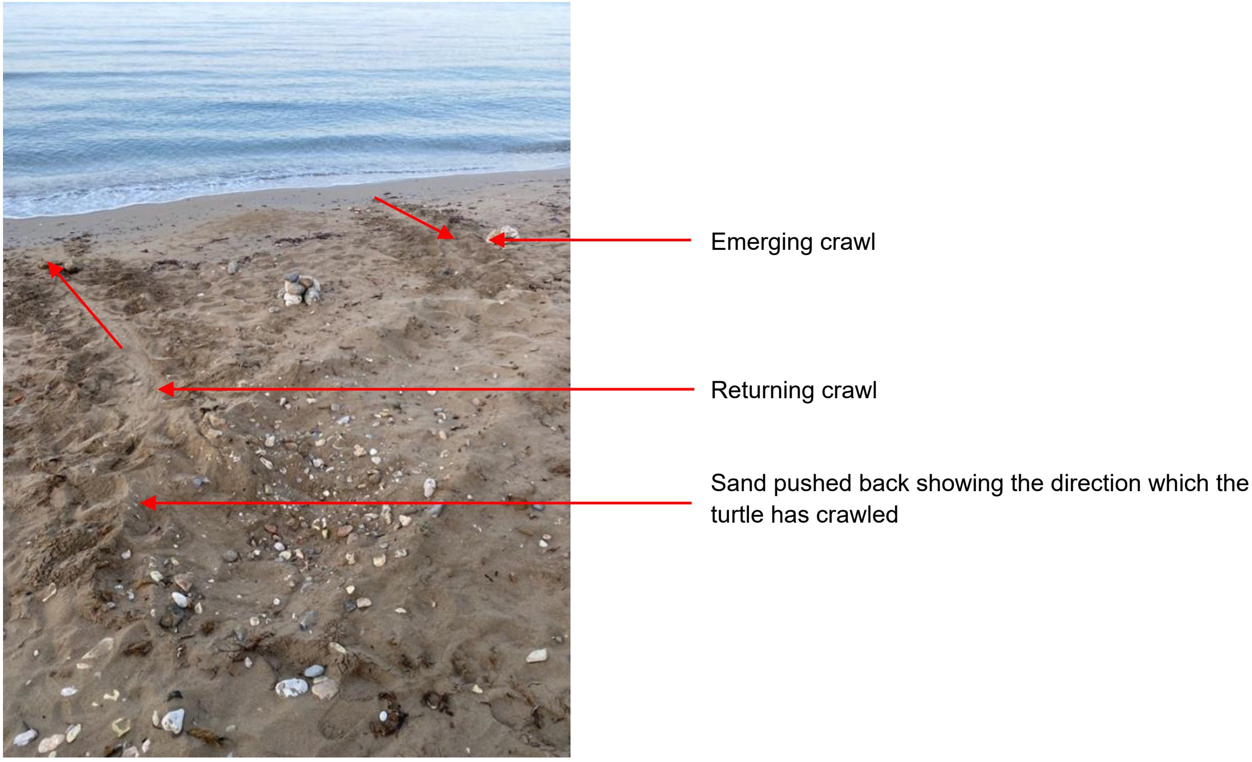

Figure 2. An investigation by a female loggerhead sea turtle on Kaminia and Potamakia beaches, Kefalonia.

Figure 3. A false crawl by a female loggerhead sea turtle on Kaminia and Potamakia beaches, Kefalonia.

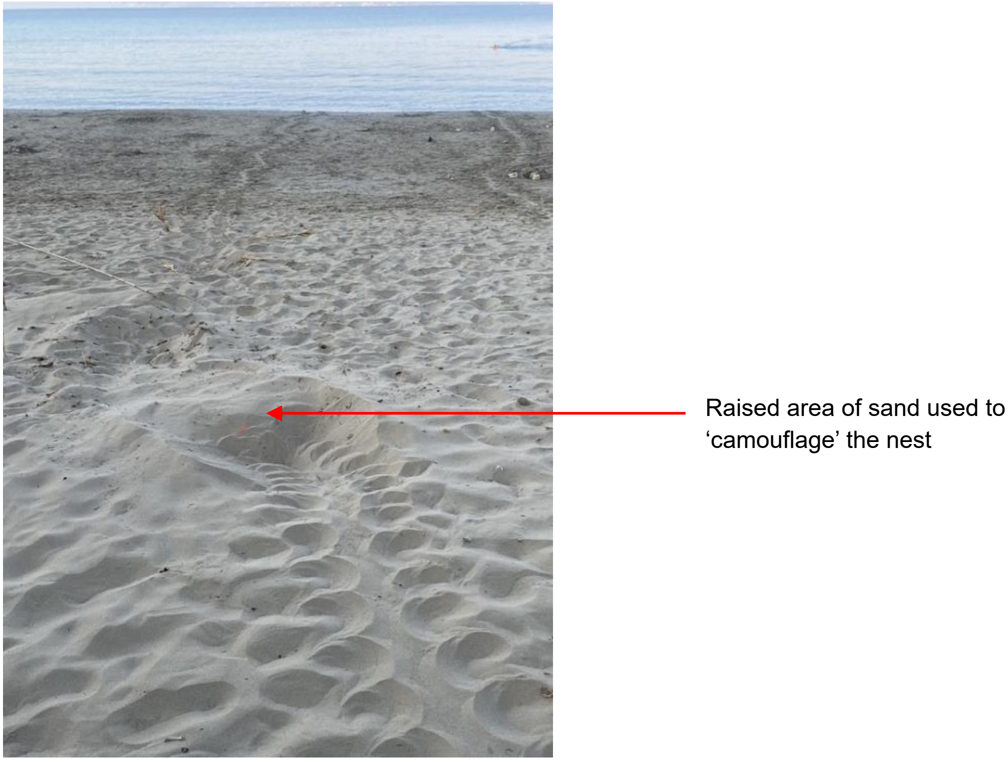

Figure 4. A female loggerhead sea turtle nest on Kaminia and Potamakia beaches in Kefalonia, showing the raised, ‘camouflaged’ area of sand of a nest.

Once a nest had been identified, data was recorded at this site. The size of turtle was calculated by measuring the width of the plastron drag track to 1 mm three times and then an average was calculated. This measurement is completed at a right angle between the two sand ridges (‘dunes’), created by the movement of turtle displacing the sand (Figure 5). The measurements were carried out on the emerging crawl from the surf, as this is more accurate measurement of the plastron drag track. The emerging crawl involves the turtle crawling uphill, whereas the return crawl involves sliding down which disturbs the sand more. The emerging crawl can be identified by the direction the sand has been pushed, with it toward the sea, as the turtle has crawled out and away (see Figure 2). This was also carried out in wetter sand, which has greater stability against wind forces and gravity, compared to dry sand, and therefore maintains the tracks and gives a more accurate measurement.

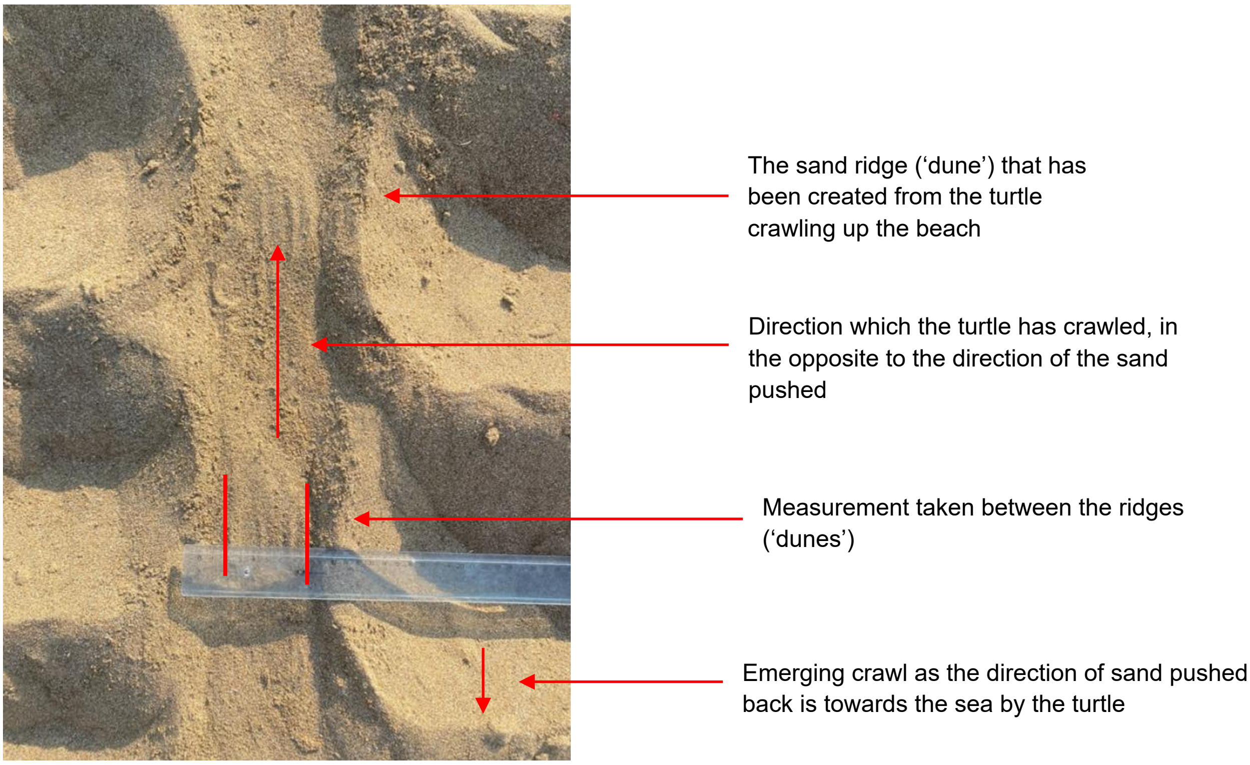

Figure 5. A female loggerhead sea turtle plastron drag track on Kaminia and Potamakia beaches, Kefalonia, showing where measurement is taken from between the two sand ridges ('dunes').

Once a nest has hatched, approximately 2 months after the nest was laid (Ilgaz et al., 2011), which is identified when tracks of hatchlings can be seen on the beach emerging from the nest (Figure 6), the nest is excavated. This is carried out after there has been three different days of tracks identified, to make sure all the eggs have hatched. Eggs are then dug and counted, including hatched and unfertilised eggs (Figure 7), with the total number giving the clutch size.

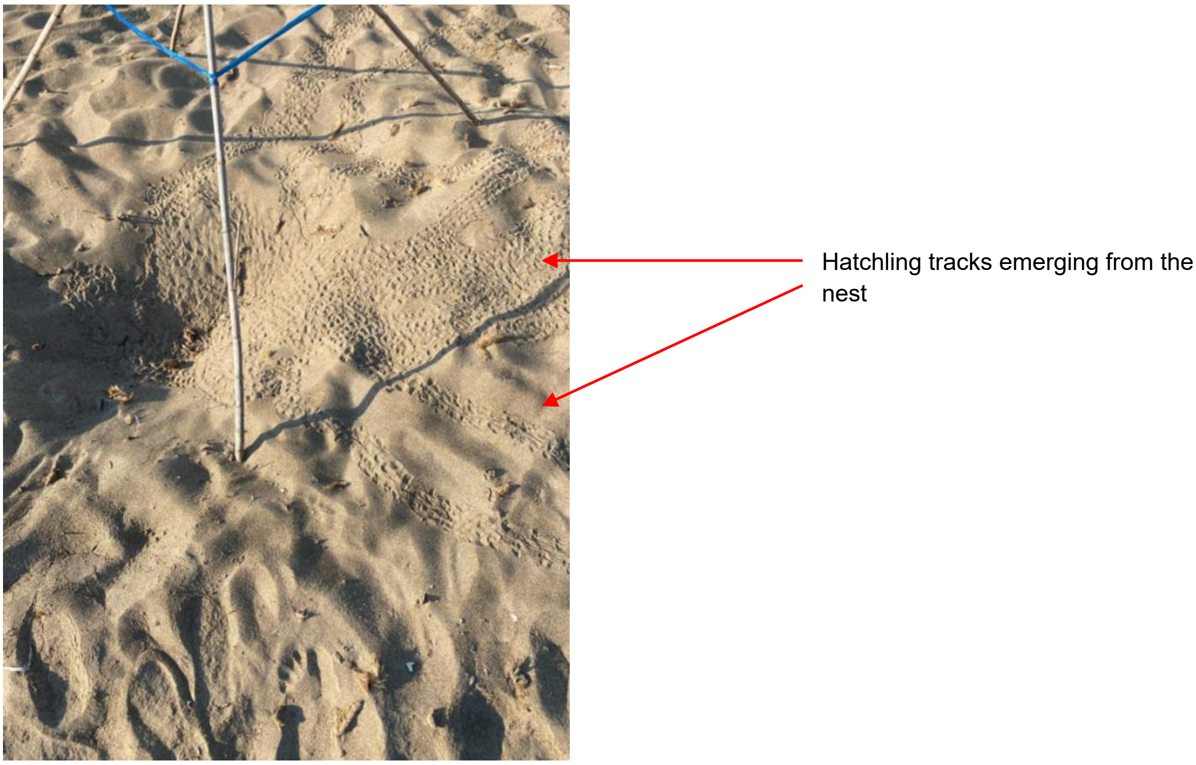

Figure 6. Hatchling tracks emerging from a nest on Kaminia and Potamakia beaches, Kefalonia.

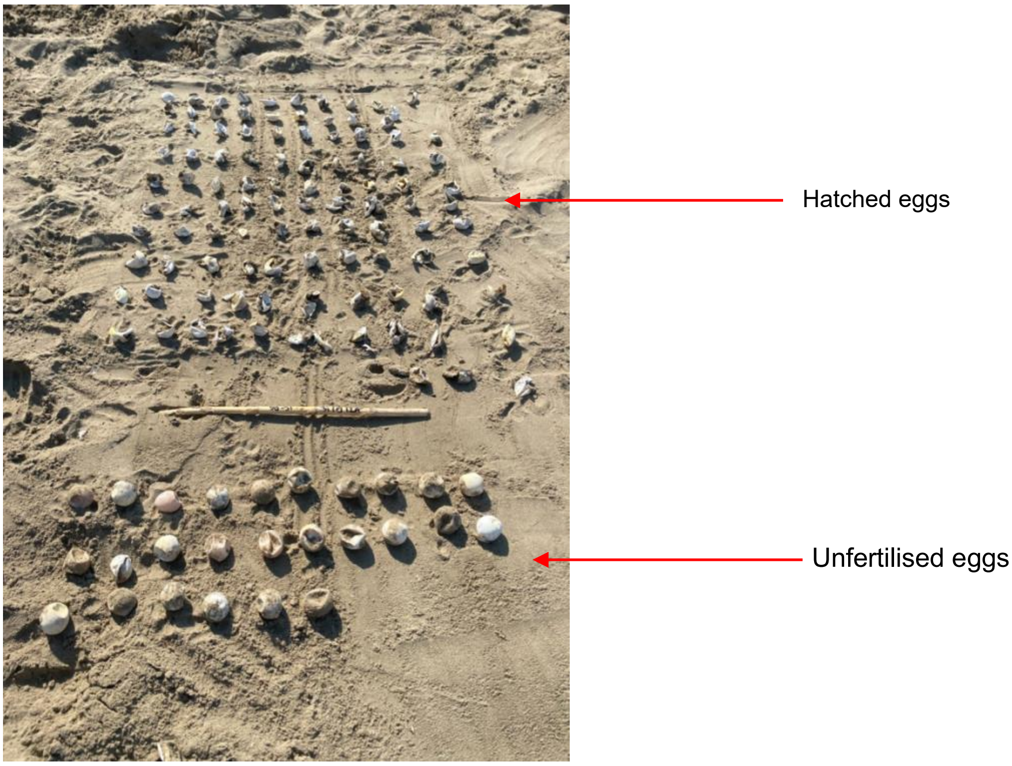

Figure 7. An excavation of a nest on Kaminia and Potamakia beaches, Kefalonia, with broken, hatched eggs at the top and unhatched, unfertilised eggs at the bottom.

Kamina and Potamakia beach marked with flags every 10 m from the west end to the east (Figure 1), ranging from 1 to 170. When a nest is identified, the previous flag number is marked down so that the location of the nest is known. Human activity is classified as quiet (low human activity) or busy (high human activity). Locations along the beach that contain beach bars, hotels and sunbeds, and therefore more people, were classified as busy, whilst the rest were classified as quiet. The distance of the nest up the beach is measured between the nest and the tide using a tape measure to the meter. The date when the nest is laid in the season is calculated as the days between the date in which the nest is observed, and the average start date of the nesting season from 2002, which is the 4th June. This gives a measurement of the days from the average start of nesting, to obtain a discrete variable which can be compared.

Statistical Analyses

Statistical analyses were performed on RStudio version 4.4.1 (R Core Team., 2024). The tidyverse (Wickham et al., 2019) and janitor (Bunch., 2022) packages were used for managing, utilising and storing data. General linear models (GLMs) were fitted using the lm() function of the car package (Fox & Weisberg., 2019) to test correlation between variables. All experiments had the same model structure, with a response variable, and a main predictor variable and control variables as fixed variables. Interaction terms were included, and removed if they were not significant. To obtain statistical data, including the p value, r^2, and number of observations (n), the summary() function of the modelsummary package was used (Sjoberg et al., 2021). Figures were created by plotting modelled data using the ggpredict() function of the ggeffects package (Lüdecke., 2018). A statistical significance of $p < 0.05$ was used for all models.

Nest count per year

We used a GLM to determine whether the nest count changed with year. The nest count was the response variable and year and $year^2$ as the fixed predictor variables. The quadratic effect ($year^2$) was significant in this experiment, and so the predicted model data was plotted with a quadratic slope. To test if there was an increase and decrease, we ran two separate GLMs between years 1984 - 2003 and 2004 - 2024, with nest count as the response variable and year as the fixed predictor variable.

Size of turtle

To investigate if the size of turtle changes with year, a GLM was used, with size of turtle as the response variable and year as the fixed predictor variable.

Clutch size

To investigate if the clutch size is associated with the size of turtle, a GLM was used, with the clutch size as the response variable and size of turtle as the fixed predictor variable. The date of oviposition, location of nest, year, and an interaction term between size of turtle and date of oviposition were added as fixed control variables.

Location of nest

To investigate if the location of nest is associated with the size of turtle, a GLM was used, with the location of nest as the response variable and size of turtle as the fixed predictor variable. Human activity, year, and an interaction term between size of turtle and human activity were added as fixed control variables.

Distance of nest from tide

To investigate if size of turtle is associated with the distance of nest from tide, a GLM was used with distance of nest from tide as the response variable and size of turtle as the predictor variable.

Date of oviposition

To investigate if size of turtle correlated with the date of oviposition, a GLM was used with date of oviposition as the response variable and size of turtle as the predictor variable. Year was added as a control variable.

Results

Inferring population trajectory

Nest count per year

The nest count data show a positive quadratic relationship between 1984 and 2024 (Table 1, Figure 8). Whether the nest count decreased and then increased was assessed. Between 1984 and 2003 there was a significant negative relationship between nest count and year (r^2

= 0.258, n = 20, p = 0.013) (Figure 9A). Between 2004 and 2024 there was a significant positive relationship between nest count and year ($r^2 = 0.550$, n = 21, p < 0.001) (Figure 9B).

Table 1. Predictors associated with the number of nests from a population of loggerhead sea turtles on Kaminia and Potamakia beaches, tested using a GLM. The nest count was measured between 1984 and 2024. Predictors in bold are significant (p < 0.05).

	Number of nests		
Predictors	*Estimates*	*CI*	*P*
Intercept	1282544.13	860683.43 – 1704404.83	**<0.001**
Year (Linear)	-1283.07	-1704.10 – -862.05	**<0.001**
Year (Quadratic)	0.32	0.22 – 0.43	**<0.001**
Observations	41		
R^2 / R^2 adjusted	0.649 / 0.631		

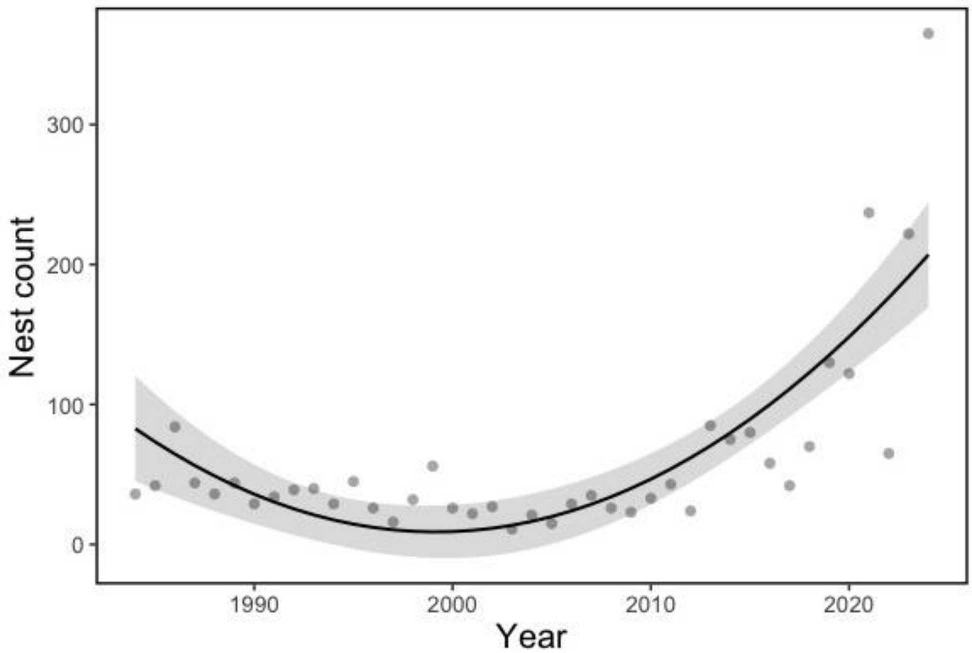

Figure 8. The relationship between the number of nests and year on Kaminia and Potamakia beaches, Kefalonia in 1984 - 2024. The predicted regression line with 95% confidence intervals shown.

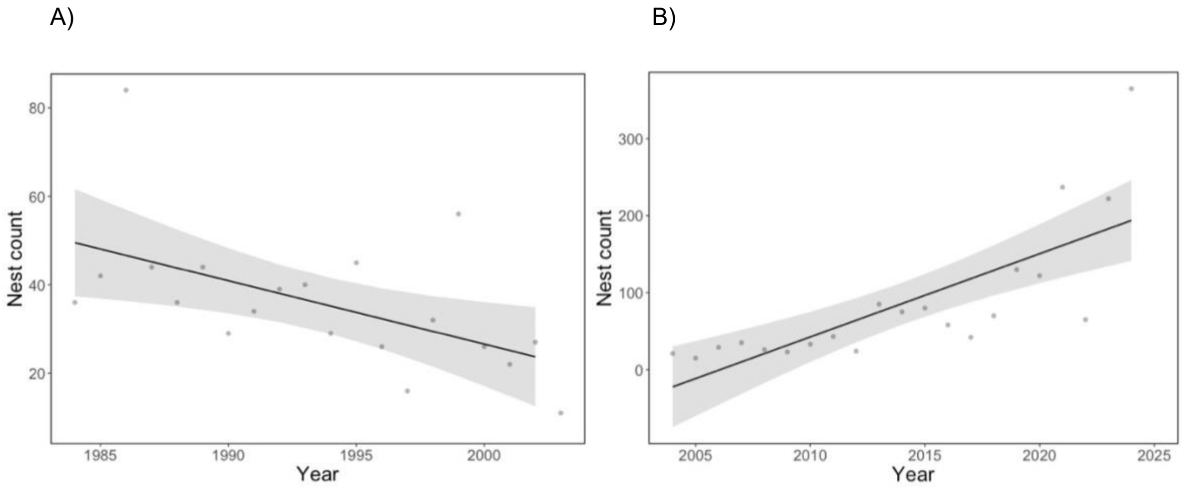

Figure 9. The relationship between nest count (number of nests) and year on Kaminia and Potamakia beaches, Kefalonia between A) 1984 - 2003 and B) 2004 - 2024. The predicted regression line with 95% confidence intervals shown.

Turtle size

The size of turtle tracks leading to nests at the nesting beach decreased significantly with year ($r^2 = 0.046$, $n = 272$, $p < 0.001$) (Figure 10).

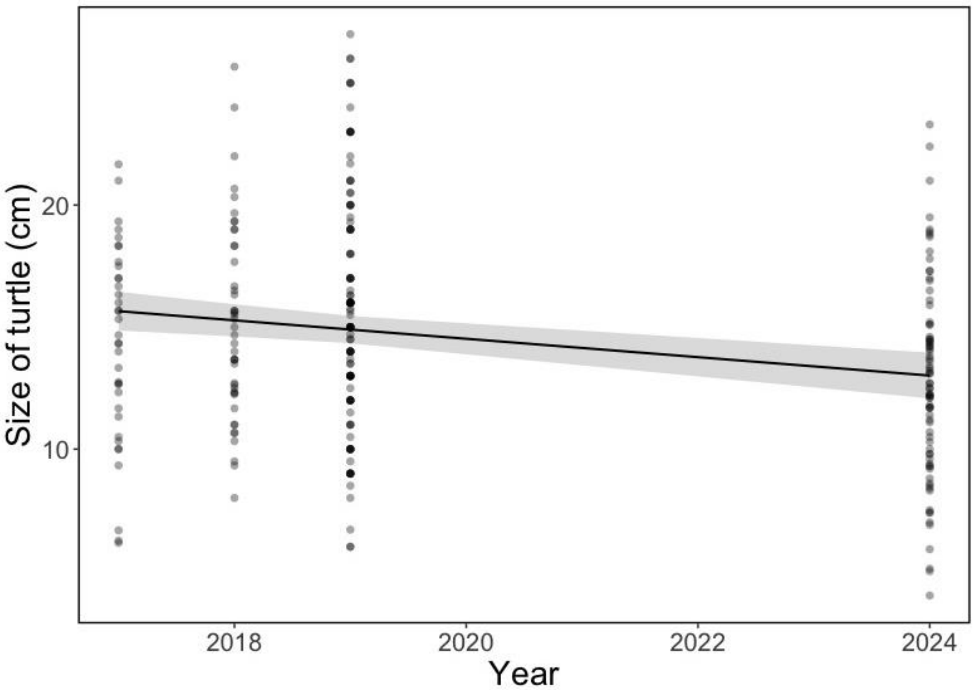

Figure 10. The relationship between size of loggerhead sea turtle tracks (cm) leading to nests and year on Kaminia and Potamakia beaches, Kefalonia in 2017, 2018, 2019 and 2024. The predicted regression line with 95% confidence intervals shown.

Size of turtle in relation to reproductive output and nesting behaviour

Clutch size

The clutch size increases significantly with turtle size (Table 2, Figure 11) but decreases in relation to the time in the season (Table 2, Figure 12). Clutch size did not significantly correlate to location or year (Table 2). The clutch size did not significantly correlate with the interaction size x oviposition date; hence is dropped from the final model to allow interpretation of main predictors.

Table 2. Predictors associated with the clutch size (number of eggs) laid by population of loggerhead sea turtles on Kaminia and Potamakia beaches, tested using a GLM. The clutch size was measured in 2017, 2018, 2019 and 2024. Predictors in bold are significant ($p < 0.05$).

	Clutch size		
Predictors	*Estimates*	*CI*	*p*
Intercept	-2670.11	-11677.46 – 6337.24	0.559
Size of turtle (cm)	1.21	0.41 – 2.01	**0.003**
Oviposition date (days)	-0.65	-0.87 – -0.44	**<0.001**
Location of nest (beach markers)	-0.01	-0.08 – 0.06	0.818
Year	1.37	-3.09 – 5.83	0.545
Observations	162		
R^2 / R^2 adjusted	0.206 / 0.186		

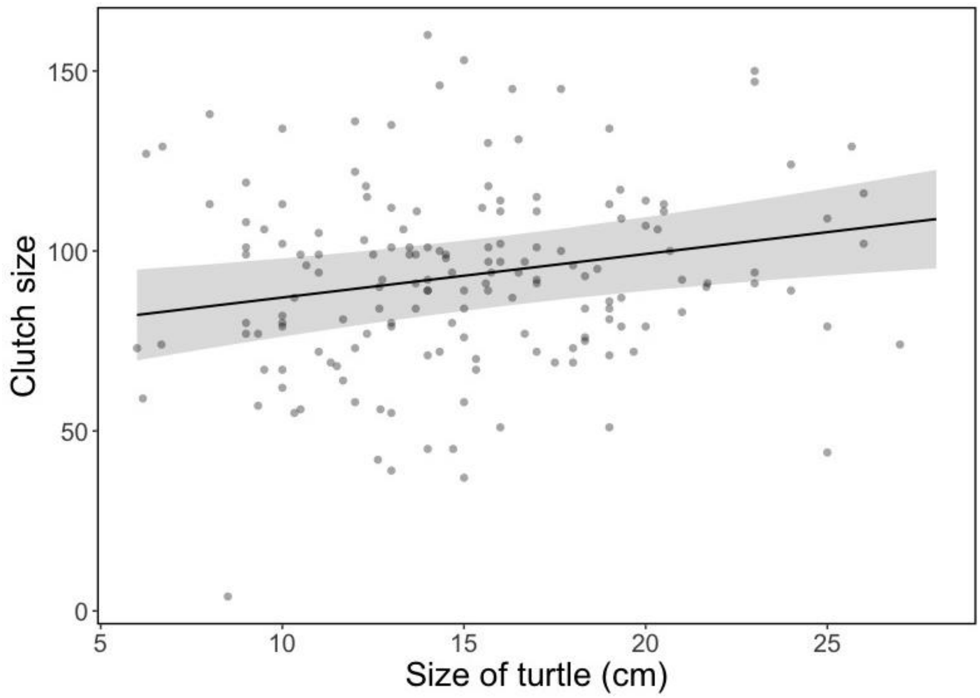

Figure 11. The relationship between clutch size (number of eggs) and size of turtle tracks (cm) leading to nests on Kaminia and Potamakia beaches, Kefalonia. The predicted regression line with 95% confidence intervals shown.

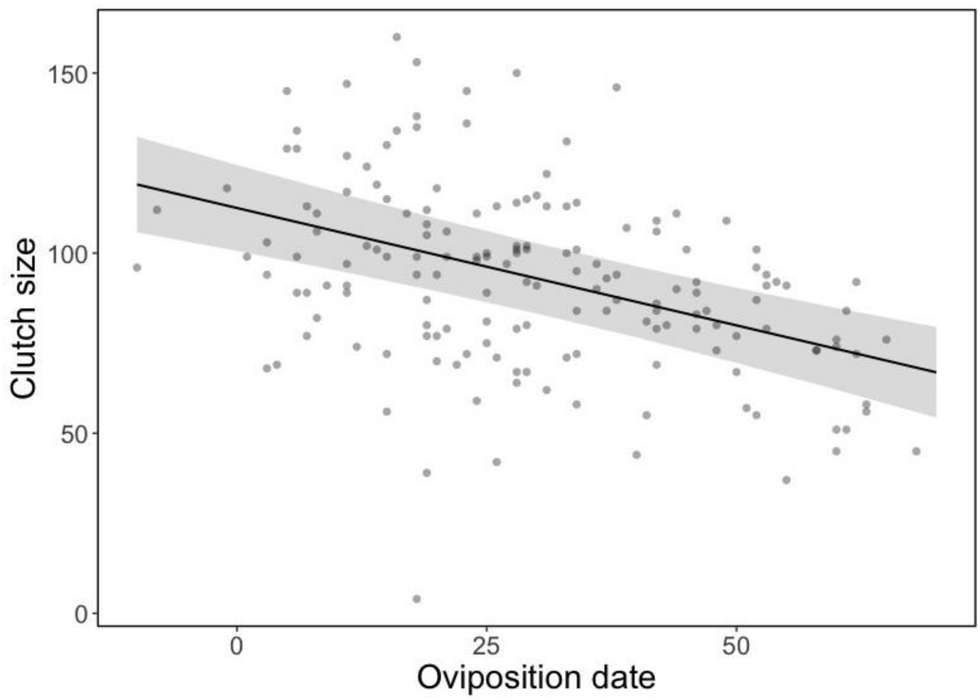

Figure 12. The relationship between clutch size (number of eggs) and date the nest is laid on Kaminia and Potamakia beaches, Kefalonia. The predicted regression line with 95% confidence intervals shown.

The location of nest laid on the beach

The location of nest significantly correlated with the size of turtle and human activity (Table 3, Figure 13) but did not significantly correlate with year (Table 3). Location did not significantly correlate with the interaction predictors size x human activity; hence is dropped from the final model to allow interpretation of the main predictors.

Table 3. Predictors associated with the location of nest laid by a loggerhead sea turtles on Kaminia and Potamakia beaches, using a GLM. The date the nest was laid was measured in 2017, 2018, 2019 and 2024. Predictors in bold are significant ($p < 0.05$).

	Location of nest		
Predictors	*Estimates*	*CI*	*p*
Intercept	-1363.17	-6195.37 – 3469.03	0.579
Size of turtle (cm)	-1.52	-2.93 – -0.11	**0.034**
Human activity	46.49	26.54 – 66.44	**<0.001**
Year	0.71	-1.68 – 3.10	0.560
Observations	272		
R^2 / R^2 adjusted	0.097 / 0.087		

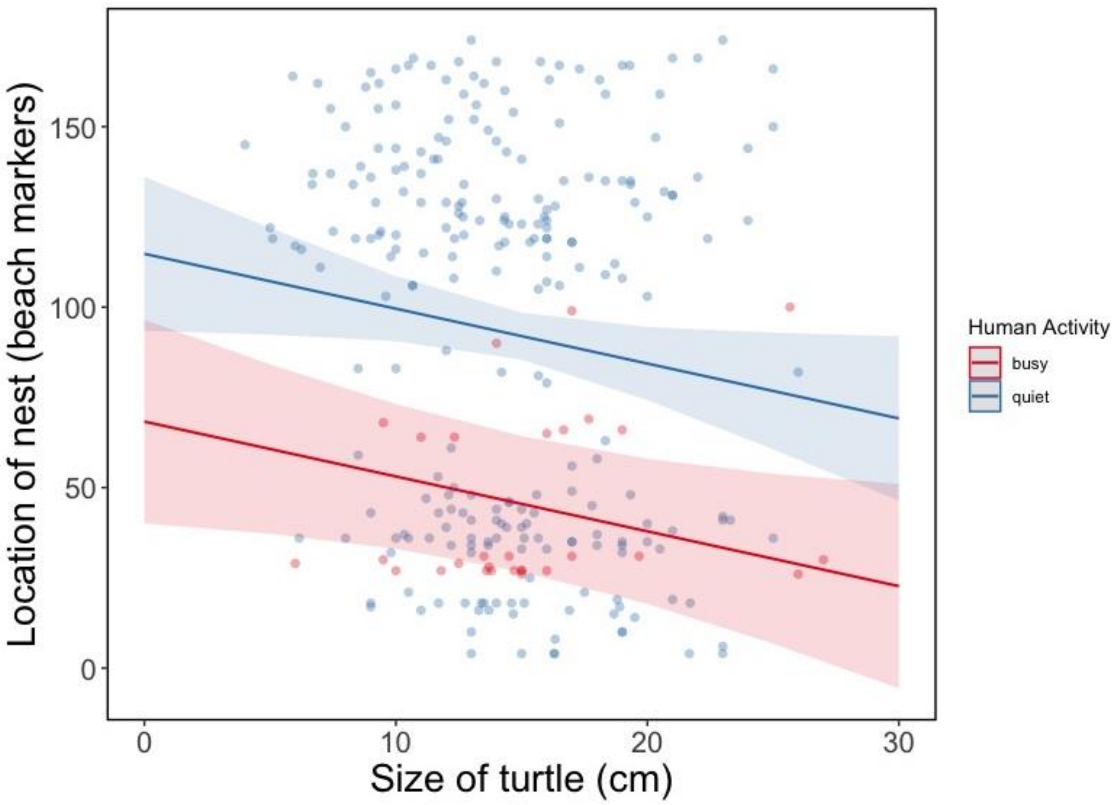

Figure 13. The location of nest laid in relation to the size of turtle tracks (cm), with coloured dots representing whether nest had been laid in a busy (red) or quiet (blue) areas on Kaminia and Potamakia beaches, Kefalonia. The predicted regression line with 95% confidence intervals shown.

Distance of the nest up the beach

The distance of nest up the gradient of the beach did not significantly correlate with the size of turtle ($r^2 = 0.014$, n = 116, p = 0.111).

Oviposition date

The oviposition date did not differ according to the size of turtle (Table 4). However, year and oviposition date did show a significant positive relationship (Table 4).

Table 4. Predictors associated with the date the nest is laid by population of loggerhead sea turtles on Kaminia and Potamakia beaches, using a GLM. The date the nest was laid was measured in 2017, 2018, 2019 and 2024 . Predictors in bold are significant ($p < 0.05$).

	Oviposition date		
Predictors	*Estimates*	*CI*	*p*
Intercept	-5109.46	-6491.61 – -3727.31	**<0.001**
Size of turtle (cm)	0.30	-0.10 – 0.70	0.145
Year	2.54	1.86 – 3.23	**<0.001**
Observations	272		
R^2 / R^2 adjusted	0.167 / 0.160		

Discussion

The results show that at the Kaminia and Potamakia beaches in Kefalonia, the number of nests increased significantly with year. Also, turtle size significantly decreased with year. Clutch size was also significantly correlated with size of turtle, with clutch size increasing with size of turtle, and clutch size was also significantly negatively correlated with oviposition date, whereby the clutch size reduces later into the season. The location of a nest was significantly correlated with the size of turtle, with different sized turtles nesting in different areas, and the location of nest was also positively correlated with human activity, with less nests being laid in 'busy' areas compared to 'quiet' areas.

Inferring the population trajectory

The nest count decreased between 1984 and 2003, from 36 to 11 nests, but increased between 2004 and 2024, from 15 to 365 nests, leading to overall much higher levels by 2024. This overall increase in nest count is similar to analyses of the loggerhead sea turtle from other regions of the Mediterranean, including Greece (Margaritoulis et al., 2023), Italy (Denaro et al., 2022) and Turkey (Sönmez et al., 2021), as well as from other sea turtle species such as the green turtle (*Chelonia mydas*) in Turkey (Sönmez et al., 2024). However, Margaritoulis., (2005) showed that the nest count of a population of loggerhead sea turtles in Zakynthos, Greece remained stable between 1984 and 2002. This leads to the question as to why the specific subpopulation of loggerhead sea turtles in Kefalonia suffered a decline in nesting activity between 1984 and 2003?

Due to the time taken, at around 25 years, for loggerhead sea turtles to reach sexual maturity (Casale & Heppel., 2016; Casale et al., 2018), it is difficult to determine reasons for changes in population sizes (Witherington et al., 2009). A decline in nests probably reflects a decrease in the population of adult female loggerhead sea turtles (Witherington et al., 2009). Why this may be the case and when this occurred is unclear. A decline can be due to past threats that happened to earlier life stages of sea turtles, such as eggs and hatchlings (Witherington et al., 2009). This could include high levels of predation, weather events, and anthropogenic disturbance at nesting beaches (Casale et al., 2015; Leighton et al., 2011; Pietroluongo et al., 2023; Witherington et al., 2009), that has reduced the recruitment of individuals in later years (Witherington et al., 2009). High mortality rates from fisheries-related accidents to juveniles and adults could also cause this decline (Witherington et al., 2009; Casale et al., 2015), with one of the most serious threats to sea turtles in the Mediterranean across the 20th century has been incidental by-catch (Case., 2011; Casale et al., 2015). However, there is little or no empirical date to support these are the cases for this population, and so can only suggest.

An increase in nesting activity between 2004 and 2024 could suggest an increase in population abundance but is difficult to determine due to the variability in clutch frequency and remigration intervals (Broderick et al., 2003: Ceriani et al., 2019; Martins et al., 2022). Therefore, the average size of turtle was used to determine the population trajectory. The mean size of loggerhead sea turtle decreased from 14.85 cm to 12.87 cm between 2017 and

2024. A decrease in size of loggerhead turtle has also been reported in Cape Verde (Hays et al., 2022), South Africa (Le Gouvello et al., 2020), Brazil (Pereira et al., 2024), as well as other species of sea turtle, including the green turtle in Seychelles (Mortimer et al., 2022; Weber et al., 2014) and western Atlantic (Bjorndal et al., 2017), the hawksbill turtle in Mexico (Pérez-Castañeda et al., 2007) and Seychelles (Evans et al., 2024) and the olive ridley turtle in India (*Lepidochelys olivacea*) (Shanker et al., 2004). As the size of turtle increases with age (Casale., 2011; Frazer., 1983; Turner Tomaszewicz et al., 2022; Van Houtan & Halley., 2011), we can infer that if the average size of turtle is decreasing, the average age of turtle in the population is decreasing alongside this.

As younger, newer turtles are typically smaller than older, re-migrant turtles (Hays et al., 2022; Martins et al., 2022; Raposo et al., 2025), the most probable explanation of these results in a population with an increasing nesting activity is an increase in recruitment of younger individuals into the adult population (Evans et al., 2024; Hays et al., 2022; Martins et al., 2022; Mortimer et al., 2022; Pérez-Castañeda et al., 2007; Raposo et al., 2025; Weber et al., 2014). Together, an increasing number of newer individuals would both increase the nest count and decrease the average size of turtle in the population (Hays et al., 2022). Thus, in conjunction with the increased number of nests this decrease in body size strongly suggest the overall population of loggerhead sea turtles in Kefalonia is increasing and recovering (Raposo et al., 2025).

This increased population size of loggerhead sea turtles at the Kaminia and Potamakia beaches, Kefalonia, possibly due from increased recruitment of turtles could be due to protection from predators and human disturbance, undertaken by ‘The Katelios Group’, that will increase the survival and abundance of hatchlings in the region (Campbell et al., 2020; Hays et al., 2022; Mazaris et al., 2009). This will eventually increase the number of sexually mature individuals in the population (Campbell et al., 2020). However, in the population assessed in the current study the turtles were not tagged and so cannot confirm whether they were new individuals nesting for the first time or re-migrants, as carried out in studies by Evans et al., (2024), Hays et al., (2022) and Raposo et al., (2025). This would be valuable to carry out in further experiments to confirm this, as well as further research on the nest count and size of turtle to continue the time series of these.

There are other possible reasons for a decrease in size of turtle, including food availability (Bjorndal et al., 2017; Phillips et al., 2021), and the mortality of larger turtles (Shanker et al., 2004). Resource availability at foraging sites influences the growth of sea turtles, and so a lack of resources may cause turtles to be smaller in the population (Bjorndal et al., 2017; Phillips et al., 2021). This could be caused by global warming (Androulidakis et al., 2024;

Bjorndal et al., 2017; Matzarakis & Nastos., 2023), in which the Mediterranean basin sea surface temperature (SST) increased by 1.3 °C between 1982 - 2019 (Pastor et al., 2020), that damages sea grass and hence reduces loggerhead sea turtle prey abundance (Patel et al., 2016). However, we do not have any data that directly correlates temperature and food availability at foraging grounds to the growth rates of this population of loggerhead sea turtles. Mortality of larger turtles, possibly from fisheries-related incidents (Shanker et al., 2004), would also decrease the mean size of turtle, but we do not have any data to confirm this. Also, neither of these would likely occur alongside an increase in nest numbers or an increasing population, compared to the recruitment of younger individuals (Mortimer et al., 2022). However, this must be considered for populations where there has not been an increase in the number of nest or population abundance (Mortimer et al., 2022).

Turtle size and reproduction

The results are in accordance with our hypothesis, whereby clutch size increases with size of turtle. This has also been reported in other studies of loggerhead sea turtles in the Mediterranean, on Potamakia beach in Kefalonia, Greece (Hays & Speakman., 1991), and Cyprus (Broderick et al., 2003), Cape Verde in the Atlantic (Martins et al., 2022) and South Africa (Le Gouvello et al., 2020), as well as green turtles in the Seychelles (Mortimer et al., 2022). Marine turtles exhibit no parental care (Hatase & Omuta., 2018), and eggs and hatchlings experience high mortality rates from predators and weather events (Leighton et al., 2011). Therefore, rather than putting all resources into one individual offspring, sea turtles maximise the number of eggs they lay to increase the reproductive success (Cassill., 2019; Gould et al., 2022; Le Gouvello et al., 2020; Raposo et al., 2025). This maximum number of eggs is dependent on the abdominal capacity of the turtle, and so larger turtles can carry more eggs and have a larger clutch size per nest (Mortimer et al., 2022; Raposo et al., 2025).

Given that my results suggest a smaller average size of turtle in the Kefalonia population, the reproductive output (number of eggs) may reduce as each nest will have less eggs (Benscoter et al., 2022; Evans et al., 2024). However, there was no significant correlation between the clutch size and year (Table 2). If this were to be the case in this population in the future, we would expect it to be offset by the suggested increasing number of breeding individuals (Evans et al., 2024; Mortimer et al., 2022), and the continued growth of the younger individuals that would have larger clutch sizes when they return in later years, and so not be a large problem (Evans et al., 2024; Hays et al., 2022; Morales-Mérida et al., 2024; Omeyer et al., 2018). As there is only a weak correlation between the size of turtle and clutch size, other interacting causes may influence the clutch size. The clutch size decreases later into the nesting season, which has also been reported in loggerhead sea turtles in Cyprus by Broderick et al., (2023). This may be due to the depletion of resources and body fat reserves for individual females as the nesting season progresses, meaning that the later clutches decrease in clutch size (Broderick et al., 2003; Le Gouvello et al., 2020).

Turtle size and nesting behaviour

The location of nest was significantly correlated to the size of turtle. The size of turtle can influence the nest construction, in which nest depth is dependent on the female body and flipper size (Rusli., 2022; Najwa-Sawawi et al., 2021, Wilson., 1998). Smaller turtles tend to dig shallower nests, and so may nest in areas with more vegetation cover to reduce the nest temperature, whilst larger turtles that dig deeper nests may nest in more open areas to increase the nest temperature, suggesting it is a way to maintain the sex ratios of hatchlings (Topping & Valenzuela., 2021; Wilson., 1998). Therefore, beach features, such as sand composition, vegetation cover and width of beach could influence where the nests are laid, depending on what beach features are more suitable for specific sized turtles (Topping & Valenzuela., 2021; Wilson., 1998). Larger turtles also have been shown to have a higher repeatability in nest site selection, possibly due to the experience developed (Martins et al., 2022), as they are older (Casale., 2011; Frazer., 1983; Turner Tomaszewicz et al., 2022; Van Houtan & Halley., 2011). As we suggest a decrease in average size of population, we may expect specific areas on the beach to be used more if they are more suitable for smaller sized individuals, which may be useful for conservation schemes in predicting which areas may be nested in more often. However, as environmental factors were not recorded in this study, we can not confirm which beach features are associated with which sized turtles. Beach features (environmental factors) and anthropogenic disturbance must also be considered when determining factors that affect the location of a nest laid by sea turtles (of all sizes) (Sisqueira-Silva et al., 2020).

The location of nest laid was also significantly correlated to anthropogenic activity, in which 1.9 nests were laid per 10 meters in areas with high human activity, compared to 3.7 nests laid per 10 meters in areas of low human activity. These results coincide with other studies including loggerhead sea turtles in Turkey (Kaska et al., 2010), Mexico (Oliver de la Esperanza et al., 2017) and Florida (Weishampel et al., 2003), and green sea turtles in Mexico (Oliver de la Esperanza et al., 2017; Zavaleta-Lizárraga & Morales-Mávil., 2013) and Florida (Weishampel et al., 2003). Anthropogenic disturbance on the beach may prevent the females from nesting (Oliver de la Esperanza et al., 2017). The presence of tourists and artificial light deters females from nesting (Lasala et al., 2023; Oliver de la Esperanza et al., 2017), and beach equipment can obstruct females crawling up the beach (Oliver de la Esperanza et al., 2017), leading them to nest elsewhere. Further experiments would be useful to extend this work and fill gaps, in particular collecting data on the beach features and environmental factors of the study site. This would allow us to investigate the association of these beach features with where turtle nests are laid and the size of turtle.

The oviposition date per year

The sea surface temperature can impact the onset of the nesting season, with warmer years having an earlier nesting season, and cooler years having a later nesting season (Rickwood et al., 2025; Weishampel et al., 2004). However, due to the restricted dataset where only nests with size of turtle measurements were included in the analysis, the year predictor is likely incorrect, as size of turtle measurements only began in the middle of the 2024 nesting season.

Conclusion

In conclusion, we find that the population of loggerhead sea turtles on Kaminia and Potamakia beaches, Kefalonia has recovered and is becoming a stable population. We also find that the reproductive output may reduce, although this would unlikely be a problem. The nesting behaviour may change with smaller turtles, although do not have enough data to report on this. We suggest that the conservation measures placed in the area by ‘The Katelios Group’ in the recent decades has played an important role in the persistence and recovery of the population of loggerhead sea turtles in Kefalonia, Greece. Therefore, I recommend the continued protection of the nesting turtles, and further research as mentioned to obtain a more extensive knowledge of the population.

Acknowledgments

I want to thank my supervisor David Richardson for his guidance, advice and feedback on this research and project.

To Chuen Lee for his support on this project.

I also want to express my gratitude to Katerina Xenopoulou and 'The Katelios Group' for supporting the fieldwork and allowing me to conduct and use the research on Kamina and Potamakia beaches.

To Victoria Butler for her assistance in the fieldwork.

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