The Origin in Variability of Nesting Period of the Loggerhead Turtle (*Caretta caretta*) in the Kuriat Islands, Tunisia

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Global temperatures have warmed by approximately 0.61 °C in the last century, at a rate that has been unprecedented in the last 1000 years (IPCC 2001). There is a large body of literature documenting advances in the phenology (timing of seasonal activities) of many animal and plant species in concert with observed climate change. Most commonly, spring events occur earlier (e.g. arrival at breeding grounds) and/or reproductive seasons end earlier (Pike et al. 2006), but there have also been records of later onset of autumnal events (e.g. delayed migration). Eighty-seven percent of species (from plants to vertebrates) reviewed by Parmesan & Yohe (2003) that exhibited shifts in phenology did so highly significantly in accord with climate change.

However, this future climate change is expected to be heterogeneous, and not all areas will experience warming or similar rates of change in temperature (IPCC 2001b). Therefore, gradual phenological shifts may be not sufficient to detect the direct effect of global warming on some species inhabiting region where heterogeneous change of temperatures are expected. This is the case in the Mediterranean Sea, where the mix between projected water current changes and increased air temperatures will produce a complex change of sea temperatures. In this context, we examined the correlation between proxies of temperature change and phenology to detect impacts of climate change. We expect that such a complex situation will generate variability in temperatures that would translate into variability of observed changes in phenology of the nesting season for marine turtles. Thus, a significant correlation between phenology of nesting and some measure of sea temperatures may reflect the winter use of that region by sea turtles using one particular site for egg laying.

The loggerhead turtle is the most abundant marine turtle species in the Mediterranean. Annually, more than 2,000 females are estimated to nest in the western Mediterranean Basin. The main nesting concentrations are in Greece, Turkey and Cyprus, with some as yet un-quantified nesting in Libya. Minor nesting aggregations have been described in Egypt, Lebanon, Israel, Italy, Syria and Tunisia (Casale & Margaritoulis 2010). Tunisia is the most westerly nesting ground for loggerheads in the southern Mediterranean. Outside of nesting, loggerhead turtles occur throughout the marine areas of the Mediterranean. The highest density of loggerhead turtles appears to occur in the westernmost part of the Mediterranean (from the Alboran Sea to the Balearic Islands), the Sicily Strait, the Ionian Sea, and the wide continental shelves in the north Adriatic, off Tunisia, Libya, Egypt, and southeast Turkey (Casale & Margaritoulis 2010).

In Tunisia, nesting primarily occurs in the two Kuriat Islands (35.8014, 11.0347): Little Kuriat (*Kuria Sgira*), which is *ca.* 0.7 km^2 and Great Kuriat (*Kuria Kbira*), which is *ca.* 2.7 km^2 (Figure 1). The most important nesting beach is located in the west of the Great Kuriat, where researcher and volunteer teams have worked from 1997 to 2010 to record numbers of nests deposited. However, the patrols did not cover the entire nesting season, with monitoring often commencing after the start of the nesting season. Also, in the middle of the 1998 season, some nights were not monitored due to logistical constraints. The occurrence of gaps in effort is common in nest monitoring programs for marine turtles, and complicates the use of indices such as the date the season's first nest was deposited, or the median nesting date. To get around these limitations, a statistical description of phenology of the nesting season has been developed (Girondot 2010). Even with incomplete information, this method can describe the nesting season by a set of equations and the parameters are fitted by maximum likelihood using negative binomial link. The advantage of the technique is that it facilitates the analysis of heterogeneous field data and produces outputs that are directly comparable.

<u>Modeling the marine turtle nesting season</u>. Understanding t to be an ordinal date, the number of nests deposited per night is modeled using the set of equations (1) (Girondot 2010).

The model requires a maximum of seven parameters that have direct biological or phenological definitions:

MinB is the mean nightly nest number before the beginning of the nesting season

MinE is the mean nightly nest number after the end of the nesting season

Max is the mean number of nests at the peak of the nesting season

P is the ordinal date of the peak of the nesting season

F is the number of days that are flat around the day *P*

B is the ordinal date of the beginning of the nesting season

E is the ordinal date of the end of the nesting season

MinB, Max, MinE are scaling parameters and P, F, B and E are shape parameters. Various constraints can be set up to simplify this model: MinB=MinE occurs when there are the same number of nests before

$$\begin{cases} \text{if } t < B \rightarrow MinB \\ \text{if } t \in [B, P - F/2] \rightarrow \left(\left(1 + \cos\left(\pi(P - F/2 - t)/(P - F/2 - B)\right)\right)/2\right)(Max - MinB) + MinB \\ \text{if } t \in [P - F/2, P + F/2] \rightarrow Max \\ \text{if } t \in [P + F/2, E] \rightarrow \left(\left(1 + \cos\left(\pi(t - P + F/2)/(E - P + F/2)\right)\right)/2\right)(Max - MinE) + MinE \\ \text{if } t > E \rightarrow MinE \end{cases}$$

Equation 1

and after the nesting season
MinB and/or MinE # 0 (eg. 10^{-9}) signifies that no nests occurred outside of the nesting season
P-B=E-P occurs when the shape of the nesting season is symmetric around P
The nesting season is defined as the interval [B, E] and its length is E-B.
Data for loggerhead nesting in Little and Great Kuriat were compiled and entered into the model. When data were available for both Little and Great Kuriat for the same year, a single set of shape parameters (B, P, F, E) was used for both time series and only the Max parameter was series-specific. As no nests are normally deposited for 9 months of the year on these beaches, the model was simplified with MinB=MinE=10^{-9}. As relatively few nests were deposited on the Kuriat islands, the model was simplified with F=0 and P-B=E-P and constant length E-B.

To test whether there was significant variability in the nesting phenology for loggerhead nesting in the Kuriat Islands, two models were fitted. In the first model, the same shape of nesting season was imposed for all years (i.e. same B, P and E value). This simplest type of model was compared with one in which the seasonality is year-specific. Comparisons were based on AIC value, which is a measure of the goodness of fit of an estimated statistical model. The AIC is not a test of the model in the sense of hypothesis testing; rather it is a test between models and is used for model selection. When the same shape was imposed for all years, the AIC value was 798.43 (17 parameters) whereas when the shape was year-specific, the AIC value was 783.35 (28 parameters). This difference of ΔAIC=15.07 is large and, based on Akaike weight (Burnham & Anderson 1998), the probability that the model with year-specific difference in peak of nesting is the best one among the two tested is p=0.999.

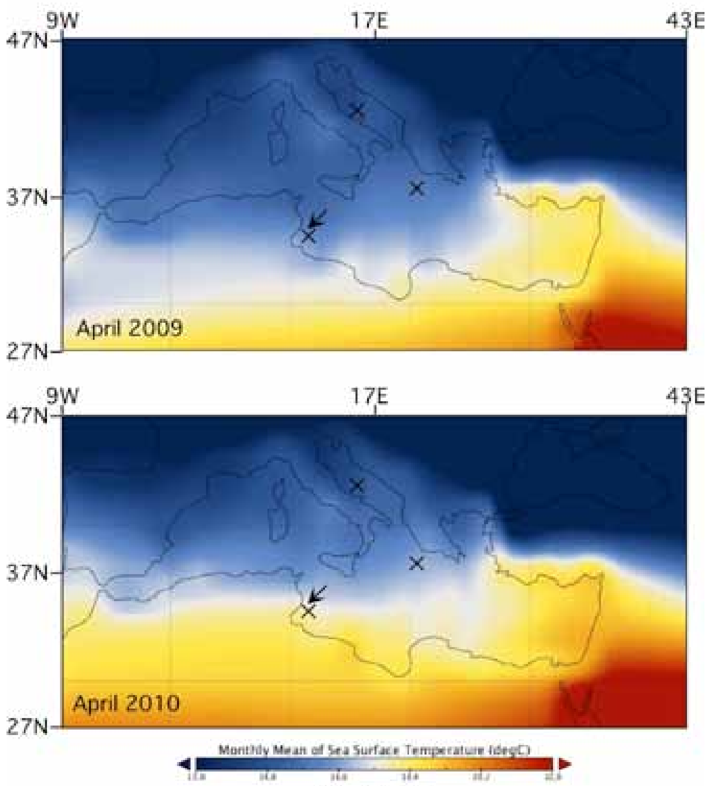

Figure 1. Sea surface temperature for the Mediterranean Sea for the coldest (2009) and warmest (2010) April months during the 12 years of analysis. Crosses show the three locations used for SST analysis and the arrow indicates the location of the Kuriat Islands.

Year	Beginning of season	Peak of nesting	End of season
1997	29/04/97	19/06/97	09/08/97
1998	09/05/98	30/06/98	20/08/98
2001	15/05/01	05/07/01	25/08/01
2002	02/05/02	22/06/02	12/08/02
2003	03/05/03	23/06/03	13/08/03
2004	08/05/04	28/06/04	18/08/04
2005	07/05/05	28/06/05	18/08/05
2006	22/05/06	12/07/06	01/09/06
2007	05/05/07	25/06/07	16/08/07
2008	09/05/08	29/06/08	19/08/08
2009	29/04/09	19/06/09	09/08/09
2010	11/05/10	01/07/10	22/08/10

Table 1. Dates of start, peak and end of the nesting season for loggerheads in the Kuriat Islands, Tunisia.

The beginning of the nesting season in the Kuriat Islands was fitted to be between the 29 April and 22 May (depending on the year) and the end of the nesting season was fitted to be between 09 August and 01 September. Note that these dates are defined statistically and are not the actual dates of the first and last nests laid on Kuriat Island. The model-generated annual dates of beginning, ending and nesting peaks for loggerheads in the Kuriat Islands are shown in Table 1.

Phenology vs. temperature on potential wintering sites. Several wintering sites are known in Mediterranean Sea for loggerheads

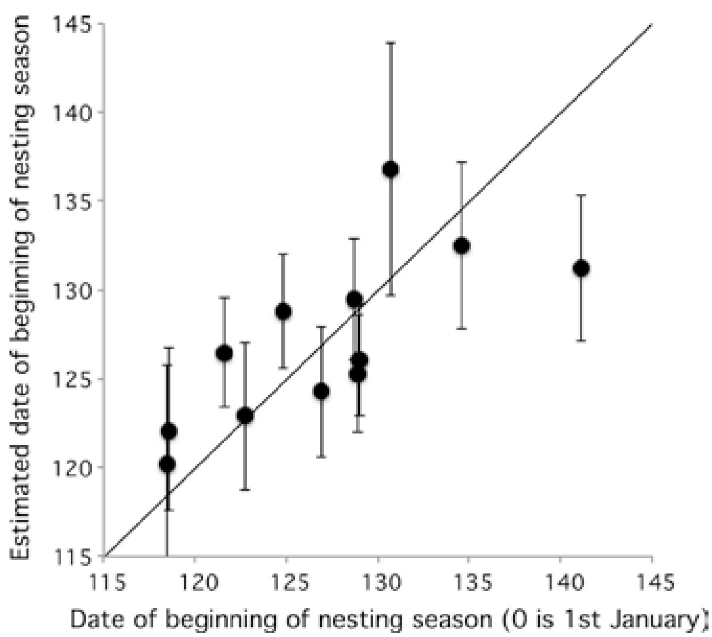

Figure 2. Observed dates of the peak of nesting in the Kuriat Islands compared to modeled values, taking into account April mean sea surface temperature in Gulf of Gabes.

(Casale & Margaritoulis 2010). We choose 3 locations where wintering loggerheads are known to occur (Figure 1): Adriatic Sea (42.5°, 15.5°), Greece (37.5°, 20.5°) and the gulf of Gabes in Tunisia (34.5°, 11.5°). These three locations represent a North-South gradient. For each of these locations, the mean monthly sea surface temperature values from January to May were extracted from a database for all the years between 1997 and 2010 (NOAA Optimum Interpolation Sea Surface Temperature V2, Reynolds et al. 2002). Then, generalized linear models (Gaussian identity link) were run to search for a relationship between the date of peak of nesting for one particular year and the monthly sea surface temperature. Only first order interactions between consecutive months were considered. A backward elimination procedure was used to simplify model with the most non-significant parameter removed in each round.

No significant effect on nesting dates in the Kuriat Islands was detected for monthly sea surface temperatures from the Adriatic Sea or Greece. However, a highly significant relationship was found between the date of beginning of nesting in the Kuriat Islands with April mean sea surface temperatures in the Gulf of Gabes ($F(1,10)=11.19$, $p=0.007$, Figure 2), which is a known wintering zone for Mediterranean loggerheads (Zbinden et al. 2008).

Based on these results, it is tempting to propose that females nesting in the Kuriat Islands are primarily over-wintering in the Gulf of Gabes. An alternative could be that adult females migrate to the nesting site from distant areas and wait for more conducive conditions before they start to nest. More data, such as from satellite tracking and/or stable isotope analyses, would help illuminate which scenario is more likely. Nevertheless, these results are useful in focusing future research efforts for understanding the behavioral ecology of adult female loggerheads that use the Kuriat Islands for nesting. This analysis also demonstrates the power of the nesting season model (Girondot 2010) to describe the phenology of nesting in marine turtles.

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