

Estimation of the nesting season of marine turtles from incomplete data: statistical adjustment of a sinusoidal function

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Abstract

Because of logistical and financial constraints, nest counts of marine turtles are often limited in time and space. To overcome this difficulty, we developed a numerical model that fits the seasonal pattern of marine turtles nesting from complete or fragmented datasets. The duration of the main nesting season, the position and amplitude of its maximum as well as the residual number of nests, outside of the main season are obtained numerically by a least square adjustment. For the seven complete time series at our disposal (*Dermochelys coriacea* and *Lepidochelys olivacea* turtles, coast of French Guiana), the model reproduces the seasonal pattern with a correlation of $r \geq 0.97$. When applied on a fragmented dataset, the model accuracy depends on the duration and on the temporal distribution of the monitoring (effort equally distributed during the entire season or concentrated on a part of it only). As a result of this study, we clearly advocate a strategy of monitoring distributed all over the nesting season. Following this recommendation, the model estimates the annual number of nests with a median error lower than 10% when considering only 50 days of monitoring.

Introduction

Worldwide, most marine turtle populations are considered to be declining because of human activities such as by-catch, poaching and pressures on nesting sites. All species are indeed endangered (www.redlist.org), but it is difficult to obtain clear trends because most marine turtles are migratory species, and are seldom observed with enough frequency in the wild.

The evolution in the number of nests counted on beaches is widely used as a crude indicator of nesting turtle population dynamics (Schroeder & Murphy, 1999). Nevertheless, nest monitoring is undertaken with a great variability in methods. In Costa Rica, the use of daily or weekly nest counts on three index beaches, coupled with aerial surveys from neighboring countries, allowed the identification of leatherback turtle *Dermochelys coriacea* trends (Troëng, Chacón & Dick, 2004). The same monitoring protocol allowed the estimation of positive trends for the green turtle nesting in Tortuguero, Costa Rica (Troëng & Rankin, 2005). This methodology is the most developed, and is currently the only method that can provide time-series long enough to allow population trends to be determined (Hays, 2004). However, this estimate remains an index of abundance, rather than an absolute indicator of the population size (Gerrodette & Taylor, 1999).

In French Guiana, the leatherback turtle has benefited from a wide tagging effort over the last years. However, the capture/recapture effort is still unbalanced from one nesting site to another, and estimating the detection probability remains challenging. Thus, inputs from tagging are not used yet at the nation-wide scale to assess population trends. The main index of abundance used for the leatherback turtle in French Guiana then, is still the number of nests recorded (Rivalan, 2004). For the other species, no comprehensive tagging effort has ever been initiated in French Guiana, and nest counts remain the only parameter available to assess population size and trends.

In order to better process field data, and obtain reliable estimates, statistical approaches are widely used, with specific adaptation for each region and for different objectives (Gerrodette & Taylor, 1999). In French Guiana, the long-term monitoring of Awala-Yalimapo beach, together with the use of robust statistical methods, has allowed the first trend assessment for the leatherback turtles in the country (Girondot & Fretey, 1996; Chevalier & Girondot, 2000; Rivalan, 2004). In parallel with this long-term monitoring effort focused on Awala-Yalimapo, several beaches have benefited from monitoring visits on the entire French Guiana coast over the last four years (2001–2004). This extended field coverage may significantly improve the understanding of the leatherback turtle status in the region,

because some recently monitored beaches were revealed to be major nesting sites, welcoming several thousands of leatherback turtle nests per year. Some of the aforementioned beaches were monitored for a short period of time; the use of the incomplete data gathered from such remote nesting sites required modeling tools to estimate the annual number of nests and other main characteristics.

Whatever the species, the number of marine turtle nests laid during a nesting season can be fitted to a mathematical function. Thus, an adjusted number of nests can be estimated from an observed number of nests. The most challenging approach currently developed aims to describe both low and high temporal fluctuations of the number of nests (P. Rivalan, J. P. Briane, M. Godfrey, S. Caut & M. Girondot, unpubl. data). Such a method is required to study the periodicity of turtle inter-nesting during the season and can provide results on the period during which the main biological and physical forcings occur. At the same time, much simpler interpolators are still widely used (Hilterman & Goverse, 2005) to estimate the annual number of nests, and these remain in operation to assess the population size and trends.

In the frame of this study, we tested different mathematical adjustments and finally adopted a sinusoidal model to fit the nesting season because of its robustness and simplicity. It can be considered as an intermediate solution, adapted to extrapolate the entire nesting season from incomplete data. The accuracy of each estimate is logically correlated with the monitoring effort (continuous or fragmented) and its duration.

The results of the model provide useful and comprehensive parameters such as the mean position of the nesting season in the year and its amplitude, the duration of the season and the annual number of nests. In the first step, the validation of the model is obtained from seven complete datasets at our disposal, describing exhaustively seven different nesting seasons monitored in the eastern part of French Guiana. Three of them correspond to the monitoring of leatherback turtle nesting and the remaining correspond to monitoring of the olive ridley turtle *Lepidochelys olivacea*. These two species exhibit specific nesting behavior, with some consequences on fit. In the second step, we present a sensitivity study that aims at defining the range of application of the model and its accuracy. The advantages and disadvantages of the model, when compared with others, are then discussed before a conclusion is drawn and proposals for future action are recommended.

Materials and methods

Field data collection

In French Guiana and Suriname, the marine turtle nesting activity for the three main species, the leatherback turtle, the olive ridley and the green turtle *Chelonia mydas*, spans from March to the end of August, with a peak in May–June for the leatherback turtles (Girondot & Fretey, 1996; this article, Table 2, among others) and in July for the olive

ridley (Fretey & Lescure, 1998; this article, Table 2). The information gathered from seven nesting seasons (three for the leatherback turtles, four for the olive ridley turtles) used in this study correspond to the monitoring of the nesting beaches on the peninsula of Cayenne, from 2000 to 2003. These sites are considered to be exhaustively monitored; nests counts are undertaken during the entire nesting season by two complementary methods: nest count every morning, and patrolling effort, performed every night from 19:00 to 06:00 h. This last method aimed first to tag animals, but also allowed us to obtain direct counts of females. This set of data is used to develop our model, with the assumption that no nests were overlooked by the monitoring teams on these intensively patrolled beaches.

Adjustment to a sinusoidal function

From the complete dataset available for these two species, we first examine the possibility of adjustment of a sinusoidal function $Y(t)$ on the time series $S(t)$ of observed nests:

$$Y\left(\left[T - \frac{tp}{2} : T + \frac{tp}{2}\right]\right) = \frac{A}{2} \cos\left(\frac{2\pi}{tp}(t - T)\right) + \frac{A}{2} + B \quad (1)$$

$$Y\left(\left[1 : T - \frac{tp}{2}\right]\right) = Y\left(\left[T + \frac{tp}{2} : 365\right]\right) = B$$

A being amplitude of the sinus function (higher number of nests estimated for the nesting season), tp the duration of the nesting season (in days), T the mean position of the nesting season in the year (in days, starting from 1 January) and B the residual number of nests laid outside of the main nesting season (in number of nests). It corresponds to the period of the year during which the nesting is incidental (fewer than 5 nests per week).

Many functions are tested by varying T and tp in a realistic range determined from the seven complete sets of field data. The parameter A is initialized to the value A_{ini} by the operator.

The characteristics of the tested functions are reported in Table 1. The model is then run to determine the values of T , tp and A that best fit the data, using the least-square adjustment. During the computation, the value of A can

Table 1 Recommended values for investigating functions of the form of (1) for the leatherback *Dermochelys coriacea* (Dc) and olive ridley *Lepidochelys olivacea* (Lo) turtle species

	$T(j)$		$tp(j)$		Nb simulations	
	$T(d)$	$tp(d)$	Minimum	Maximum	1st loop	2nd loop
Lo ($A_{ini}=12$)	180	200	80	115	14 000	9600
Dc ($A_{ini}=20$)	140	170	140	170	18 000	14 400

T , mean position of the nesting season in the year (in days, starting from 1 January); tp , duration of the nesting season (in days); A_{ini} , initial amplitude of the sinus function.

Results of the adjustment are reported in Table 2.

Table 2 Results of the sinusoidal model for olive ridley turtle *Lepidochelys olivacea* (Lo) and leatherback turtle *Dermochelys coriacea* (Dc)

	Year	T	tp	A	B	Nb_{sin}	ε (%)	r
Lo	2000	197	107	8.2	0.02	453	0.9	0.63
	2001	192	102	12.3	0.06	639	0.0	0.74
	2002	189	92	20.8	0.01	951	-0.7	0.70
	2003	190	105	18.8	0.00	999	-1.2	0.73
Dc	2001	166	148	35.5	0.38	2730	-1.3	0.86
	2002	151	165	4.3	0.12	387	1.2	0.78
	2003	156	151	15.7	0.06	1212	-0.4	0.81

T , mean position of the nesting season in the year (in days, starting from 1 January); tp , duration of the nesting season (in days); A , amplitude of the sinus function; B , residual number of nests laid outside of the main nesting season; Nb_{sin} , total number of nests; ε , relative error to the total number of nests observed; r , coefficient of correlation between the model and observed data.

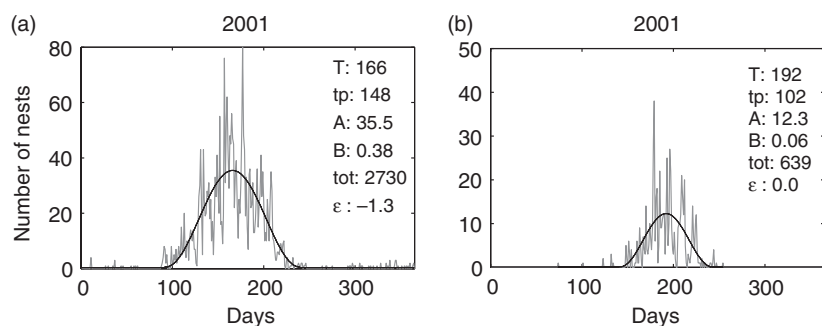


Figure 1 Adjustment of a sinusoidal function $Y(t)$ (black curve) to the temporal distribution of nests $S(t)$ (gray line): (a) leatherback turtle *Dermochelys coriacea*; (b) olive ridley turtle *Lepidochelys olivacea*. T , mean position of the nesting season in the year (in days, starting from 1 January); tp , duration of the nesting season (in days); A , amplitude of the sinus function; B , residual number of nests laid outside of the main nesting season; ε , relative error to the total number of nests observed.

vary in the range $[0.1A_{\text{ini}}; 1.9A_{\text{ini}}]$. The two-loop calculation optimizes the computational time and allows to define the best-adjusted function from a set of 20 000–30 000 of simulated sinusoidal functions.

The reliability (or accuracy) of the method is examined through the value of the correlation coefficient $r(Y, S)$ and the error ε (in per cent) on the estimate of the annual number of nests:

$$\varepsilon = \left(\sum_{t=1}^{365} Y(t) - \sum_{t=1}^{365} S(t) \right) / \sum_{t=1}^{365} S(t)$$

Results

Complete nesting season

Results for the 2001 nesting season are illustrated in Fig. 1. Results from the seven complete datasets are given in Table 2. As seen in Fig. 1, the temporal distribution of the nests shows high temporal frequency fluctuations, while the seasonal pattern is satisfactorily described by the sinusoidal function.

As can be seen in Table 2, there are significant annual fluctuations for the period of survey. The total number of nests (Nb_{sin}) varies by a factor of two for the olive ridley turtles (2000 vs. 2002) and by a factor of seven for the leatherback turtles (2002 vs. 2001). These variations are principally because of a modification of the amplitude, A , of the seasonal peak while the mean position, tp , and the period, T , do not fluctuate that much (4–15%).

The range of variation of the input parameters (Table 1) and the numerical resolution of the computing are appropriate to ensure a good estimate of the annual number of nests Nb_{sin} , so that the relative error ε is very small (-1.5–1.5%). This good estimate is, however, not indicative of a good adjustment of $Y(t)$ to $S(t)$ because errors in the estimation of each parameter (T , tp , A , B) can counter-balance each other. Actually, ε is of real interest to estimate the quality of the adjustment when the computation is run from an incomplete dataset, as done in the following sections of the paper. At this stage, the small error ε is only indicative of a good numerical accuracy. On the other hand, the correlation coefficient, r , is a good means of validating the method. For all seasons, it is of the order of 0.7 (0.63–0.74) for the olive ridley turtles and of the order of 0.8 (0.78–0.81) for the leatherback turtles. The interspecies difference is because of a difference in nesting patterns: olive ridley turtles develop an ‘arribada’ (mass nesting event) strategy, with greater variations in the daily number of nests laid. The coefficients of correlation are high enough to consider that the sinusoidal function fits well with the seasonal pattern of the field data. However, r values are highly diminished by the temporal fluctuations that occur within a short timescale in the order of a few days. The influence of these short-term fluctuations is demonstrated in Fig. 2.

For the complete dataset, the correlation between field data and the model exceeds 0.97 when filtering fluctuations occur at a timescale lower than 15 days. The filter considered herein is a simple moving average (SMA); the values of T , tp , A and B are the ones presented in Table 2, as a result of the computation. For a smoothing of data over a duration of

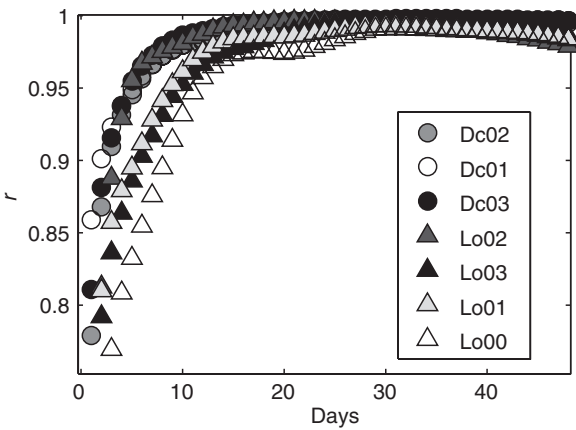


Figure 2 Correlation of the smoothed data to the best-adjusted sinusoidal functions presented in Table 2. Circles: leatherback turtle *Dermochelys coriacea* (Dc) for different years; triangles: olive ridley turtle *Lepidochelys olivacea* (Lo) for different years.

about 30 days, the correlation to the adjusted sinusoid is better than 0.99, as reported in Table 3. The skewness coefficient C_s is also very low, so the hypothesis of symmetry of the nesting season is validated, at least for the seven complete sets of data at our disposal.

It is particularly interesting to note that the duration corresponding to the better correlation is very close to the period of a complete lunar cycle (full moon to full moon). When smoothing data beyond thirty days, all of the high temporal fluctuations are filtered, in particular, the ones corresponding to the inter-nesting period.

The very good correlation between the model $Y(t)$ and field data $S(t)$ validates the approach for the particular dataset used. So, it is interesting to investigate its reliability in estimating an entire nesting season from incomplete sets of data. This is done by applying the method to a section of the complete datasets.

Duration of monitoring

We examine the relevance of the method for the prediction of the annual number of nests when considering an incomplete survey of 20, 30, 50 and 100 consecutive days. Simulations are performed for windows centered on consecutive dates that cover the range $[T-tp/2$ to $T+tp/2]$ with a time step of 3 days. As previously, the model is run with the specifications given in Table 1. Results are summarized in Fig. 3 by examining the variation of ϵ with the width of the windows of monitoring. It is based on a total of 670 individual runs of the model.

For the two species, the relative error ϵ is very important when the duration of the monitoring lasts 20 days. The relative error has a median value of 13% for the leatherback turtle with an inter-quartile range of 21%. For the olive ridley turtle, the relative error has a median value of 30% with an inter-quartile range of 34%. For this species, the scattering on ϵ is very high. For example, the simulation with a window centered on day 160 for the season in the year

Table 3 Coefficients of correlation (r) and of skewness (C_s) between the dataset $S(t)$ smoothed on 30 days and the best-adjusted sinusoidal function $Y(t)$

	Year	r (30 days)	C_s
Lo	2000	0.991	-0.17
	2001	0.993	0.06
	2002	0.994	0.04
	2003	0.994	0.05
Dc	2001	0.996	0.14
	2002	0.995	0.12
	2003	0.998	0.04

Lo, olive ridley turtle *Lepidochelys olivacea*; Dc, leatherback turtle *Dermochelys coriacea*.

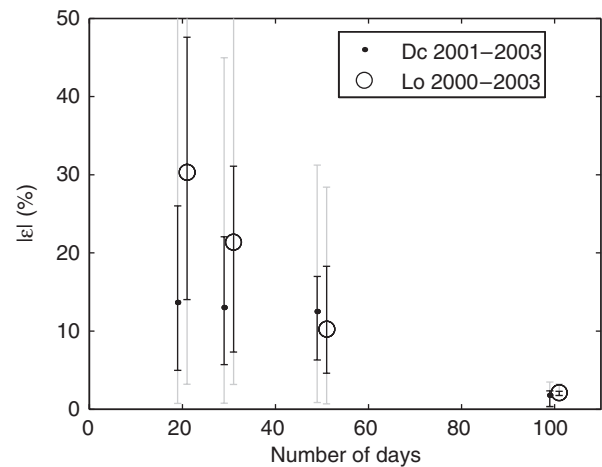


Figure 3 Variation of the predicted annual number of nests with the width of the window of monitoring. Dc, leatherback turtle *Dermochelys coriacea*; Lo, olive ridley turtle *Lepidochelys olivacea*. Dots and circles correspond to the median value of $|\epsilon|$; black error bars correspond to the interquartile range; gray error bars correspond to the 5–95% limits. Note that symbols are slightly shifted (not centered on 20, 30, 50 and 100 values) for legibility.

2000 of the olive ridley turtles overestimates the annual number of nests by nearly two times ($\epsilon \approx -197.8\%$). The following simulation, centered on day 163, is far better and estimates the annual number of nests with a relative error, $\epsilon \approx -1.2\%$. Such variations are because of the very important temporal fluctuations in the nesting activity that occur at a short time scale. For windows of monitoring lasting less than 50 days, the prediction is of a lower quality for the olive ridley turtles because of their specific ‘arribadas’ mass-nesting strategy. For windows of monitoring of 50 days or more, this effect is smoothed and the predictions are similar for leatherback and olive ridley turtles. The median value of ϵ becomes lower than 10–15% and its inter-quartile range reduces to about 10%. For monitoring windows of 100 days, the estimate of the annual number of nests is very good, ϵ being lower than 3%. Note that for such wide windows of monitoring, almost the entire nesting season is

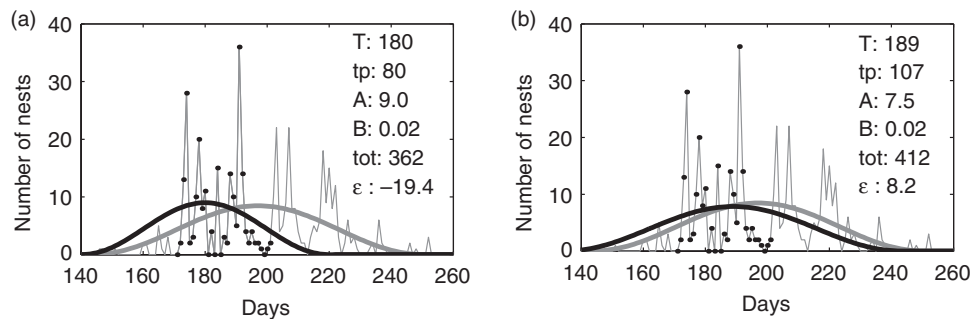


Figure 4 Illustration of the role of the range of investigation of the parameters of (1) from the olive ridley nesting activity in 2000. The gray line corresponds to the complete field data, and the bold gray curve represents the corresponding sinusoid function (see Table 2: $T=197$, $tp=107$, $A=8.2$, $B=0.02$). The black dots represent the window of monitoring used for the run. The bold black curve represents the associated sinusoid function for two different sets of input parameters: (a) $180 \leq T \leq 200$; $80 \leq tp \leq 115$ and $A_{ini}=12$ (see Table 1), (b) $189 \leq T \leq 197$; $92 \leq tp \leq 107$ and $A_{ini}=12$ (see Table 2). T , mean position of the nesting season in the year (in days, starting from 1 January); tp , duration of the nesting season (in days); A , amplitude of the sinus function; B , residual number of nests laid outside of the main nesting season; ϵ , relative error to the total number of nests observed.

covered for the olive ridley turtle and more than 2/3 for the leatherback turtle.

Range of investigation of T , tp and initialization of A

In this section, we examine how inter-annual variation is to be considered to optimize the numerical simulation. To obtain a good prediction, the difficulty lies in the investigation of realistic sinusoidal functions, for the site and turtle species considered. The input range of variation of the parameters T , tp and A_{ini} must be sufficiently wide to take into account possible fluctuations from year to year, but also sufficiently restricted to prevent unrealistic simulations.

The methodology is illustrated from a fragmented data set of the olive ridley turtle during the 2000 season (Fig. 4). Here, we consider patrols every nights from night 170 to the night 200 (black dots), and we consider that no data were available beyond this period. The complete season (in gray) is only reported for comparison.

In Fig. 4a, only general information on the behavior of the olive ridley turtle is considered (the model is run with the specifications in Table 1). The peak of maximum nesting occurs too early in the season ($T=180$) and the duration of the season is too short ($tp=80$). As a consequence, the model (black curve) significantly underestimates the annual number of nests $\epsilon \approx -19.4\%$. This prediction results from the strong drop in field data beyond day 193 (black dots below five nests per night). The amplitude A is well estimated ($A=9.0$).

In Fig. 4b, we took into account the knowledge of the inter-annual variations gathered in Table 2. The model is run with the input ranges of parameters $T=[189-197]$ and $tp=[92-107]$. These ranges correspond to the extreme values of T and tp measured in the field from 2000 to 2003. For this simulation, T is still slightly underestimated but the model gives a better estimate of the annual number of nests and $\epsilon \approx -8.2\%$.

This example shows that prior knowledge of the nesting behavior can significantly improve the results of the model by investigating only realistic scenarios.

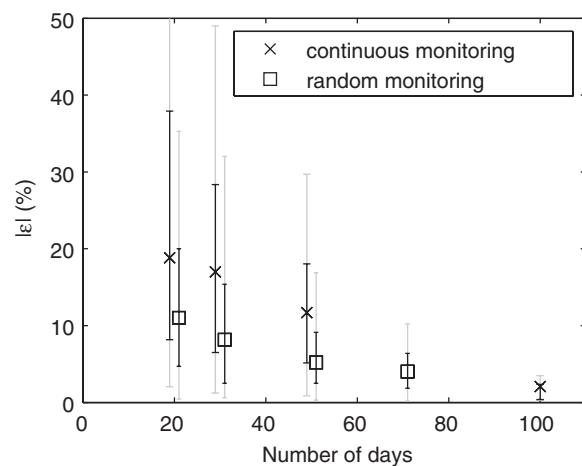


Figure 5 Importance of the strategy of monitoring on the prediction of the annual number of nests: crosses and squares correspond to the median value of $|\epsilon|$; black error bars correspond to the interquartile range; gray error bars correspond to the 5–95% limits. Note that symbols are slightly shifted (not centered on 20–30–50 values) for legibility.

Monitoring protocol

In the case of a limited number of days of monitoring, the monitoring strategy is an important issue to deal with. An intuitive field strategy may consist of monitoring the beach continuously during the presumed peak in nesting. Actually, this strategy does not appear to be appropriate because the erratic fluctuations that exist at a short timescale induce a very important scattering on ϵ . This is particularly clear for windows of monitoring reduced to 20–30 days, as illustrated in Figs 3 and 4.

The synthesis of computations for incomplete, but continuous, monitoring is presented in Fig. 3. We now propose to compare it with the case of a monitoring randomly distributed over the nesting season. For each year and each species, 20 simulations are performed from uniformly distributed random entries of 20, 30, 50 and 70 dates, chosen on

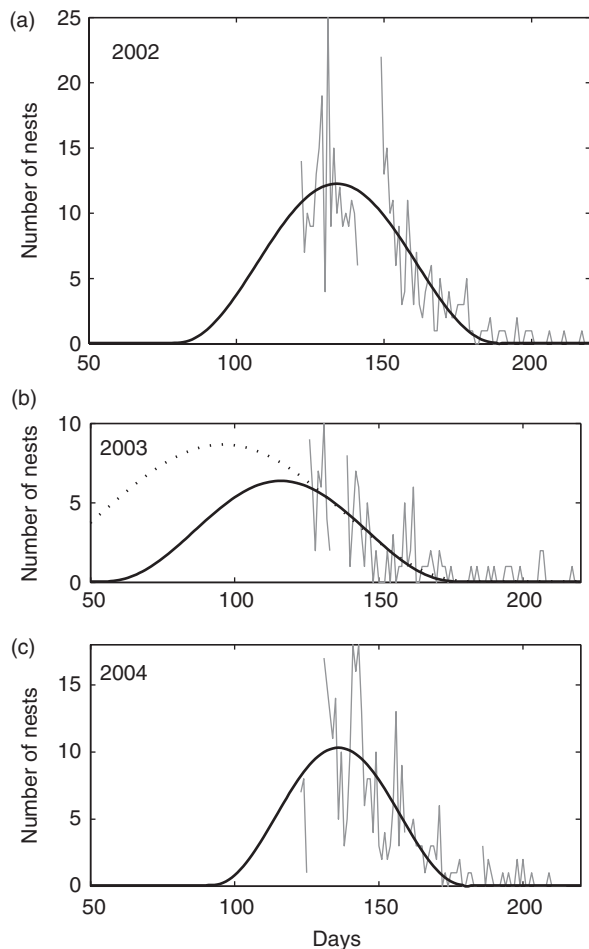


Figure 6 Adjustment of a sinusoidal function $Y(t)$ (black curve) to the incomplete green turtle data set (gray line): (a) year 2002, Irakompapi beach; (b) year 2003, Pointe Isère beach; (c) year 2004, Pointe Isère beach.

the interval [100–200] days for the leatherback turtle and on the interval [150–240] days for the olive ridley turtle. These ranges broadly correspond to the nesting season (range $T - tp/2$ to $T + tp/2$ in Table 2). The comparison of a continuously, or randomly distributed monitoring effort, all species confounded is reported in Fig. 5.

The implementation of a random monitoring method statistically gives the best prediction. The difference is particularly clear when the number of days of monitoring is small. For 20 days of continuous monitoring, the prediction of the annual number of nests presents a median error ε of about 20% with an inter-quartile range of 30% (cross). In comparison, the randomly distributed monitoring provides a relative error of only 10% with an inter-quartile range reduced to 15%.

Example of application

The model presented in this paper is now applied to three incomplete series for the green turtle species. These data were

Table 4 Results of the model applied to the incomplete green turtle data set presented in Fig. 6

Year	T	tp	A	B	Nb_{sin}	ε (%)
2002	134	110	12.3	0.05	681	10
2003	116	120	6.4	0.05	401	15–20
2004	136	87	10.3	0.06	469	10

T , mean position of the nesting season in the year (in days, starting from 1 January); tp , duration of the nesting season (in days); A , amplitude of the sinus function; B , residual number of nests laid outside of the main nesting season; Nb_{sin} , total number of nests; ε , relative error to the total number of nests observed.

obtained in 2002 along the beach of Irakompapi and in 2003 and 2004 along the beach of Pointe Isère. Another data set was obtained in 2002 along the beach of Organabo but it was considered unsuitable because it contained less than 20 days of monitoring. The results are reported in Fig. 6 and in Table 4. They should be viewed as an index to abundance because it is very probable that some nests were overlooked during the night patrols. The model is run by considering that the nesting season spans from early March (day 60) to the end of June (day 180), as reported in the literature (Girondot & Fretey, 1996). This implies that tp should not exceed 120 days. Furthermore, it seems reasonable to consider that tp should exceed 30 days. These conditions on tp fix the range of possible values for T [(75–165)]. A is arbitrarily initialized to $A_{\text{ini}} = 15$. If the information of Girondot & Fretey (1996) is not taken into account, the model provides the same result for the years 2002 and 2004 and an unrealistic prediction for the year 2003 (dotted line in Fig. 6b).

As previously reported for the leatherback and olive ridley turtles, the interannual variation in the number of nests is principally attributed to a variation of the amplitude A ; T and tp being relatively stable. In Table 4, the mean position of the season T fluctuates between day 116 and day 136, and the duration of the season tp fluctuates between 87 and 120 days. A fluctuates much more, in the range [6.4 12.3]. Because no complete data sets are used here, it is not possible to perform a rigorous estimation of ε as the ones reported in Figs 3 and 5. So, it is difficult to estimate the uncertainty for the total number of nests Nb_{sin} presented in Table 4.

If we assume that green turtles do not really develop an ‘arribada’ (mass nesting event) strategy, the estimate of the total number of nests should be better than the one presented in Fig. 3 for the olive ridley turtle (circles). In Fig. 6, observed data covered *c.* 50 days of the main season for the years 2002 and 2004 and 35–40 days for the year 2003, so we may presume a median error of around 10% and 15–20%, respectively.

Conclusion and recommendations

The adjustment of a sinusoidal function to fragmented field data provides an estimate of the annual number of nests with precision (ε lower than 15%) when the number of days of monitoring exceeds 50 days. The understanding of the patterns of the turtle nesting season (duration, amplitude) derived

from several years of exhaustive monitoring can have a positive effect on the quality of prediction. This is because it allows the operator to fit the model specifications (Table 1) to the most realistic range, which is now the case in French Guiana. Because of the high variability of the number of nests at a short timescale, we advocate a strategy of monitoring distributed throughout the entire season. Following this recommendation, the precision of the estimated annual rate of nests derived from 50 days of monitoring becomes better than 10% (third quartile on $|\varepsilon|$). When the duration of monitoring is lower than 30 days, a monitoring effort distributed along the entire season appears to be the only suitable strategy for reasonable predictions of the annual number of nests (precision better than 20% for the third quartile on $|\varepsilon|$).

A similar recommendation can be made when considering other models currently in use: the Lagrange interpolation method, previously used by Girondot *et al.* (2002a), gives a satisfactory estimate on the annual number of nests for a distributed monitoring over the year but cannot provide extrapolations (Girondot, Viseux & Rivalan, 2002b). To overcome this limitation, Girondot *et al.* (2002b) developed a double sigmoid model that consists of the adjustment of a multiple parameters function to the nesting season. It is likely to demonstrate a behavior similar to the model presented herein because it is developed from a similar approach. Note that the double sigmoid model allows asymmetry in the nesting season. Somehow, it may open the range of simulations to poorly realistic cases (at least for the set of data at our disposal), with repercussions potentially similar to the ones presented in this paper (Fig. 4 and corresponding subsection). The most recent approach, developed by P. Rivalan, J. P. Briane, M. Godfrey, S. Caut & M. Girondot (unpubl. data), takes into account both low and high temporal variations. Such a method is particularly promising in the understanding of forcing (biological and physical) that governs the inter-nesting dynamic. In the near future, it should be of scientific interest to compare the models and obtain an optimized policy of monitoring.

As presented in Fig. 2, the model fits very well to the field data when filtered over 30 days ($r > 0.99$). So, the sinusoidal function is clearly appropriate for the description of the global pattern of the turtle nesting season in French Guiana, at least for the two species considered. As our model fits two different nesting behaviors (aggregated for the olive ridley, solitary for the leatherback), and as marine turtle nesting behavior is considered as highly stereotypic (Meylan & Meylan, 1999), further testing could prove it to be adapted to other marine turtle species, in other regional contexts. Finally, its simplicity and low computational time should be particularly attractive to the majority of conservation biologists who are interested in the study of turtle population trends and turtle conservation policies.

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