

Contrasted trends for leatherback and Oliver Ridley marine turtles nesting in Congo

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Abstract

Six marine turtles species are observed in the shore of Republic of the Congo and among them, nesting by leatherbacks (*Dermochelys coriacea*) and olive ridleys (*Lepidochelys olivacea*) takes place annually from September to April on Congolese beaches. These species are classified as Critically Endangered and Endangered respectively by UICN. Whereas these categories should not be used in their literal sense, it denotes at least some concern about their long-term survival. We developed a methodology to model the nesting season of marines turtles and use this methodology on the time series of nest counts from 6 nesting beaches monitored during 2 to 4 years. We show a decline of olive ridleys nest during this period whereas leatherback nesting is enhanced. We propose that differential threats for these two species explain such a contrasted pattern.

Introduction

Marine turtles are recognized internationally as species of conservation concern. All marine turtle species are experiencing serious threats to their survival. The main threats are pollution and changes to important turtle habitats, especially coral reefs, seagrass beds, mangrove forests and nesting beaches. Other threats include accidental drowning in fishing gear, over-harvesting of turtles and eggs, and predation of eggs and hatchlings by foxes, feral pigs, dogs and goannas.

Africa can be considered still as a *terra incognita* for marine conservation (Shumway, 1999) and particularly for marine turtles (Formia et al., 2003). All six of the Atlantic species have been reported to occur from Morocco to South Africa: green turtle (*Chelonia mydas*), leatherback (*Dermochelys coriacea*), hawksbill (*Eretmochelys imbricata*), olive ridley (*Lepidochelys olivacea*), loggerhead (*Caretta caretta*) and Kemp's ridley (*Lepidochelys kempii*). Nesting occurs nearly all along the coast but very few quantitative data exists to establish a trend there. Such a situation is particularly concerning because reports indicate high level of local consumption of eggs and meat of marine turtles (Barnett et al., 2004) as well as high level of by catching in fishing nets (Carranza et al., 2006; Lewison & Crowder, 2007). In Congo, nesting by leatherbacks (*Dermochelys coriacea*) and olive ridleys (*Lepidochelys olivacea*) takes place annually from September to April (Bal et al., 2007). Exceptionally, green turtles (*Chelonia mydas*) can be seen to nest but the rarity of the observations makes any analysis impossible for this species.

Number of nests laid by a population can be used as an index of population size (Gerrodette & Taylor, 1999) and permits to define a trend for population (e.g. Troëng et al., 2004). To assess the more precisely the status of a population, times-series of nest counts must be

analyzed using adequate statistical tools. Considerable work has been done in the area of time series for counts. Cox (1981) classified time-series models for serially-correlated data into two classes: observation-driven and parameter-driven. Observation-driven models specify the conditional distribution of a response at time t as a function of past responses. Although theory exists for irregularly spaced observations (Omori, 2003), which are common in environmental applications, many existing methods are difficult to adapt to such irregularity. This is particularly true of observation-driven methods, since some of the historical observations are essentially missing. In contrast, parameter-driven models specify an underlying serially correlated latent process. Recent approaches to time series data in environmental applications use a semiparametric approach, where a time effect is included in the mean (Coull et al., 2001; Samoli et al., 2001). The advantage of such an approach is that it more flexibly models nonstationarity in the time effect.

The counts of nest number obtained since 4 years along the 170 km of coast of Congo Republic were analyzed using a derivation of a previously statistical model of nesting season develop for nesting beaches with high level of nesting (Girondot et al., 2006). We show that this model over-estimates nest number when the highest number of nests per night is very low, e.g. up to 3 at maximum per night. We build a new model changing the model of nest distribution per night and use this model for the 16 times series obtained since 4 years in this region. We show a positive trend for leatherbacks nest number but a negative one for olive ridleys. The reason of such a contrasted trend is discussed in the light of the knowledge of ocean use for these two species and threats along the coast.

Material and methods

1/ Study area and field work

The Republic of the Congo (République du Congo), is also known as Congo-Brazzaville (locally, "Congo-Brazza") or the Congo. Congo is located in the central-western part of sub-Saharan Africa, Equator. To the south and east of it is the Democratic Republic of Congo. It is also bounded by Gabon to the west, Cameroon and the Central African Republic to the north, and Cabinda province in Angola to the southwest. It has a short Atlantic coast of 170 km (figure 1).

Along this coast, sandy beaches in front of mangrove cover the most part of this littoral. It should be noted a rocky structure near the center of the coast around Pointe Indienne and Pointe Noire (see figure 1).

Field patrols for nest counts occur at the morning on 2 (2003-2004) to 6 (2005-2006) beaches covering from 20 km (2004-2005) to 59 km (2005-2006). Because the adult females leave wide deep tracks on the beach after nesting, it is a relatively easy task to identify a sea turtle nesting crawl (Schroeder & Murphy, 1999). Experienced field-workers can differentiate tracks with a body pit that indicates a successful oviposition from a female disturbed during the nesting process that had not deposited eggs. Only the Northern beaches at the border of Gabon within the Conkouati-Douli National Park were not patrolled by RENATURA association and are not included here. The Wildlife Conservation Society works these beaches on. During patrols, activity of nesting is recorded. This work is done on a daily basis on Djeno and Bellelo beaches and Mvassa in 2006-2007 and weekly basis in the other beaches during the entire nesting season from November to April.

2/ Model for nesting season

We use essentially the model develop by Girondot et al. (2006) to model the nesting season. It is described here briefly.

Nesting seasons of marine turtles are typically characterized by a peak of nesting approximately during the middle of the nesting season. The number of nests at the start and end of the nesting season is low ; generally less than one nest per week or per month in some populations. This typical pattern has been modeled using the product of two sigmoid equations, the first one ranging from 0 to 1 and the second one from 1 to 0. The product shows a 0-1-0 pattern if the transition of the first equation is observed at an abscissa of lower value than the second one. For each sigmoid equation, we use a modified form of the Verhulst equation (1846) that allows asymmetry to be set.

$$M(d) = \left(1 + \left(2^{e^K} - 1 \right) e^{\left(\frac{1}{S} (P-d) \right)} \right)^{-1/e^K} \quad (1)$$

where d is the Julian date, P is related to the dates before and after the peak nesting day when there is an observed maximum rate of change (increase or decrease) in nest numbers, and S and K are related to the change in nest numbers at date P .

The value of $M(d)$ ranges from 0 to 1 with $M(d)=0.5$ for $P=d$, with d being the number of days since the start of the nesting season. The steepness of $M(d)$ at $P=d$ depends on S and K values. $M(d)$ is increasing when S is negative (*i.e.* at the start of the nesting season) and decreasing when S is positive (*i.e.* at the end of nesting season). Asymmetry around P is determined by a positive or negative value of K . The equation (1) is reduced to a simple logistic equation (*i.e.* symmetrical around P) when $K=0$.

The mathematical description of a nesting season can therefore be expressed as:

$$N(d) = \min + (\max - \min) \cdot (M_1(d) \cdot M_2(d)) \quad (2)$$

with $M_1(d)$ and $M_2(d)$ being the first and second halves of the nesting season, respectively.

The difference between the two largely rests on the sign of the S parameter: S_1 is negative, S_2 is positive. The parameter \min is the basal level of nesting outside the nesting season and $\max - \min$ is a scaling factor. Note that \max is not the maximum of the function because $(M_1(d) \cdot M_2(d))$ can be lower than 1 at the peak of nesting season. The maximum must be calculated numerically as well as the length of the nesting season. We define $l_x\%$ the length of the nesting season which encompass all the period where the nest number is higher than $x\%$ of the number of nests observed at the peak of the nesting season.

The entire nesting season can be expressed using equation (2), which is based on 8 parameters. The number of parameters can be reduced using the Verhulst equation around P_1 ($K_1=0$), P_2 ($K_2=0$), or both. The basal level of nests \min can be fixed to 0. Also, if it is assumed that the beginning and the end of nesting season show similar shapes, this can be expressed by setting $S_1=-S_2$ and $K_1=K_2$. The most reduced form of equation 2 uses only 4 parameters ($\min=0$, $K_1=K_2=0$, $S_1=-S_2$). In the use of this model for Congo beaches, the \min parameter, which describes the daily number of nests outside the nesting season, is fixed to 0 as no nest is observed during half of the year (GB and NB personal observations). The nesting season boundaries used here are from early October to late April.

3/ Error distribution and parameter estimation

The parameters have been fitted using maximum likelihood statistical methodology. In short the parameter values that maximized the likelihood of observations in the model are searched for using a non-linear fitting algorithm (Lasdon et al., 1978; Lasdon & Waren, 1981). In a previous analysis Girondot *et al.* (2006) postulate that nest number distribution in a particular day could be approximated by a Gaussian distribution with variable standard deviation to take into account heteroskedasticity. The assumption that a Gaussian probability distribution underlies the observed data can be questioned for several reasons. First, the normal distribution represents probabilities associated with a continuous variable that can theoretically take on any possible value within a plausible range, including fractional values if the observational method has the necessary precision. Nest number data are discrete counts of the organisms that were collected in the samples and can only be represented by nonnegative integers. Nest number data are also characterized by low mean values and high variances. In this event, because of its symmetry, the normal probability distribution can imply a substantial probability of observing a negative number of nests. An alternative Poissonian distribution will be implemented.

In probability theory and statistics, the Poisson distribution is a discrete probability distribution that expresses the probability of a number of events occurring in a fixed period of time if these events occur with a known average rate, and are independent of the time since the last event. The probability that there are exactly x occurrences (x being a non-negative integer, $x = 0, 1, 2, \dots$) while the expected number of occurrences is λ equals:

$$f(k, \lambda) = \frac{e^{-\lambda} \lambda^k}{k!}$$

4/ Model selection and quality of fit

Model selection was performed using the Akaike Information Content (Akaike, 1974). This is a ranking measure that takes into account the quality of the fit of the model to the data while penalizing for the number of parameters used:

$$\text{AIC} = -2 \ln L + 2 M$$

where L = maximum likelihood, and M = the number of parameters. The models with the lowest values of AIC were retained as good candidate models and Δ_{AIC} was calculated as the difference in value of AIC between a particular model and the one with the lowest AIC. Akaike weights ($w_i = \exp(-\Delta_{\text{AIC}}/2)$ normalized to 1) were used to evaluate the relative support of various tested models (Burnham & Anderson, 1998). Akaike weights can be directly interpreted as conditional probabilities for each model. Ideally, the model with the lowest AIC was kept for further testing. When two or more models possessed similar Akaike weights, the model with the lowest number of parameters was selected. When several of these models had the same number of parameters, the model with the lowest AIC among them was selected.

The quality of fitting was estimated by comparison of the deviance of the saturated model D_{full} with the one of the fitted model D_{fitted} . The statistic $D_{\text{fitted}} - D_{\text{full}}$ is distributed as a χ^2 with a degree of freedom equal to the number of observations minus the number of parameters fitted from these observations.

5/ Standard error on parameters and nest number

Standard error on the mean nest number has been estimated from a bootstrap sampling of the counts of nests (Efron & Tibshirani, 1993). This strategy is used to alleviate the technical difficulties in estimate confidence interval of mean of Poisson distribution (Sahai & Khurshid, 1993). The bootstrap strategy cannot be used for beaches with one count per week during 3 months. In this case, the parameters describing the shape of nesting season obtained from bootstrapped samples were used and only the *max* parameter was fitted with all the nest count data for that beach.

The total number of nests deposited during the entire season was the sum of the number of nests laid per night. Daily estimate from October to April are used for leatherbacks and September to April for olive ridleys. When the nest number for a particular night was known, the observed value is used for the total estimate. The confidence interval on total nest number is estimated using the bootstrapped samples.

6/ Trend analyses

Data are available for 4 years on only two nesting beaches: Djeno and Bellelo. The trend for the number of nests for these two nesting beaches has been obtained based on an exponential growth model. The number of nests upon year is fitted using maximum likelihood with Gaussian error model with a fitted standard deviation. The significance of the rowth rate is obtained by comparison of the AIC obtained with fitted *r* value with a constrained constant model. Akaike weight (Burnham & Anderson, 2002) is used to evaluate the relative support of both models.

Results

Fit of nesting seasons for *Dermochelys coriacea*

First a single model of nesting season shape for all the years is implemented but *max* value is beach and year-specific. The likelihood of the model with K_1 and K_2 fitted is only slightly better than when K_1 and K_2 are fixed to 0 ($-\ln L=1075.94$ vs. 1075.95). Therefore the K_1 and K_2 values will be discarded thereafter. The fit of the model cannot be rejected (residual deviance: 1262.68; DF 1725; $p=1$).

When a yearly-based model is implemented for the shape of the nesting season (S and P values are different each year), some years cannot be fitted because data are lacking at the beginning of the nesting season. Therefore this model cannot be tested.

The total number of nests estimated for each year and beach is shown on table 1 and the fits for Djeno and Bellelo beaches are shown in figure 2.

Fit of nesting seasons for *Lepidochelys olivacea*

When a single model of nesting season shape for all the years is implemented, the fit of the beginning of the nesting season cannot be done. Field patrols begin too late to allow an estimation of the beginning of the nesting season. As an alternative a constraint on S_1 can be setup from the value of S_2 . For example, if $S_1=S_2$, then the shape of the nesting season is symmetrical around P_2-P_1 day. Such a symmetry has been implemented in Gratiot *et al.* (2006) but it appears to be an extremely strong hypothesis that data do not validate. Indeed, several different populations of marine turtles display asymmetrical peaked patterns

associated with their nesting season (e.g. Diamond, 1976; Steyermark et al., 1996; Duque & Paez, 2000).

As an alternative, we fit several time-series of *Lepidochelys olivacea* nest number from French Guiana (not shown). We show that the end of the nesting season is sharper than the beginning ($|S_2| > |S_1|$). The average ratio of $|S_2|/|S_1|$ is 1.33. We use this ratio here to constraint S_1 based on S_2 . P_1 value is still fitted.

The likelihood of the model with K_1 and K_2 fitted is only slightly better than when K_1 and K_2 are fixed to 0 (-Ln L=875.2 vs. 876.56). Therefore the K_1 and K_2 values will be discarded for the rest of the analysis. The fit of the model cannot be rejected (residual deviance: 1106.50; DF 1695; p=1). Again a yearly-based model cannot be implemented because lack of early nesting season data.

The total number of nests estimated for each year and beach is shown on table 2 and the fits for Djeno and Bellelo beaches are shown in figure 3.

Trend analyses

For *Dermochelys coriacea*, the instantaneous growth rate of the exponential growth model (r) is positive for both beaches (0.62 and 0.16 for respectively Bellelo and Djeno beach; figure 4A). When compared with a constrained constant model ($r=0$), the model with r fitted is selected for (AIC 50.74 vs. 66.60: Akaike weight=0.999). For *Lepidochelys olivacea*, the instantaneous growth rate is negative for both beaches (-0.10 and -0.12 for respectively Bellelo and Djeno beach, figure 4B). When compared with a constrained constant model ($r=0$), the model with r fitted is selected for (AIC 50.51 vs. 53.78: Akaike weight=0.830).

In conclusion, the trend for these 4 seasons on these two beaches is positive for *Dermochelys coriacea* but negative for *Lepidochelys olivacea*.

Discussion

Olive ridleys are classified as endangered by UICN (Red List Standards & Petitions Subcommittee, 1996) and leatherbacks as Critically Endangered (Sarti Martinez, 2002). Whereas these categories are probably not reflective on the true status of marine turtles (Mrosovsky, 2004), they indicate at least some concern about their long-term survival. Therefore time series of quantification of presence of these species is of particular interest. The methodology we propose to analyze time-series of nest count appears to be well suited for the various constraints classically observed with fieldwork. It can use long time-series as well as short ones and takes all the information in these. It permits also to test hypotheses using environmental covariates influencing the phenology of nesting (Girondot et al., 2006).

When applied to Congo data, the previously published methodology (Girondot et al., 2006) failed because the normal approximation used for error distribution makes the distribution biased when the number of nests is small or as large as the variance. It should be noted that least-square fitting used by Gratiot et al. (2006) for a similar objective suffers the same bias because least-square fitting supposes homoskedastic Gaussian error distribution (Hilborn & Mangel, 1997). Generally for time series of marine turtles nest counts, both the homoskedasticity and the Gaussian distribution are not valid assumptions.

The use of Poisson distribution for nest numbers appears to correct for these problems. When applied with the Congo data, the fit of the model appears to not be rejected and no zero-

inflated model is necessary (Agarwal et al., 2002; Cunningham & Lindenmayer, 2004). This observation comforts our choice for this distribution and shape model for the nesting season.

The total level of nesting for *Lepidochelys olivacea* and *Dermochelys coriacea* can be finally obtained for two year on the entire survey area. The total number of nests is 479 [CI 95%, 337-610] in 2004-2005 and 439 [CI 95%, 337-535] in 2005-2006 for olive ridleys and 421 [CI 95%, 380-466] in 2004-2005 and 497 [CI 95%, 470-525] in 2005-2006 for leatherbacks. We prefer not to try to convert these values in number of females, because we lack information on the mean number of nests per female in this region and the distribution of such statistics.

Four times series of fours years were obtained, for two species and two beaches. The two olive ridley time series show a decrease of the nesting activity during these fours years whereas during the same time laps the nesting of leatherbacks increases on these two beaches. It is tempting to conclude about population status from these observations, however one should be aware that many factors could be at play to change the observed level of nesting on one particular location: abandon of nesting beach by nesting females, change in the probability to skip a nesting season or change in the mean number of nests per female have been envisaged as reason of change of frequentation of nesting site (Girondot et al., 2007). Even a human sampling effect could produce an increase in nest density from year to year if the patrols are more trained to find the nests. For the Congo data, such a sampling bias does not appear to be the cause of the conclusion because the nest density for one species in enhanced but reduced for the other. Also the strong hypothesis we have used to define the shape of the beginning of the nesting season in olive ridley is questionable. For this species the estimates of the total number of nests for one particular year/ beach should be used with

caution but the relative changes during these four seasons are not altered by this hypothesis. For next year, the monitoring of the beach should begin in early September.

After these precautions, the differential trend between these two species can be linked to at sea and level of threatens for these species. Since two years, communication has been conducted to fishermen of the villages. When a turtle is caught, a local member of the RENATURA association is phoned. If the turtle is free alive, material is given to repair the net. A total of 1500 releases in one year have been done and it permits to draw a scheme on the yearly use of coastal habitat by marine turtles. Olive ridleys are present all along the year in the coast whereas leatherbacks are present only during nesting season (Figure 5). This observation when coupled with the much smaller size and mass of olive ridleys could produce a differential threat for these two species. Indeed, along the coast piles of olive ridley's carapaces are sometimes observed (Figure 6). The contrasted trend for these two species could be a direct consequence of differential threats.

The four-years time-series appear to be short to draw definitive conclusion but we urge the authorities to support the effort of RENATURA and the fishermen to release Olive Ridley's, and more generally marine turtles, when caught. Since one year this program has been stopped due to lack of financial support and probably hundreds of individuals have been killed. We urge authorities as well as conservation organization to take this problem into account to enhance this program that is really benefited for marine turtles in Congo.

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Table 1: Number of leatherback nests observed and corrected for partial temporal sampling from 2003-2004 to 2006-2007 nesting seasons on Congo coast.

	Beach name	Beach length	Nights patrolled	Nests observed	Corrected number of nests		
					Average	Confidence interval at 95%	
2003-2004	Bellelo	10 km	170	18	19.22	18.54	19.86
	Djeno	10 km	158	52	59.94	57.94	63.55
2004-2005	Bellelo	10 km	171	22	22.74	22.23	23.22
	Djeno	10 km	162	51	54.33	52.69	56.33
2005-2006	Bellelo	10 km	136	69	74.06	72.14	76.42
	Tchissaou	10 km	7	3	49.14	38.47	63.2
	Bas Kouilou Sud	8.9 km	8	5	78.76	69.86	87.59
	Mvassa	10 km	8	6	92.81	82.27	103.16
	Djeno	10 km	114	72	79.03	75.50	82.78
	Cabinda frontier	4.5 km	8	3	47.42	41.56	52.86
	Total				421	380	466
2006-2007	Bellelo	10 km	175	113	115.05	114.01	116.31
	Tchissaou	10 km	167	75	77.42	76.16	78.77
	Bas Kouilou Sud	8.9 km	8	2	28.41	25.18	31.62
	Mvassa	10 km	12	9	128.96	114.42	143.56
	Djeno	10 km	175	88	89.74	88.82	90.82
	Cabinda frontier	4.5 km	11	4	57.84	51.32	64.36
	Total				497	470	525

Table 2: Number of olive ridley nests observed and corrected for partial temporal sampling from 2003-2004 to 2006-2007 nesting seasons on Congo coast.

	Beach name	Beach length	Nights patrolled	Nests observed	Corrected number of nests		
					Average	Confidence interval at 95%	
2003-2004	Bellelo	10 km	170	47	65.24	53.03	78.96
	Djeno	10 km	158	50	90.5	66.49	115.94
2004-2005	Bellelo	10 km	171	40	48.2	41.52	55.43
	Djeno	10 km	162	59	79.62	63.1	95.49
2005-2006	Bellelo	10 km	136	30	46.56	32.39	57.64
	Tchissaou	10 km	7	2	47.61	31.86	63.09
	Bas Kouilou Sud	8.9 km	8	1	22.9	14.73	30.81
	Mvassa	10 km	8	4	85.54	54.64	115.5
	Djeno	10 km	114	66	89.11	69.27	105.96
	Cabinda frontier	4.5 km	8	9	187.36	135.04	237.43
	Total				479	337	610
2006-2007	Bellelo	10 km	175	42	48.2	42.65	53.82
	Tchissaou	10 km	167	49	70.63	54.6	84.68
	Bas Kouilou Sud	8.9 km	8	2	31.09	23.13	38.86
	Mvassa	10 km	12	10	167.48	121.5	211.48
	Djeno	10 km	175	44	53.83	46.13	60.44
	Cabinda frontier	4.5 km	11	4	68.37	49.44	86.47
	Total				439	337	535

Figure 1. Map of the coast of Congo. Beaches are indicated with bold lines parallel to the coast. Closed lines indicated beaches monitored by RENATURA association and opened ones are the beaches located within the National Park of Conkouati-Douli monitored by the Wildlife Conservation Society (not included in this study). The total coastline encompasses 170 km.

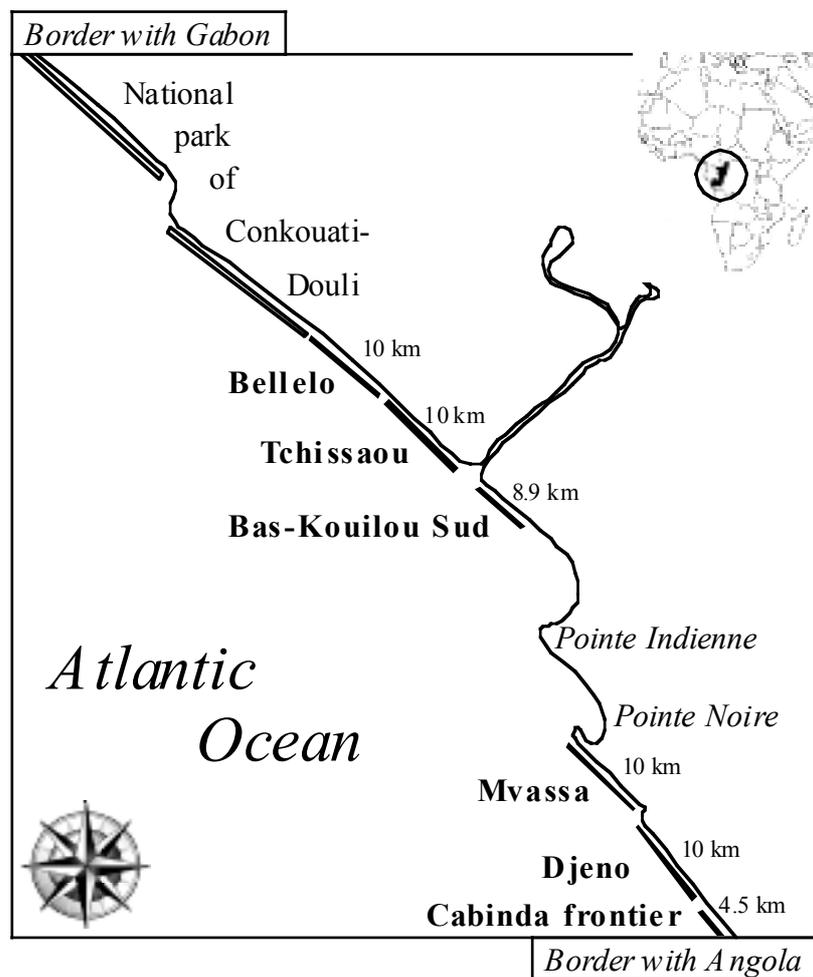


Figure 2: Number of leatherback nests on two beaches monitored for 4 nesting seasons. Bold line is the best-fitted distribution for daily nest number and the two lines surrounded it are its 95% confidence interval based on bootstrapped samples.

Number of leatherback nests per night

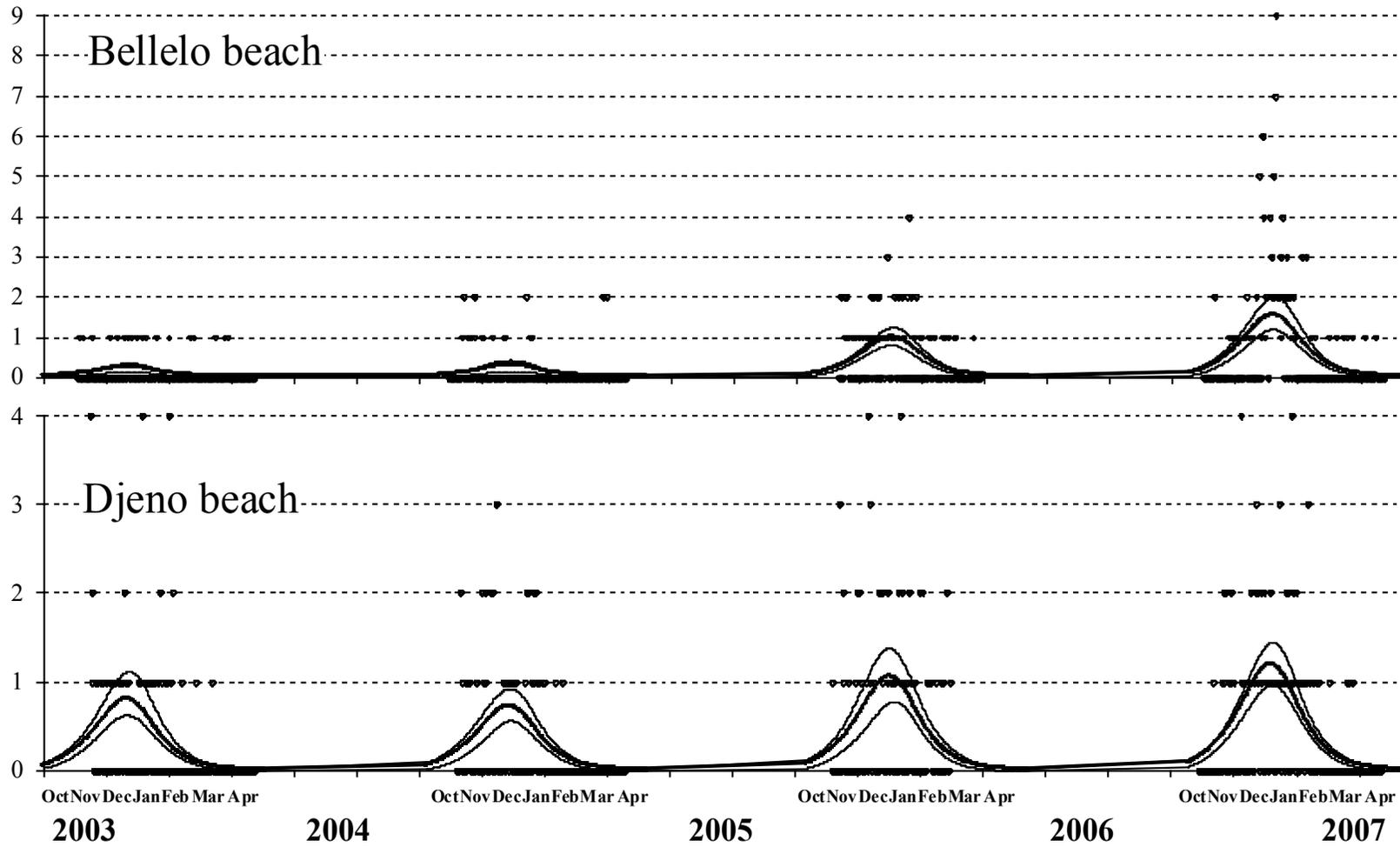


Figure 3: Number of olive ridley nests on two beaches monitored for 4 nesting seasons. Bold line is the best-fitted distribution for daily nest number and the two lines surrounded it are its 95% confidence interval based on bootstrapped samples.

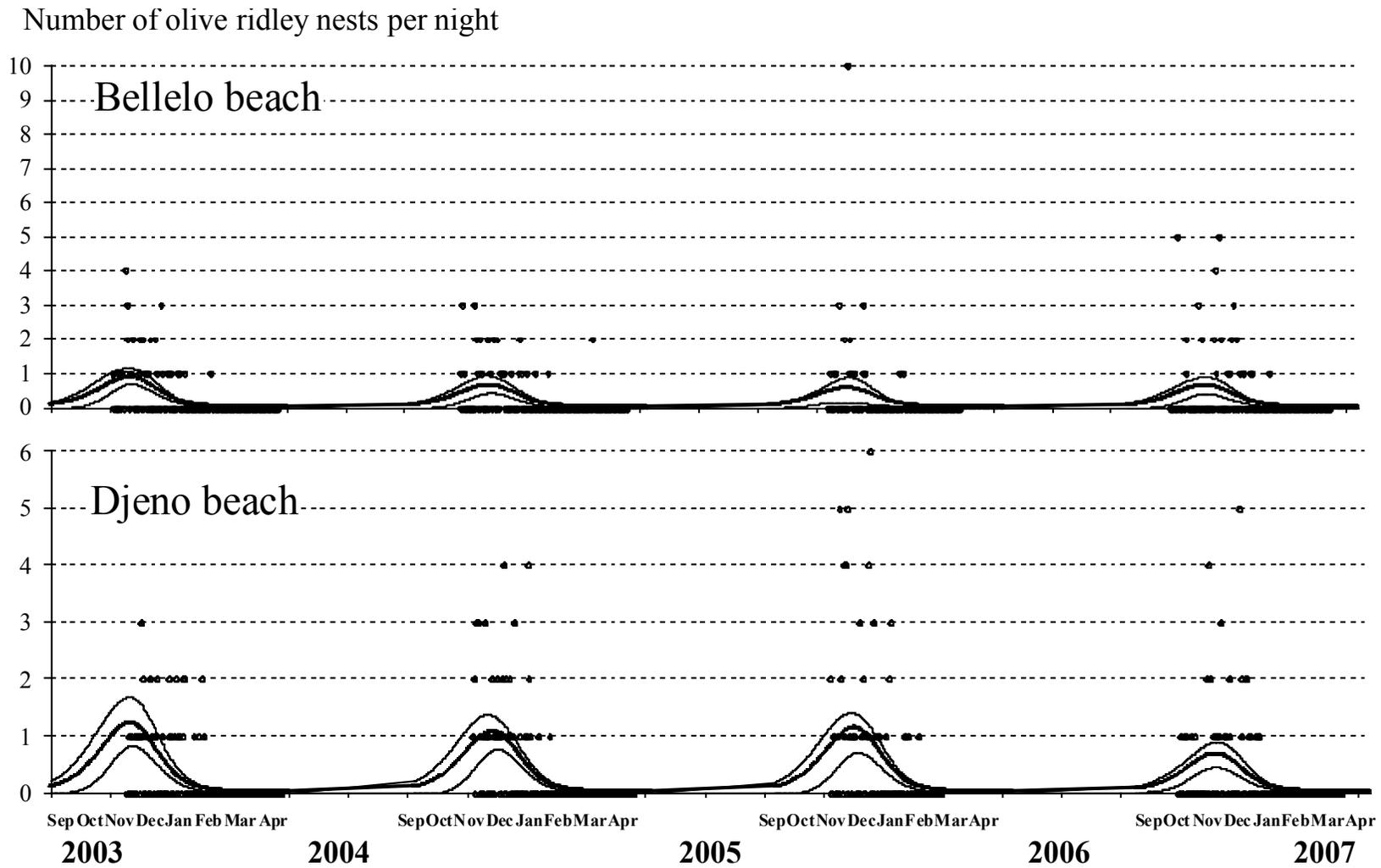
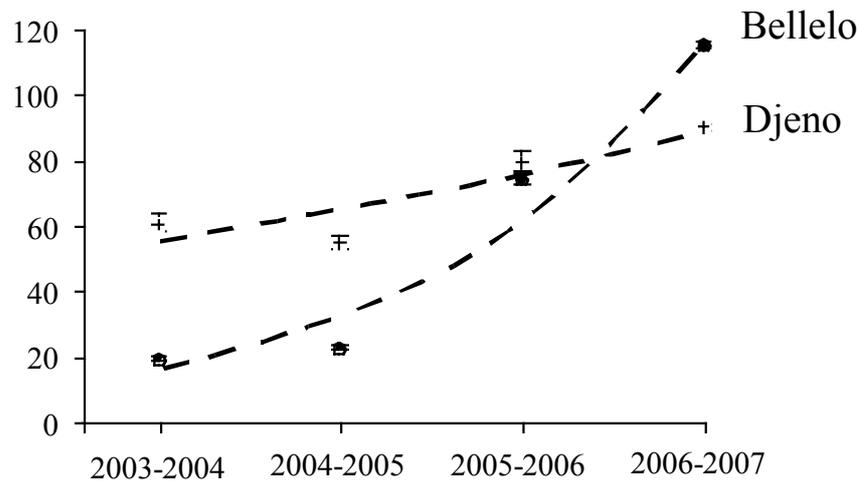


Figure 4: Trend for leatherback and olive ridley nests on two beaches of Congo for four nesting seasons.

A. Leatherbacks

Number of nests during the season



B. Olive ridleys

Number of nests during the season

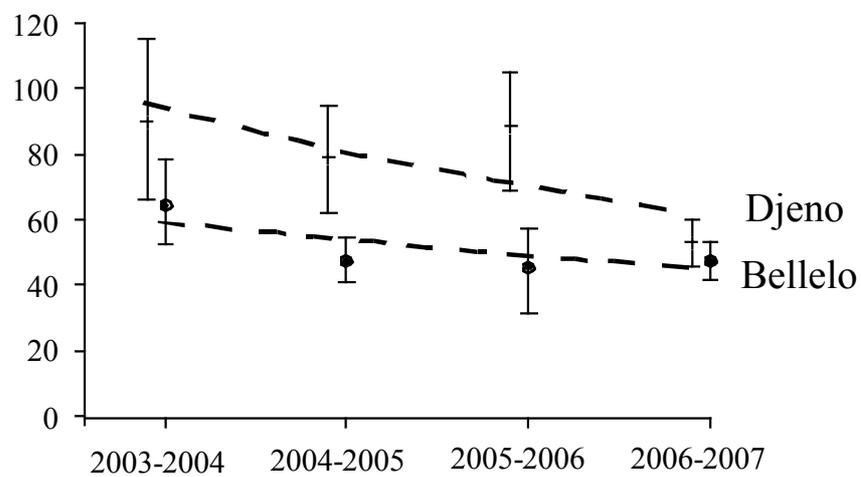


Figure 6: Number of alive turtles released from fishing nets in all Congo coast during the year 2006.

Number of alive released turtles from fishing nets

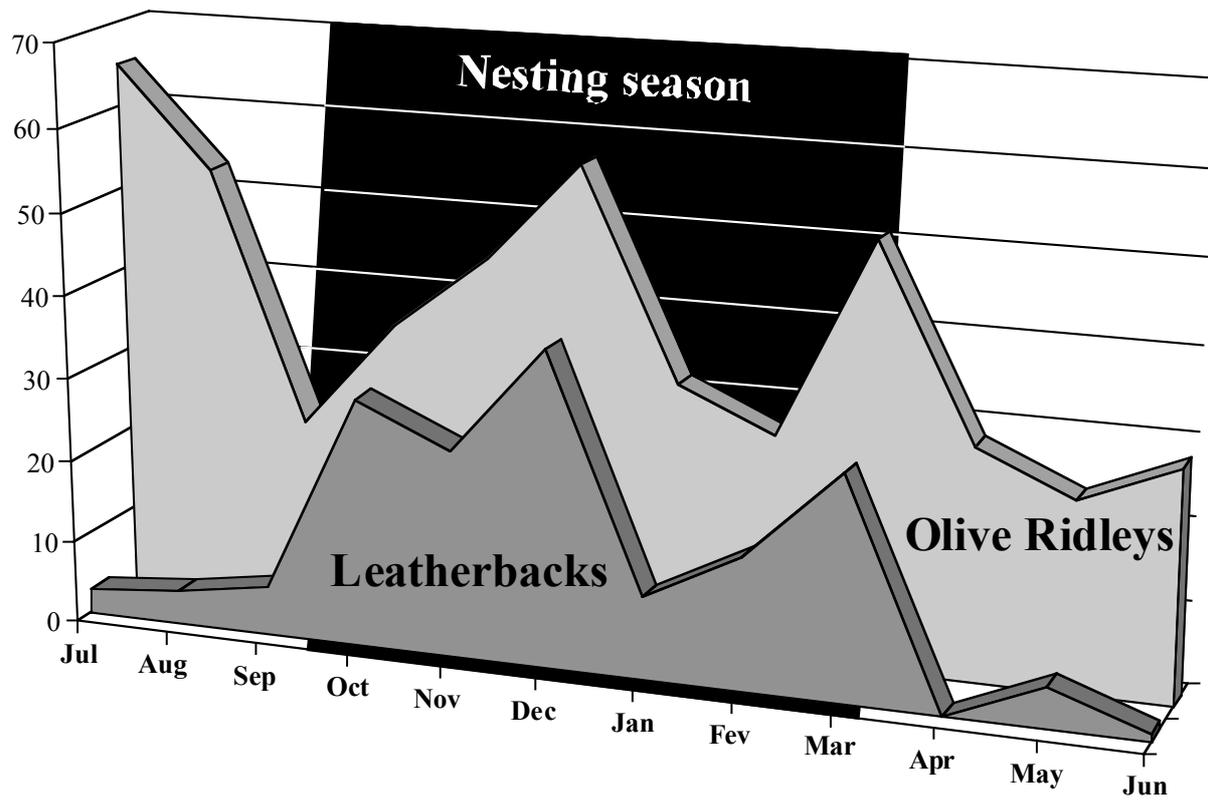


Figure 7: Olive ridley's carcasses behind the Tchissaou beach.

