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Aerial surveying of the world's largest leatherback turtle rookery: A more effective methodology for large-scale monitoring

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A B S T R A C T

For many marine megavertebrate species it is challenging to derive population estimates and knowledge on habitat use needed to inform conservation planning. For marine turtles, the logistics required to undertake comprehensive ground-based censuses, across wide spatial and temporal scales, are often insurmountable. This frequently leads to an approach where a limited number of index nesting beaches are monitored in great detail by foot. In this study we use nationwide aerial surveying interfaced with ground assessments across three seasons of leatherback turtle nesting in Gabon (Equatorial West Africa), highlighting the importance of a synoptic approach to marine turtle monitoring. These surveys allow the first complete population assessment of this nesting aggregation to be made, identifying it as the world's largest for the species (36,185–126,480 clutches, approximating to 5865–20,499 breeding females per annum and a total estimate of 15,730 to 41,373 breeding females). Our approach also serendipitously provides insights into the spatial appropriateness of Gabon's protected areas network, for example (mean ± 1SD) 79 ± 6% (range 67–86%) of leatherback turtle activities recorded during aerial surveys ($n = 8$) occurred within protected areas (345 km, 58%, of surveyed coastline). We identify and discuss sources of potential error in estimating total nesting effort from aerial surveying techniques and show that interannual variation in nesting is considerable, which has implications for the detection of statistically significant changes in population size. Despite its relative costliness per day, aerial surveying can play an important role in providing estimates of relative population abundance of large vertebrates dispersed over extensive areas. Furthermore, it can provide data on habitat use and deliver real-time information on the spatial efficacy of protected area networks.

1. Introduction

Deriving population estimates and gaining knowledge of habitat use has become increasingly important for marine megavertebrate species that face anthropogenic risks throughout their range (Hall et al., 2000; Lewison et al., 2004). Such data are essential for identifying changes in abundance and for developing spatially and temporally explicit management plans. Estimating the size of populations that are widely dispersed (e.g. across an ocean basin) is complex but can be made easier if species exhibit predictable migrations and/or form seasonal aggregations (e.g. albatrosses

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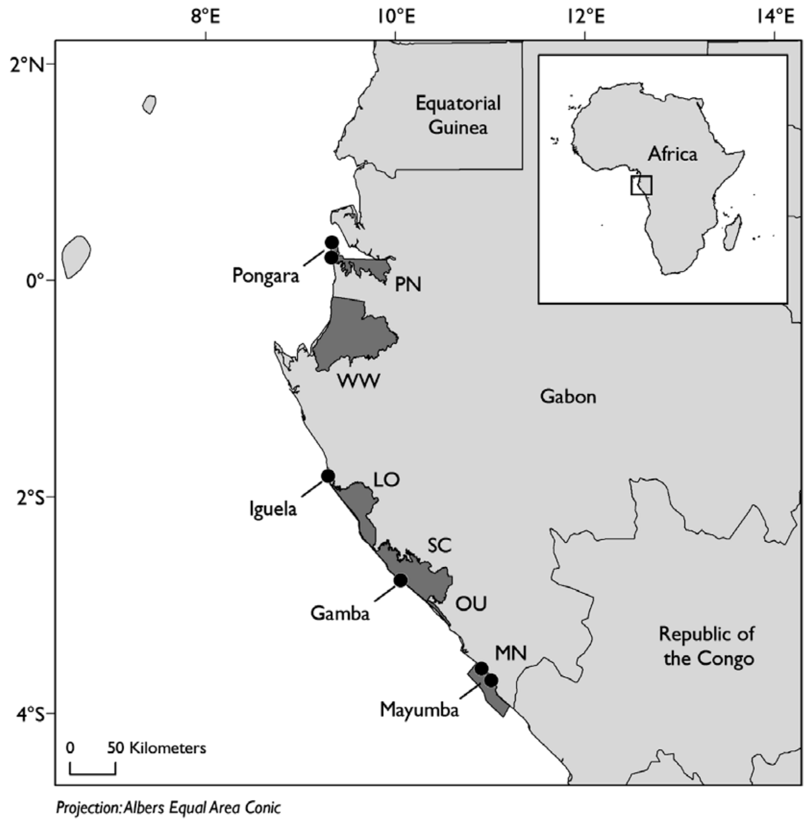

Fig. 1. National Parks and Reserves (i.e. protected areas) of Gabon bordering the Atlantic Ocean. Filled circles indicate locations where ground truthing was undertaken. Labelled regions (Pongara, Gamba and Mayumba) contributed data on the daily frequency of leatherback turtle nests counted. Labels: Pongara National Park (PN), Wonga Wongue Reserve (WW), Loango National Park (LO), Sette Cama Reserve (SC), Ouangu Reserve (OU) and Mayumba National Park (MN).

(Poncet et al., 2006), seals (Thompson et al., 2005), whales (Stevick et al., 2006) and marine turtles (Broderick et al., 2006). In non-breeding years, leatherback turtles (*Dermochelys coriacea*) disperse widely over oceanic areas (Benson et al., 2007; Ferraroli et al., 2004; Hays et al., 2006; Hughes et al., 1998) but a proportion of adults seasonally aggregate near a small number of major rookeries where nesting can be enumerated as an index of population size (Spotila et al., 1996). Although this behaviour facilitates enumeration the logistics of undertaking comprehensive ground-based censuses are often insurmountable (i.e. transport, geography, personnel, safety and fiscal cost), leading to an approach where a limited number of beaches are monitored in great detail.

While population estimates of marine turtles are commonly based on ground-derived counts of nests, several studies have used aerial surveying to enumerate nesting over extensive spatial areas (Hitipeuw et al., 2007; Hopkins-Murphy et al., 2001; McGowan et al., 2008); most notably for the leatherback turtle by Pritchard (1982). Aerial surveying has also been used to enumerate turtles in foraging habitats (Houghton et al., 2006; Marsh and Saalfield, 1989). The method provides an unparalleled approach for the swift collection of data over considerable spatial scales (many 100's km), which facilitates more meaningful and coherent estimates of population size, but also aids the understanding of nesting habitat preference and threats (Laurance et al., 2008).

For some of the most globally significant leatherback turtle nesting populations it has been possible to estimate population size, trends and patterns of habitat use (Kelle et al., 2007). For example, the Indo-Pacific population has experienced declines (Hitipeuw et al., 2007; Reina et al., 2002; Spotila et al., 2000; Tomillo et al., 2007); whereas, some nesting populations in the North Atlantic are increasing (Girondot et al., 2007; Dutton et al., 2005; McGowan et al., 2008). In contrast, the status of other Atlantic populations is more uncertain. In the eastern South Atlantic, leatherback turtles nest on the West African coast from Mauritania to Angola (Bal et al., 2007; Fretey et al., 2007; Rader et al., 2006; Weir et al., 2007) with the largest and globally significant aggregation occurring along the coast of Gabon (Fretey, 1984; Fretey et al., 2007). The Gabon nesting aggregation contributes a significant proportion of nesting effort in the South Atlantic and is geographically and genetically distinct from the North Atlantic population (P. Dutton personal communication). Based on a ground survey of the Gabon coastline between Mayumba and Gabon's border with the Republic of the Congo (Fig. 1, approximately 90 km coastline) Billes et al. (2000, 2003) estimated 29,700 and 37,150 nesting emergences in the 1999–2000 and 2000–2001 seasons, respectively.

In this study we use aerial surveying over three nesting seasons along the coast of Gabon (600 km). Our specific aims were to: (1) ascertain the usefulness of aerial surveying as a means of counting leatherback turtle nesting activity, (2) estimate the number of clutches laid each nesting season and the numbers of females nesting each year, (3) derive a total population estimate for the Gabon rookery, (4) describe spatial patterns of nesting and (5) provide a preliminary overview of the spatial adequacy of the protected Areas network.

2. Materials and methods

2.1. Aerial surveying

Aerial surveys were conducted using light aircraft (Cessna 182 and 202) travelling at speeds of 180–190 km h^{-1} at an altitude of

80–100 m. During each survey the position of the aircraft was recorded using two global positioning system (GPS) hand-held receivers.

Aerial surveys were conducted in each of three nesting seasons (i.e. 2002–2003, 2005–2006 and 2006–2007) over approximately 600 km of the coastline of Gabon flying from north to south. Aerial surveys, $n = 3$ per season, were timed to encompass the seasonal peak of nesting (December–February). All flights commenced at dawn so that a low sun angle would aid track detection (Schroeder and Murphy, 1999) and each survey typically took place over two mornings and took 4.3 ± 1.0 h in total to complete. An optimum window of opportunity with regard to survey timing occurred every 2 weeks, where the night-time high tide occurred between 21:00 and 01:00 h, hence, maximising beach width on which tracks could be made during typical nesting hours while leaving 5–6 h of daylight for surveying the following morning before tracks were erased by the next high tide. All surveys commenced within a four day window of neap tides, when changes in tidal range are less than the average.

Each aerial survey utilised a video camera to record leatherback turtle tracks made on the narrow sandy margin of the Gabon coastline. Following each survey, video footage was used to count leatherback tracks visible below the most recent high tide line so as to count only recent activity (<12 h old). Counts of leatherback turtle tracks were undertaken by two people and were binned into 500 m sectors. Video footage enabled the validation and where necessary recount of tracks, particularly in areas with high levels of activity. This post-hoc method also minimised observer error that might otherwise have resulted from surveyor fatigue. In 2002–2003 aerial surveys were conducted in the second and fourth weeks of January and in the second week of February. Surveys during the 2005–2006 and 2006–2007 nesting seasons occurred in the second week of December and the fourth week of January and February. Surveying on day one occurred between the northern point of Pongara National Park (0.3°N, 9.3°W; Fig. 1) and Iguela (1.8°S, 9.3°W). On day two the survey continued to the border of Mayumba National Park with the Republic of the Congo (3.9°S, 11.2°W). The third survey of 2002–2003 was conducted on a single day; however, heavy rain in the region of Mayumba National Park prevented a complete count of leatherback tracks. Data from this survey were excluded from numerical analysis.

2.2. Ground truthing

As part of a longer-term monitoring programme, leatherback turtle tracks were counted from the ground each morning at several locations along the Gabon coastline. Using data from these ground counts it was possible to evaluate the accuracy of aerial based counts of leatherback turtle tracks. Comparisons of aerial and ground counts of tracks were made at six locations during the 2006–2007 nesting season (Fig. 1; Pongara National Park (two sites), Iguela, Gamba and Mayumba National Park (two sites).

2.3. Nesting emergence

Female marine turtles can make non-nesting emergences on to the nesting beach prior to egg laying (Miller, 1997). As such, to derive estimates of total nests laid from aerial survey counts of leatherback turtle tracks we calculated a nesting emergence correction factor, which was the proportion of emergences on to the nesting beach that result in clutch deposition. This factor was derived from daily ground count data taken from each of the three monitoring locations during the 2006–2007 nesting season (i.e. Pongara National Park, Gamba and Mayumba National Park).

2.4. Spatial patterns of nesting

We used a waveform repeatability analysis (Lee, 2006) to determine the spatial consistency of leatherback activity along the Gabon coastline. The 500 m aerial sector counts were first aggregated to a 10 km latitudinal resolution. Waveform repeatability analyses were then conducted across all surveys performed within a season and among the first, second and third surveys undertaken in each season. Each waveform repeatability analysis calculated the correlation of multiple coefficients (CMC). CMC may be interpreted in the same manner as Pearson and Spearman correlation coefficients (Lee, 2006), where 1.0 represents a statistically significant positive correlation, −1.0 represents a statistically significant negative correlation and values tending towards 0 suggest no linear relationship (Lee, 2006). For each survey we also calculated the number of activities occurring within National Parks and Reserves (i.e. protected areas) by identifying the 500 m aerial sectors counts spatially coincident to these areas. We used only sectors occurring completely within protected areas therefore providing a conservative estimate of nesting within these areas.

2.5. Effects of tide

To examine the relationship between daily nesting effort and lunar/tidal phase we determined the number of nests counted on days of spring tides ($n = 8$) and neap tides ($n = 8$) during the 2006–2007 nesting season at each of the three monitoring locations (i.e. Pongara National Park, Gamba and Mayumba National Park). We calculated the difference between the number of nests counted and the number of nests expected on these days. The expected nesting frequency was derived from a site-specific seasonal curve constructed using a smoothing spline in Matlab (The MathWorks, Massachusetts) from the daily proportion of nesting at each site. The differences (residuals) between observed and expected counts were then calculated, allowing us to construct a tidal correction factor.

2.6. Calculating seasonal nesting effort

We estimated total nesting effort of leatherback turtles for each aerial surveying season following the method of Hopkins-Murphy et al., (2001). We first constructed two frequency distributions that represented daily patterns of nesting. Distribution one was created from daily ground counts of nests conducted at three monitoring locations during the 2006–2007 nesting season (i.e. Pongara National Park, Gamba and Mayumba National Park), this distribution incorporated any spatial variability of nesting across Gabon. It was necessary to interpolate the number of nests laid on occasions when ground counts were not undertaken due to bad weather, public holidays or logistical constraints ($n = 13$ days for Pongara and $n = 12$ days for Mayumba). Rather than using linear interpolation (Godley et al., 2001) we used a cubic spline approach. The daily proportion of seasonal nesting effort in distribution one was calculated to be mean of the daily proportions of nests counted at each of the three monitoring locations. Distribution two was created from daily ground counts of nests recorded over four seasons (2003–2004 to 2006–2007) at the Gamba complex of protected areas; the only site for which such complete data has thus far been collected. This distribution incorporated any temporal (interannual) variability in the seasonality of nesting (Verhage et al., 2006). The daily proportion of nesting effort in this distribution was taken to be the mean of the daily proportions recorded in each of the nesting seasons (e.g. proportion of nests laid on 12 December was the mean of the proportion of nests laid on 12 December in 2003, 2004, 2005 and 2006). Both distributions one and two were subsequently smoothed using kernel density smoothing in Matlab to moderate the effects of daily variability in nesting.

Each aerial survey's sector counts of leatherback turtle tracks were first summed. These values were corrected to represent estimates of nesting using the nesting emergence correction factor. These values were then subsequently adjusted using the tidal correction factor. From each frequency distribution (distribution one and distribution two) we then determined the proportion of nests expected on days of aerial surveying, these proportions were summed for each nesting season. The total number of clutches laid within each aerial surveying season was then estimated by dividing the sum of all nests counted from aerial surveys by the sum of the expected proportions of nests occurring on days of aerial surveying. This procedure was used with each of the two nesting frequency distributions.

Given that aerial surveys provide an overview of the spatial pattern of nesting we were able to scale up leatherback turtle nesting effort reported by Billes et al. (2003) for the region of Mayumba, to a Gabon wide estimate of nesting effort for the seasons 1999–2000 and 2000–2001. We first calculated the mean proportion of nesting that the Mayumba region received during each of the three aerial surveying seasons. From these values we determined the minimum and maximum proportions and used these to estimate total nesting effort for the entire coastline using the following approach: total nests counted in each of the 1999–2000 and 2000–2001 seasons in the Mayumba region divided by both the minimum and maximum proportions, from these values we then calculated median nesting effort for the 1999–2000 and 2000–2001 seasons.

2.7. Power analysis

We undertook a power analysis using the observed interannual coefficients of variation in nesting effort, derived separately from distribution one and two, to investigate the relationship between annual rates of minimum detectable change in nesting effort and long-term survey duration (i.e. 10, 15 and 20 years). Power analysis was conducted in Trends 3.0 (Gerrodette, 1993) with a significance level of 0.05 and power of 0.8. Power typically represents the probability of rejecting a null hypothesis which is false (Gerrodette, 1987).

3. Results

3.1. Ground truthing

The utility of aerial surveying as a method to accurately quantify leatherback turtle tracks was ascertained at six locations ($n = 15$ occasions) during the 2006–2007 nesting season. These locations varied in coastline length from 3.6 to 15.9 km (mean 7.4 ± 4.0 km 1SD) and encompassed a range of track densities from 0 to 15.6 km^{-1}. There was a highly significant positive linear relationship between ground and aerial estimates of leatherback turtle track densities (tracks km^{-1}) ($y = 1.08x + -0.11$, $R^2 = 0.98$, $F_{1,14} = 2147$, $p < 0.01$). Given this highly significant relationship we chose not to adjust the aerial counts of leatherback turtle tracks using a density dependent correction factor.

3.2. Nesting emergence and tidal correction factors

The nesting emergence factor was calculated from data collected at three ground monitoring locations during the 2006–2007 nesting season, when coverage was most complete at all sites, and was conservatively set at 96%, the lowest observed nesting emergence (Pongara National Park $n = 2746$ tracks, 99% nesting emergence; Gamba $n = 550$ tracks, 96% nesting emergence and Mayumba $n = 4952$ tracks, 98% nesting emergence). Tidal phase (i.e. spring and neap tides) had a demonstrable effect on nesting effort at all three monitoring locations. The mean of mean residual nesting effort in 2006–2007 was (mean ± 1SD) 0.14 ± 0.04 ($n = 3$ sites, $n = 8$ tides, range 0.10–0.18) for neap tides and −0.18 ± 0.10 ($n = 3$ sites, $n = 8$ tides, range −0.25 to −0.07) for spring tides. Due to the relationship of increased nesting on days of neap tides, when aerial surveying occurred, we adjusted the total counts arising from surveying, subsequently expressing these counts at 88% of their original value.

3.3. Spatial patterns of leatherback turtle activity

Leatherback turtle tracks recorded from each aerial survey (Fig. 2) indicated that northern and southern extents of Gabon received the highest densities of activity. Waveform repeatability analysis indicated that the spatial pattern of leatherback turtle nesting was correlated strongly within (mean CMC 0.7 ± 0.1 ISD; range 0.6–0.8) and among seasons (mean CMC 0.5 ± 0.2 1SD; range 0.4–0.7). National Parks and Reserves, stretching approximately 345 km (58% of the surveyed coastline) received a considerably greater proportion of tracks 79 ± 6% (range 67–87%) than the remaining coastline. Mayumba National Park (MN, Fig. 3) consistently received the greatest number of tracks within any single aerial survey, 47 ± 10% ($n = 8$ surveys. range 32–56%) while representing only 60 km (10%) of the surveyed coastline (600 km). On days of aerial surveying in the 2006–2007 nesting season, ground monitoring regions received, in total, 24.2% (survey 1), 10.0% (survey 2) and 4.1% (survey 3) of activities.

3.4. Seasonal nesting distributions

Based on data in hand, the 2006–2007 nesting season started on November 21st 2006 and finished on March 31st 2007. The median day of nesting activity recorded at the three ground monitoring locations during the 2006–2007 season were January 6th, January 11th and December 25th for Pongara National Park, Gamba and Mayumba National Park, respectively. These nest count data (Fig. 4a) were used to construct distribution one (Fig. 4c). A longer time series of data were available for Gamba. The median day of nesting for each of the nesting seasons at Gamba was for 2003–2004; 1st January, 2004–2005; 31st December, 2005–2006; 2nd January and 2006–2007; 10th January. Distribution two (Fig. 4d) was constructed from this time series (Fig. 4b).

3.5. Estimating seasonal nesting effort

Median estimates of nests laid in Gabon were for 2002–2003; 111,960 nests (range 97,440–126,480), 2005–2006; 42,566 nests (range 36,185–48,947) and 2006–2007; 81,004 nests (range 66,387–95,621). Distribution two consistently produced the higher of the two estimates of total nesting effort calculated for each season. The mean coefficient of variation of within season estimates of total nesting effort (i.e. comparing the estimate generated from distribution one and two within a season) was (mean ± 1SD) 0.22 ± 0.04 (for 2002–2003; 0.18, for 2005–2006; 0.21 and for 2006–2007; 0.26). The coefficient of variation calculated among seasonal estimates ($n = 3$ seasons) for distribution one was 0.46 and for distribution two 0.43. In addition to the aerial survey based estimates of nesting effort, data reported by Billes et al. (2003) was used to estimate nesting effort in 1999–2000 and 2000–2001. In these seasons, respectively, 29,700 and 37,150 nests were estimated to have been laid based on periodic ground counts along 85 km section of nesting beach between Mayumba and Gabon's border with the Republic of the Congo. Aerial surveying indicated this region received between 47% and 52% of nesting effort directed

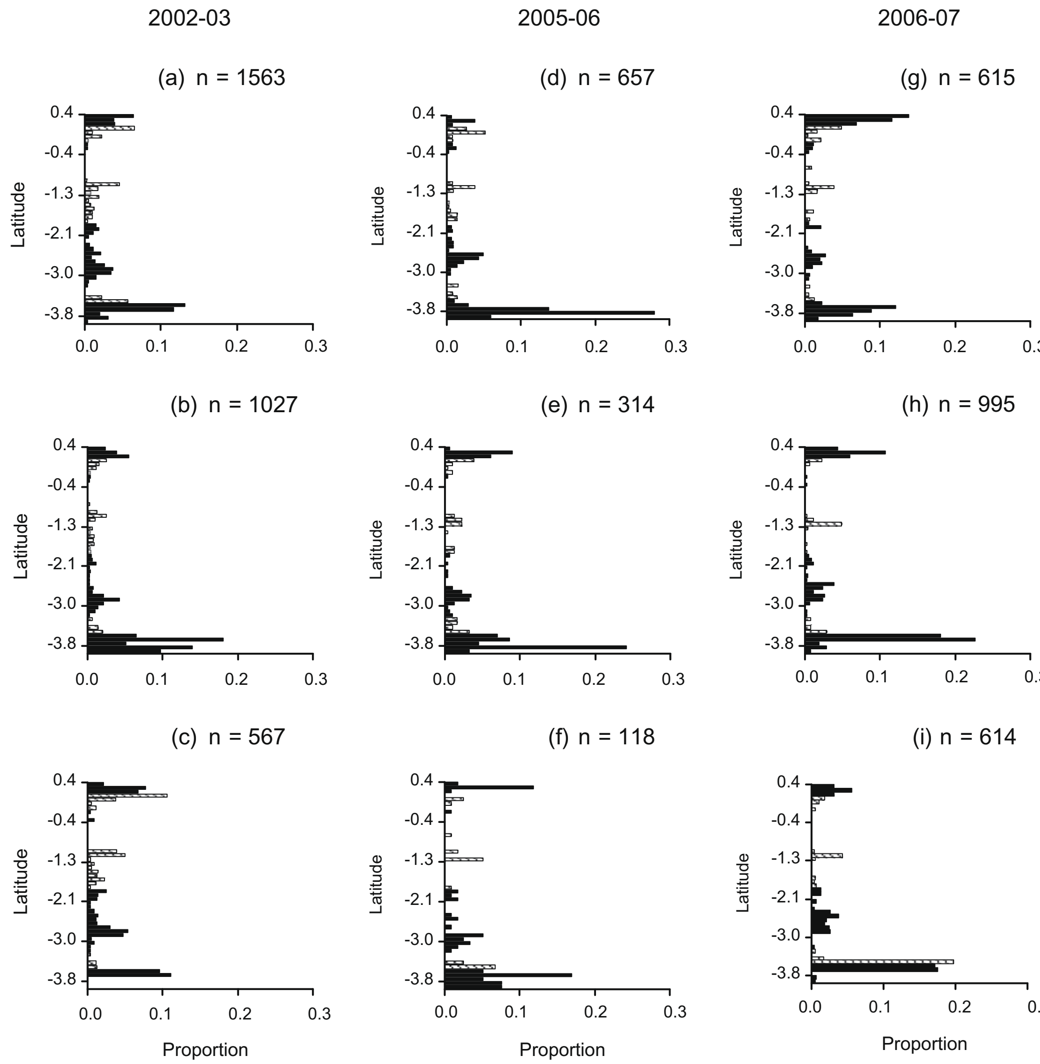

Fig. 2. Spatial patterns of activity. Proportion of leatherback turtle tracks occurring in 10 km latitudinal bands, (a–c) aerial surveys 1–3, 2002–2003, (d–f) aerial surveys 1–3, 2005–2006 and (g–i) aerial surveys 1–3, 2006–2007. Solid bars indicate 10 km bands occurring within National Parks and Reserves; hatched bars are those outside these areas.

towards the Gabon coast within a season. Based on these upper and lower estimates, median estimates of nests laid in Gabon were for 1999–2000; 60,153 nests (range 57,115–63,191) and 2000–2001; 75,242 nests (range 71,442–79,043), Fig. 5.

3.6. Power analysis

Given the similarity between the coefficients of variation of interannual nesting effort derived using distribution one and distribution two we undertook a power analysis using a single coefficient of variation of 0.45. The minimum detectable annual rates of change in nesting effort were 0.18, 0.09 and 0.06 for programmes lasting 10, 15 and 20 years, respectively.

4. Discussion

All species of marine turtles are of conservation concern (Sarti Martinez, 2000), as such reliable data on their population status, spatial distribution and habitat use are important, especially on regional scales. Given the reported precipitous decline and potential extirpation of some Pacific leatherback turtle populations (Spotila et al., 2000) estimating population size and their trajectories are essential. However, despite several decades of research such knowledge remains incomplete (see Patino-Martinez et al., 2008 for the recent quantitative description of the site of a globally significant rookery).

Aerial surveying provides a valuable tool for the assessment of marine turtle nesting habitats otherwise inaccessible to ground monitoring. Although the magnitude of nesting effort was highly variable between seasons, spatial patterns of nesting were highly consistent. Our results show that aerial surveying can provide an understanding of the consistency and magnitude of habitat use outside regions that are, or can be, routinely monitored. This is particularly important for this species as they demonstrate variable site fidelity to nesting areas (Kelle et al., 2007; Witt et al., 2008). Complete spatial coverage, albeit from limited temporal coverage, allows limited ground counts, such as those by Billes et al. (2003) to be extrapolated into overall estimates. Additionally, aerial surveying suggests that Gabon's network of coastal protected areas encompasses a considerable proportion of nesting effort (67–86% of nests on 345 km, 58% of aerial surveyed coastline), with close to half of all nesting being described in Mayumba National Park. Stretches of coastline outside this network also receive appreciable levels of nesting and these regions are worthy of future investiga-

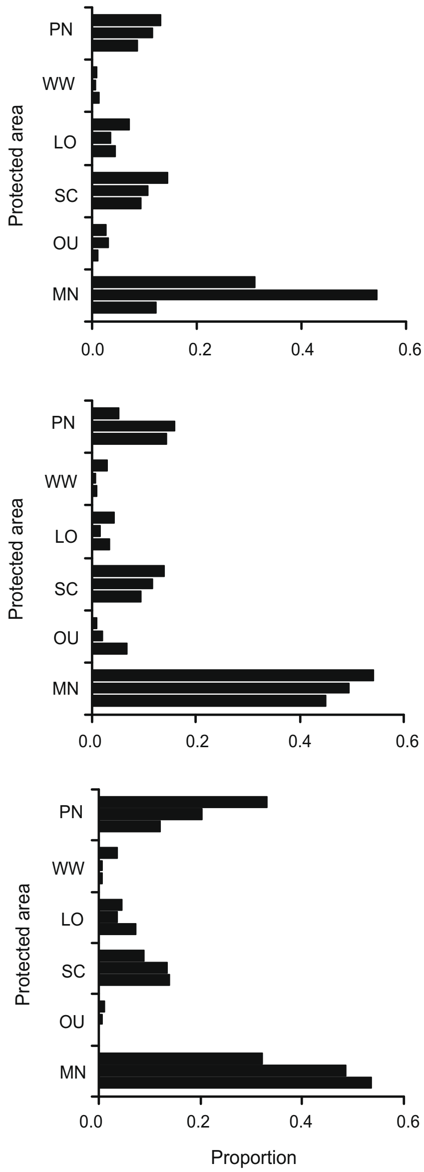

Fig. 3. Nesting within National Parks and Reserves (i.e. protected areas). Proportion of leatherback turtle tracks counted within Gabon's protected area network during 1st, 2nd and 3rd aerial surveys for (a) 2002–2003, (b) 2005–2006 and (c) 2006–2007. National Park and Reserve labels continued from Fig. 1.

tion. Assessing overlaps between protected areas and core nesting regions is an important step to assist in conservation management planning; however, it can not describe the total level of protection afforded to nesting females and their clutches as illegal activities or threats with sources external to protected areas occur, see Laurance et al. (2008).

Our synoptic approach has provided the first comprehensive assessment of the Gabon nesting aggregation, which suggests it hosts the world's largest nesting population of leatherback turtles. Comparing our minimum and maximum estimates of nesting effort across the three nesting seasons subject to aerial surveying (36,185–126,480 nests) with other nesting populations demonstrates the considerable size of reproductive effort directed towards Gabon's coast (French Guiana and Suriname 13,291–63,294 nests (Girondot et al., 2007); Central America 11,465–19,354 nests (Patino-Martinez et al., 2008); Trinidad 6000 females annually (Eckert, 2006)). Deriving female population size from these estimates (see Gerrodette and Taylor (1999)) is complicated by resource availability at distant foraging areas, which likely drives plasticity in remigration interval (Broderick et al., 2001; Reina et al., 2008; Saba et al., 2007) and clutch frequency (Broderick et al., 2003). Using an estimated clutch frequency of 6.17 nests per female (Miller, 1997), we estimated the number of females nesting in each of the aerial surveying seasons as 15,793–20,499 for 2002–2003, 5865–7933 females for 2005–2006 and 10,760–15,498 females for 2006–2007. Using a minimum remigration interval for the leatherback turtle of 2.28 years (Miller, 1997) multiplied by the range of median estimates of females nesting in each of the three study years (6899–18,146 females) gives a total estimate of the number of breeding females as 15,730 to 41,373 females, which is considerably higher than preliminary estimates of 10,000 to 15,000 females (Turtle Expert Working Group, 2007).

Estimating seasonal nesting effort from aerial surveys requires an understanding of the potential errors that may be introduced by the technique and the methodological treatment of the data. Likely sources of error may be grouped in to three categories. (1) Errors relating to the detection of nests. Leatherback turtles make recognisable tracks in the sand that are highly species specific and nesting related activity is almost entirely focused towards a narrow coastal strip that aids a high detection rate. The ground truthing exercise identified minimal error in the detection of leatherback turtle tracks by aerial survey method. Post-hoc enumeration of tracks from video minimises detection error, particularly in high density areas where re-counts can be made. (2) Errors relating to nesting emergence. Leatherback turtles demonstrate a high level of nesting emergence in the Gabon rookery, which was largely invariant across sites. While not all emergences result in clutch deposition and misclassification of false crawl activity as nests might occur, the overall effects of the nesting emergence correction factor are minimal. (3) Errors relating to tidal state. Of greater importance is the relationship between nesting effort and tidal state. We found that the number of tracks per day increased during periods of neap tides, when aerial surveys occurred, necessitating the use of a tidal correction factor, which was applied to the total aerial counts so to avoid inflated estimates of total nesting effort. (4) Errors relating to the nesting frequency distributions. The nesting distributions are central to the estimation of total nesting effort and their effects on the final estimates are considerably greater than the potential errors associated with the aerial to ground and nesting emergence correction factors. Nesting frequency distributions can be refined over time, as can assessments of the factors that influence day to day variation in nesting (see Reina et al. (2002) who investigate time of leatherback turtle emergence with the daily tidal cycle). Since nesting effort can be highly variable between days, it is prudent to utilise smoothing functions. Several mathematical approaches, including sinusoidal waveforms, have been used to construct seasonal curves (Girondot et al., 2006; Gratiot et al., 2006), however, we smoothed our seasonal curves using a kernelling technique. We felt this approach gave adequate smoothing while maintaining the apparent underlying shape of the nesting season and ultimately this approach incorporates the observed biological pattern.

Given the variable status of leatherback turtle populations globally (Spotila et al., 1996) we undertook a power analysis to investigate future surveying durations that would enable the detection of statistically significant changes in nesting effort. Debate exists around the use of trend analysis (Gerrodette, 1991; Link and Hatfield, 1990; Reed and Blaustein, 1997) and that monitoring strategies may focus too heavily on trend detection in place of survey rigour and accuracy (Seavy and Reynolds, 2007); however, the procedure has become a well used approach to assess monitoring programs for their ability to describe changes in biological metrics through time, including those for marine turtles (Jackson et al., 2008; Sims et al., 2008). The coefficients of variation of interannual

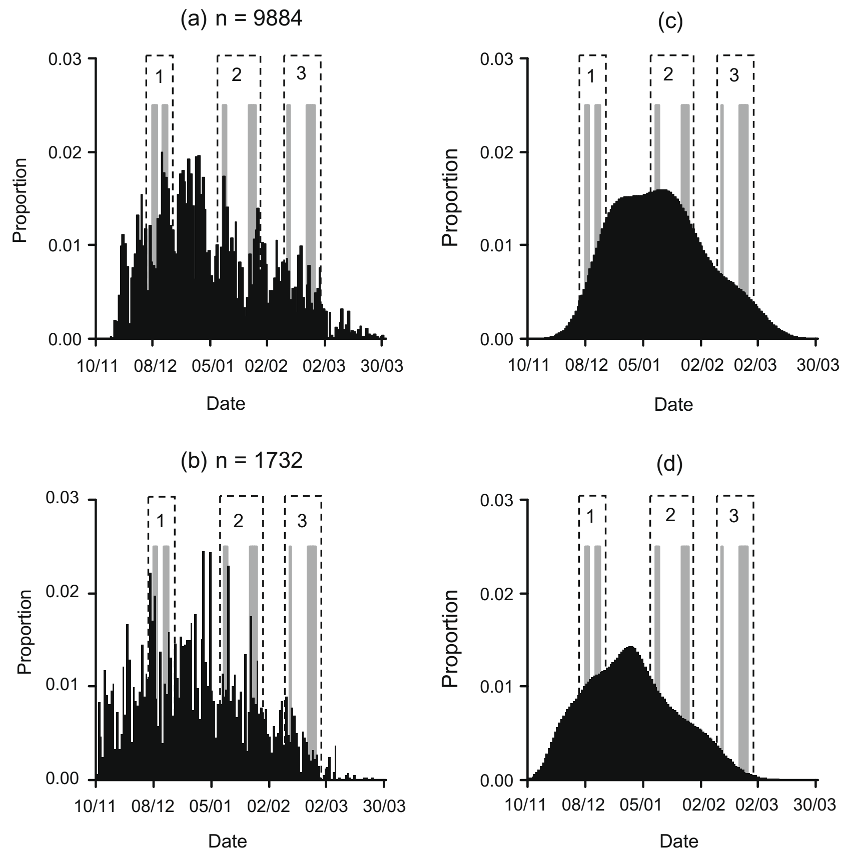

Fig. 4. Seasonal curves. (a) Mean daily proportion of nests counted at Pongara National Park, Gamba and Mayumba National Park during the 2006–2007 nesting season. (b) Mean daily proportion of nests counted at Gamba derived from nesting data collected between 2003–2004 and 2006–2007. (c and d) Kernel density estimates of frequency histograms shown in parts a and b, respectively, constructed using a 7 day smoothing window. Vertical grey bars indicate days of aerial surveys conducted over three seasons, date range of 1st, 2nd and 3rd surveys in each season are enclosed by boxes.

estimates of nesting effort were considerably larger than those of within season estimates. The large observed interannual coefficient of variation highlights why only sizable year-on-year changes in nesting effort can be robustly detected in this population within several decades and identifies the need for well designed wildlife monitoring programmes that have wide spatial and temporal coverage with adequate accuracy and precision, particularly for species where non-annual breeding is commonplace.

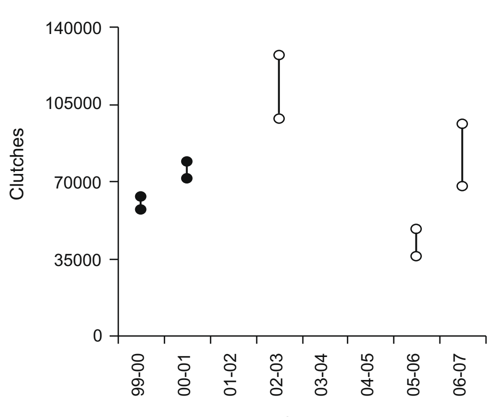

Fig. 5. Estimates of total nesting effort. Upper and lower estimates derived from Billes et al. (2003) (filled circle). Upper and lower estimates derived from aerial surveying and seasonal curves (empty circle).

With respect to expense, there are few aircraft operators that can be used for aerial surveying of the coastline of Gabon and flights costs approximately 17,500 USD per season. The annual cost of a ground monitoring programme for a single location is approximately 8500 USD (A. Formia personal communication). Each survey method has its associated benefits and shortfalls. For example, aerial surveys provide country-wide information, data on use of protected areas by leatherback turtles and could enable reactive management measures based on evaluation of threats. In contrast, ground patrols provide in depth data on nesting and females, including fate of nests, internesting intervals and remigration intervals. Although it is possible to derive total seasonal nesting effort from parsimonious counts at ground monitoring locations (Jackson et al., 2008), without a thorough knowledge of the spatial distribution of nesting and its temporal variability on intra- and interannual scales, such estimates could be poorly conditioned and would present an incomplete picture. We feel that when appropriately interfaced, the information gained from aerial surveying and ground monitoring combined provides a powerful approach.

We have highlighted the rapid positive inroads that can be made into extensive status assessment of a large vertebrate species. Although, aerial surveying should be truthed with ground monitoring at strategic sites, as evidenced here, it is apparent the methodology offers great power for population monitoring, both temporally and spatially and is a technique that is currently underused. As a result, current status assessments in many cases, particularly for marine turtles, are based on census data with inadequate spatial coverage. A clear example of this would be the Atlantic coast of Africa which, in many parts, has not been adequately surveyed. Although we have now surveyed the coast of Gabon, data collection needs to be integrated with the known nesting grounds in neighbouring Republic of the Congo (Bal et al., 2007) and other Atlantic African nations (Fretey, 1998).

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