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Monitoring of Nesting Leatherback Turtles (*Dermochelys coriacea*): Contribution of Remote Sensing for Real-Time Assessment of Beach Coverage in French Guiana

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Abstract. – **Over 4 years, 2001–2004, leatherback-turtle monitoring was conducted on all the potential nesting sites in French Guiana. We estimated minimal leatherback turtle nest numbers of 23,107, 12,229, 13,480, 11,012, respectively. The Awala-Yalimapo Beach, sometimes considered a good estimator of the overall nesting activity for the country, has hosted a significant proportion of the leatherback turtle nests (42% ± 2%), but this percentage is much lower than formerly described. The relative importance of this nesting site is discussed in light of remote sensing data, suggesting that nest numbers recorded in Awala-Yalimapo may have misrepresented leatherback turtle population trends. Indeed, remote sensing data indicate that the total sandy shoreline available in French Guiana has regularly evolved over the last decades, allowing leatherback turtle nesting attempts out of the scope of monitoring. The importance of a monitoring effort integrating the specific coastal dynamic of the Guianas region is highlighted.**

Over the last decades, some leatherback turtle (*Dermochelys coriacea*) rookeries have faced dramatic decline (Sarti et al. 1996; Spotila et al. 1996, 2000). As a result, this species is ranked as critically endangered by the World's Conservation Union (Sarti Martinez 2000) and investigating the status of leatherback turtle nesting aggregations worldwide is then mandatory.

Among the significant leatherback turtle nesting rookeries, the one within Suriname and French Guiana has long been considered as one of the largest in the world (Pritchard 1973). This species main nesting season (April–August) has been monitored in French Guiana for more than 3 decades (Fretey and Lescure 1998). Since the first monitoring efforts, the high coastal dynamic has represented a source of difficulties.

The entire coastline of the Guianas' shelf, from the Amapà (Brazil) to the Orinoco (Venezuela), is characterized by alternate phases of erosion and accretion (Fig. 1), with mudbanks that migrate at a mean annual rate of about 1–3 km/y (Augustinus 1978; Gardel and Gratiot 2005). These mudbanks significantly modify the beach profiles at pluri-annual timescales (Anthony and Dolique 2004), with severe consequences on marine turtles nesting possibilities (Reichart and Fretey 1993; Hilterman et al. in press). In addition, the high number of nesting females each night and the logistical difficulties to monitor some remote nesting sites make the leatherback turtle census challenging in French Guiana.

Since 2001, nesting counts were conducted simultaneously for the first time to cover both the western part of the country (Awala-Yalimapo and remote oceanic nesting sites), Kourou, and Cayenne Peninsula. As a result of monitoring all potential nesting areas, we present reliable estimates of the leatherback turtle nesting activity for the entire French Guiana coastline over the period 2001–2004. We also used remote sensing data to monitor beach erosion and accretion over a broader timescale. Such a cross-cutting approach highlights the relative importance of the Awala-Yalimapo nesting site compared with the total number of nests recorded in French Guiana over the last decades. Remote sensing data led to 3 major outputs: 1) a better understanding of the spatial distribution of the past nesting effort in relation to the coastal dynamic, 2) a review of leatherback turtle trends in the region, 3) an opportunity for a more adaptive monitoring effort.

Methods. — On the Cayenne Peninsula, nest counts were taken every morning during the nesting season (early April to mid-August), together with nightly patrols (1900–0600 hours) to count nesting females. Based on this intensive monitoring effort, we assumed that no nesting attempt was overlooked on these beaches.

At Kourou, monitoring was limited to weekly nest counts for most of the nesting season. Daily nest counts were made during the peak nesting season only (May–June).

Monitoring at west oceanic nesting sites (Pointe Isère, Farez, Irakompapi, and Organabo) consisted of a daily census of nesting crawls (early May to mid-August). For the year 2002, no distinction was made between nesting and false crawls at Irakompapi, because the latter was considered exceptional on this wide beach. For all narrower nesting sites, differentiation between nesting and false crawls was made.

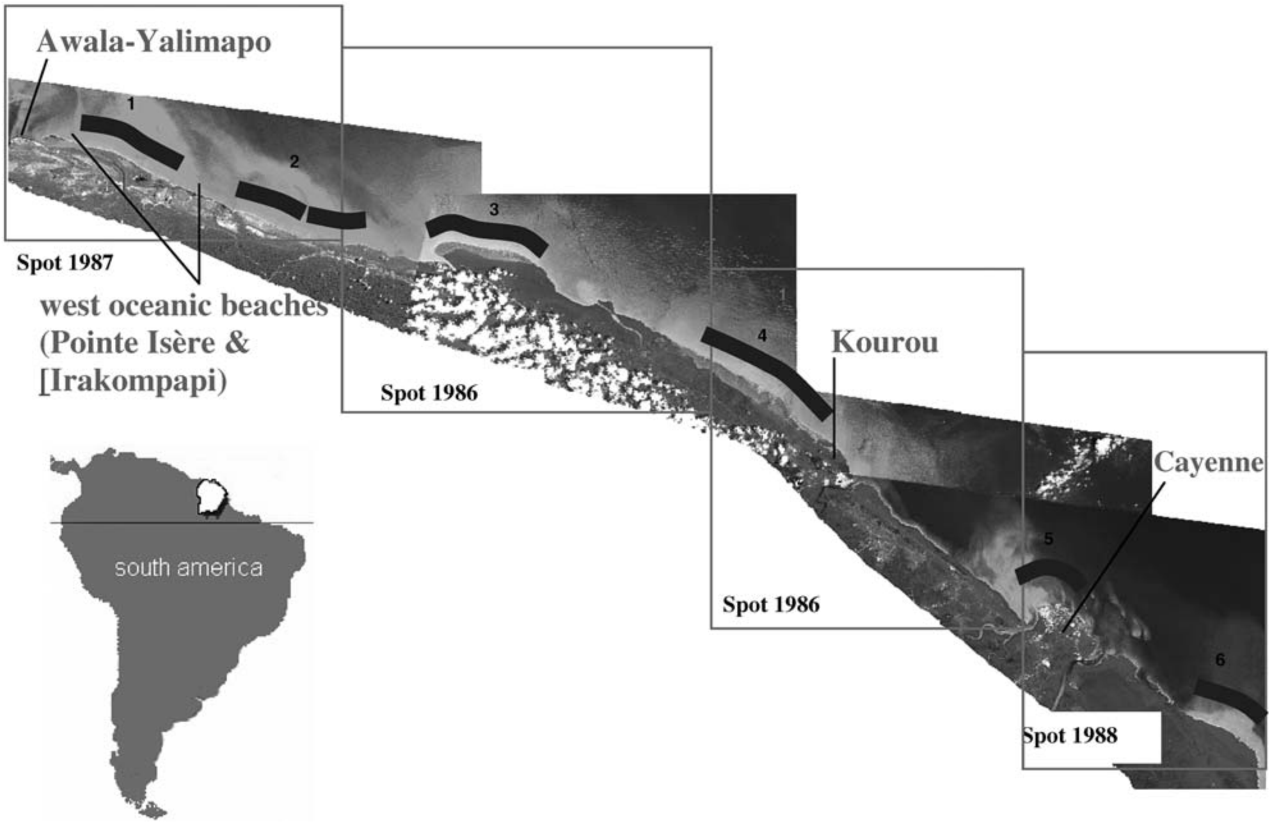


Figure 1. Mosaic of SPOT satellite images along the coast of French Guiana, from the Approuague (eastward) to the Maroni (westward) Rivers. Adapted from Gardel and Gratiot, 2004. Thick black lines: mudbanks (numbered from 1 to 6). Main nesting areas indicated.

At Awala-Yalimapo, a daily count of nest crawls was performed (early April to mid-August) from 2001 to 2003. Nesting females were counted 1 night per week. In 2004, only the daily count of nest crawls was performed.

Because some oceanic nesting sites were not monitored over the entire nesting season, the total number of nests was estimated by applying the statistical model proposed by Gratiot et al. (2006):

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

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

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

In this model, the adjustment of the nesting season to a sinus function provides an estimate of the annual number of nests, with an error lower than 15% when the monitoring effort is distributed all over the nesting season and exceeds 30 days (Gratiot et al. 2006).

Remote sensing data (SPOT satellite images) by using 50 satellite images, covering 1986–2004, were previously analyzed by Gardel and Gratiot (2004) to study the migration of mudbanks along the coast. The image data set principally contained some SPOT images with a resolution of 15 m. Depending on several parameters, including tide level during image acquisition and turbidity of coastal water, images were reanalyzed to estimate the dynamic of sandy beaches and their potential suitability for nesting.

Results. — Because information for some remote sites is scarce (i.e., absence of continuous monitoring in Irakompapi nesting site) and because the counting of nesting crawls sometimes underestimates the real nesting effort, we present here the minimum numbers of leatherback turtle nests laid in French Guiana: 23,107 for 2001, 12,229 for 2002, 13,480 for 2003, and 11,012 for 2004 (Table 1). Over this time period, the beach of Awala-Yalimapo did not suffer major geomorphic change and has hosted a regular proportion of the leatherback turtle nests recorded in French Guiana (42% ± 2%). However, great

Table 1. Estimated number of leatherback turtle nests laid in French Guiana 2001-2004.[a]

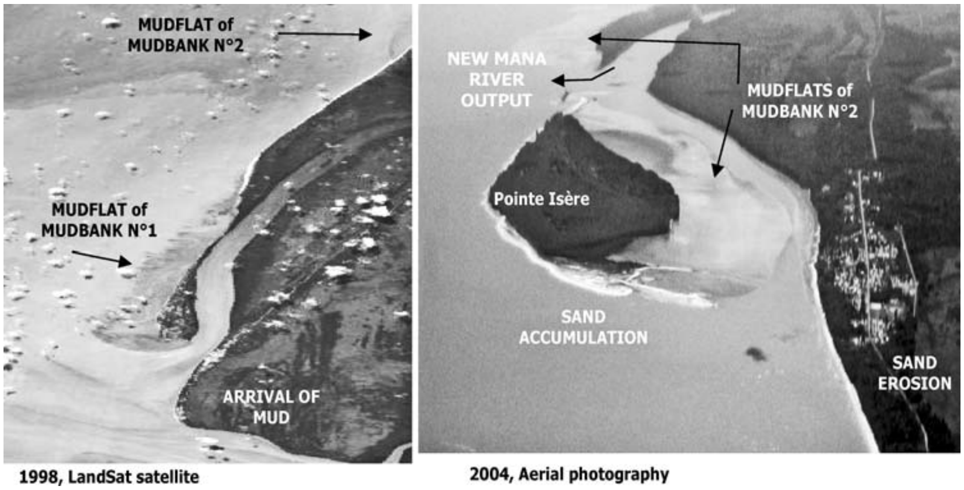
		West oceanic beaches						
Year	Awala-Yalimapo	Pointe Isère	Farez	Irakompapi	Organabo	Kourou	Cayenne	Total
2001	**10,305**[b]	**6548**[b]	**3405**[b]	?	?	**53**[c,d]	**2796**[e,f]	**23,107**
	44.6%	28.4%	14.7%			0.2%	12.1%	100%
2002	**4905**[b]	**4858**[b]	**154**[b]	**1615**[f,g]	**256**[d,g]	**33**[c,d]	**408**[e,f]	**12,229**
	40.1%	39.7%	1.3%	13.2%	2%	0.3%	3.4%	100%
2003	**5541**[e]	**5999**[f,g]	**0**	?	**534**[d,g]	**75**[c,d]	**1331**[e,f]	**13,480**
	41.1%	44.5%			4%	0.5%	9.9%	100%
2004	**4799**[c]	**2941**[f,g]	**0**	?	**1789**[d,g]	**80**[c,d]	**1403**[e,f]	**11,012**
	43.6%	26.7%			16.3%	0.7%	12.7%	100%

[a] Data presented in this table may differ from other publications that use other statistical approaches.
[b] Estimates based on a nonlinear adjustment (see Viseux et al. 2003).
[c] Number of nesting crawls.
[d] Estimate based on field monitoring from 20 to 30 days; error lower than 20%.
[e] Number of nesting crawls and female census.
[f] Estimate based on field monitoring exceeding 90 days; error lower than 10%.
[g] Estimate based on the adjustment of a sinusoidal function (see Methods).

fluctuations appeared in the number of nests recorded in each of the other nesting sites, giving highly variable individual contribution to the annual nest estimate for French Guiana (Table 1).

The French Guiana coastline is characterized by alternating zones of mudbanks and interbanks. During the mid-1980s, 6 coastline areas were welded by mudbanks (black lines labeled from 1 to 6 in the eastward direction; Fig. 1). The preserved beaches were located in the west (Awala-Yalimapo, Pointe Isère, Irakompapi areas) (SPOT image of 1986). In the early 1990s, mudbanks nos. 1 and 2 migrated westward and mud progressively covered the beach of Pointe Isère and Irakompapi. During this time period, the beach at Awala-Yalimapo was the only major sandy beach for the entire French Guiana coastline and thus the only suitable nesting site. A narrow beach was forming at the same time in Cayenne Peninsula (SPOT images of 1991 and 1992). Four years later, mudbank no. 5 left the Cayenne Peninsula, and the beach of Kourou received a large amount of sand, recovering suitable conditions for the nesting (SPOT images of 1995 and 1996).

Since the mid-1990s, major geomorphic events occurred around the mouth of the Mana River (Fig. 2). In 1997, a significant amount of mud migrated from mudbank no. 1 to accumulate on the beach of Awala-Yalimapo. As a consequence, this beach lost part of its attractiveness for marine turtles (SPOT image of 1997 and Landsat Image of 1998). At the same time, 2 large sandy beaches were formed between Pointe Isère and Irakompapi areas, offering new nesting possibilities. Since 2000, Awala-Yalimapo Beach has suffered from the arrival of mud, coupled with significant erosion of its sandy areas. At the same time, a crucial geomorphic change occurred at the mouth of the Mana Estuary. The spit-like feature that was developing along the right side of the Mana River became an isolated distal tip (Pointe Isère). As a result, the mud supplied from mudbank no. 2 accumulated in the



1998, LandSat satellite

2004, Aerial photography

Figure 2. Remote sensing data of the mouth of the Mana River. On the left, Landsat image from 1998, on the right, aerial photography from 2004.

Table 2. Estimated number of leatherback turtle nests laid in western French Guiana nesting beaches (from Fretey and Lescure 1979).

			West oceanic beaches				
Year	Les Hattes (Yalimapo)	Awara (Awala)	Kawana	Pointe Isère	Farez	Organabo	Total
1977[a]	**5715**	**1905**	**9572**	**4428**	**7915**	**4428**	**33,963**
	16.9%	5.6%	28.2%	13%	23.3%	13%	100%
1978[b]	**6875**	**3479**	**9451**	**8275**	**726**	**9248**	**38,036**
	18%	9.1%	24.9%	21.8%	1.9%	24.3%	100%
1979[c]	**11,577**	**2796**	**6438**	**1286**	**1945**	**1945**	**25,987**
	44.5%	10.7%	24.8%	5%	7.5%	7.5%	100%

[a] **1977** monitoring effort: 3 April to 4 July, nightly counting of nesting females in Kawana and Les Hattes; weekly counting of tracks in Pointe Isère; counting of tracks every 2 weeks in Farez; no indication for Awara and Organabo.

[b] **1978** monitoring effort: 1 July to 31 August nightly counting of nesting females in Awara and Les Hattes; weekly counting of tracks in Pointe Isère and Kawana; other beaches visited.

[c] **1979** monitoring effort: 1 May to 31 July; nightly counting of nesting females in Awara and Les Hattes; weekly counting of tracks in Pointe Isère and Kawana; other beaches visited.

former Mana River mouth (Fig. 2). Under the new hydrodynamic conditions, the sand supplied by the Mana River accreted predominantly along the isolated distal tip (Pointe Isère), progressively reducing the suitability of the Awala-Yalimapo Beach for nesting.

In the Cayenne Peninsula region, the 2001–2004 time period was characterized by the migration of a small mudbank, probably part of mudbank no. 6. The interaction of the mudbank with beaches induced alternate phases of small-scale sand drift but was not associated with any phase of generalized siltation and preserved the nesting grounds.

Discussion. — During the first years of the leatherback turtle survey in French Guiana, the main nesting areas were located on western remote oceanic beaches (Pritchard 1973). These nesting spots moved westward, to reach the east side of the Maroni River. The number of nests along the west beaches for the 1977–1979 period highlights the relative importance of each individual nesting site (Table 2). From year to year, the beaches bordering the east side of the Maroni Estuary (Les Hattes, Awara) welcomed an increasing percentage of nesting females (22%, 27%, and 52% in 1977, 1978, 1979, respectively), so that, from 1980 to 2001, the monitoring effort mostly focused on the Maroni Estuary area.

Over the last 30 years, the beach of Awala-Yalimapo has represented the only permanent nesting beach in French Guiana. This nesting ground has been considered a representative estimator of the turtle nesting effort for the region, assuming that it was hosting more than 90% of the leatherback turtle nests laid in French Guiana (Girondot and Fretey 1996). This assumption was used until the late 1990s (Chevalier and Girondot 1998a; Chevalier et al. 1999).

Data gathered over the last decades led to the assessment of the leatherback turtle population size. Fretey and Lescure (1979) suggested an estimate of 13,966–19,596 nesting females. The exceptionally high nesting season observed in French Guiana in 1988 led former estimations to be reevaluated (Fretey and Girondot 1989). An estimated number of 5100–9700 nesting females was finally published for the Suriname/French Guiana region (Spotila et al. 1996).

Based on the same data set, population trends were estimated. An increasing number of nests had been noted from the mid-1970s until the early 1990s (Girondot and Fretey 1996). A sharp decline was then reported (Chevalier and Girondot 1998a), interpreted as a potential decline of the French Guiana leatherback turtle rookery (Chevalier et al. 1998), or even of the entire Guianas nesting aggregation (Chevalier et al. 1999). A shift of the leatherback rookery to other nesting beaches was foreseen (Chevalier and Girondot 1998a, 1998b) but did not seem relevant to explain the apparent decline of nests recorded in Awala-Yalimapo as an aerial survey did not reveal any other major nesting grounds (Chevalier et al. 1998).

Our analysis of remote sensing data highlights the fact that major geomorphic events, like beach creation or erosion, occur periodically along the coast of French Guiana. These coastal evolutions have undoubtedly influenced the relative importance of the Awala-Yalimapo nesting beach over the last decades. Indeed, a comparison of nest number trends recorded in Awala-Yalimapo, with the sandy shoreline evolution in French Guiana, reveals that the highest numbers of nests recorded in Awala-Yalimapo (late 1980s to early 1990s) coincide with the period during which no other beaches were available. Moreover, the observed nest decline in Awala-Yalimapo (late 1990s) corresponds with the creation of several other beaches along the coastline of French Guiana.

In light of the remote sensing data and the evolution of sandy beaches along the coast, the statement asserting that the number of nests recorded in Awala-Yalimapo was, for a long period of time, close to the total number of leatherback nests laid in French Guiana must be qualified.

Recent nest estimates show that, for the 2001–2004 period, Awala-Yalimapo still hosted a significant and remarkably stable percentage of the total number of leatherback nests recorded in French Guiana. But, together with remote sensing data, it also highlights the geographic evolution of the leatherback nesting effort in the region over the 1994–2004 period of time; whereas, Awala-Yalimapo was most likely the only beach available during the early-1990s, other beaches have progressively appeared, offering new nesting possibilities in the region. Depending on beach accretion or erosion, the relative importance of any single beach fluctuates considerably at a regional scale. Thus, it is unlikely that a single nesting site hosted a constant proportion of leatherback nesting attempts over multiple decades.

Most recent works on trend analysis in French Guiana and Suriname aimed at estimating potential numbers of leatherback nests that could have been laid on unmonitored nesting areas. When doing so, nest number trends seem to have been stable or have even shown a slight increase (Girondot et al. 2007). Nevertheless, because of the lack of reliable data for some nesting areas, several assumptions have been used, and a real understanding of leatherback nesting trends will need several years of regional beach monitoring to be clarified.

As previously proposed (e.g., Chevalier and Girondot 1998a; Chevalier et al. 1999), we recommend that each single beach be monitored during the leatherback nesting season in the Guianas. Such monitoring effort could be significantly reduced by distributing the scientific coverage throughout the nesting season (Gratiot et al. 2006). Monitoring 20 to 30 days per beach would be sufficient to assess nesting dynamics and would provide valuable information to update the regional conservation status of this critically endangered species.

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Alternative Techniques for Obtaining Blood Samples from Leatherback Turtles

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ABSTRACT. – **We describe a low-risk, alternative technique for sampling blood from leatherback turtles (*Dermochelys coriacea*) using interdigitary vessels in their flippers. Because this technique allows for repeated, large-volume blood samples without requiring restraint of turtles, the technique is preferred over using the dorsal cervical sinus in almost all cases of blood sampling from leatherbacks, and also applies to other sea turtle species.**

Blood sampling of wild, captive, and stranded sea turtles is fundamental to a wide variety of experimental, analytical, and health assessment applications. Specifically, analyses of blood samples have been used for population genetics studies (Dutton et al. 1999; Crim et al. 2001) and contaminant monitoring (Keller et al. 2006); to describe an individual turtle's reproductive status (Rostal et al. 1996); to assess levels of stress hormones associated with reproduction, the nesting process, and handling by humans (Gregory and Schmid 2001); to determine hemostatic processes (Soslau et al. 2004, 2005); and can be employed in field experiments of metabolism (Southwood et al. 2006; Wallace et al. 2005) and trophic ecology (Wallace et al. 2006; Seminoff et al. 2006). In addition, analyses of blood samples from stranded animals can provide information concerning the animals' physical condition, which can then be used to determine the health care necessary to rehabilitate the animal and possibly establish the cause of the stranding.

Traditionally, blood samples have been collected from the dorsal cervical sinuses (DCS) of sea turtles (Owens and Ruiz 1980). These vessels generally are convenient to access because they are superficial, the biventer and transverse cervical muscles provide consistent landmarks to facilitate easy location of the DCS (Wyneken 2001), and large volumes of blood can be obtained. For these reasons, sampling blood from the DCS is advantageous in most sea turtle species. However, sampling from the DCS of adult leatherback turtles (*Dermochelys coriacea*) is particularly challenging due to the animals' thick, muscular necks, the deep location of their sinuses relative to their neck surface (Wyneken 2001), and lack of repeatable, identifiable external landmarks among individuals used to locate and sample from the DCS. Furthermore, large needles (3.5–6 inches by 18 gauge) are required, and repeated samples are very difficult to obtain from the DCS in leatherbacks due to tissue swelling.

To ensure accurate location of the DCS of leatherbacks, the optimal time to sample blood would be while the animals are quiescent or motionless. Therefore, to obtain a quality blood sample from the DCS, restraint of the turtle generally is necessary. Whereas capture and restraint of other sea turtle species is regularly achieved (see Jacobson et al., http://accstr.ufl.edu/blood_chem.htm, for example), restraining leatherbacks involves significant logistical difficulties, given the massive body size of these animals (200–900 kg). Considering the challenges listed above, the DCS technique can be rather invasive and exceedingly difficult when applied to leatherbacks. Thus, alternative blood-sampling techniques for these animals would be highly useful and preferable. Here, we describe an effective, low-risk technique for obtaining blood

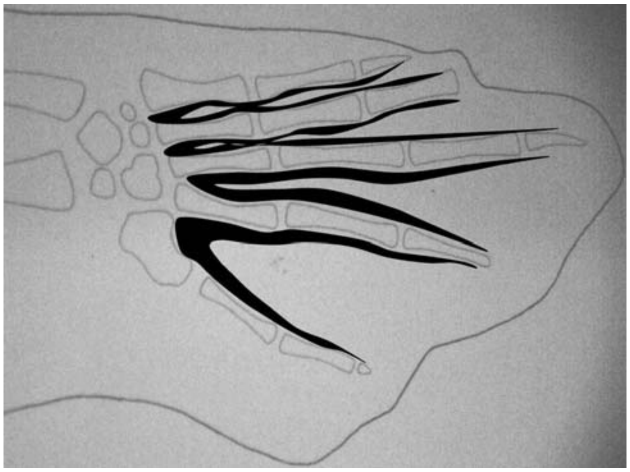

Figure 1. Schematic diagram of phalanges and interdigitary vessels (in black) of a leatherback rear flipper.

samples from adult leatherbacks using interdigital vessels (IDV) in their flippers.

Methods. — The IDV in either anterior or posterior flippers offer multiple sites for easily obtaining repeated, relatively large-volume blood samples from adult leatherback turtles. The IDVs follow the length of the phalanges and are best sampled at bifurcations located in the angles formed by the first phalanges of the digits (Fig. 1). At each bifurcation, there is a venous plexus between each pair of digits in the anterior and posterior flippers. The arrangement of the IDVs in leatherbacks (and other sea turtles) compares to that present in pinniped flippers, and the blood-sampling technique we describe here is similar to that used for pinnipeds (Bossart et al. 2001).

The IDVs between any pair of digits are accessible, but the first and second digits (from the tail) in the posterior flippers are probably the easiest to access. Because the IDVs are relatively superficial (ca. 1 inch or 2.5 cm deep), a 1-inch by 20–22 gauge needle (with a Vacutainer blood collection tube; Becton Dickinson, Franklin Lakes, NJ) generally is sufficient; even an extremely large leatherback can be sampled effectively using this method. After the interdigitary region of the skin has been sanitized (using a 70% ethanol solution, for example), the needle is inserted along the side of the phalanx, at an angle of approximately 20°–30° to the flipper surface, about 1 inch (ca. 2.5 cm) from the boney angle (interdigitary venous plexus) (Fig. 2). With Vacutainer tube connected, the needle is inserted parallel to the first phalanx and advanced toward the boney angle (interdigitary plexus) until blood enters the Vacutainer tube.

The IDVs in the anterior flippers are also parallel to the phalanges and can be located most effectively in an area up to 6 inches (ca. 15 cm) proximal or distal to the palpable joint formed by the first and second phalanges (P1 and P2). The needle is inserted through the skin in the shallow interdigital depression between the second and third digits. The needle insertion procedure is similar to that described above.

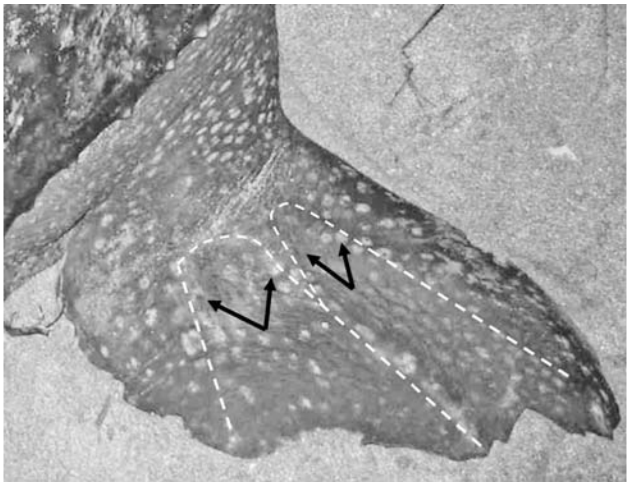

Figure 2. External landmarks on leatherback rear flippers used for interdigitary vessel blood-drawing technique. The optimal needle insertion points (indicated by black arrows) are approximately 1-inch distal to the junctions of each pair of phalanges (phalanges highlighted by white dashed lines).

Discussion. — The IDV technique is a highly effective, low-risk method for obtaining blood samples from leatherbacks. There are several distinct advantages to this IDV technique. First, repeated samples from the same turtle can be taken by using sampling sites between different digits on the same flipper or on different flippers. For example, multiple samples can be taken from a front flipper if the initial sample is taken from a distal location and subsequent samples are taken at progressively more proximal sites. Wallace et al. (2005) used the IDV technique to obtain sequential blood samples from different sites on the rear flippers of individual leatherbacks.

Second, restraint of individual nesting leatherbacks is not necessary for the IDV technique. During oviposition, for example, 1 of the posterior flippers is usually flat and motionless on the sand surface outside of the nest chamber and can be accessed easily for blood sampling. In addition, because the terrestrial gait of adult leatherbacks is characterized by a series of lunges punctuated by brief periods of no movement (Wyneken 1997), either rear flipper can be accessed for blood sampling using the IDV technique while the turtle is motionless during a resting pause on its post-nesting return to the sea. For example, Wallace et al. (2006) obtained blood samples from 18 different individual leatherbacks at Parque Nacional Marino Las Baulas, Costa Rica, during oviposition or while turtles were returning to the ocean after completion of the nesting process. Thus, the IDV technique can be used during multiple phases of the nesting process without restraining the turtle.

Third, it is possible to obtain large volumes of blood using the IDV technique. Recent studies successfully obtained samples of 5 to 20 ml using the IDV technique (Soslau et al. 2004, 2005; Wallace et al. 2005, 2006). In addition, because vasculature in flippers of other sea turtle species is similar to that in leatherback flippers, the IDV technique can be effectively applied not only to leatherbacks, but to other sea turtles species as well.

It is worth noting that recent blood biochemistry analyses on sea turtles indicate more variability in samples taken from hind limbs than from jugular veins (Jacobson et al., http://accstr.ufl.edu/blood_chem.htm). However, Wallace et al. (2005) reported that concentrations of stable isotopes in samples taken from the hind flippers were similar to those from the DCS. Thus, comparisons of biochemical analyses of blood samples from different anatomical locations should be implemented where relevant to ensure accurate interpretation of analytical results. Considering its anatomical and logistical advantages, the IDV technique is preferable to the DCS sampling technique in almost all cases where blood sampling from leatherbacks is necessary, whether on wild, captive, or stranded individuals.

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