Ultralight aircraft surveys reveal marine turtle population increases along the west coast of Reunion Island

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Abstract Reunion Island in the south-west Indian Ocean once had significant nesting populations of marine turtles but they declined rapidly after human colonization. In 1996, after regular sightings of turtles offshore, an aerial survey programme was initiated to monitor the occurrence of marine turtles and their distribution along the west coast of the island. Between 1998 and 2008, along a 30-km coastline transect between Saint Leu and Saint Paul, a total of 1,845 marine turtle sightings were recorded during 146 flights with an ultralight aircraft. The mean number of turtle sightings per survey increased significantly between 1998 and 2008, and a variety of sizes were recorded throughout the year. Marine turtles were found over coral reef zones and on the outer reef slopes. Spatial distribution may be linked to the topography and substrate of the bottom, which determine the availability of food and shelter. The marine protected area located off Saint Paul seems to have benefited marine turtles as they frequent this area more than other regions on the west coast. These results are encouraging for local organizations working for the conservation of marine turtles on Reunion Island.

Keywords Abundance, aerial survey, conservation, Indian Ocean, marine turtles, Reunion Island

Introduction

Reunion Island is a French territory located in the south-west Indian Ocean, 800 km east of Madagascar and 120 km south of Mauritius. During the 17th century the west coast of Reunion was known to be an important nesting site for marine turtles (Dubois, 1669). However, human colonization resulted in intensive harvesting of eggs and nesting females, which led to a catastrophic decline in the nesting numbers of the green turtle *Chelonia mydas* (Hughes, 1973; Frazier, 1975; Bertrand et al., 1986), the only species known to have nested at Reunion Island (Ciccione & Bourjea, 2006).

Nesting by green turtles still occurs but rarely compared to other sites in the Indian Ocean (Frazier, 1975; Mortimer, 1988; Bourjea et al., 2006, 2007; Ciccione & Bourjea, 2006; Lauret-Stepler et al., 2007; Ciccione et al., 2008). In the 1990s reports were received that green turtles and hawksbill turtles *Eretmochelys imbricata* were regularly observed along the coastline of Reunion Island by scuba-divers and from ultralight aircraft.

Hawksbill and green turtles are globally categorized as Critically Endangered (Mortimer & Donnelly, 2008) and Endangered (Seminoff, 2004), respectively, on the IUCN Red List but population trends for these species around Reunion Island are not known. Monitoring marine turtle status with population estimates is considered essential because such data can be integrated into conservation plans. Marine turtles are considered indicators of the health of marine ecosystems (Frazier, 1999).

To monitor the distribution of marine turtles along the west coast of Reunion an aerial survey programme using ultralight aircraft was initiated in 1996. Aerial survey is the most appropriate technique to obtain abundance estimates for marine turtles and other species that spend time regularly at the surface as it allows the coverage of large areas in a short period of time (Bayliss, 1986; Marsh & Sinclair, 1989; Henwood & Epperly, 1999; Marsh et al., 2004; Slooten et al., 2004; Roos et al., 2005; Gomez de Segura et al., 2006; Rowat et al., 2009) and has the advantage that animal behaviour is unlikely to be affected by human presence, which has proved a problem with boat surveys (Slooten et al., 2004).

This aerial survey programme is the first attempt to monitor and assess the marine turtle populations of Reunion Island. It was designed to provide baseline data for plotting maps of density distributions, which are essential for planning in-water studies (Marsh & Saalfeld, 1989) and to facilitate conservation planning.

Methods

Reunion Island is a volcanic island that originated 3 million years ago in the south-west Indian Ocean (Fig. 1). Most of

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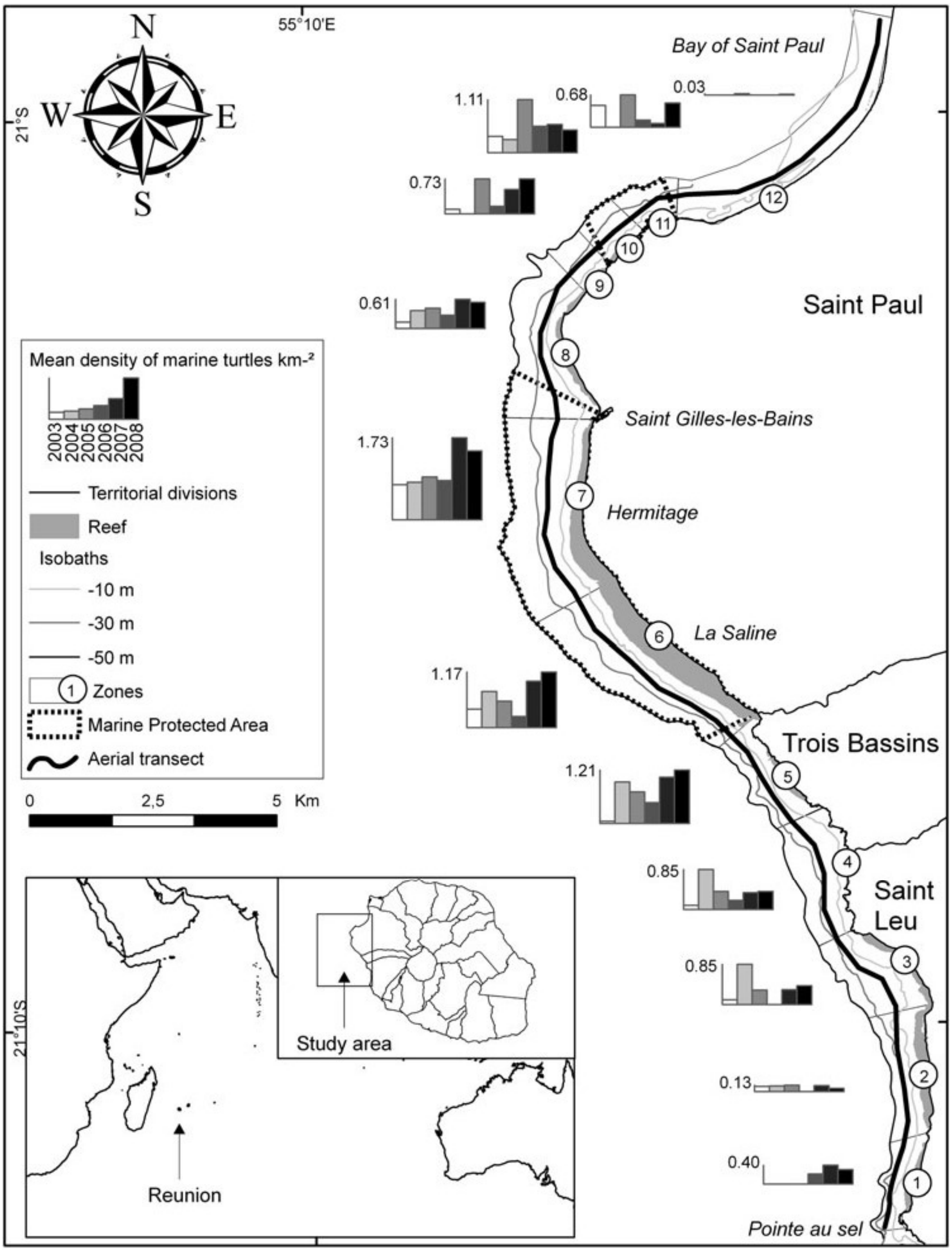

FIG. 1 Characteristics of the survey area on the west coast of Reunion Island and its position within the south-west Indian Ocean (inset). The histograms indicate the mean density of marine turtles per flight per km^2 per year for 2003–2008 for the 12 Zones. The number to the left of each histogram shows the highest value observed for each area.

the continental shelf is located on its west coast, which is protected from trade winds. This area provides suitable nesting and foraging habitats for both hawksbill and green turtles.

Between 1996 and 1997 the survey work consisted of exploring multiple transect lines on the west coast between Saint Leu and Hermitage (Fig. 1), which showed that a significant number of marine turtles occurred in the area throughout the year (Sauvignet et al., 2000). From July 1998 shoreline transects were extended to include the 30 km of coral reef and rocky coasts from Pointe au Sel to the Bay of Saint Paul, which also includes parts of the marine protected area of Reunion Island. Choosing a unidirectional transect avoided multiple counts of the same individuals. Transects have been surveyed with the same protocol since 1998.

To study spatial density differences the area was divided into 12 zones (numbered from south to north; Fig. 1). The limits of the zones were set by the Marine Park and were also based on the geomorphology of the reef and coastline.

Zones 1, 3, 5, 8 and 10 are predominantly platform reef, Zones 2, 6 and 7 consist of a fringing reef, Zone 4 is a rocky coast without reef, Zones 9 and 11 are characterized by a bank reef, and Zone 12 consists of an alluvial coast.

Aerial transects were carried out from a three-axes ultralight aircraft with high-wing configuration that allowed a side-viewing platform. Transects were flown at a mean altitude of 180 m and a mean speed of 90 km h^{-1}, facilitating the sighting of small turtles. Surveys were only conducted when weather conditions provided optimal visibility (wind and waves oriented towards the east or south-east, wave height < 1.9 m and cloud cover < 20%). The entire area was covered in 20 minutes between 08.00–10.00. This time frame was chosen to make use of optimal environmental conditions (low wind, calm sea and minimal sun glare from the surface) as this may affect aerial counts of marine megafauna (Bayliss, 1986; Marsh & Sinclair, 1989; Epperly et al., 1995; Henwood & Epperly, 1999; Slooten et al., 2004) and also avoids any bias from putative diel behavioural patterns (Ogden et al., 1983; Taquet et al., 2006). Anthropogenic activities (fishing, scuba-diving and jet skiing), which could disturb the behaviour of marine turtles at the surface, were usually low during that time of the day.

Flight frequency depended on environmental conditions and on the availability of observers and aircrafts. Surveys were carried out throughout the year from 1998 to 2008 except for 2001 when surveys could not be conducted because of the closure of the aircraft base for renovation. Data collected were submitted to the Reunion Island Marine Park, which collects and centralizes all data relating to the marine protected area.

The crew consisted of the pilot and an observer seated behind, which allowed viewing from both sides of the ultralight. Doors were opened during the surveys, providing forward, aft and downward trackline visibility. The observer recorded the total number of turtles sighted at the surface or just below and the geographical position of each sighting. Prior to 2002, positions were plotted on a map but from 2002 onwards they were recorded using a global positioning system. Species and sex could not be determined but size class (small, medium and large) was recorded when possible.

Mean turtle densities were calculated for the different Zones. Surface area was estimated, using the geographical information system *ArcGis v. 9.2* (ESRI, Redlands, USA), by superimposing all the location data of turtle sightings on a map and delimiting the area covered by the surveys.

Results

A total of 146 flights (mean 13.3 ± SD 7.58 $year^{-1}$, range 4–25), comprising a total of 4,380 km of transects, were conducted between 1998 and 2008 (Fig. 2; Table 1) in which observers sighted a total of 1,845 marine turtles. Since 1998 there has been a significant increase in the mean number of marine turtles observed per transect (Spearman's rank correlation, $r_s = 0.93$, $n = 10$, $P < 0.05$), which is consistent with previous studies also based on similar aerial surveys over Reunion (Sauvignet et al., 2000; Michalowski, 2007).

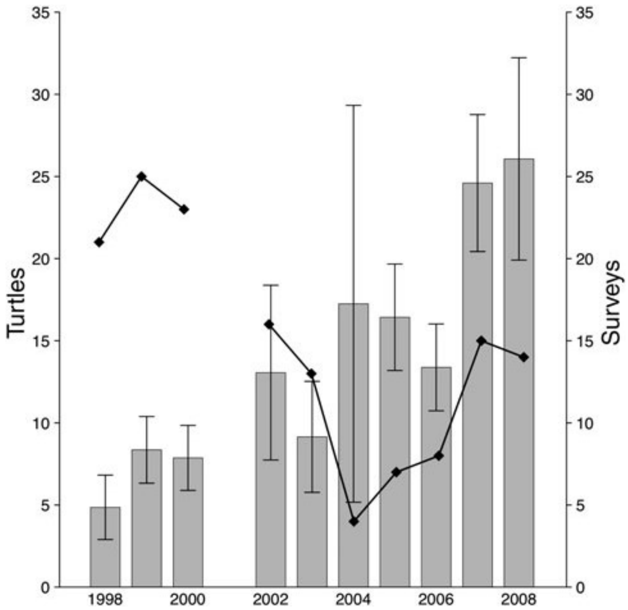

FIG. 2 Mean number of marine turtles (grey bars; ± 5% confidence interval) sighted during aerial surveys off Reunion Island (1998–2008). Also shown is the annual number of surveys conducted (black diamonds).

On the west coast of Reunion marine turtles were present in significant numbers throughout the year (Table 1). There were no significant differences in the mean number of sightings per flight between the two main seasons, austral summer (November–April; 514.2 ± SD 40.4) and austral winter (May–October; 526.6 ± SD 44.5; Kruskal-Wallis test, $K = 19$, $P = 0.46$). Marine turtles were recorded on the outer reef slopes but most frequently in coral reef zones (fringing, platform and bank reefs). No turtles were sighted on the reef plateau.

During 2008 the average surface density per flight of sightings in the whole study area was 0.768 turtles km^{-2} and marine turtle mean surface densities per flight ranged from 0.014 turtles km^{-2} in Zone 12 to 1.44 turtles km^{-2} in Zone 7. Fig. 1 illustrates the surface density for 2003–2008 for each zone and shows that the highest density of turtles was observed in Hermitage. During 2007–2008 turtle densities were highest in the area between Zones 5 and 10, which consists mainly of the marine protected area.

Discussion

Aerial surveys

The ultralight aircraft surveys conducted along the coast of Reunion Island have provided important information on

Table 1 Ultralight aircraft counts (number of individuals sighted, with number of surveys in parentheses) of marine turtles along Reunion Island's west coast (Fig. 1) during 1998–2008. Note that surveys were not conducted in 2001.

Month	1998	1999	2000	2002	2003	2004	2005	2006	2007	2008
Jan.		19 (2)	2 (2)		9 (2)	30 (1)		46 (3)		
Feb.		33 (3)	25 (2)		15 (4)	14 (1)		16 (1)		54 (2)
Mar.		22 (3)	21 (1)		23 (2)		32 (2)		55 (3)	42 (1)
Apr.		14 (3)	12 (2)				18 (1)	23 (2)	45 (2)	34 (2)
May		25 (2)	13 (1)				24 (2)	22 (2)	96 (3)	18 (1)
June		17 (3)			21 (1)				51 (2)	17 (1)
July	27 (3)	1 (1)	53 (8)	65 (2)	42 (3)	25 (2)			23 (1)	48 (2)
Aug.	2 (3)		30 (4)	71 (5)					27 (1)	41 (1)
Sep.	11 (4)	33 (3)	10 (1)	29 (3)			18 (1)			19 (1)
Oct.	30 (4)		3 (1)	30 (3)	9 (1)				27 (1)	19 (1)
Nov.	14 (4)	16 (1)	12 (1)	7 (1)			23 (1)		45 (2)	48 (1)
Dec.	18 (3)	29 (4)		7 (2)						25 (1)
Total	102 (21)	209 (25)	181 (23)	209 (16)	119 (13)	69 (4)	115 (7)	107 (8)	369 (15)	365 (14)

the relative abundance and distribution of marine turtle populations over a period of 10 years. Various types of aircraft have been used for aerial surveys but ultralights have been used infrequently. The only other study of which we are aware that used ultralights for marine turtle surveys was in Mayotte (Roos et al., 2005).

Flight parameters maintained during our surveys were different from other studies. The airspeed of 90 km $hour^{-1}$ was slower (150–225 km $hour^{-1}$; Marsh & Saalfeld, 1989; Shoop & Kenney, 1992; Slooten et al., 2004; Gomez de Segura et al., 2006), increasing the likelihood that the observer spotted every turtle on both sides of the aircraft. However, our flight altitude of 180 m should be reduced to 150 m, the recommended height for marine turtle studies (Henwood & Epperly, 1999), to facilitate comparisons with other aerial surveys. Most surveys of marine turtles have used line or strip transects to prevent double-counting of individuals. Although the area covered by the ultralight in our study was smaller than the area typically surveyed by aircraft the coastline transect was sufficiently wide to spot most individuals of the coastal marine turtle population in this area. Prospecting further offshore, however, would indicate whether the survey area should be enlarged.

Aerial surveys have both advantages and limitations. This technique provided us with rapid coverage of the 30-km transect with minimal disturbance of marine turtles at the sea surface. However, biological information such as species, sex or size of individuals is difficult to obtain from aerial sightings and requires in-water studies (Epperly et al., 1995; Henwood & Epperly, 1999; Roos et al., 2005). The density distributions illustrated in Fig. 1 indicate the zones of interest for such future studies. As marine turtles spend the majority of their time under water to forage, move or rest, aerial counts can only provide an index of abundance. Therefore, aerial surveys should ideally be combined with in-water studies, to include submerged turtles for a more accurate and complete assessment. As nesting turtles are rare on Reunion, in-water studies will primarily assess the use of Reunion waters as feeding habitat.

Turtle abundance and distribution

This study was not designed to produce absolute estimates of abundance but to provide an indication of distribution and trends of marine turtle populations. The results demonstrated a significant increase in the number of turtle sightings at the surface over time and established that turtles are present throughout the year. That the mean number of turtle sightings per flight was not significantly different between the austral summer and winter is consistent with the small variations of sea surface temperatures around the island (means of 23.4°C in winter and 28.0°C in summer; Conand et al., 2007). This apparent site fidelity without seasonal migrations was also observed in immature loggerhead turtles in the Algerian Basin, which is thermally homogeneous (Revelles et al., 2007).

Surface sightings alone are limited in their value insofar as feeding, diving and sleeping behaviours influence the time spent at the surface (Hays et al., 2000). This is the case in temperate and subtropical regions where low temperatures during winter will reduce activity and metabolic rate of marine turtles and, consequently, dive duration and post-dive surface intervals will be increased (Southwood et al., 2003, 2006; Hochscheid et al., 2007). The lack of information regarding surfacing and diving times at Reunion does not allow accurate extrapolation of the data collected and abundance estimates of the population. As species identification was not possible because of the altitude of the flights, data collected during the surveys were recorded as mixed species of marine turtle (green and hawksbill). However, scuba-diving and ship-based observations indicated that hawksbill turtles are less frequently observed than green turtles around Reunion (one out of 10 turtles observed is a hawksbill; J. Bourjea, pers. obs.). It is therefore likely that most of the aerial sightings were of green turtles.

Infrequent nesting activity on Reunion (Ciccione & Bourjea, 2006; Ciccione et al., 2008) indicates that marine turtles observed around the island belong to populations that only forage in its waters. The fact that, throughout the study, with no seasonal differences, a wide range of turtle sizes were observed, indicates a renewal of the population during the study period.

While nesting of green turtles has been studied on many islands of the south-west Indian Ocean (Frazier, 1975; Le Gall, 1988; Bourjea et al., 2006, 2007; Lauret-Stepler et al., 2007), little is known about foraging habitat use (Taquet et al., 2006; K. Ballorain, unpubl. data). Aerial surveys and snorkelling censuses have been conducted for green turtle foraging areas in Mayotte, an island in the northern Mozambique Channel (Roos et al., 2005). The mean density of turtles estimated to frequent that area on a daily basis was much higher (1,400 turtles km^{-2} day^{-1}) than our estimate for 2008 (0.768 turtles km^{-2} $year^{-1}$). However, the Mayotte study estimated the total number of turtles present in the transect (at the surface, on the bottom and between), thus giving an estimate of the entire population frequenting the foraging area, and the area was much smaller than the area covered in our study and had depths of 1.2–1.7 m. The density observed in this particular seagrass bed in Mayotte may not be representative for other foraging areas. In contrast, surface densities of turtles in Reunion were comparable to the 1.03 turtles km^{-2} recorded in aerial surveys in the northern Great Barrier Reef Marine Park (Marsh & Saalfeld, 1989), in which turtle sightings on reefs or inshore seagrass beds were most likely of green turtles.

In our study turtles were sighted only behind the external reef slope, which is considered to be the richest and most diversified part of the reef (Montaggioni, 1978), with large quantities of red algae between 10 and 30 m (E. Ballesteros, unpubl. data) and invertebrates on which green and hawksbill turtles may feed (Mortimer, 1982; Bjorndal, 1985; Meylan, 1988; Léon & Bjorndal, 2002; Seminoff et al., 2002; Arthur et al., 2008). The reef plateau typically hosts seagrass patches of *Syringodium isoetifolium* (Letourneur, 1992), generally selected by green turtles in Mayotte (K. Ballorain, unpubl. data) but probably insufficient in quantity around Reunion to support a large number of green turtles. Red algae are probably the main food for green turtles as stomach content analyses undertaken in Reunion revealed large quantities of red algae, particularly *Carpopeltis* spp., *Amansia* spp. and *Beckerella bisserata* (Ciccione, 2001). In our study, the greatest number of turtles was observed in the Hermitage zone (Fig. 1). This may be related to the topography and bottom substrate, which is suitable habitat for the development of red algae.

Food resources alone may not completely explain the spatial distribution of marine turtles as the internal reef slope may also provide caves and channels as shelters, especially for immature marine turtles, against predators such as sharks (Musick & Limpus, 1997). Increasing human activities in some areas may influence the distribution of marine turtles (Mirault, 2006). The two marine protected areas located off Saint Paul seem to have benefited turtles as they appear more numerous in this area than other regions of the west coast (2008; 1.05 turtles km^{-2} off Saint Paul, Zones 6–11, compared to 0.43 turtles km^{-2} off Saint Leu and Trois basins, Zones 1–5; Fig. 1).

Conservation implications and future research

The increase in the number of turtle sightings during our surveys, despite the urbanization of the coast of Reunion, is encouraging. This may be the first fruits of public awareness programmes initiated in 1977 by Ferme Corail, now Kélonia, which may have changed attitudes towards marine turtles and raised peoples' awareness about the need for turtle conservation. In addition, the prefectorial order promulgated locally to protect marine turtles in 1983 appears to have had positive results. Measures to protect the marine environment that culminated in the creation of a marine protected area in July 1997 (Fig. 1), which was extended to cover a larger area in February 2007, and further departmental orders that came into effect in 2000 and 2005, may also have allowed the marine turtle population to increase. The marine protected area now protects most of the coral reef ecosystems of the island and this should have positive impacts on marine biodiversity and marine turtle populations.

Although this study found a clear increase in the number of turtles sighted, further studies are needed to improve our knowledge of the general biology and ecology of marine turtle populations of Reunion Island. In-water studies on the habitat use of green and hawksbill turtles will help to explain the distribution patterns observed along the west coast and evaluate any seasonal variations in marine turtle diving behaviour. This would also give complementary information about the effectiveness of the marine protected area.

No data are currently available on the origin of the marine turtles frequenting the Reunion coast, and there is no information about the duration of their stay or foraging site fidelity. In 2005 a photo identification programme was initiated to track marine turtles, the results of which may provide a better understanding of Reunion Island marine turtle populations.

This aerial survey programme is ongoing, with a survey by one ultralight flight per month. Data collected during 2009 confirm the results described here. The number of turtles sighted on the west coast is still increasing, particularly around the marine protected area.

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