Spatio-temporal nesting distribution of the loggerhead turtle (*Caretta caretta*) at the Ponta do Ouro Partial Marine Reserve, Mozambique

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Introduction

Marine turtles are migratory species with a global distribution. Worldwide, there are seven extant species of marine turtles that inhabit nearly all oceans and occupy broad geographical ranges (Wallace *et al*. 2010a). Populations nesting on beaches and feeding on waters of the African continent are globally significant with representative numbers of leatherbacks in Gabon (Fossette *et al*. 2008), loggerheads in Oman (Rees *et al*. 2010) and Cape Verde (Marco *et al*. 2011), greens in Guinea Bissau (Catry *et al*. 2002) and hawksbills in the Seychelles (Sheppard *et al*. 2012) and the Chagos Archipelago (Mortimer 1984; Sheppard *et al*. 2012). Five species of marine turtles nest in Mozambique: greens, hawksbills, leatherbacks, loggerheads and olive ridleys (Louro *et al*. 2006).

The southern Mozambique region is an important nesting area for loggerhead (*Caretta caretta*) and leatherback turtles (*Dermochelys coriacea*), as well as a feeding area for green (*Chelonia mydas*) and hawksbill turtles (*Eretmochelys imbricata*) (Hughes 1971; Louro *et al*. 2006). Typically, the turtle nesting season in southern Mozambique starts in October and lasts until March (Gove 1996; Louro *et al*. 2006). The loggerhead turtle is the most common species nesting at the Ponta do Ouro Partial Marine Reserve (POPMR), accounting for approximately 95% of the total nests (Fernandes *et al.* 2015). This species is listed by the IUCN Redlist as Vulnerable at the global scale, and the south-west Indian Ocean subpopulation is listed as Near Threatened (Casale & Tucker 2015).

Monitoring of turtle nesting and female tagging in the study area, in a stretch of coast from Ponta Malongane to Ponta Dobela, began in the 1993/1994 season and was led by Mr Pierre Lombard with technical support from Dr George Hughes, who at the time was coordinating the marine turtle programme in South Africa (Lombard 2005; Pereira *et al*. 2014).

With the proclamation of the POPMR as a marine protected area in August 2009 (Decree 42/2009, of 21 August), structural, financial and technical developments within the reserve allowed for the expansion and consolidation of the monitoring programme, which included daily patrols throughout the nesting season, as well as the entire length of coastline (Pereira *et al.* 2014).

Many studies show that spatial distribution of loggerhead turtle nests is correlated with nest site selection variables (e.g. Botha 2010; Wood & Bjorndal 2000). Nest site selection is defined as the non-random placement of eggs within a particular location of a nesting beach (Botha 2010) and can be divided into three phases: beach selection, emergence of the female and nest placement (Wood *et al*. 2000). Pereira (2008) showed that dune height, soil compaction, electrical conductivity (a proxy for soil salinity), beach slope and beach width were the most important variables for loggerhead nest site selection from Ponta Dobela to Ponta Malongane.

This paper presents the spatial distribution of emergences and nests by loggerhead turtles for the past five seasons (2010/11 to 2014/15) in the POPMR. The inter-nesting interval, number of nesting turtles per season, emergences and nests per turtle are estimated based on tag and recapture data.

Methods

Study area

This study was conducted at the POPMR, located in southern Mozambique in a stretch of beach from Ponta do Ouro (26°50'49.55"S and 32°53'42.75"E) to Santa Maria (26°6'37.49"S and 32°57'35.18"E) of approximately 86km (Fig. 1).

The POPMR, with a total area of 678km^2, extends from Ponta do Ouro, at the border with South Africa, to Inhaca in the north. The POPMR extends from the high tide mark up to three nautical miles into the Indian Ocean and one nautical mile into Maputo Bay (DNAC, 2011). This marine protected area is zoned into three categories: i) sanctuary zone or no-take zone, (ii) restricted use zone and iii) multiple use zone. Commercial fisheries are forbidden within the entire reserve, and rules are applied for permitted activities such as recreational and sport fishing, diving, swimming with dolphins and whale watching (DNAC 2011).

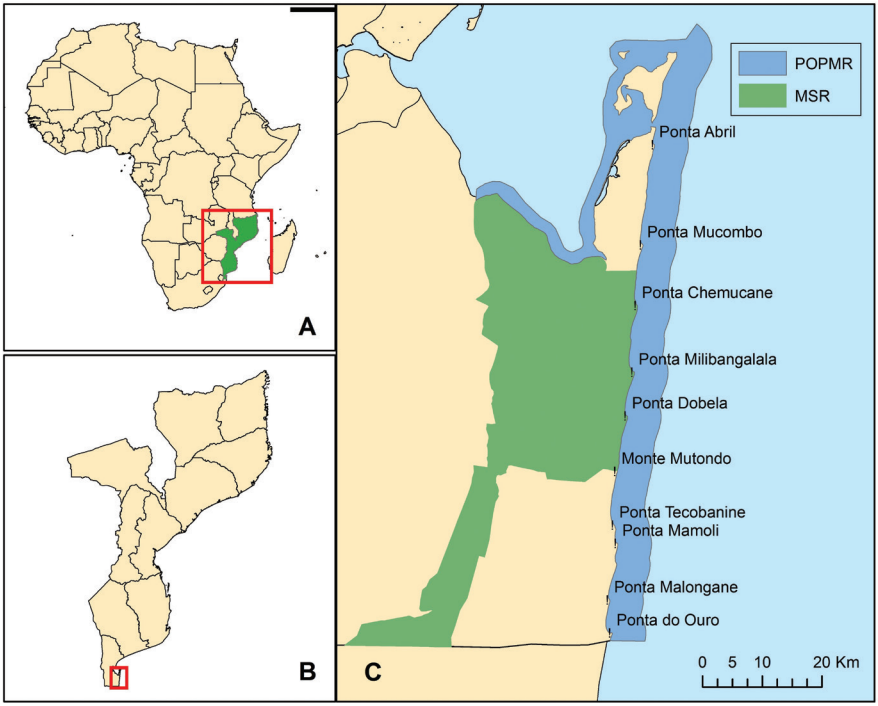

Fig. 1. Location of Ponta do Ouro Partial Marine Reserve (POPMR) and Maputo Special Reserve represented in blue and green respectively and sites mentioned in the text.

The study area encompasses several ecosystems, including vegetated coastal dunes, coastal lagoons, sandy beaches, warm clear waters and coral reefs, combined with a scenic landscape (Hatton 1995). The coast consists primarily of wide sandy beaches and is exposed to strong winds and tidal forces (Robertson *et al*. 1996).

Data collection and analysis

Data on nesting activity and tagged/recaptured turtles were collected by 40 to 50 marine turtle community monitors employed by the POPMR, tourism operators and civil society organizations, as well as from observations made by the POPMR staff, the latter being especially relevant to detect emergences before the beginning of the official nesting season. Marine turtle monitors patrolled the beaches every night from October to March for the season 2010-11 to 2013-14 and from September to March for the season 2014-15. The location of each emergence was obtained by the use of a handheld Garmin Etrex GPS, the odometer of the patrol vehicle, natural landmarks such as rock headlands (which intersperse

the beaches and are called 'Pontas'), or marked poles (positioned every 500m), as well as other infrastructure.

Marine turtles were tagged with titanium tags from the beginning of the program in 1993/94, albeit with irregular effort. These long-term datasets were used to analyse remigration intervals to have more information on each recaptured turtle as suggested by Broderick *et al*. (2002), Horvitz & Thompson (1952) and Thorson *et al*. (2012).

Several metrics were calculated in order to infer the intra and inter-annual trends and spatial variation in nesting and emergence activity over the study period. To further investigate the spatial dynamics of the tracks and nests, a density map was constructed. This was done using the kernel density tool of *Arcmap 10*, with a cell size of 30m and a search radius of 1,000m. The values were chosen to reduce the effects of georeferencing errors and to obtain a smooth gradient.

Results

Monitoring data

From 2010/11 to 2014/15 a total of 8,105 tracks and 3,811 nests were observed, and 900 loggerhead turtles were tagged. An average of 1,621.0 (±288.1 SD) tracks per season were recorded, varying from 1,273 to 1,997 tracks respectively for 2012-13 and 2013-14 (Table 1). The number of nests per season varied from 632 (2012-13) to 906 nests (2013-14; Table 2), with an average of 762.2 (±120.6 SD) nests per season. Non-nesting emergences and unconfirmed nest emergences varied from 612 (2013-14) to 1,154 (2014-15) with an average of 858.8 (±239.4 SD) per season (Table 3).

Table 1. Loggerhead turtle tracks (number, average and standard deviation – SD) per season and beach section

Season	Ponto do Ouro – Ponto Malongane	Ponto Malongane – Monte Mutondo	Monte Mutondo – Ponto Mucombo	Ponto Mucombo – Santa Maria	Total	Tracks associated to a tagged female	Average of tracks per female (SD)		Max
2010-11	59	735	441	256	1491	208 (14%)	1.3	0.6	3.0
2011-12	116	808	505	397	1826	208 (11%)	1.3	0.5	3.0
2012-13	51	552	465	205	1273	286 (22%)	1.3	0.6	4.0
2013-14	54	870	392	202	1518	888 (58%)	1.5	0.8	6.0
2014-15	155	1359	289	194	1997	431 (22%)	1.5	0.8	8.0
Total	435	4324	2092	1254	8105	2021 (25%)	1.4	0.7	8.0
Average	87.0	864.8	418.4	250.8	1621.0				
(± SD)	46.5	300.9	83.1	85.3	288.1				

Table 2. Loggerhead turtle nests (number, average and standard deviation – SD) per season and beach section.

Season	Ponto do Ouro – Ponto Malongane	Ponto Malongane – Monte Mutondo	Monte Mutondo – Ponto Mucombo	Ponto Mucombo – Santa Maria	Total
2010-11	43	340	105	158	646
2011-12	67	375	167	175	784
2012-13	27	294	194	117	632
2013-14	48	453	290	115	906
2014-15	72	565	107	99	843
Total	257	2027	863	664	3811
Average	51.4	405.4	172.6	132.8	762.2
(± SD)	18.3	106.5	76.1	32.1	120.6

Table 3. Loggerhead turtles non-nesting emergences (number, average and standard deviation – SD) per season and beach section. Note that non-nesting emergence includes cases where it was not possible to confirm if the turtle nested.

Season	Ponto do Ouro – Ponto Malongane	Ponto Malongane – Monte Mutondo	Monte Mutondo – Ponto Mucombo	Ponto Mucombo – Santa Maria	Total
2010-11	16	395	336	98	845
2011-12	49	433	338	222	1042
2012-13	24	258	271	88	641
2013-14	6	417	102	87	612
2014-15	83	794	182	95	1154
Total	178	2297	1229	590	4294
Average	35.6	459.4	245.8	118.0	858.8
(± SD)	30.9	199.5	102.5	58.3	239.4

Within the study period (2010/11 to 2014/15), 900 loggerhead turtles were tagged. The average number of new turtles tagged per season was 180.0 (±28.3 SD) and varied from 153 to 228 turtles respectively in 2010-11 and 2013-14.

The 780 loggerhead turtles recaptured during this period also included turtles tagged in other seasons, as well as turtles tagged in South Africa. Recaptured turtles per season averaged 156.0 (±78.6 SD) and varied from 90 (2011-12) to 259 (2014-15).

The number of identified turtles (tagged and first recaptured) per season has increased along the years, varying from 250 to 450 turtles respectively in 2010-11 and 2013-14 (Table 4; Fig. 2).

Table 4. Tagged and first recaptured loggerhead turtles (number, average and standard deviation – SD) per season and beach section.

Season	Ponto do Ouro – Ponto Malongane	Ponto Malongane – Ponto Mutondo	Ponto Mutondo – Ponto Mucombo	Ponto Mucombo – Santa Maria	Total Tagged	Recaptured	Identified turtles per season
2010-11	4	127	12	10	153	97	250
2011-12	4	138	30	7	169	90	269
2012-13	2	110	49	12	173	112	285
2013-14	2	197	16	13	228	222	450
2014-15	1	172	4	0	177	259	436
Total	13	744	111	42	900		
Average	2.6	148.8	22.2	8.4	180.0	156.0	
(± SD)	1.3	35.2	17.7	5.2	28.3	78.6	

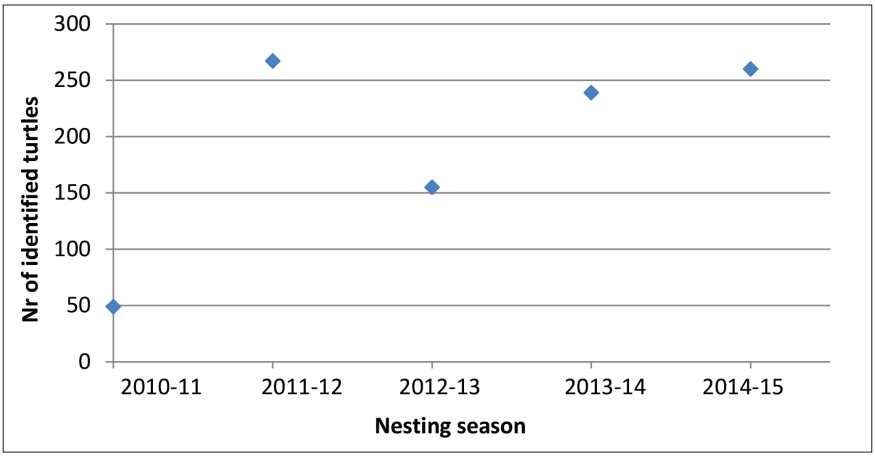

Fig. 2. Total number of turtles identified with a titanium tag mark per season, at the Ponta do Ouro Partial Marine Reserve.

Intra-seasonal nesting activities

Generally, nesting activities started in September (2010/11 and 2014/15) or in October (2011/12 and 2012/13) (Fig. 3). For the 2013/14 nesting season two earlier nesting emergences were observed, one in July and the other in August. The median nesting activity was observed during early or mid December.

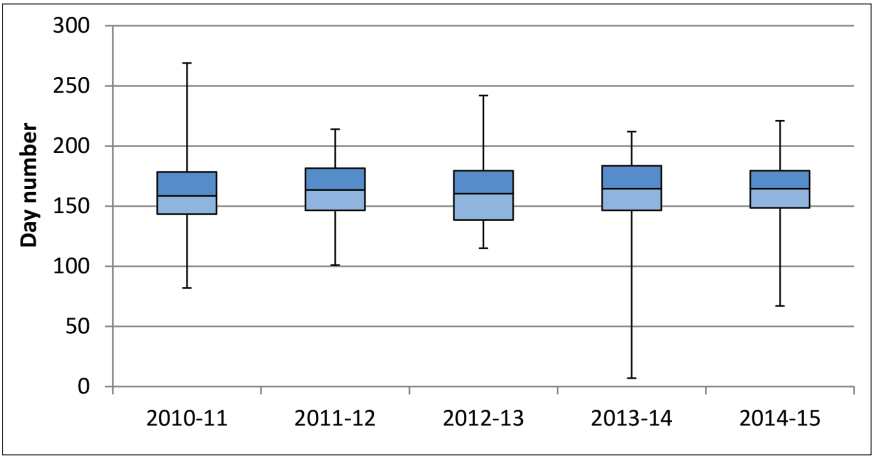

Fig. 3. Variation of nesting activity per day for seasons 2010/11 to 2014/15. Day 1 represents 1 July and day 272 represents 30 March. The lower bar represents the first day and the top bar represents the last day for each season. Mid-line represents the median nest. Total sample size corresponds to 3,868 nests.

Based on the tag and recapture information, an average 1.1 nests per turtle (±0.4 SD; maximum of two nests per turtle) was estimated for 2010/11 to an average of 1.7 nests per turtle (±0.5 SD; maximum of three nests per turtle) for 2013/14. The non-nesting emergences showed an average of 1.0 non-nesting emergences per turtle (±0.1 SD) for 2012/13 to an average of 1.9 non-nesting emergences per turtle (±0.3 SD) for 2013/14 (Fig. 4). The present data shows that 73% of the turtles tagged laid only one nest, 20% two nests, 5% three nests and 1% four nests. Given the range of one to four nests per female and the total of counted nests, it is estimated that the number of nesting females is between 190 and 762 turtles per season. The weighted average of nesting females per season was 480.2 (±76.0 SD).

Loggerhead turtles inter-nesting migration varied from one (consecutive season) to 11 seasons with an average of 3.2 seasons (±1.9 SD) (Figure 5).

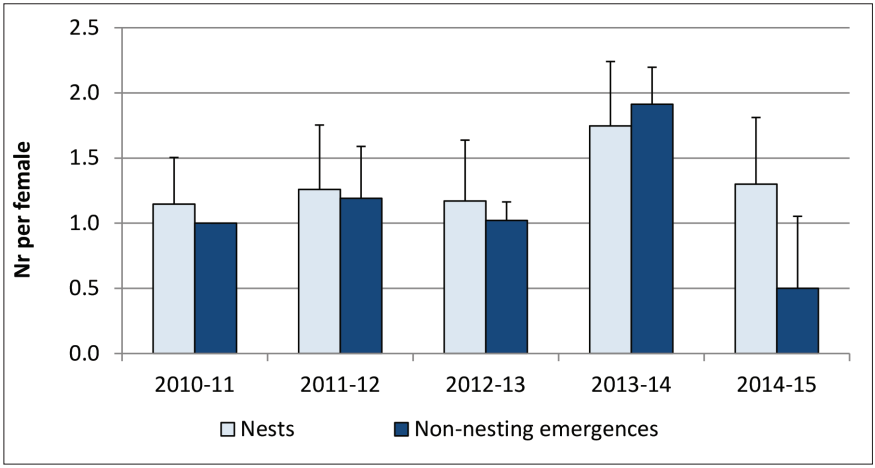

Fig. 4. Frequency histogram of number of nests per female (light bars) and number of non-nesting emergences per female (dark bars). Total sample size corresponds to 1,005 female loggerhead turtles tagged/recaptured with 1,029 confirmed nesting emergences and 460 non-nesting emergences.

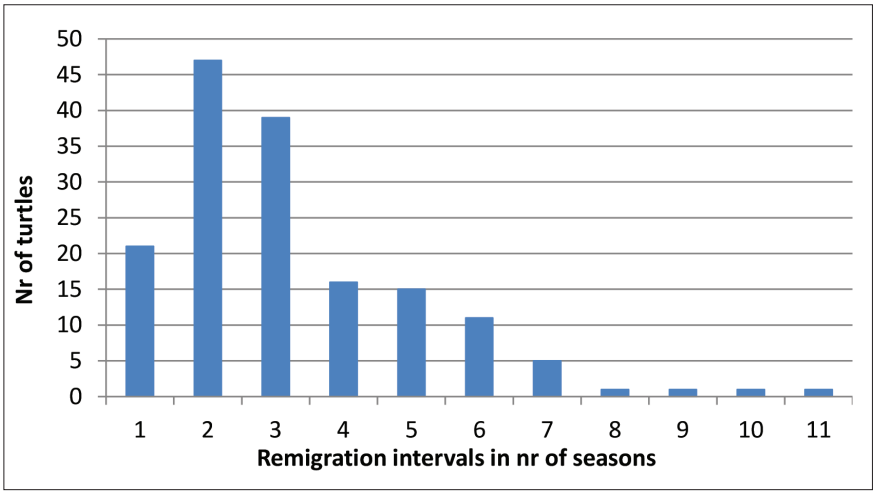

Fig. 5. Frequency histogram of remigration intervals in number of seasons. Note that 1-11 represents consecutive seasons (sample size of tagged turtles with historic data on recaptures = 134).

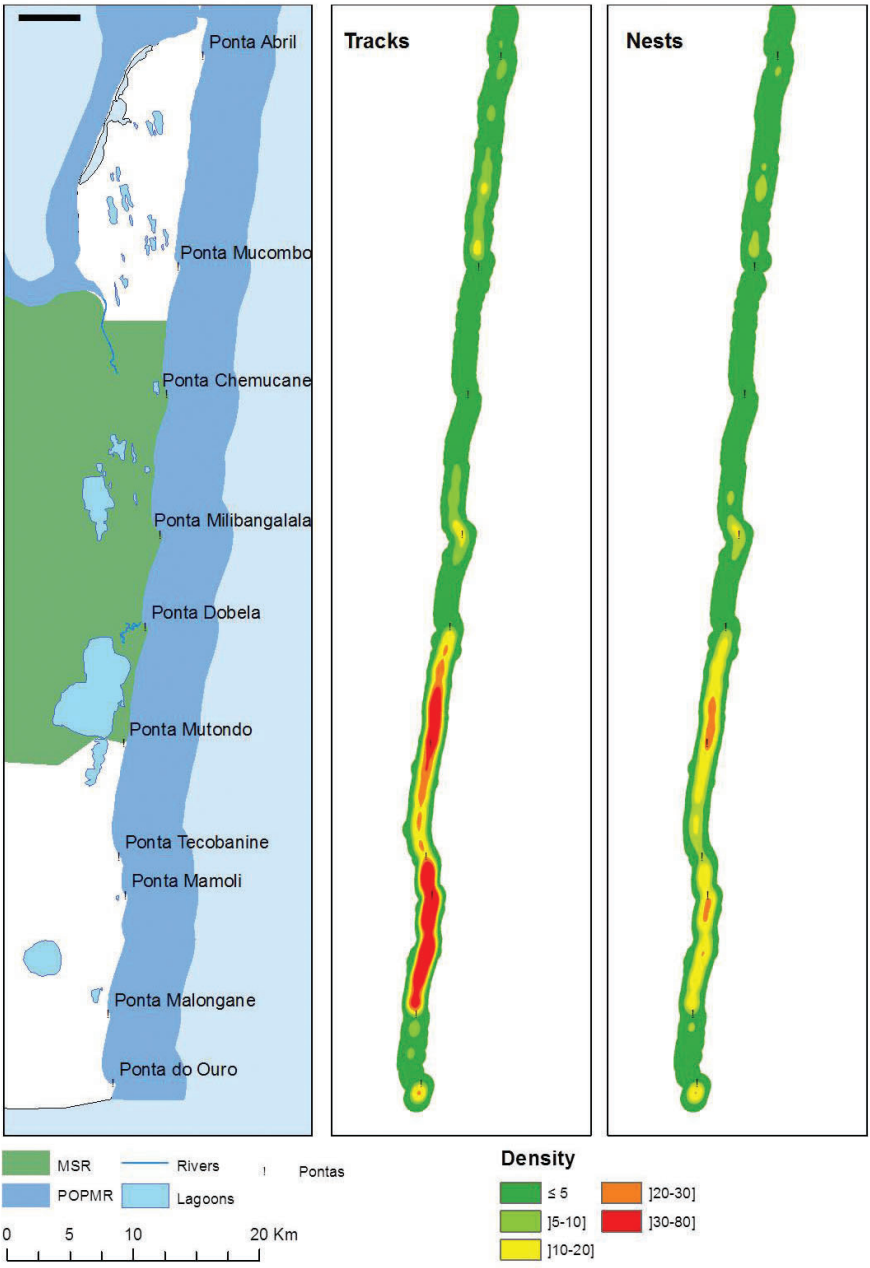

Fig. 6. Loggerhead turtle densities for track and nests. Densities are expressed as number per square km per year.

Spatial distribution

A total of 7,665 tracks were recorded from 2010/11 to 2014/15. Some of the tracks had incomplete information with regard to location and were removed, resulting in a total of 7,460 tracks which were analysed. Of these, 3,458 corresponded to actual nests, and the remaining were non-nesting emergences.

The area from Ponta Malongane to Ponta Mamoli and around Mutondo had a high nesting activity (30 to 80 nests per km^2 per season) as shown in Figure 6.

Discussion

The present analysis showed a variation of one to four nests per turtle, with a mode of one nest per turtle. According to Fernandes (2015), the higher percentage of turtles laying one nest can be explained by the fact that less than 50% of the total nests are associated to a tagged turtle but also could be because the same loggerhead turtles also nest in South Africa. Therefore, further sampling is required, especially regarding the number of nests associated to tagged females, which will allow a better estimation of the number of nesting females. From studies conducted in South Africa, on the same population of loggerhead turtles, an average of 3.7 nests per season is laid per turtle (Nel *et al*. 2013). So, taking this average in consideration, the number of nesting females is estimated to be 206 (±32.6 SD) turtles per season at the POPMR. This figure is very similar to the 193-428.6 effective population size based on genetic analysis with microsatellite markers (nuclear DNA polymorphic loci) and 54 samples from nesting females collected from 2010 to 2013 (Fernandes 2015). Effective population size refers to the minimum number of reproductive individuals required to maintain the observed genetic diversity in the offspring (Hare *et al*. 2011). Fernandes (2015) also analysed different scenarios to detect a bottleneck event, though many were able to show a clear sign of population size reduction based on the allelic frequency data. On the other hand, Halpern *et al*. (2008) made a global analysis of types of ecosystems and anthropogenic pressures showing that southern Mozambique is highly impacted; and Mellet (2015), studying fisheries bycatch of marine turtle species in the SWIO region and based on a dataset between 2000-2011, showed that in Mozambique the threat of long-line fisheries by-catch constitutes a concern for two vulnerable species, the loggerhead and the leatherback turtles.

This study presents an inter-nesting migration variation from 1 to 11 seasons with an average of 3.2 seasons (±1.9 SD). An irregular inter-nesting migration pattern was also reported by Hughes (1974) for Tongaland, showing that it is difficult to estimate the total population size based on these data.

The south-west Indian Ocean loggerhead population seems to be the second most important nesting population from East Africa in terms of population size, after Oman's population (Rees *et al*. 2010). Post-nesting migration shows that adult females can perform near coast migration to south Asia (Luschi *et al.* 2003; 2006), increasing the possibility of genetic connectivity with the Oman population.

Higher densities found from Ponta Malongane to Ponta Mamoli and around Mutondo are consistent with Pereira *et al.* (2014), who described higher numbers of loggerhead occurrences from Ponta Malongane to Ponta Dobela. Fernandes (2015) estimated an average of 9.2 to 14.2 nests per km per season from Ponta Malongane to Ponta Dobela (a stretch of coast of about 32km).

The section between Ponta Malongane and Ponta Dobela is characterized by the presence of coastal lagoons that may play an important role on the beach site selection. The success rate of nesting and hatching is poorly known at the POPMR. Therefore, it is important to improve some aspects of the monitoring programme, including number of hatched/un-hatched eggs, survival of the hatchlings and local environmental factors. Beach profiles studies are also deemed important, as these may prove crucial to predict climate change impacts and if necessary the implementation of translocation plans. Curiously, half of the tracks were not associated to a nest, but it is not clear if the abortion is a result of natural conditions of the site or human environmental changes.

Conclusion

These results show the importance of the POPMR nesting beaches for the most south-western nesting population in the Indian Ocean. This area is also the most important loggerhead nesting area in Mozambique.

Further studies are required to improve knowledge on population size and vulnerability to threats both at sea and on land.

The long-term monitoring is deemed fundamental for acquiring knowledge on conservation status of this loggerhead subpopulation. It also serves as a valuable protection tool that contributes to the reduction of direct threats to nesting females. Thus, efforts to keep this programme running and ensure its improvement are of paramount importance. Additional attention should be given to nest site selection and successful nests, as well as analysis on the viability of establishing a community-based ecotourism turtle watching programme.

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