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Impact of human activities on green turtle populations in a protected area at Mayotte Island

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Abstract

Marine protected areas are efficient tool for green turtles (*Chelonia mydas*) conservation. Development of ecotourism in these areas, a form of tourism that is usually wildlife based and careful of the environment, can contribute to conservation but may also results in disturbances of turtles and habitat degradation. N'Gouja bay (Mayotte Island), protected since 2001, host both nesting and feeding green turtles populations. This area is also an attractive site for tourists and residents. A hotel, located behind the beach and well involved in the conservation of marine turtles, offer activities on turtles to its guests, such as observation of nesting turtles. From 2003 to 2014, N'Gouja beach was monitored for nesting activity. The frequentation level of the beach by the turtles followed the same pattern that the one observed in other major nesting beaches of the island and stayed constant over the 12 years study period. Nesting activities occurs all the year with a peak from April to July. Nesting success was estimated at 42.72 ± SD 4.41 %. However we recorded a heterogeneous nests distribution due to the light pollution emitted by the hotel on the 2008-2014 period. The frequentation of the seagrass meadow by green turtles was assess in 2014 and seems not decrease according to the number of snorkelers. Our results show that human activities and conservation are compatible on condition to establish rules and control human affluence. However, there still is a lack of data available in the literature to assess the impact of underwater turtle observation on their behavior and physiology.

Key words: *Chelonia mydas*, ecotourism, nesting activities, light pollution, seagrass meadow

1. Introduction

Marine ecosystems are strongly affected by human activities: overexploitation of resources, bycatch, pollution, climate change, invasive species and coastal development disturb ecosystems equilibrium and affect species (Halpern et al. 2008). The Marine Living Planet Index shows that marine species had decreased by 22% between 1970 and 2008, with a fall of 60% in tropical ecosystems. This index is based on the trend of 2395 populations of 675 vertebrate species as fishes, birds, turtles and mammals (WWF 2012).

The IUCN classify the green turtle as endangered and list the main threats faced by the species (IUCN 2013): harvest of eggs, harvest of juveniles/adults on nesting beaches and foraging grounds, by catch (Robins 1995, Pandav et al. 1997, Hays et al. 2003), marine debris ingestion (Lutz 1990, Bugoni et al. 2001), habitat degradation and light pollution (Witherington and Martin 2000, CT ONCFS 2008, Claro and Bardonnet 2011, Kamrowski et al. 2012). Green turtles do not use the same areas to feed and reproduce and these ones are usually distant. Adults migrate between their feeding and nesting areas, and are not feeding during their entire period of reproduction. This characteristic of their life cycle makes them difficult to protect at a regional scale (Bourjea et al. 2013).

In order to preserve sensitive sites for biodiversity, protected areas were created all around the world (IUCN and UNEP 2010). The benefits of protected areas to protect biodiversity had been shown by numerous studies (Halpern and Warner 2002, Gell and Roberts 2003, Claudet et al. 2006). Threats encountered by sea turtles as poaching, light pollution or habitat degradation can be reduced and some stocks can be restored by protecting nesting and feeding areas (Chaloupka et al. 2008). However, the attraction of natural areas increases when they become protected. Ecotourism, which is a form of tourism that is usually wildlife based and careful of the environment (Weaver 2001), can contribute to conservation in these areas. The economic and educational benefits of ecotourism had been shown (Wight 1993, Tisdell and Wilson 2000a, Tisdell and Wilson 2000b), but it may result in ecosystem degradation and wildlife disturbance too (Milazzo et al. 2002).

For green turtle, tourists can disturb nesting turtles (Arianoutsou 1988, Jacobson and Lopez 1994), degrade seagrass meadows (Short and Wyllie-Echeverria 1996) or induced a change of feeding and resting behaviour (Balazs et al. 1987, Balazs et al. 1996, Meadows 2004). Nesting turtles can be disturbed by the use of flashlights, tourists who are too close or who touch them and movements by tourists near nests. A turtle arriving from the sea can stop and turn around if there are people walking on the beach (Jacobson and Lopez 1994). It is therefore important to follow rules of approach.

Mayotte, with 130 nesting beaches and extensive seagrass meadows (Loricourt 2005, Quillard 2012), is an important nesting and feeding site for green turtle in the Indian Ocean (Bourjea et al. 2007, Roos et al. 2007, Ballorain et al. 2010, Philippe et al. 2014). The major habitats are monitored and protected but the pressure on coastal ecosystem increases with urbanization, population growth and tourism development (Ballorain and Nivert 2009). With 570 inhabitants/km² the population quadrupled in 30 years (Insee 2009) and tourism increased by 38% between 2008 and 2013 (Insee 2014).

Protected since 2001, the bay of N'Gouja is an important habitat for two green turtle populations: a nesting population and a feeding population (Ballorain et al. 2010, PAGE-N'Gouja 2012). The reputation of the site, famous for its turtles and lemurs, as well as a hotel located behind the beach, make it one of the most attractive beach of the island for residents and tourists, especially on week-ends and holidays. The hotel is well involved in the conservation of marine turtles and cooperate with research organizations.

The aim of this study is to assess the impact of human activities at the N'Gouja site on the nesting and feeding green turtles distribution, in a management purpose. For this, we first assess the frequentation of the beach by turtles over the last ten years and their nesting success. We also evaluate the impact of the light pollution on nests distribution. Our results will allow us to determine if the activities proposed by the hotel are compatible with a nesting activity and if the management measures are sufficient. If not our results will enable us to target the management efforts.

Finally, we assess the frequentation of the seagrass meadow by green turtles according to the number of snorkelers. This will give us a first approach to determine if the observation of the turtles on their foraging ground have to be more controlled or if the maximum capacity of the site to the public is reached. Moreover, an expansion project of the hotel being in the permit procedure, the results of this study will be used as an initial point in order to compare the disturbance level of the hotel on turtles before and after its expansion.

2. Materials and methods

2.1. Study site

This study was conducted in the bay of N'Gouja, located on the southern coast of Mayotte Island (12°58'S, 45°05'E, Comoros Archipelago, South Western Indian Ocean, SWIO), (**Fig. 1**).

N'Gouja is a protected area since 2001. The studied part of the site is an important nesting and feeding site for green turtle with a 700m beach and a 13ha multispecific seagrass meadow. There are two different green turtle populations on the site: one feeding on the seagrass meadow and one nesting on the beach. The feeding population is formed by both immature and mature green turtles.

A hotel "le Jardin Maoré" is implanted close to the beach. It can host 50 people in 18 bungalows, well integrated in the backshore. The beach is attractive for residents and tourists, especially on week-end and holidays. The hotel is well involved in the conservation of marine turtles as it try to subdue its lights sources, maintains information signs and offers brochures about turtles biology and preservation. An eco-guide, based at the hotel, informs and educates the users of the site and supervises the guests to see nesting turtles.

2.2. Impact of human activities on reproduction of green turtles

2.2.1 Impact of tourism on frequentation of the beach by sea turtles

Turtle tracks were counted on the beach from July 2003 to June 2014. For each pair of tracks found (one track ascending, one descending), it was noticed if the turtle lay successfully or not. From 2008, each nest position was recorded with a GPS (Global Positioning System, Garmin etrex10, ±3m). To assess the frequentation of the beach by the turtles, a frequentation level, expressed as the ratio "number of pairs of tracks" (Nt) on "monitoring effort in days", was calculated by month.

The nesting success (Ns) is a percentage calculated as the ratio between the number of nests observed (Nn) and Nt:

$$\mathbf{Ns = Nn/Nt*100}$$

As the monitoring effort differs between years, only the months when the effort was superior to 75% (23-24 days) were taken into account to calculate Ns.

2.2.2 Impact of light pollution on nests distribution

Two sectors were defined according to the light pollution on the beach: the sector “H” in front of the hotel and the sector “NH” where there is no artificial light. In 2014, each artificial light source visible from the beach by the observer was described in order to identify which ones have the most impact. GPS position, light intensity, distance to the vegetation limit, use duration and color of each light source were noted and used to attribute a score to each one following a grading scale (**Appendix 1**). In July 2014, the light sources in use were identified at 20h30 and 4h30 during one week and the mean use duration per night and per light was calculated.

2.3 Impact of tourism on frequentation of the seagrass meadow by green turtles

2.3.1 Evolution of the abundance and the distribution of green turtles on the seagrass meadow

Between January and June 2014, feeding turtles were counted by snorkeling on a defined route on the seagrass meadow (**Fig.1**). Turtles are habituated to humans and do not move as long as the snorkeler does not approach too close, what made these censuses possible. For each turtle encountered, its size class and its GPS position were noted. The size class was defined by three categories, depending of the curved carapace length (CCL): adults “A” (>80cm), juveniles “J” (45cm to 80cm) and young juveniles “N” (< 45cm). When the carapace length was not obvious, the turtle was measured.

The water visibility was estimated in three points at the beginning and at the end of each census respectively **(Fig.1)** using a horizontal tape measure, held perpendicular to the route taken over the seagrass meadow. The mean water visibility was used to estimate the surface covered by census and to calculate the number of turtles encountered per m^2.

The seagrass meadow was divided in three sectors **(Fig.1)**: the first 50m of the seagrass meadow, the next 50m (between 50m and 100m) and the rest (from 100m to 180m).

2.3.2 Evolution of the public frequentation

From September 2013 to June 2014, people on the site were counted every day at 11a.m., 3pm. and after each snorkeling census. The days were separated in two categories: “week-ends” (= Saturday, Sunday and bank holiday) and “week” (all the others days). To assess the percentage of people who could have an impact on feeding turtles, 450 of them were asked for their swimming habits between January and May 2014: if they stay on the beach, if they just swim near the beach or if they go everywhere on the seagrass meadow.

2.4 Data analyses

Quantum GIS software (QGIS) was used for nest and light pollution cartography and for GPS data analyzes.

Statistical analyses were conducted using R 3.0.2 software and significance was accepted when p-value < 0.05. Before conducting parametric analysis, all data were tested for normality and heteroscedasticity by means of Shapiro-Wilk and Breusch-Pagan tests, respectively. Values are mean ± SD.

ANOVA or Kruskal-wallis test (associated with Siegel-Castellan posthoc test) were used to assess if we have differences in frequentation level of the beach by the turtles and in Ns between months, and years.

Location of the nests was tested for random distribution with a Chi² test. The longitude increases regularly along the beach and were used as a quantitative variable to summarize the location of the nests. Chi² test was also used to compare the nests distribution between H and NH sectors. Bonferroni confidence intervals were calculated following the method developed by Neu et al. (1974) to identify which sectors are preferred or avoided by turtles.

To assess if there is a relationship between the number of people and the frequentation of the seagrass meadow by turtles, linear regressions (LM) were used. Frequentation of the seagrass meadows by green turtles is expressed as a number of turtles per m². When autocorrelation was found in residuals, a linear model using Generalized Least Squares (GLS) was used instead of linear regression. When the residuals of the linear regression were not normally distributed, Spearman correlation was used to assess if the number of people and the number of turtles per m² are correlated.

3. Results

3.1. Impact of human activities on reproduction of green turtles

3.1.1. Impact of tourism on frequentation of the beach by sea turtles

From July 2003 to June 2014, no significant differences in frequentation level of the beach by green turtles were found between years (Kruskal-Wallis chi-squared = 11.23, $p > 0.05$, n=12 years). However if we focus by month, ANOVA showed that we have differences between years in April (ANOVA, F= 19.77, $p<0.01$, n=11 years), May (ANOVA, F=7.14, $p<0.05$, n=10 years) and December (ANOVA, F=6.21, $p<0.05$, n=8 years) (**Fig. 2**).

We had a significant difference in frequentation level of the beach by green turtles between months (Kruskal-Wallis chi-squared = 67.61, $p <0.001$, n=110 months), with higher level in April (different from December, t = 3.38, $p<0.05$), May (different from September to January, $p<0.05$), June (different from September to February, $p<0.05$) and July (different from November and December, $p<0.05$).

For the nesting success Ns, no significant differences were found between years (Kruskal-Wallis chi-squared = 7.69, $p > 0.05$, n= 12 years) or months (Kruskal-Wallis chi-squared = 11.41, $p > 0.05$, n=89 months) (**Fig. 2**). By taking into account the years with an observation effort > 274 days (n =4 years), we estimated an average Ns of 42.7± 4.4 % with a minimum of 41.1± 20.5 % and a maximum of 45.8± 27.3 % in 2008 and 2007 respectively (**Table 1**).

3.1.2. Impact of light pollution on nests distribution

Between 2008 and 2014, the nests distribution on the beach did not follow a random distribution (X-squared = 613.48, df = 11, $p < 0.001$, n=620 nests) and this is true for each year of the period (**Fig. 3**).

The study of the spatial distribution of the nests on the beach showed that, in the 2008-2014 period, turtles laid more in the NH sector than in the H sector (X-squared = 231.63, $p < 0.001$, n=602 nests) and this is true for each year of the period (**Table 2**). The Bonferroni intervals showed that the H sector is used less than would be expected by chance and this, in any year of the study period (**Table 2**).

These results are accentuated by the comparison between the light location and the nests location. **Fig. 3** shows than since 2008, there were significantly more nests in the dark side of the beach than front of the hotel. All the lights sources visible from the beach are represented on the map in **Appendix 2**.

3.2. Impact of tourism on frequentation of the seagrass meadow by green turtles

The average public frequentation of N'Gouja is 50 ±36 people at 11a.m. (n=263 days) and 122 ±99 people at 3 p.m. (n=259 days), week and week-end combined. There were 25±17 people on the beach at 11a.m (n=134 days) and 52 ±29 at 3p.m (n=129 days) during the week. On week-ends, these numbers rose to 75 ±43 people at 11a.m (n=129 days) and 192 ±97 at 3p.m (n=130 days) (**Fig. 4**). The maximum frequentation of the site was 458 people at 3p.m. on Sunday afternoon.

On the 450 people asked, 2% stay on the beach, 98% swim in the first meters and 79% swim everywhere on the seagrass meadow.

To investigate the possible effect of tourism on the feeding green turtles, the number of tourists on the site and the total number of turtles feeding on the seagrass meadow were compared using GLS regression analysis and no significant relationship was found (**Table 3**, Phi=0.53, $p > 0.05$, n=28 censuses). No link was found neither when comparing these two variables by zone with linear regression analysis (zone 0-30m: $F_{1,26}=0.55$, $r^2=0.02$, $p > 0.05$, n=28 censuses). When focusing on young juveniles N, no significant relationship was found between the number of tourists and the number of feeding N (LM, $F_{1,26}=0.13$, $r^2=0.01$, $p > 0.05$, n=28 censuses) and this, in any of our three zones 0-30m (LM, $F_{1,26}=0.10$, $r^2=0.004$, $p > 0.05$,n=28 censuses), 30-150m (LM, $F_{1,26}=0.15$, $r^2=0.01$, $p > 0.05$, n=28 censuses) and 150-180m (Spearman correlation, S=2651.1, rho=0.27, $p > 0.05$, n=28 censuses). We obtained the same results when focusing on juveniles J and adults A (**Table 3**).

4. Discussion

4.1. Impact of human activities on reproduction of green turtles

4.1.1. Impact of tourism on frequentation of the beach by sea turtles

At N'Gouja, nesting occurs all year round, with a peak from April to July. These results are similar to these obtained by Bourjea et al. (2007) on Saziley beaches, one of the major nesting site of the island. The frequentation level of the beach by the turtles stayed constant over the 12 years study period, even during the high tourist season that is school holidays and austral winter months.

If the environment is not favorable (roots, rocks, etc.) or if they are disturbed, turtles can return to the sea before the lay and re-emerge the next night (Miller et al. 2003). The proportion of successful nests is represented by the nesting success Ns. If turtles are disturbed during the nest procedure, Ns will reduce.

To the best of our knowledge, there are very few studies about the nesting success at a population scale (Godley et al. 2001, Garnier et al. 2012, Petit et al. 2012). In these studies nesting success values are 33 ±8 % (n= 25 beaches, ~ 1 year of study) at Ascension Island (Godley et al. 2001) and 37.7 ±7.14 % (5 years of study) at Tetiaroa atoll, Society Islands (Petit et al. 2012). In the Indian Ocean, Ns values of 42 ±4.12 % and 75% were measured respectively at Moheli (7 years of study, Ciccione S et al. unpublished data) and Vamizi Island (5 year of study, Garnier at al. 2012). These results are close to the value of 42.72 ±4.41 obtained in this study. The variations between these studies can be explained by the differences of climate, sand type and data collection season and duration between the sampling areas (Limpus et al. 2003).

Tourism seems to be compatible with a nesting activity. This can be explained by the fact that at N'gouja, except the guests of the hotel, almost nobody walks on the beach at night. Guests are alert to wear dark clothes, to do not use light when they walk on the beach and are supervised to see the lay. On average there is 4 or 5 people including the eco-guide walking on the beach during one hour near the high tide. Walks are not organized all nights, especially in low tourist season. People not staying at the hotel are few and at least in 2013-2014, were aware by the eco-guide. However the presence of an eco-guide on the site is not continuous and data are not available for the absence periods.

Jacobson and Lopez (1994) show that even in an ecotouristic way, turtle watching can be disturbing for nesting turtles if there are too large groups walking on the beach or people too close of the turtles. This does not seem to occur at N'Gouja yet, but with the tourism development and the hotel expansion, it will be important to keep the presence of an eco-guide and to control the public frequentation at night.

4.1.2. Impact of light pollution on nests distribution

Numerous studies showed that light pollution has a negative effect on sea turtle reproduction, breeding females avoiding illuminated beaches (Witherington and Martin 2000, Salmon 2003, CT ONCFS 2008, Magyar 2009, Claro and Bardonnet 2011, France G.T.M. 2011, Kamrowski et al. 2012).

This study is no exception and aims to assess the current situation in order to improve the light pollution management. Our results on turtles frequentation level and nesting success suggest that human activities are compatible with turtle nesting activity. However the light pollution impact is clearly visible as nests distribution is not homogenous. Turtles laid more in the dark side of the beach. The ends of the beach are less adapted to a nesting activity as they are immerged at high tide and as the sand thikness is inadequate. For this reason and because the hotel stretches on a large part of the beach, only 33% of the beach linear is ideal for a nesting activity. This can induce several issues: choice of an inappropriate nesting site (Worth and Smith 1976), increase of the probability that a turtle destroys an existing nest (Witherington and Martin 200), and predator concentration near nesting sites (Harewood and Horrocks 2008). This is all the more important as light pollution increases mortality (predation, exhaustion, dehydration) of hatchling turtles by modifying sea-finding behavior (Tuxbury and Salmon 2005, Bourgeois et al. 2009, Karnad et al. 2009). At N'Gouja, the author found several times disoriented hatchlings near the light sources.

The hotel installed covers to subdue several light sources but following our results this is not sufficient. Several light sources have a particularly strong impact, especially those at the edge of the beach and the restaurant. Light pollution could be managed by reducing the lights use duration, installing a ground lighting with more effective covers, plant a vegetation screen, change light bulb to ones adapted to turtles, etc. Witherington and Martin (2000) suggest a large variety of ways to reduced light pollution. In the hotel expansion context, the most important is to not increase the polluted area.

However, it should be noted that light pollution has been evaluated only in 2014 and we have no data about the light pollution level before this date. This evaluation, conduct on a very short period of time (one week), might be not representative of the light pollution level at a year scale, leading to a possible over- or underestimation of the use duration.

Other factors than light pollution could explain the nests distribution. For example, several physical and chemical factors, such as sand grain size, dune configuration, sand temperature and olfaction have been suggested as potential cues that could stimulate nest site selection (Carr et al. 1966, Stoneburner and Richardson 1981).

4.2. Impact of tourism on frequentation of the seagrass meadow by green turtles

Informations about the possible effect of snorkelers' interactions with feeding turtles are spares (Meadows 2004, Landry and Taggart 2010). In Hawaii, Balazs et al. (1987) noted a decline in turtle sightings due to the presence of fishermen but later, the same author reported a change in green turtles behavior which became more tolerant to humans (Balazs 1996).

At N'Gouja, turtles are tolerant to the presence of humans at reasonable distance but not to the attempts by snorkelers to chase, touch, and ride them. The distribution of the turtles on the seagrass meadows depends of their class size. The young juveniles seem to feed mainly close to the beach, the juveniles everywhere and the adults mainly near the reef (Ballorain et al. 2010). Therefore we could think that we would get different degrees of human impact on the feeding turtles according to the size class of the turtle and of its location on the foraging ground. In this way, young juveniles should be the most impacted, as swimmers are more concentrated in their principal foraging area and as they are younger, so less habituated to humans. Following our results, this is not the case.

However, the touristic affluence counted in parallel with our turtles censuses (average of 79 people with maximum of 246 people) is far from the maximal affluence observed on the site during our study (458 people, Sunday 3p.m.) and far also from the maximal affluence observed at N'Gouja (490 people, Sunday 3p.m., Page-N'Gouja 2012). It would be interesting to have the distribution of people on the seagrass meadow in addition to their number, especially as everybody do not swim at the same time. Moreover our censuses were carried out when the seagrass meadow was immerged to have most of the turtles feeding. At this time, people had not a maximal impact as they could not walk everywhere. Last, our results are based on 28 censuses, which is not enough to assess a general trend.

Even if no significant relationship was found between the number of people and the number of feeding turtles, human impact on feeding turtles goes beyond the variables studied here. It would be interesting to study individual parameters. Meadows (2004) noted that turtles switch behavior more often in presence of snorkelers. Changes in behavior could cause alteration of feeding success by wasting energy and reducing the feeding duration. Factors as growth rate or fitness could be reduced. Human disturbances might also cause stress or physiological changes as it was measured for marine mammals and stingrays (Landry and Taggart 2010).

Greater interest and appreciation of marine coastal areas results in a rapid expansion of tourism (Badalamenti et al. 2000, Wilkinson 2004) as is the case in Mayotte, increasing disturbance of the ecosystems as turtles habitats. Poorly managed, human can disturb wildlife but can degrade ecosystems as well. Others major threats on protected turtles habitats are nest trampling, water pollution by cosmetics and seagrass meadow degradations. Nest trampling can compact the sand and makes it difficult to dig for the hatchling or can activate the emergence (Arianoutsou 1988). The impact of cosmetics on seagrass had not been evaluated yet, but several studies reported that they impact marine bacterioplankton and coral reefs (Danovaro and Corinaldesi 2003, Danovaro et al. 2008). Seagrass meadows can be degraded by boats anchorage (Creed et al. 1999, Francour et al. 1999, Milazzo et al. 2004) and human trampling (Eckrich et Holmquist 2000, Milazzo et al. 2002), decreasing seagrass density and diversity and affecting associated fauna.

However, as we saw in this study, human activities and conservation are compatible on condition to establish rules and control human affluence. There still is a lack of data available in the literature to assess the impact of underwater turtle observation. Studies like this one have to be completed to better understand the potential impact of human activities in marine protected areas and improve their management.

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References

Arianoutsou, M. 1988. Assessing the impacts of human activities on nesting of loggerhead sea-turtles (*Caretta caretta L.*) on Zakynthos Island, Western Greece. Environmental Conservation, 15(04), 327-334.

Badalamenti, F., Ramos, A. A., Voultsiadou, E., Sánchez Lizaso, J. L., D'Anna, G., Pipitone, C., Mas, J., Ruiz Fernandez, J.A., Whitmarsh, D., Riggio, S. 2000. Cultural and socio-economic impacts of Mediterranean marine protected areas. Environmental Conservation, 27(02), 110-125.

Balazs, G.H, Forsyth R., Kam A. 1987. Preliminary assessment of habitat utilization by Hawaii green turtles in their resident foraging pastures. NOAA Technical memorandum, NOAA-TMNMFS-SWFC-71

Balazs, G.H. 1996. Behavioral changes within the recovering Hawaiian green turtle population. In: J.A. Keinath, D.E. Barnard, J.A. Musick, & B.A. Bell (compilers). Proceedings of the 15th Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFSC-387. pp. 16-20.

Ballorain K. and Nivert N. 2009. L'évolution statutaire de Mayotte et les enjeux environnementaux : l'exemple de la protection des tortues marines. Revue Juridique de l'Océan Indien 9 :107-135

Ballorain, K. 2010. Ecologie trophique de la tortue verte *Chelonia mydas* dans les herbiers marins et algueraies du sud-ouest de l'océan Indien. Thèse de Doctorat, Université de La Réunion, CNRS-IPHC, Kélonia, Ifremer.

Ballorain K., Ciccione S., Bourjea J., Grizel H., Enstipp M., Georges J.Y. 2010. Habitat use of a multispecific seagrass meadow by green turtles *Chelonia mydas* at Mayotte Island. Marine Biology, vol. 157, Issue 12:2581–2590

Ballorain K., Bourjea J., Ciccione S., Grizel H., Enstipp M., Georges J.Y. 2011. 4- Early assessement of trends in a multispecific seagrass meadow exploited by green turtles at Mayotte Island. *In :* Ecologie trophique de la tortue verte *Chelonia mydas* dans les herbiers marins et algueraies du sud-ouest de l'océan Indien. Thèse de Doctorat, Université de La Réunion, CNRS-IPHC, Kélonia, Ifremer. p.71

Bourgeois, S., Gilot-Fromont, E., Viallefont, A., Boussamba, F., Deem, S. L. 2009. Influence of artificial lights, logs and erosion on leatherback sea turtle hatchling orientation at Pongara National Park, Gabon. Biological Conservation, 142(1), 85-93.

Bourjea J., Frappier J, Quillard M., Ciccione S., Roos D., Hughes G., Grizel H. 2007. Mayotte Island: another important green turtle nesting site in the southwest Indian Ocean. Endangered Species Research Vol. 3, p. 273-282

Bourjea J., Ciccione S., Dalleau M. 2013. DYMITILE - Dynamique migratoire des tortues marines nidifiant dans les iles françaises de l'Ocean indien. Rapport final Phase I et II. Ifremer, RST-DOI/2013-02, 55 p.

Bugoni, L., Krause, L.,Virgínia Petry, M. 2001. Marine debris and human impacts on sea turtles in southern Brazil. Marine Pollution Bulletin, 42(12), 1330-1334.

Carr, A., H. Hirth , L. Ogren. 1966. The ecology and migrations of sea turtles, 5. The hawksbill turtle in the Caribbean Sea. Amer. Mus. Nov. 2248

Chaloupka, M., Bjorndal, K. A., Balazs, G. H., Bolten, A. B., Ehrhart, L. M., Limpus, C. J., ... Yamaguchi, M. 2008. Encouraging outlook for recovery of a once severely exploited marine megaherbivore. Global Ecology and Biogeography, 17(2), 297-304.

Ciccione S, Taquet M., Roos D., Taquet C., Ballorain K. 2003. Assistance à la DAF de Mayotte pour l'encadrement scientifique et la formation des agents sur les programmes d'études et de conservations des tortues marines et de leurs habitats à Mayotte. Rapport de mission CEDTM/IFREMER.

Claro F. and Bardonnet C. 2011. Les tortues marines et la pollution lumineuse sur le territoire française. Rapport GTMF-SPN 2. MNHN-SPN, Paris, 40p.

Collen, B., Loh, J., Whitmee, S., McRAE, L., Amin, R., Baillie, J. E. 2009. Monitoring change in vertebrate abundance: the Living Planet Index. Conservation Biology, 23(2), 317-327.

Creed, J. C., Amado Filho, G. M. 1999. Disturbance and recovery of the macroflora of a seagrass (Halodule wrightii Ascherson) meadow in the Abrolhos Marine National Park, Brazil: an experimental evaluation of anchor damage. Journal of Experimental Marine Biology and Ecology, 235(2), 285-306.

CT ONCFS 2008. Caractérisation des pollutions lumineuses sur les sites de nidification des tortues marines de la Martinique. Propositions de mesures de gestion. Rapport technique ONCFS 2008. CT Martinique. DROM

Danovaro R, Bongiorni L, Corinaldesi C, Giovannelli D, Damiani E, Astolfi P, Greci L, Pusceddu A 2008 Sunscreens Cause Coral Bleaching by Promoting Viral Infections. Environ Health Perspect. 116:441–447.

Danovaro R. and C. Corinaldesi, 2003 Sunscreen products increase virus production through prophage induction in marine bacterioplankton, Microb. Ecol., 45, 109–118.

Eckrich, C. E., Holmquist, J. G. 2000. Trampling in a seagrass assemblage: direct effects, response of associated fauna, and the role of substrate characteristics. Marine ecology. Progress series, 201, 199-209

France, G.T M. 2011. Les tortues marines et la pollution lumineuse sur le territoire français.

Francour, P., Ganteaume, A., & Poulain, M. 1999. Effects of boat anchoring in Posidonia oceanica seagrass beds in the Port-Cros National Park (north-western Mediterranean Sea). Aquatic Conservation: Marine and Freshwater Ecosystems, 9(4), 391-400.

Godley, B. J., Broderick, A. C., & Hays, G. C. 2001. Nesting of green turtles (*Chelonia mydas*) at Ascension Island, South Atlantic. Biological Conservation, 97(2), 151-158.

Halpern, B. S., Walbridge, S., Selkoe, K. A., Kappel, C. V., Micheli, F., D'Agrosa, C.Watson, R. 2008. A global map of human impact on marine ecosystems. Science, 319(5865), 948-952.

Harewood, A., & Horrocks, J. 2008. Impacts of coastal development on hawksbill hatchling survival and swimming success during the initial offshore migration. Biological Conservation, 141(2), 394-401.

Hays G., C., Broderick A., C., Godley B., J., Luschi, P., Nichols, W., J. 2003. Satellite telemetry suggests high levels of fishing-induced mortality in marine turtles. Mar Ecol Prog Ser. Vol. 262: 305–309

Insee 2009. Mayotte : Recensement de la population de 2007. Insee Première N° 1231

Insee 2014. Enquête flux touristique à Mayotte en 2013. Insee Mayotte Infos. N°77

IUCN 2013. IUCN Red List of Threatened Species. Version 2013.2. <www.iucnredlist.org>. Downloaded on 19 January 2014

IUCN and UNEP. 2010. The World Database on Protected Areas (WDPA). UNEP-WCMC. Cambridge, UK. <www.protectedplanet.net> Downloaded on 19 January 2014

Jacobson S., K., and Lopez A., F. 1994. Biological Impacts of Ecotourism: Tourists and Nesting Turtles in Tortuguero National Park,Costa Rica. Wildlife Society Bulletin, Vol. 22, No. 3, pp. 414-419

Kamrowski, R., L., Limpus, C., Moloney, J., Hamann, M. 2012. Coastal light pollution and marine turtles: assessing the magnitude of the problem. Endang Species Res Vol. 19: 85–98

Karnad, D., Isvaran, K., Kar, C. S., & Shanker, K. 2009. Lighting the way: Towards reducing misorientation of olive ridley hatchlings due to artificial lighting at Rushikulya, India. Biological Conservation, 142(10), 2083-2088.

Landry, M. S., Taggart, C. T. 2010. “Turtle watching” conservation guidelines: green turtle (Chelonia mydas) tourism in nearshore coastal environments. Biodiversity and conservation, 19(1), 305-312.

Limpus, C. J., Miller, J. D., Parmenter, C. J., & Limpus, D. J. 2003. The green turtle, Chelonia mydas, population of Raine Island and the northern Great Barrier Reef: 1843-2001. Memoirs-Queensland Museum, 49(1), 349-440.

Loh, J., R.E., Green, Ricketts, T., Lamoreux, J., Jenkins, M., Kapos, V., Randers, J. 2005. The Living Planet Index: using species population time series to track trends in biodiversity. Philosophical Transactions of the Royal Society B: Biological Sciences, 360(1454), 289-295.

Loricourt, A. 2005. Etude des herbiers à Phanérogames marines de Mayotte. Rapport de Master 2, Université de La Réunion, Kelonia, DAF-Mayotte.

Lutz, P., L. 1990. Studies on the ingestion of plastic and latex by sea turtles. In Proc. Int. Conf. Marine Debris. Eds. RS Shomura & ML Godfrey. NOAA-TM-154 pp. 719-735.

Magyar T. 2009. The impact of artificial lights and anthropogenic noise on Loggerheads (Caretta caretta) and Green Turtles (Chelonia mydas), assessed at index nesting beaches in Turkey and Mexico. Thèse de doctorat. Universitäts-und Landesbibliothek Bonn.

Meadows D. 2004. Behavior of green sea turtles in the presence and absence of recreational snorkellers. Mar Turt Newsl 103:1–4

Milazzo, M., Chemello, R., Badalamenti, F., Camarda, R., Riggio, S. 2002. The impact of human recreational activities in marine protected areas: what lessons should be learnt in the Mediterranean sea? Marine ecology, 23(s1), 280-290.

Milazzo, M., Badalamenti, F., Ceccherelli, G., Chemello, R. 2004. Boat anchoring on Posidonia oceanicabeds in a marine protected area (Italy, western Mediterranean): effect of anchor types in different anchoring stages. Journal of Experimental Marine Biology and Ecology, 299(1), 51-62.

Miller, J. D., Limpus, C. J., & Godfrey, M. H. 2003. Nest site selection, oviposition, eggs, development, hatching, and emergence of loggerhead turtles. Loggerhead sea turtles, 125-143.

Neu, C.W., Byers, C.R., Peek, J.M. 1974. A Technique for Analysis of Utilization-Availability Data. The Journal of Wildlife Management, Vol. 38, No. 3., pp. 541-545.

PAGE-N'Gouja (Ballorain K coord.) 2012. Programme Actions en faveur d'une Gestion Eco-intégrée du site naturel remarquable de N'Gouja – Version 1.3. CARA ecology.

Pandav, B., Choudhury, B.,C, Kar C.,S. 1997. Mortality of Olive Ridley turtles *Lepidochelys olivacea* due to incidental capture in fishing nets along the Orissa coast, India. Oryx 31:32–36

Petit M., Gaspar C., Besson M., Bignon F., 2012. Suivi des pontes de tortues vertes sur l'atoll de Tetiaroa (saison 2011-2012) et évaluation des populations de tortues marines sur la pente externe de Moorea. Te mana o te moana.

Philippe JS., Ciccione S., Bourjea J., Ballorain K., Marinesque S., Glenard Z. 2014. Plan national d'actions en faveur des tortues marines des territoires français de l'océan Indien : La Réunion, Mayotte et îles Eparses (2015-2020). Ministère de l'Ecologie, du Développement durable et de l'Energie, Direction de l'Environnement, de l'Aménagement et du Logement de La Réunion. Biotope, Kelonia, Ifremer, Parc naturel marin de Mayotte /AAMP, Taaf, Phaeton Traduction. 4 volumes, 403 p.

Quillard, M. 2012. Observatoire des tortues marines : rapport d'activités 2010 – août 2011. Conseil Général de Mayotte / DEDD / SPN/ Observatoire des tortues marines

Robins J.B. 1995. Estimated catch and mortality of sea turtles from the east coast otter trawl fishery of Queensland, Australia. Biol Conserv 74:157–167

Roos D., Pelletier D., Ciccione S., Taquet M., Hughes G. 2007. Aerial and snorkelling Census Techniques (observations) for estimating green turtle abundance on foraging areas: a pilot study in Mayotte Island (Indian Ocean). Aquatic Living Resources, 18, p. 193-198

Salmon, M. 2003. Artificial night lighting and sea turtles. Biologist, 50(4), 163-168.

Seminoff J.A, Jones T.T, Resendiz A, Nichols W.J, Chaloupka M.Y. 2003. Monitoring green turtles (*Chelonia mydas*) at a coastal foraging area in Baja California, Mexico: multiple indices to describe population status. J Mar Biol Assoc UK 83:1355–1362

Short F.T and Wyllie-Echeverria S. 1996. Natural and human-induced disturbance of seagrasses. Environmental Conservation 23 (1): 17-2

Taquet, C., Taquet, M., Dempster, T., Soria, M., Ciccione, S., Roos, D., Dagorn, L. 2006. Foraging of the green sea turtle Chelonia mydas on seagrass beds at Mayotte Island (Indian Ocean), determined by acoustic transmitters. Marine Ecology Progress Series, 306, 295-302.

Tisdell C.A. and Wilson C. 2000a. Wildlife-based tourism and increased support for nature conservation financially and otherwise: evidence form sea turtle ecotourism at Mon Repos. Economic, Ecology and the Environment, Working Paper No. 54. Department of Economics, The University of Queensland, Brisbane, Australia.

Tisdell C.A. and Wilson C. 2000b. Environmental education and ecotourism: a study of turtle-watching. Economics, Ecology and Environment, Working Paper No. 55. Department of Economics, The University of Queensland, Brisbane, Australia.

Tuxbury, S. M., and Salmon, M. 2005. Competitive interactions between artificial lighting and natural cues during seafinding by hatchling marine turtles. Biological Conservation, 121(2), 311-316.

Weaver D.B. 2001. Ecotourism in the context of other tourism types. In: Weaver B. (ed.), The Encyclopaedia of Ecotourism. CABI Publishing, Wallingford, UK, pp. 73–83.

Wight P. 1993. Sustainable tourism: balancing economic environmental and social goals within an ethical

framework. Journal of Tourism Studies 4: 54–66.

Wilkinson C. 2004 Status of Coral Reefs of the World: 2004. Townsville, Australia: Australian Institute for Marine Science

Witherington, B., E, and Martin R., E. 2000. Understanding, assessing, and resolving light-pollution problems on sea turtle nesting beaches. 2nd ed. rev. Florida Marine Research Institute Technical ReportTR-2. 73 p.

Worth, D. F., and J. B. Smith. 1976. Marine turtle nesting on Hutchinson Island, Florida, in 1973. Florida. Marine Research Publication 18:1-17.

WWF. 2012. Rapport Planète Vivante 2012. WWF International, Gland, Suisse.

List of Figures

Fig.1: Map of the study site in the N'Gouja Bay. The track for snorkelling turtle censuses is indicated by the white line. The six points where the water visibility was measured are indicated by cross symbol. The seagrass meadow was divided in three sectors delimited by the black lines: the first 50m of the seagrass meadow (1), 50m to 100m (2) and 100m to 180m (3). Insert: (a) Geographic position of Mayotte in the SWIO; (b) Geographic position of N'Gouja in the south of Mayotte as indicated by the circle.

Fig. 2: **(a)** Green turtles frequentation level and ANOVA results on N'Gouja beach between June 2003 and July 2014, expressed by the ratio number of tracks/monitoring effort. Months where effort was < 7days were removed (n=110 months, in yellow: no data) **(b)** Nesting success of green turtles on the N'Gouja beach between July 2003 and June 2014. The nesting success (Ns) is a percentage calculated as the ratio between the number of nests observed (Nn) and the number of tracks observed (Nt): *Ns = Nn/Nt*100*. Only the months with a monitoring effort > 75% were taken into account (n=89 months, in yellow: no data). **(c)** Average nesting success by year between 2003 and 2014. The data labels correspond to the monitoring effort in months. Only the months with a monitoring effort > 75% were taken into account (n=89 months).

Fig. 3: Location of nests and light sources on N'Gouja beach respectively from 2008 to 2014 and in 2014. The green line represents the limit between H (inhabited) and NH (uninhabited) sectors. The light sources are represented by colored lines graded following their score from yellow to red. The score was calculated following the grading scale presented in **Appendix 1** in 2014. χ^2 tests were used to assess if the nest location follow a random distribution.

Fig. 4: Frequentation of the N'Gouja Beach by public at 11a.m (n= 263 days) and 3p.m (n= 259 days) between September 2013 and June 2014 during the week and on week-ends.

Table 1: Summary of the monitoring (from 2003 to 2014) on N'Gouja beach: number of nests and pairs of tracks counted and the respective equivalent effort in day monitoring. Only the months with a monitoring effort > 75% were taken into account. [1] The uncertain lays were removed from the data set. [2] The nesting success (Ns) is a percentage calculated as the ratio between the number of nests observed (Nn) and the number of tracks observed (Nt): *Ns = Nn/Nt*100*. The values are the average Ns by year and the bold values correspond to a monitoring effort > 75% = 274 days.

Year	Nb of nests	Nb of tracks[1]	Effort (d)	Ns (%) [2]	SD
2003	19	51	56	37,7	4,5
2004	29	57	178	48,6	18,7
2005	58	155	237	37,5	22,2
2006	58	145	133	44,3	20,9
2007	102	229	294	***45,8***	27,3
2008	96	262	366	***41,1***	20,5
2009	67	166	296	***41,5***	19,3
2010	125	340	321	***42,5***	15,6
2011	92	243	239	37,9	6,9
2012	10	25	58	40,0	0,0
2013	50	189	266	33,1	20,8
2014	81	267	181	29,9	7,7
Total	787	2129			
Average				40,0	
				42,7	
SD				5,2	
				4,4	

Table 2: Comparison of the nests distribution on N'Gouja beach by sector (H and NH) between 2008 and 2014 based on Chi² statistics and Bonferroni confidence intervals. [1] We used + for attraction and – for avoidance.

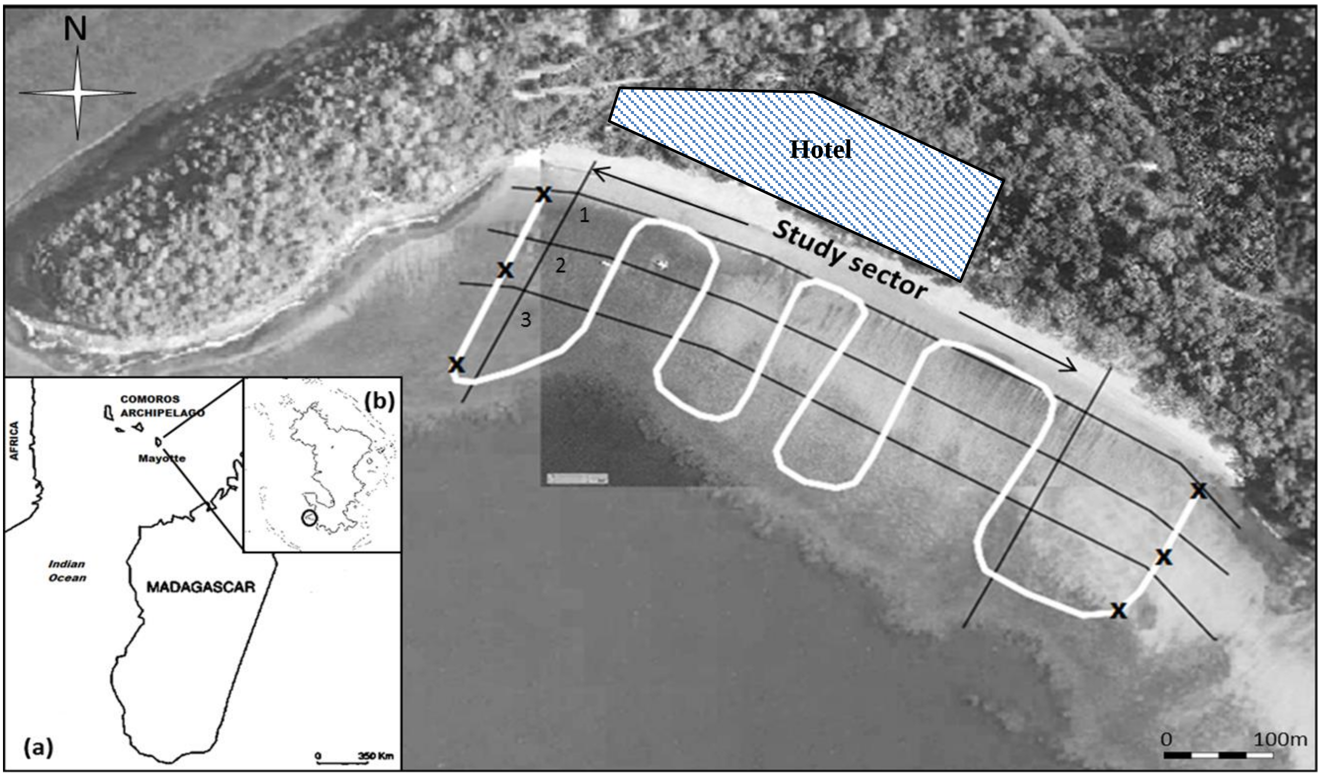
Year	Location	Beach linear length	Proportion of linear (pio)	Nbr of nests observed	Total nbr of nests observed	Nbr of nests expected	Proportion observed in each area (pi)	Bonferroni confidence interval on proportion of occurrence (pi)		Comparative use [1]	Chi²	p-value
2008	**H**	445	0,6357	18	94	60	0,1895	0,0989	0,2800	-	80,1	< 0,001
	NH	255	0,3643	76		35	0,8000	0,7076	0,8924	+		
2009	**H**	445	0,6357	20	70	45	0,2857	0,1648	0,4067	-	37,0	< 0,001
	NH	255	0,3643	50		26	0,7143	0,5933	0,8352	+		
2010	**H**	445	0,6357	42	130	83	0,3231	0,2312	0,4150	-	54,9	< 0,001
	NH	255	0,3643	88		47	0,6769	0,5850	0,7688	+		
2011	**H**	445	0,6357	45	102	65	0,4412	0,3311	0,5513	-	16,7	< 0,001
	NH	255	0,3643	57		37	0,5588	0,4487	0,6689	+		
2012	**H**	445	0,6357	15	42	27	0,3571	0,1915	0,5228	-	14,1	< 0,001
	NH	255	0,3643	27		15	0,6429	0,4772	0,8085	+		
2013	**H**	445	0,6357	25	73	46	0,3425	0,2181	0,4669	-	27,1	< 0,001
	NH	255	0,3643	48		27	0,6575	0,5331	0,7819	+		
2014	**H**	445	0,6357	38	91	58	0,4691	0,3520	0,5863	-	18,7	< 0,001
	NH	255	0,3643	53		33	0,5824	0,4666	0,6982	+		
2008-2014	**H**	445	0,6357	203	602	383	0,3372	0,2940	0,3804	-	231,6	< 0,001
	NH	255	0,3643	399		219	0,6628	0,6196	0,7060	+		

Table 3: Results of linear regression models, generalized least squares models and Spearman correlation tests, performed on 28 censuses (1,143 turtles) at N'Gouja, Mayotte, between January and June 2014. [1] The young juveniles are noted N and have a curved carapace length (CCL) < 45cm, the juveniles are noted J (CCL = 45cm to 80cm) and adults are noted A (CCL > 80cm). [2] The independent variable is the number of tourists. This number was multiplied by 0.79 as we have 79% of the public who swim everywhere on the seagrass-meadow.

Dependant variable [1]			**Linear regression Nb of tourists [3]**			**Generalized least squares Nb of tourists**			**Spearman correlation Nb of tourists**		
	N	**Ddl**	**$F_{1,26}$**	**R^2**	**p**	**Ddl**	**Phi**	**p**	**S**	**rho**	**p**
Total	28	26	-	-	-	28	0.53	>0.5	-	-	-
ln(N total)	28	26	0.126	0.0049	>0.5	-	-	-	-	-	-
J total	28	26	-	-	-	28	0.41	>0.5	-	-	-
ln(A total)	28	26	1.427	0.0520	>0.5	-	-	-	-	-	-
$((\text{Total zone 1})^{\lambda}-1)/\lambda$	28	26	0.548	0.0207	>0.5	-	-	-	-	-	-
ln(Total zone 2)	28	26	0.997	0.0369	>0.5	-	-	-	-	-	-
ln(Total zone 3)	28	26	0.0312	0.0012	>0.5	-	-	-	-	-	-
ln(N zone 1)	28	26	0.103	0.0039	>0.5	-	-	-	-	-	-
N zone 2	28	26	0.150	0.0058	>0.5	-	-	-	-	-	-
N zone 3	28	26	-	-	-	-	-	-	2651.1	0.27	>0.5
J zone 1	28	26	-	-	-	-	-	-	4339.1	-0.19	>0.5
ln(J zone 2)	28	26	0.133	0.0051	>0.5	-	-	-	-	-	-
J zone 3	28	26	0.005	0.0002	>0.5	-	-	-	-	-	-
A zone 1	28	26	-	-	-	-	-	-	4851.3	-0.33	>0.5
A zone 2	28	26	-	-	-	-	-	-	4432.1	-0.21	>0.5
A zone 3	28	26	0.007	0.0003	>0.5	-	-	-	-	-	-

Table 4: Results of the censuses between January 2014 and June 2014 at N'Gouja (N=28). The number of tourists was multiplied by 0.79 as we have 79% of the public who swim everywhere on the seagrass-meadow. [2] The young juveniles are noted N and have a curved carapace length (CCL) < 45cm, the juveniles are noted J (CCL = 45cm to 80cm) and adults are noted A (CCL > 80cm). [3]The seagrass meadow was divided in three sectors: the first 30m of the seagrass meadow (1), 30m to 150m (2) and 150m to 180m (3).

Nb of tourists [1]	Number of turtles per m² x $e10^{-4}$															
	Zone 1 : 0 - 50m [3]				Zone 2 : 50-100m				Zone 3 : 100 - 180m				Global			
	N [2]	J	A	T	N	J	A	T	N	J	A	T	N	J	A	T
4,74	5,81	1,94	0,97	8,72	1,55	17,04	3,10	21,69	0,94	16,99	0	17,93	2,92	11,33	1,10	15,34
9,48	14,73	5,89	0	20,62	4,71	28,277	0,00	32,99	0	18,86	7,253	29,01	6,95	16,80	2,90	27,81
10,27	9,10	6,62	0	15,72	3,92	9,1393	7,83	20,89	0,86	9,41	1,712	11,98	5,01	8,69	2,67	16,38
13,43	5,14	2,06	2,06	9,25	0,00	13,184	6,59	19,78	0,00	18,42	4,848	24,24	1,99	11,54	4,38	18,30
16,59	2,64	3,96	1,32	7,92	3,83	7,664	5,75	19,16	1,14	11,40	2,281	14,83	2,41	8,20	2,89	13,98
18,96	11,16	11,16	0	22,31	0,00	11,496	0,00	11,50	0	11,24	2,043	13,28	4,11	11,86	0,91	16,88
19,75	15,16	12,64	1,68	29,48	2,69	8,0742	2,69	13,46	0,85	16,12	5,091	22,06	7,07	13,46	3,36	23,89
19,75	19,94	15,51	2,22	37,66	6,92	41,524	6,92	55,37	0	24,78	4,13	30,97	9,43	26,58	4,29	41,15
24,49	10,38	20,77	4,15	35,30	6,20	21,706	0,00	27,91	3,67	22,00	7,333	34,83	6,95	22,41	4,64	34,77
26,86	5,26	5,26	0	10,52	5,14	1,7121	5,14	11,98	7,66	17,50	5,469	30,63	6,51	9,76	3,72	19,99
29,23	2,61	7,82	0	10,42	0,00	18,486	1,85	20,33	1,12	16,82	4,484	22,42	1,45	14,94	2,41	18,79
32,39	10,54	7,02	1,76	19,32	2,90	5,798	1,45	10,15	0,83	14,17	3,333	18,33	5,14	9,93	2,40	17,47
34,76	7,44	1,24	0	8,68	3,83	13,392	0,00	17,22	1,14	25,01	4,547	30,69	4,52	15,07	2,01	21,60
36,34	6,06	12,12	2,02	20,21	6,28	3,142	3,14	12,57	3,26	32,65	1,632	37,54	5,14	19,82	2,20	27,16
41,87	3,10	4,65	0	7,74	8,98	15,71	0,00	24,69	1,31	9,18	3,936	14,43	3,96	9,62	1,70	15,28
44,24	7,36	3,15	0	10,52	1,60	7,9901	1,60	11,19	4,18	16,71	3,133	25,07	4,89	9,79	1,63	16,72
51,35	10,48	1,75	0,87	13,97	0,00	5,1759	5,18	11,65	0	6,80	2,55	9,35	4,08	4,76	2,72	12,24
59,25	9,29	5,80	0	15,09	1,56	1,5581	1,56	4,67	2,56	10,26	3,419	16,24	4,67	7,01	1,95	13,63
85,32	5,09	5,09	1,45	11,63	3,59	3,5851	1,20	9,56	1,34	9,41	2,689	13,45	3,38	6,76	1,97	12,40
101,12	6,48	0,00	0	6,48	0,00	7,1799	0,00	7,18	3,15	22,05	3,15	28,35	3,73	10,56	1,24	15,54
103,49	8,00	6,22	1,78	16,00	4,58	18,312	1,53	24,42	1,00	10,99	0,999	12,99	4,85	11,20	1,49	17,54
146,94	8,80	7,54	1,26	17,6	9,65	15,444	1,93	27,03	2,29	10,32	4,587	17,2	6,78	11,15	2,91	20,84
154,84	10,06	7,54	0	17,6	4,02	14,064	2,01	20,09	2,38	14,28	4,761	21,42	5,91	12,31	2,46	20,68
169,06	7,62	1,27	0	8,9	0,00	2,054	4,11	6,16	0	26,15	4,98	31,13	3,04	11,65	3,04	17,73
176,17	4,73	5,68	0	10,4	3,29	9,8567	0,00	14,79	1,05	13,67	3,155	18,93	3,19	9,96	1,20	15,14
195,92	11,54	4,33	0	15,9	2,40	14,403	2,40	19,20	0	18,55	3,092	21,64	5,31	12,38	1,77	19,46
208,56	7,86	1,57	0	9,4	2,37	9,4672	2,37	14,20	1,59	15,90	4,77	22,26	4,34	9,29	2,48	16,10
245,69	4,31	9,69	0	14,0	1,78	10,71	1,78	14,28	2,13	17,05	3,198	23,45	3,00	13,27	1,71	18,41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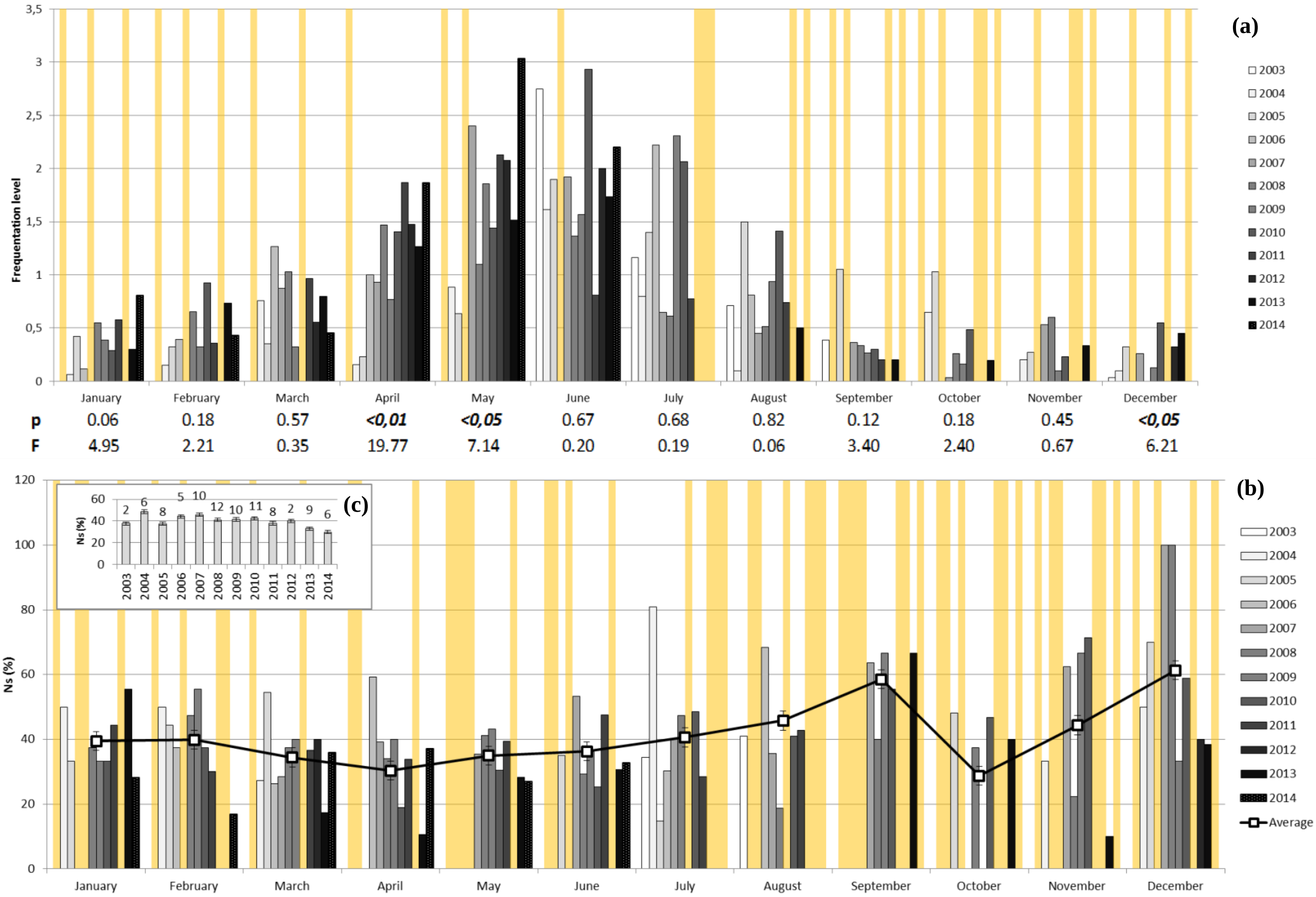
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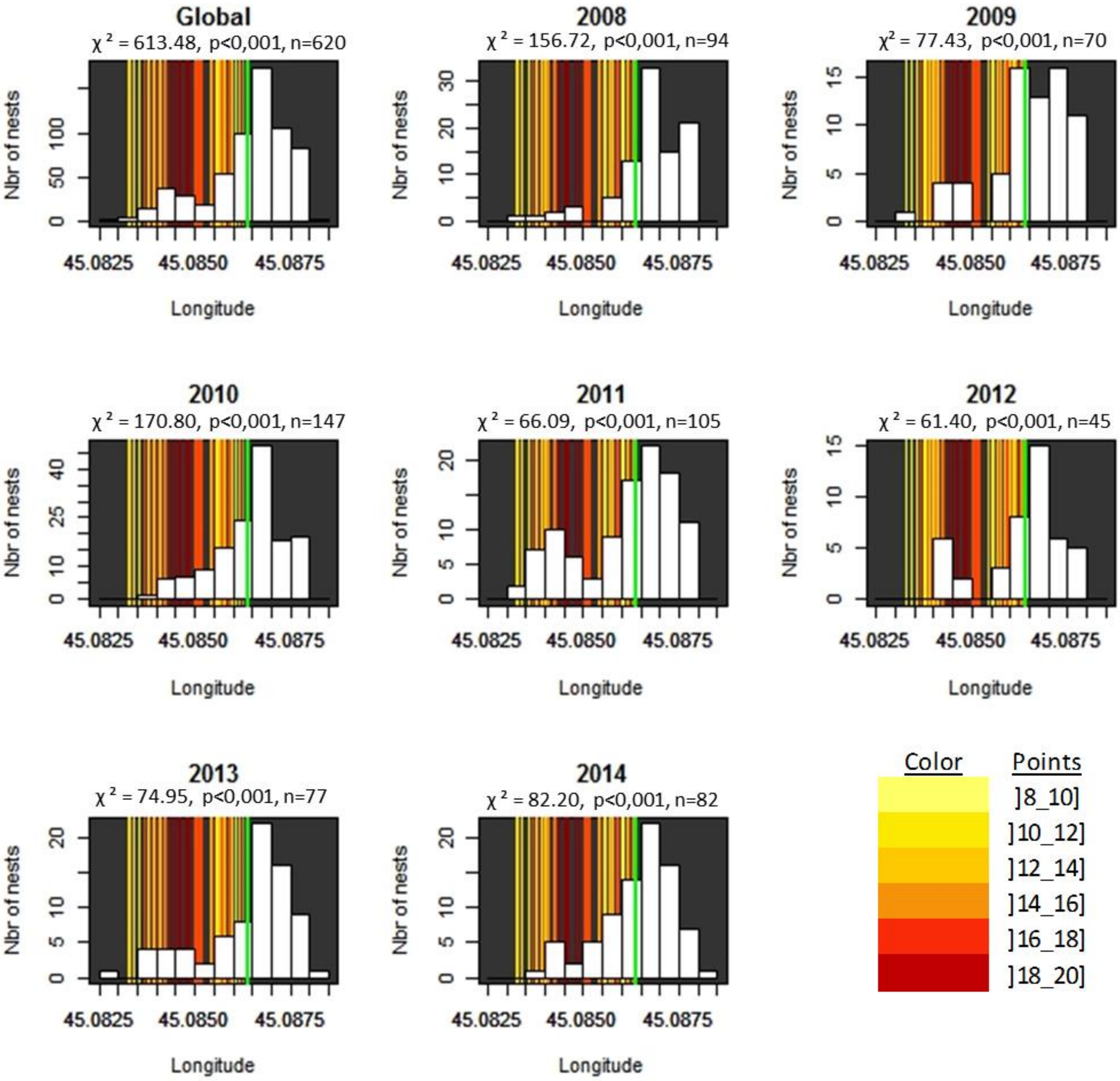
(c)
Ns (%)
60
40
20
0
2 6 8 5 10 12 10 11 8 2 9 6
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014

Fig. 2



Global
χ² = 613.48, p<0,001, n=620
2008
χ² = 156.72, p<0,001, n=94
2009
χ² = 77.43, p<0,001, n=70
2010
χ² = 170.80, p<0,001, n=147
2011
χ² = 66.09, p<0,001, n=105
2012
χ² = 61.40, p<0,001, n=45
2013
χ² = 74.95, p<0,001, n=77
2014
χ² = 82.20, p<0,001, n=82
Nbr of nests
Longitude
45.0825
45.0850
45.0875
Color
Points
]8_10]
]10_12]
]12_14]
]14_16]
]16_18]
]18_20]

Fig. 3

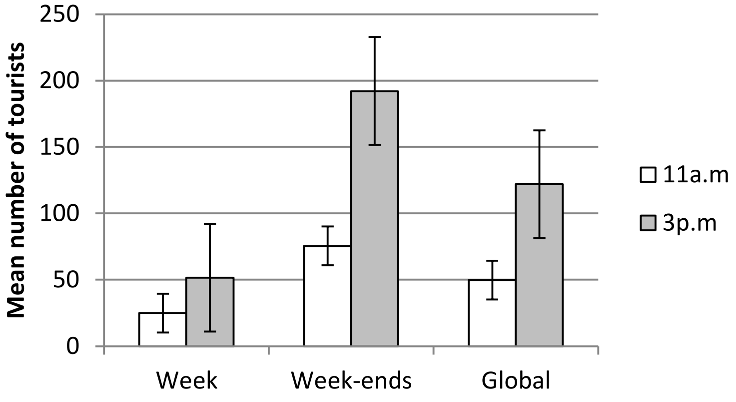

Mean number of tourists
250
200
150
100
50
0
Week
Week-ends
Global
11a.m
3p.m

Fig. 4

Appendix

Appendix 1: Grading scale used to classify the light sources by their degree of disturbance on N'Gouja beach. For the bungalows, the mean use duration was calculated per night and per bungalow. [1]For the use duration, the light sources on were identified at 20h30 and 4h30 during one week and the mean use duration per night was calculated. A 1.5 factor was given to use duration to give it more weight.

Scale	Color	Intensity	Distance to the vegetation limit	Use duration by night x1,5 [1]	Malus	Bonus
-0,5	-	-	-	-	Vegetation or obstacle	-
0,5	-	Windows	-		-	-
1	Orange	-	]75-105]	[0-2h]	-	Broad light field
2	White	Bungalows terraces	]50-75m]	]2-4h]	-	
3	-	Path	]30-50m]	]4-6h]	-	-
4	-	-	]15-30m]	]6-8h]	-	-
5	-	Restaurant	]5-15m]	]8-10h]	-	-
6	-	Spotlight	[0-5m]	]10-12h]	-	-

Appendix 2: Spatial distribution of the green turtle nests on N'Gouja beach and location of the light sources of the hotel. The purple points represent all the turtle nests from 2008 to 2014 and the yellow ones represent all the light sources visible from the beach in 2014. The H sector is the inhabited area in front of the hotel and the NH sector is the uninhabited area.