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Light Pollution and Sea Turtles Nest-Site Selection. Is it Possible a Practical Management of the Problem?

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Abstract
Artificial light at night (ALAN) pollution is a topic of growing concern globally, in particular along coasts where the number of cities is increasing. The problem is both economic and environmental, as in the case of the selection of the nesting site by the Caretta caretta sea turtles. In fact, even in a poorly lit municipality like Castiglione della Pescaia (Tuscany, Italy), 140 light sources have been identified near the beaches with different types of shielding and intensity. The localization and characterization of these night lighting sources was achieved through both field and satellite measurements. In this paper we propose a practical management of both the general and the specific problem of the case study with an approximate estimate of the costs involved in replacing the lamps with the greatest impact on the conservation of sea turtles.

Keywords: conservation; Italy; light pollution; nest-site selection; sea turtles; Tuscany

1. Introduction

Light pollution (*Artificial light at night* - ALAN) is the alteration of natural lighting levels in the nocturnal environment due to the introduction of artificial light by man (Falchi et al. 2011). It often represents an underestimated form of pollution, albeit widespread globally (Davies & Smith, 2018). It is estimated that 23% of the earth's surface between 75° N and 60° S is exposed to this artificial glow and that over 80% of the world population is subject to this form of pollution (Falchi et al. 2016), with an annual increase of 6% (Hölker et al. 2010), mainly due to the growing diffusion of LEDs. This diffusion has led to economic advantages (Gaston et al. 2012) and an improvement in color rendering for human vision with the transition to whiter lighting (Gaston et al. 2015); however, it has also entailed disadvantages in terms of health both for humans (Davis & Smith 2018) and for many types of organisms (Gaston et al. 2015).

Among the most developed countries, Italy is the most polluted by artificial light (Falchi et al. 2016). One of the reasons for this sad record could be to have a high perimeter/surface ratio and therefore a wide coastline in which numerous cities have been built, which obviously need lighting.

Due to the increase in coastal urbanization (Pulgar et al. 2019), the impact of ALAN on marine ecosystems is becoming a topic of growing concern (Luijendijk et al. 2018). The

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presence of light pollution is in fact growing in coastal and intertidal habitats, which offer important ecosystem services such as coastal protection and climate regulation (Garratt et al. 2019). In fact, it is estimated that 22% of coastal areas (Davies et al. 2014) and 20% of the world's marine protected areas (Davies et al. 2016) are subjected to nocturnal pollution. In coastal marine systems the most studied impact of ALAN concern sea turtles. It has been observed that the presence of night lighting is able to influence the choice of nesting site by sea turtles (Price et al. 2018); in fact, they tend to nest during the night (Silva et al. 2017), avoiding in most cases the sections of beach disturbed by ALAN. The presence of artificial lighting causes these organisms to choose places less suitable for nesting, such as areas that could be flooded during high tide or areas with denser vegetation (Salmon 2006). This could represent a serious threat to the sea turtle hatchlings due to the increased concentration of terrestrial and marine predators in such areas and therefore to their conservation (Salmon 2003). The only presence of artificial lighting leads to a decrease in both nesting attempts of 20-35%, and the reproductive success of sea turtles (Silva et al. 2017). There is in fact a significant relationship between density of sea turtle nesting sites and level of light pollution, with more nests in darker beach regions (Windle et al. 2018) as artificial lighting discourages adult females from nesting (Hu et al. 2018). In particular, broad-spectrum white light could inhibit nesting (Witherington 1992a), such as that found in the now widespread LED lighting (Corfitsen 1996).

In this study we tried to understand how the presence or absence of ALAN influences the choice of sea turtles *Caretta caretta* (Linnaeus, 1758), a species protected by numerous regulations and international conventions, in the selection of nesting site. Finally, suggestions and practical measures are illustrated in order to better manage the problem of light pollution with a summary estimate of the costs to achieve an optimal level of illumination for the conservation of these sea turtles.

2. Materials and Methods

2.1 Study site

The study area is located within the municipality of Castiglione della Pescaia in the province of Grosseto (Tuscany, Italy), bordered on the north by Torre Civette (42° 50' 40.02" N, 10° 46' 35.1" E) and on the south by Le Marze (42° 45' 19.5" N, 10° 54' 25.3" E), for a total distance of about 15 km (fig.1). The area between the port of Punta Ala and Le Rochette (marked in red in fig. 1) was excluded because it has a rocky shore, unsuitable as sea turtle nesting site. This study site was selected due to the choice of sea turtles to nest in this area from 2013 to 2021.

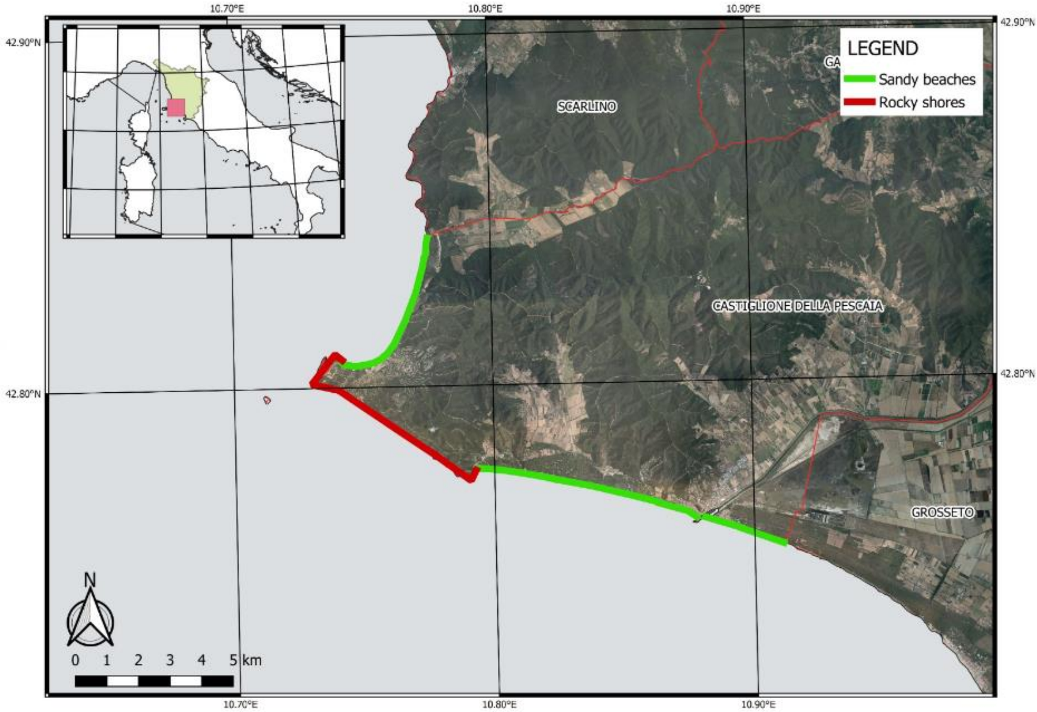

Fig. 1 – Study area

2.2 Measurement method

The measuring device was the lux meter (Digital Lux Meter LX1330B, range 0,1-200.000 lux) which is able to provide the luminous intensity (lux) that reaches the sensor. The lux meter was placed on a tripod at a height of 1 meter above the ground and at a distance (dx) of 12 meters from the seashore, a measure that considers the width of the beaches and the likely position of the nesting sites (fig. 2). The position of the lux meter allowed to obtain orthogonal measurements, resulting from the artificial light reaching the sensor. We took a measurement every 500 m and where there was a different source of ALAN. All measurements were made from 19/07/2022 to 03/08/2022, in the middle of the nesting period.

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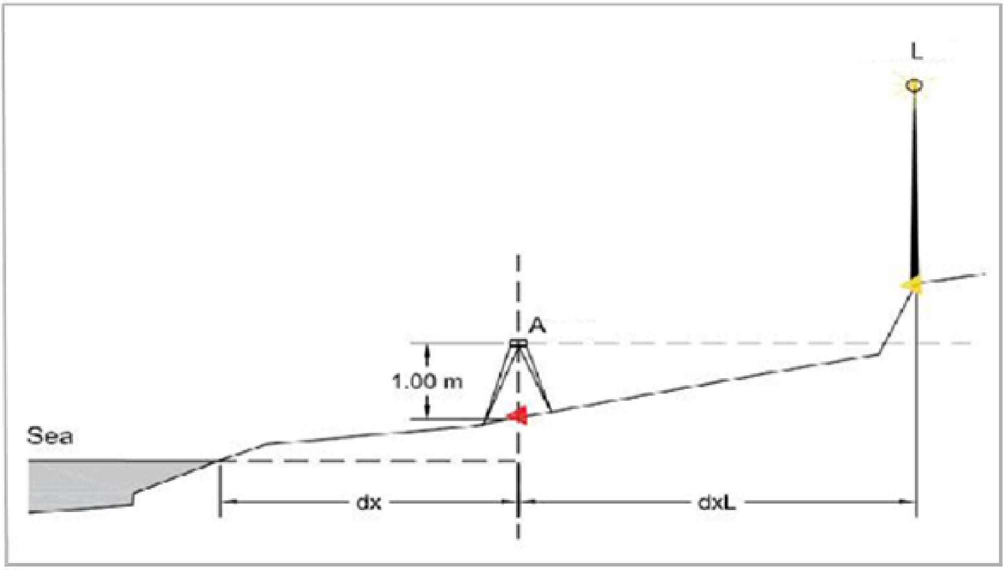

Fig. 2 – Graphical representation of the measurement method; dx: distance from the tripod to the seashore, dxL: distance from the tripod to the light source, A: sensor (lux meter), L: light source

The data, obtained from the lighting measurements, are displayed in a map (fig. 4), in which the stretches of coast have been identified by light intensity classes and related to nesting sites of sea turtles in the examined area (Hochscheid et al. 2022). The brightness measurements, that is the light emitted towards the sky, were retrieved from the https://www.lightpollutionmap.info site and were displayed on a map of radiance (nW/cm^2/sr) (fig. 5). These satellite data were compared with field data to verify the existence of a correspondence that allows them to be interchangeable as measurements for following studies.

2.3 Data analysis

A georeferenced database was released in Open Source GIS (QGIS 3.10) with homogeneous linear segment containing the number of light sources and the intensity of light pollution. In this database is inserted the georeferenced point and link of the photos of the light sources. R 4.0.2 was used for statistical analysis on the georeferenced data and plotting graphs.

3. Results and discussion

3.1 Study site characterization

The light pollution of the sandy coasts of the municipality of Castiglione della Pescaia is generally not widespread, extended only to areas where there are bathing establishments and in correspondence with the city of Castiglione della Pescaia. In fact, very high values of ALAN represent only 3% of the total coasts investigated, while about 85% are low level of light pollution (fig. 3).

ALAN levels have been divided into 4 classes: Low: 0-10 lux, Medium: 10-20 lux, High: 20-30 lux, Very high: > 30 lux. The values obtained range from 0 lux in areas without ALAN to 154 lux, at a bathing establishment in the stretch of beach between Capezzolo and Roccamare.

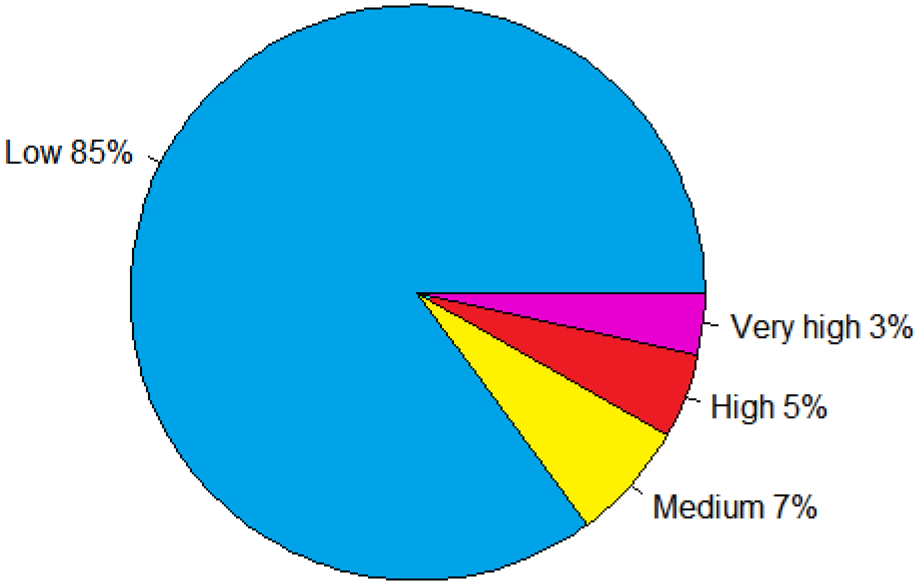

Fig. 3 – Distribution of light pollution classes in the study area

3.2 Sea turtle nest-site selection

In the study area all 6 nesting sites were located away from areas with high intensity light sources. In particular, 5 nests were present in areas with a low level of light pollution and only 1 at medium level (fig.4). In fact, no nests were laid at sites with greater light pollution, where more than 20 lux was measured. Even if the data are too small to make general assessments, however, they already give us a first indication that can be confirmed (or denied) by future studies in areas with a greater number of nests.

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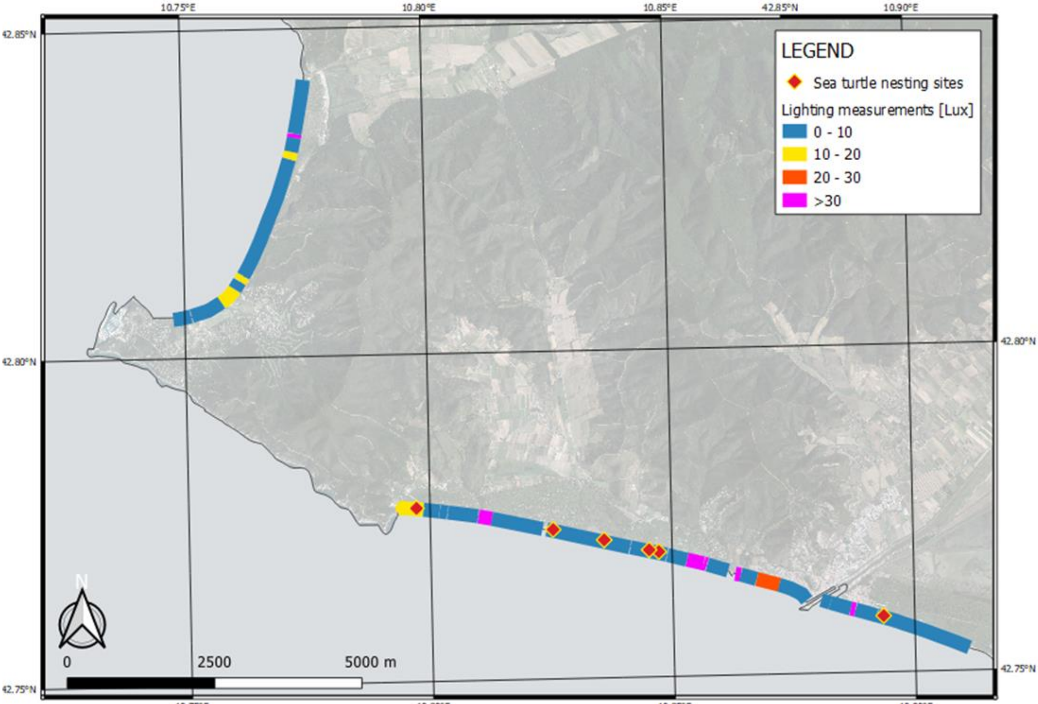

Fig. 4 – Spatial distribution of ALAN pollution in relation to nesting sites

3.3 Satellite data

Satellite data also shows the presence of sea turtle nests far from major sources of ALAN (fig. 5), confirming what was found by field measurements. However, the comparison between field and satellite measurements does not result in a significant correlation for the narrowed study area. Further studies could provide new hints about the possibility of interchange these measurements and facilitate sampling over larger extensions.

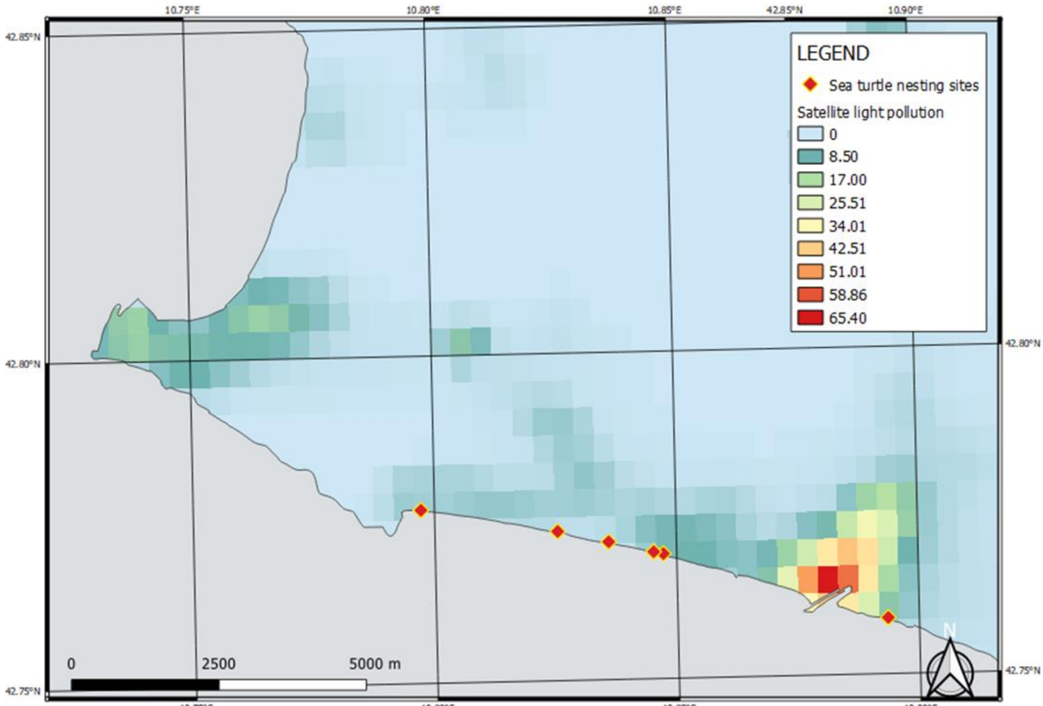

Fig. 5 – Spatial distribution of satellite ALAN pollution in relation to nesting sites

3.4 Practical management of light pollution

There are several practical and effective methods to manage and limit ALAN pollution. The following are the main measures that could be applied by the competent local authorities:

- Keep a proper distance between two adjacent light sources. It would be advisable to leave a dark area between them (fig. 6a) or at least the lights should not overlap. In this way, it would also be possible to eliminate unnecessary light sources, to restrict the lighting to the area where is needed (Falchi et al. 2011);
- Reduce the intensity of the light source to that strictly necessary to carry out the activity for which it was appointed. Very often this adjustment is not implemented and this is often easily visible due to the strong emission of light produced, illuminating areas as day (fig. 6b);

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a) b)

Fig. 6 – Light source with proper direction of the light beam (best) and right light intensity to illuminate a promenade by the sea (a). Light source with evident incorrect direction of the light beam (worst) and excessive light intensity produced on a beach a night (b)

- Turn off lights when not needed. It might seem trivial, but often both indoor and outdoor lights remain on for no reason throughout the night (Falchi et al. 2016). Automated switching on and off systems by movement would also be useful, however in outdoor lighting these options are rarely available (Falchi et al. 2011);
- Replacement of obsolete and underperforming types of lighting, with high cost and consumption, with others with a lower environmental impact. In recent decades, we are observing the replacement of narrow spectrum light sources, such as Low Pressure Sodium (LPS) and High Pressure Sodium (HPS) lamps, which emit mainly yellow or amber light, with wider spectrum white sources, such as Metal Halide (MH) lamps and Light Emitting Diodes (LED) (Gaston et al. 2012), which, however, can affect, because of this property, a greater number of organisms that are sensitive to specific wavelengths of the visible spectrum. Therefore, it is necessary to carefully evaluate the advantages and disadvantages that current sources of lighting present and not only to focus on economic profits at the expense of human health and that of other organisms.
- Correct direction of the light beam. ALAN pollution is compounded by poor design, installation and maintenance of lighting that result in the emission of light in unnecessary or unwanted directions. For example, street lighting is usually necessary to illuminate the road surface and objects below the light source, but poor lighting design can lead to light emissions upward or almost horizontally, and, in particular, the latter can propagate over a long distance thus greatly increasing the illuminated area (Gaston et al. 2012) and obscuring night sky. This can be avoided by using shielding on lighting fixtures (fig. 7) (Falchi et al. 2016). In fact, 75% of light pollution is emitted directly from ALAN sources and the other indirectly from the reflection of illuminated surfaces. This means that a total replacement of obsolete lights with fully shielded ones could reduce sky brightness by 25%. Nevertheless, as mentioned, even if the best control of light and its proper quantity were reached, there would always remain a certain upward emission of light, due to the

reflection from illuminated surfaces and this is an unavoidable by-product of the same lighting operation (Falchi et al. 2011).
In particular, in the case study 140 light sources were identified along the sandy coastal area of the municipality of Castiglione della Pescaia. Most of these light sources (92) belong to the type without shielding (worst, fig. 6b) and they are also the most impactful both from economic and ecological point of view because they are the ones with greater consumptions and diffusion, due to the increased propagation of artificial light. While for the other 3 categories we find respectively: 19 with partial shielding (bad), 18 with shielding (good) and only 11 with full shielding (best, fig. 6a).

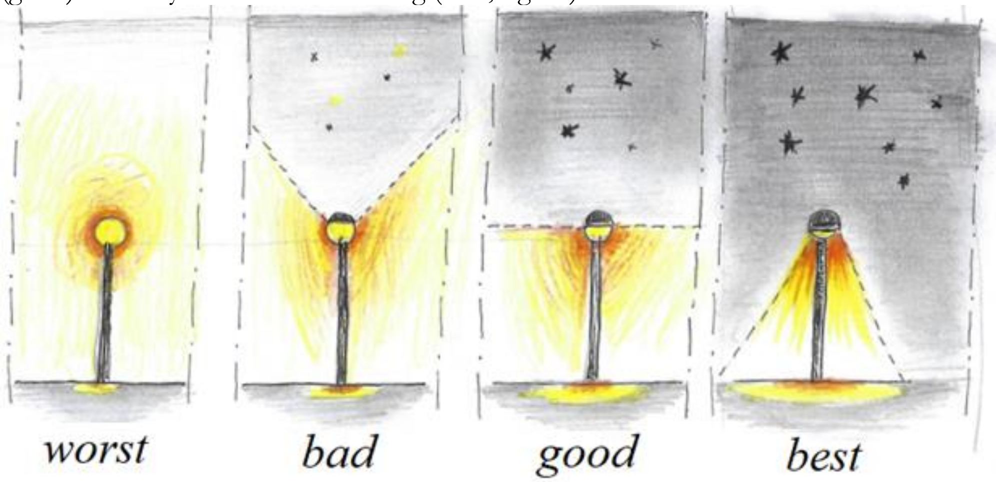

Fig. 7 – Light sources with different levels of shielding

The following table (fig. 8) shows the distribution of the 140 light sources if we compare the propagation, influenced by the different shielding, and the intensity of the light sources that reach the nesting areas of sea turtles on the beach. The colors indicate the bands of increasing impact from left to right and from top to bottom.
From the table we observe that most of the light sources are of the type with worse shielding, but in many cases, they are located far enough from the beach so as not to be an important disturbing factor for the selection of nesting sites of sea turtles.

SHIELDING / INTENSITY	BEST	GOOD	BAD	WORST
LOW	10	4	6	64
MEDIUM	1	7	4	16
HIGH	0	2	3	3
VERY HIGH	0	5	6	9

Fig. 8 – Table of the main disturbing factors of light sources, divided by impact bands, present long the sandy coasts of the municipality of Castiglione della Pescaia

Now we might ask: how much would it cost to replace the most impactful emitters, which are those with less shielding and with greater light intensity? Below we propose a possible solution applicable in two phases, based on the funds useful for this purpose.

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Step 1: replace all emitters of extreme disturbance (indicated purple in the table). A realistic estimate for each of the replacement of the 18 most impactful lighting sources would amount to approximately 400 € (Gong 2022), including replacement work and construction labor costs (https://prezzariollpp.regione.toscana.it/2023/grosseto), for a total of 7.200 €.
Step 2: replace all emitters of high disturbance (indicated orange in the table). In this case the light sources to be replaced would be 24 with a total price of 9.600 €.
Then, for each emitter, the average annual consumption will be estimated, evaluating the savings given by the efficiency of the new LED light source with shielding and by the decrease in light intensity, necessary to illuminate only the area concerned. Obviously, this estimate is to be considered approximate, but that nevertheless gives us an idea of the costs necessary to mitigate the effect of ALAN pollution on the choice of *Caretta caretta* sea turtles of nesting sites.

4. Conclusions

In the municipality of Castiglione della Pescaia ALAN pollution is not particularly widespread, but mainly limited to bathing establishments and in correspondence of the city of Castiglione della Pescaia. However, despite the presence of a largely unlit coastal territory, as many as 140 lighting sources have been detected that show us how important it is to carefully manage the problem by local authorities. Artificial lighting disrupts the selection of nesting sites by *Caretta caretta* sea turtles.
In fact, sea turtles assess the quality of a possible nesting site while they are still in the water (Witherington 1992a), so they nest far from light sources and this can determine the choice of less suitable nesting places (Salmon 2006). Instead, other times it is the presence of large silhouettes produced by tall apartment buildings and trees to influence sea turtles and to create preferential nesting habitats (Salmon et al. 1995a).
Future studies should investigate wider areas that validate this hypothesis and address other possible effects of ALAN on sea turtles such as predation and disorientation of hatchings along Italian coast, currently little studied compared to other parts of the world.
Concerning the management of the problem of ALAN pollution, Italy represents one of the countries with the highest expenditure on public lighting in Europe with an average total cost in recent years of 1.8 billion euros. The higher costs are explained by the use of obsolete lighting systems and the presence of a greater number of street lamps than necessary, which involves a high expense for their construction, assembly, maintenance and energy consumption. Therefore, a policy of waste reduction is needed through the continuation of the replacement of lights with LED lamps, an intensive use of innovative systems such as motion sensors and adaptive lighting and following the management measures proposed in this and other papers.
In general, the application of all these requirements would allow proper lighting of our cities with consequent energy and economic savings. At the same time, it would protect ourselves, other organisms and the environment from the most negative effects of light pollution (Falchi et al. 2011) and reduce CO_2 emissions, one of the main causes of climate change globally.

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