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Can satellite-based night lights be used for conservation? The case of nesting sea turtles in the Mediterranean

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ABSTRACT

Artificial night lights pose a major threat to multiple species. However, this threat is often disregarded in conservation management and action because it is difficult to quantify its effect. Increasing availability of high spatial-resolution satellite images may enable us to better incorporate this threat into future work, particularly in highly modified ecosystems such as the coastal zone. In this study we examine the potential of satellite night light imagery to predict the distribution of the endangered loggerhead (*Caretta caretta*) and green (*Chelonia mydas*) sea turtle nests in the eastern Mediterranean coastline. Using remote sensing tools and high resolution data derived from the SAC-C satellite and the International Space Station, we examined the relationship between the long term spatial patterns of sea turtle nests and the intensity of night lights along Israel's entire Mediterranean coastline. We found that sea turtles nests are negatively related to night light intensity and are concentrated in darker sections along the coast. Our resulting GLMs showed that night lights were a significant factor for explaining the distribution of sea turtle nests. Other significant variables included: cliff presence, human population density and infrastructure. This study is one of the first to show that night lights estimated with satellite-based imagery can be used to help explain sea turtle nesting activity at a detailed resolution over large areas. This approach can facilitate the management of species affected by night lights, and will be particularly useful in areas that are inaccessible or where broad-scale prioritization of conservation action is required.

1. Introduction

Coastal zones are experiencing rapid population growth around the world (Turner et al., 1996) and attract increasing levels of tourism, trade and development (Shi and Singh, 2003; Stancheva, 2010). These anthropogenic pressures threaten biodiversity in the coastal environment, affecting the dynamics of flora and fauna populations and ecosystem processes (Chapin et al., 2000; Crain et al., 2009). While the effects of some human-caused threats have been examined in detail, our understanding of the consequences of artificial night lights on biodiversity in coastal areas, which have rapidly increased in both spatial extent and intensity in recent decades, remains limited (Longcore and Rich, 2004).

Researchers have studied the effect of night lights on species for many years (Longcore and Rich, 2004). Previous studies exploring the impact of artificial lights on organisms were mainly conducted by ecologists studying species of birds (e.g. Longcore, 2010), sea turtles (e.g. Lorne and Salmon, 2007), bats (e.g. Jung and Kalko, 2010) and freshwater fish (e.g. McConnell et al., 2010). Results from these studies demonstrate that night lights can attract, repel, and disorientate organisms in their natural settings. These reactions can further alter behavioral patterns such as reproduction, foraging, migration, communication and predator–prey relationships (Longcore and Rich, 2004). Such studies provide evidence that artificial lights often have adverse effects on organisms (Salmon 2003; Bird et al., 2004; Longcore and Rich, 2004; Bourgeois et al., 2009; Kempenaers et al., 2010; Longcore, 2010).

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The threats of artificial night lights to biodiversity are rarely explored at a broad spatial scale. Previous studies were predominantly conducted at a local scale in field or laboratory settings (Witherington and Bjorndal, 1991; Salmon et al., 1995b; Grigione and Mrykalo, 2004). However, broader, regional spatial patterns of activities and processes that threaten the existence of species are important to examine, especially when management practices are applied at larger spatial scales, as is often the case in regional conservation planning for large marine and terrestrial mammals and reptiles (Watzold et al., 2006). Today, with our improved ability to estimate anthropogenic pressures and activities from advanced sources such as satellite imagery and remote sensing, we are able explore the impact of human-threats on species at various scales (Kerr and Ostrovsky, 2003).

Few studies have used satellite night light data for the assessment of threats and impacts on species, biological or environmental factors. Of the limited studies, night light imagery has been used in conservation to derive an index for environmental sustainability (Sutton, 2003), has been used to explore the temporal impact of light pollution on marine ecosystems (Aubrecht et al., 2010a) and has been incorporated into the management of protected areas (Aubrecht et al., 2010b). However, the effect of artificial light sources and the night environment has largely been neglected in reserve system or corridor designs (Bird et al., 2004; Longcore and Rich, 2004). No studies, as far as we are aware, have explicitly examined the potential of using satellite night light imagery as a tool for examining the distribution of sea turtle nests and its further conservation application.

1.1. Sea turtles – threats and factors affecting nesting patterns

Sea turtle species *Caretta caretta* (Linneaus, 1758, loggerhead turtle) and *Chelonia mydas* (Linneaus, 1758, green turtle) are globally endangered (Calase and Margaritoulis, 2010). Their worldwide conservation status underlines the importance of understanding factors that influence their distribution and vulnerability. Sea turtles display philopatry, where nesting turtles return to their original place of birth (Carr, 1975; Bowen et al., 1994). This behavior is known to operate at a relatively coarse regional scale ~10 km–50 km (Miller et al., 2003) and factors that drive nesting sea turtles within this coarse spatial-scale are poorly understood (Weishampel et al., 2003; Garcon et al., 2009).

One important factor that is known to affect sea turtle behavior is the presence of night lights. Ecologists have found artificial lights disrupt sea turtle behavior in two ways. First, night lights reduce the ability of sea turtle hatchlings to find the sea. Hatchlings are either attracted to the artificial light source or are disorientated (Salmon, 2003; Tuxbury and Salmon, 2005; Lorne and Salmon, 2007; Kawamura et al., 2009). Disoriented turtle hatchlings may fail to find the sea, thereby reducing population viability (Lorne and Salmon, 2007; McConnell et al., 2010).

Second, there is the poorly understood phenomenon of artificial beach-front lighting preventing turtles from nesting. Nesting females of *C. caretta* and *C. mydas* are deterred by artificial lighting (Witherington, 1992; Salmon et al., 1995b; Witherington and Martin, 2000; Bourgeois et al., 2009). The repellent effect could be dose dependent so that highly lit areas deter all nesting and poorly lit areas have a minor impact (Margaritoulis, 1985; Witherington, 1992). Most of these studies are on beach sites along the coast of Florida (Salmon et al., 1995b; Witherington and Martin, 2000; Salmon, 2003; Weishampel et al., 2006; Aubrecht et al., 2010a). Sea turtle researchers along the coast of the Mediterranean Sea seldom investigate this relationship (Kaska et al., 2003; Aureggi et al., 2005) and very few studies have explored this issue at a regional or broad spatial scale. Overall, the relationship between night lights and its effect on sea turtle nesting is poorly understood.

Previous studies found that sea turtles nest in non-random patterns and their selection of nest site is influenced by specific factors (Mellanby et al., 1998; Weishampel et al., 2003). Besides night lights, variables that are considered to influence sea turtle nesting include: beach dimensions (Kikukawa et al., 1996; Mazaris et al., 2006), beach slope (Wood and Bjorndal, 2000) sand characteristics (Le Vin et al., 1998; Kikukawa et al., 1999), beach nourishment (Brock et al., 2009), climate change (Van Houtan and Halley, 2011), predation (Leighton et al., 2011), human settlements (Kikukawa et al., 1996) and coastal development such as seawalls (Rizkalla and Savage, 2011). Understanding the impact of these variables on sea turtle nesting is important for setting spatial conservation priorities (Moilanen et al., 2009).

In this paper we investigate whether night lights, as quantified using space-borne images, can be used to help predict the distribution of sea turtle nests and we discuss the potential application of this tool in future conservation applications. The major questions we test in this study are:

(1) Can night lights derived from satellite imagery help us explain the distribution of sea turtle nests?
(2) Do night lights remain important at predicting sea turtle nest activity when considering additional anthropogenic and environmental variables?

2. Materials and methods

2.1. Study area

The Mediterranean Sea coastline of Israel is ~190 km long and has a north–south orientation (with the exception of the Carmel and Haifa Bay; Schattner, 1967; Fig. 1). The overall width of beaches in Israel is between 20 and 100 m, with wider areas at river mouths. Israel's southern beaches (south of Tel Aviv) are characterized by relatively wider, sandy beaches (compared with northern beaches) with transverse sand dune fields, which have formed behind the shore in the past 1000 years (Schattner, 1967; Tsoar, 2000). In comparison, northern beaches are generally narrower and bordered by aeolionite (kurkar) cliffs. There are 32 rivers and ephemeral streams that flow through this coastal stretch into the sea (Lichter et al., 2010) and tidal movements in Israel are limited to a range of 15–40 cm (Lichter et al., 2010).

Rectangular spatial units along the Israeli coastline were designed to examine the relationship between turtle nesting sites, night lights and associated anthropogenic and environmental factors. A buffer of 500 m to the east and west of the coastline was constructed and 336 spatial units of 1 × 0.5 km were positioned in this space. The buffer was chosen to allow for longitudinal location errors, as sea turtle nest surveyors sometimes reported only the latitudes. The dimensions of the spatial unit were based on the resolution of available night light imagery and expert advice regarding nesting turtle behavior.

2.2. Sea turtle data

Sea turtle data for this study were provided by Israel's National Parks Authority (NPA). We used nesting data of the two sea turtle species, *C. caretta* and *C. mydas*, which nest on the Mediterranean beaches of Israel (Kuller, 1999; Levy, 2003). The annual number of sea turtle nests have been increasing exponential within the past two decades, however specific reasons for their increase are unknown (Levy, 2011; see Appendix Fig. A1). Sea turtle surveys along the entire coast of Israel were performed by Israel's Nature and Parks Authority since 1993, during the turtle nesting season from May to August. At the start of the nesting season (May), surveys were conducted two or three times a week. During peak season