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Exploring scenarios of light pollution from coastal development reaching sea turtle nesting beaches near Cabo Pulmo, Mexico

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ABSTRACT

New coastal development may offer economic benefits to resort builders and even local communities, but these projects can also impact local ecosystems, key wildlife, and the draw for tourists. We explore how light from Cabo Cortés, a proposed coastal development in Baja California Sur, Mexico, may alter natural light cues used by sea turtle hatchlings. We adapt a viewshed approach to model exterior light originating from the resort under plausible zoning scenarios. This spatially explicit information allows stakeholders to evaluate the likely impact of alternative development options. Our model suggests that direct light's ability to reach sea turtle nesting beaches varies greatly by source location and height—with some plausible development scenarios leading to significantly less light pollution than others. Our light pollution maps can enhance decision-making, offering clear guidance on where to avoid elevated lamps or when to recommend lighting restrictions. Communities can use this information to participate in development planning to mitigate ecological, aesthetic and economic impacts from artificial lighting. Though tested in Mexico, our approach and free, open-source software can be applied in other places around the world to better understand and manage the threats of light pollution to sea turtles.

1. Introduction

Declines in sea turtle populations around the world have been linked to various threats posed by humans including habitat degradation and loss, incidental capture, ingestion of plastics, poaching of eggs, and overhunting (Campbell, 2007; Epperly, 2003; Eckert, 1995). Egg-laying female sea turtles exhibit site fidelity, returning to their natal nesting beaches to reproduce (Nichols, 2003). Disturbances from development to critical nesting sites can modify a beach's physical features (e.g., slope, orientation, width) and certain nesting conditions preferred by mothers, including moisture content, temperature, and salinity (López-Castro et al., 2004; Mortimer, 1995; Salmon et al., 1995a). Recent increases in urban

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development near nesting beaches have introduced artificial illumination in places traditionally lacking a large human presence (Kyba et al., 2011; Troy et al., 2011). The ecological consequences of light pollution associated with new coastal development near sea turtle nesting beaches are twofold. First, anthropogenic light can deter nesting females from coming onshore, leading them to choose less ideal locations to lay eggs (Deem et al., 2007; Rich and Longcore, 2005) or to abandon their nesting efforts once started (Witherington and Martin, 2000). More frequently studied and better understood is the potential of artificial light originating from human settlements to disrupt the normal sea-finding behavior of sea turtle hatchlings (e.g., Berry et al., 2013, Karnad et al., 2009, Witherington, 1992).

1.1. Sea turtle hatchlings

Sea turtle hatchlings are extremely sensitive to light as they rely on visual cues during the sea-finding process (Kawamura et al., 2009; Salmon, 2003; Mrosovsky and Kingsmill, 1985). Introduction of artificial light presents a serious threat to hatchlings as they typically emerge from their nests and journey towards the ocean at night to avoid opportunistic predators (Salmon et al., 1995b; Witherington et al., 1990). Hatchlings' primary cues are light intensity and horizon elevation. In the absence of artificial light, the horizon over the ocean appears brighter than a landward dune or vegetation because water has a higher albedo than land (Nicholas, 2001). Hatchlings will therefore orient away from the shadows and high silhouettes created by beach vegetation or dunes (Salmon et al., 1992) and towards the lowest and brightest horizon (Limpus and Kamrowski, 2013; Bourgeois et al., 2009; Witherington and Martin, 2000). Newborn sea turtles are also sensitive to a particular range of colors in the visible light spectrum and will preferentially orient to short wavelength and higher intensity lighting from artificial sources (Karnad et al., 2009). Arena trials and field observations indicate that visible point sources and the sheer glow of artificial light can disorient hatchlings and hinder their ability to find the ocean (Limpus and Kamrowski, 2013; Berry et al., 2013; Karnad et al., 2009). When hatchlings that emerge from nests are exposed to artificial light, they experience difficulty aligning with the most direct path to the ocean. A circular pattern of movement with frequent changes in direction has been observed in newborn sea turtles when artificial light is present (Tuxbury and Salmon, 2005; Witherington and Martin, 1996). Even lighting from a distant human settlement can affect turtle orientation because it creates a haze of light (called sky glow) on the horizon that is perceived as similar to the light over the ocean horizon. This artificial illumination of the sky can result in greater mortality among newborns, mainly from exhaustion or dehydration (Deem et al., 2007; Rich and Longcore, 2005; Witherington and Martin, 2000). Studies in Cape Verde and US Gulf of Mexico show that more than half of hatched nests had disoriented newborns when artificial lights from nearby beachfront development spilled into nesting areas (Taylor and Cozens, 2010; Nicholas, 2001). Celestial and atmospheric conditions including the absence of a full moon, dense cloud cover, or higher than normal levels of particulate matter, can amplify artificial light pollution (Kyba et al., 2011; Troy et al., 2013). While different factors can either expand or reduce the reach of ecological light pollution, new urban development near sea turtle nesting areas poses a serious threat to the reproductive success of sea turtles.

1.2. Sea turtles in Baja California peninsula, Mexico

Seven species of sea turtles have a near global range throughout the tropics. Many have documented the local importance of these charismatic megafauna in terms of their existence value and as sentinel species (e.g., Finkbeiner, 2009, Aguirre and Lutz, 2004, Burkhalter, 1999). For five species of sea turtles, dating back millions of years, the Baja California peninsula in Mexico has served as an important foraging and development area along with being the northernmost breeding ground for two species (Nichols, 2003). Local threats to nesting sites include poaching of eggs, artificial light pollution, loss of suitable habitat due to coastal development, and longer-term impacts from climate change such as sea level rise and greater wave action (López-Castro et al., 2004). The olive ridley (*Lepidochelys olivacea*) and leatherback (*Dermochelys coriacea*) turtles are two species known to regularly nest on the beaches of the southern portion of the peninsula, Baja California Sur (Nichols, 2003). Both are listed as vulnerable by IUCN (2014) and endangered by the Mexican government's national red list (SEMARNAT, 2010). In just twenty years, from 1980 to 2000, leatherback numbers in the Pacific Ocean have declined by 95% or more (Bjorndal and Jackson, 2003; Spotila et al., 2000). There are more mixed findings from surveys to estimate olive ridley nests along the Baja California peninsula and Central America. At La Escobilla beach in Oaxaca, Mexico, olive ridley nesting has increased dramatically since 1990 when a ban on hunting was announced. Nearly three-quarters of a million nests were recorded during the 1994–1995 season alone (Márquez et al., 1996). This dramatic rebound is evidence of how sea turtle populations can respond to protection. In Baja California Sur, overlap of olive ridley and leatherback nesting occurs from the southern Pacific coast (near Todos Santos) around the East Cape region, which includes Cabo Pulmo Marine Park, and up to La Paz (Fig. 1). Green sea turtles (*Chelonia mydas*) have also been documented to nest along the Baja California peninsula but more sporadically (Nichols, 2003). The nesting season for the olive ridley in Baja California Sur is June to December with peak nesting from August through October (Olguin-Mena, 1990; Márquez et al., 1982). Leatherbacks nest from October through January (Fritts et al., 1982) but may not nest every year in the area (CONANP *per. communication*).

Sea turtles inhabiting the Baja California peninsula are of critical ecological and cultural importance. The recent surge in human activity near foraging and nesting beach areas threatens turtles and their ecological, cultural and economic role in these communities (Finkbeiner, 2009; Campbell, 2007; Nichols, 2006). Ecologically, sea turtles were once the most abundant