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Sea-finding in marine turtle hatchlings: What is an appropriate exclusion zone to limit disruptive impacts of industrial light at night?

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ABSTRACT

Artificial light is increasingly being recognized as a globally-significant ecological threat, but appropriate management has lagged behind that of other environmental pollutants. Industrial developments associated with the extraction of natural resources generate large amounts of artificial light. Marine turtles are particularly vulnerable to disruption from artificial light, thus effective management of lighting is critical in areas where industrial developments occur close to nesting habitat. Given the complexity of managing lighting in industry, ensuring an adequate lighting exclusion zone between the development and the beach may be the most effective strategy for limiting impacts, yet there appears to have been little focus on clearly delineating a distance which constitutes an 'adequate' buffer. Using arena assays, we assessed flatback turtle (*Natator depressus*) and green turtle (*Chelonia mydas*) hatchling sea-finding ability in response to three standard industrial light sources (high pressure sodium (HPSV), metal halide (MH) and fluorescent white (FW)), positioned at distances of 100, 200, 500 and 800 m. Sea-finding in both species was disrupted by all three light types when lights were positioned 200 m or closer, but not when lights were positioned ≥500 m away. However, when shielding the lights so that light glow, but not the luminaire itself, was visible from the arena, the observed sea-finding disruption was considerably reduced. Given that facilities are typically lit by numerous luminaires, our findings demonstrate that future industrial developments should be separated from nearby nesting beaches by a buffer of at least 1.5 km, as previously theorized, with all installed lighting appropriately shaded. Such measures will help minimize lighting impacts on marine turtles as extractive resource operations continue to encroach on nesting beaches around the world.

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1. Introduction

Although extractive industries have been deemed one of the 'most environmentally disruptive' of human activities (Peck & Sinding, 2003, p. 131), modern society remains dependent upon fossil resources to meet energy needs (Shafiee & Topal, 2009), and both cost and demand for these resources is increasing (Moran, Lodhia, Kunz, & Huisingh, 2014). Broad-scale assessments have shown that industrial developments associated with the extraction of natural resources generate large amounts of nighttime light (Elvidge et al., 2009; Kamrowski, Limpus, Moloney, & Hamann, 2012), yet artificial lighting is a potential pollutant which may be overlooked or underestimated in industrial environmental management (e.g., Lyytimäki, Tapio, & Assmuth, 2012).

Artificial light-use has dramatically altered nocturnal environments, with detrimental health and fitness consequences recently observed in virtually all taxa (Gaston, Duffy, Gaston, Bennie, & Davies, 2014; Rich & Longcore, 2006). Light pollution has also been linked to serious physiological effects on human health (Fonken et al., 2010; Kloog, Portnov, Rennert, & Haim, 2011), as well as important costs to social well-being (Hölker et al., 2010). However, modern humans have little to no experience of a naturally dark night, and tend to consider an artificially lit night to be normal and preferable to darkness (Kyba, Hanel, & Hölker, 2014; Lyytimäki & Rinne, 2013).

One situation where the necessity of managing light has been well-recognized is in areas close to marine turtle nesting beaches around the world (e.g., Department of Environment and Conservation, 2007; Witherington & Martin, 2000). A brightly lit landward horizon at the nesting beach can discourage adult females from nesting (e.g., Salmon, Witherington, & Elvidge, 2000) and disorient hatchlings during their beach crawl to the ocean (e.g., Kamrowski, Limpus, Pendoley, & Hamann, 2014; Pendoley, 2000;

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Tuxbury & Salmon, 2005). Indeed, a recent study estimates that increases in artificial lighting since the early nineties have resulted in the loss of ~2000 marine turtles at some important rookeries (Brei, Pérez-Barahona, & Strobl, 2014). Management recommendations for lighting close to nesting beaches include shielding light sources, reducing light where possible, replacing standard lights with 'turtle-friendly' longer wavelength lights (Witherington & Martin, 2000; but see Robertson, 2013), and implementing a 'no development' buffer zone behind the nesting beach (Choi & Eckert, 2009; Salmon et al., 2000).

In spite of these recommendations, implementing lighting management in industrial facilities is challenging (Kamrowski, 2014). First, given modern society's preference for an artificially lit night, efforts to reduce lighting may be opposed by the workforce (e.g., Qi, Shen, Zeng, & Jorge, 2010). Second, extractive industries are widely acknowledged as hazardous work environments (Gardner, 2003), and inadequate lighting may lead to industrial accidents (Osterhaus, 1993). Most nations have legislated minimum lighting standards to ensure the safety of nightshift workers (Mills & Borg, 1999). For example, Australian lighting standards are governed by the Workplace Health and Safety Act and Regulation 1995, 2008, which state that lighting must be sufficient for hazard identification and to facilitate visual tasks, producing a safe and comfortable visual environment (Rushworth, Talbot, Von Glehn, Lomas, & Franz, 2001; Workplace Health and Safety Queensland, 2013). Determinations of 'sufficient' lighting are somewhat dependent upon value-based judgements (Lyytimäki, 2013), likely resulting in individual-specific illumination preferences (Mills & Borg, 1999), and optimal levels of light for task performance do not always correlate with perceptions of 'comfortable' lighting levels (Smith & Rea, 1980). Indeed, industrial workers were found to have a preference for increased lighting (Taiwo, 2010). Third, there have been links made between increased productivity and increased illuminance levels in industrial environments (Juslén & Tenner, 2005; Juslén, Wouters, & Tenner, 2007).

Consequently, despite a large body of research focused on managing lighting impacts through light reduction initiatives and lighting technologies (e.g., Bertolotti & Salmon, 2005; Kamrowski, Sutton, Tobin, & Hamann, 2014a, 2014b; Sella, Salmon, & Witherington, 2006), effective management of industrial lighting close to marine turtle nesting beaches may also benefit from increased management focus and effort towards ensuring an adequate buffer zone between the development and the beach. Limpus (2002) reasoned that a buffer distance of 1.5 km would be appropriate for locating developments close to nesting beaches; yet this suggested distance has not, to the best of our knowledge, been substantiated with experimental data and there appears to have been little further focus on clearly delineating an appropriate distance required to provide an 'adequate' buffer.

1.1. Study context

Marine turtles nest across the entire northern half of Australia's coastline (Limpus, 2009), and the North West Shelf region of Western Australia (WA) is considered to have the most light-exposed nesting beaches, primarily due to coastal industrial activities (Kamrowski et al., 2012; Kamrowski, Limpus, Jones, Anderson, & Hamann, 2014). Some industrial developments in WA are located very close to nesting beaches e.g. oil extraction infrastructure on Varanus Island is sited approximately 100 m from hawksbill (*Eretmochelys imbricata*) nesting habitat (Pendoley, 2005), and liquid natural gas infrastructure on Barrow Island is sited ~500 m from flatback (*Natator depressus*) nesting beaches (Chevron Australia, 2009). As a result, there is recognition of artificial lighting as being a major stressor for marine turtles in WA (Department of Environment and Conservation, 2007). Environmental impact assessment of proposed WA developments is the responsibility of the Environmental Protection Agency (EPA) (Morrison-Saunders & Bailey, 2003); however, while the EPA offers advice in recognition of the potential impact of industry lighting (Environmental Protection Agency 2010, p. 14), no siting distance recommendations are provided.

In addition, the North West Shelf is one of the most data deficient areas of Australia in relation to published marine turtle studies, despite large turtle populations (Pendoley et al., 2014). The ability to specify an adequate buffer zone may therefore be hampered by limited population-specific knowledge regarding turtle response to industrial lighting in this region.

Due to ongoing industrialization in coastal regions of Australia (Ford, Steen, & Verreynne, 2014), assessing hatchling response to standard light types used in industry, at different intensities - as a function of distance from the light source, would produce useful management information. In this paper, we present such data collected in 2004 and 2005 using green (*Chelonia mydas*) and flatback hatchlings, with the overarching aim of informing management related to the lighting and siting of future developments close to nesting beaches globally. Specific objectives were to:

- Assess the effect of re-testing hatchlings in the presence of different light sources over multiple trials.
- Record the sea-finding ability of hatchlings exposed to three types of standard industrial light (at 250 W and 500 W intensity), positioned at distances between 100 m and 800 m.
- Determine whether observed sea-finding disruption may be reduced by shielding the light source so that the luminaire itself was not visible from the test arenas at beach level.

2. Methods

2.1. Study site and species

Barrow Island is located on the North West Shelf of Western Australia (Fig. 1), approximately 55 km offshore from the mainland, at 20° 46′S and 115°24′E (Bradbury & Williams, 1996). Designated as a Class A nature reserve, the island is managed by the Western Australian Department of Parks and Wildlife. It has also been the site of an operating onshore oil and gas field for 50 years. Although currently the site of the Gorgon Gas Project, considered to be Australia's largest ever resource project (Government of Western Australia, 2010), final approvals for the project to begin were not given until 2009, four years after data collection occurred in this study.

Barrow Island supports nesting by flatback, green and hawksbill turtles, although only the former two species nest in significant numbers (Pendoley, 2005). Given the greater significance of nesting by flatback and green turtles (and thus the greater availability of hatchlings) we only tested these two species in the present study. Green hatchlings were collected from in-situ nests at John Wayne, Olivia and V beaches (Fig. 1) the afternoon or evening the trials were run, with hatchlings held for no longer than 6 h prior to trial commencement, and no longer than 9 h total. Flatback hatchlings were collected from in-situ nests at Yacht Club Beach (Fig. 1) the same evening as trials were run, and held for no more than 2 h prior to the experiments, and no longer than a total of 5 h. No more than 20 hatchlings from each clutch encountered were used during testing. All hatchlings were held in the dark in a plastic crate until used, and on completion of the experiments all hatchlings were immediately released on a dark beach.

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