Coastal light pollution in Australia: Insights and implications for marine turtle conservation

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Abstract

Increases in artificial light which occur as coastlines are developed pose a significant threat to marine turtles at the nesting beach because of the importance of light for their natural orientation. Globally significant numbers of marine turtles nest on Australian beaches; however the human population of Australia is also heavily concentrated along the coast, and coastal regions are undergoing rapid urbanisation and industrialisation. As a result, the mitigation of disruption caused by increasing levels of light pollution has become an important component of marine turtle conservation strategies within Australia.

The formulation of effective light mitigation strategies is hampered by several important knowledge gaps: 1) We lack understanding of the potential light pollution impact on marine turtles at ecologically-relevant scales. This knowledge is important for management prioritisation, but also to assess species' and population resilience in the face of coastal change. 2) We have little knowledge of the orientation behaviour of endemic flatback turtle hatchlings, which are being increasingly exposed to large scale development. This information is necessary to prevent management measures being based on behavioural knowledge extrapolated from different species and populations with possible behavioural differences. 3) Little attention has been paid to the human dimension of managing light close to nesting beaches. Effective lighting management will require widespread stakeholder support and participation; however, gaining support for lighting management initiatives is difficult because light at night is an integral aspect of modern society. My thesis addresses these knowledge gaps and aims to provide a scientific basis to inform and guide more effective marine turtle conservation strategies related to mitigation of light pollution. Given the disparate nature of the knowledge gaps, to meet this aim necessitated an interdisciplinary approach.

I began by overlaying nesting data onto remotely-sensed nighttime lights data. First, I assessed the proportion of marine turtles potentially exposed to light pollution, and identified the Australian nesting areas which have the highest exposure (Chapter 2). I found that all species of marine turtle reliably nesting in Australia were exposed to light pollution, demonstrating the management value of this thesis. Management units (MU) of turtles which nest at higher latitudes in Western Australia and Queensland were found to be the most vulnerable to light pollution. The risk to turtles from light generated by industrial developments, and to a lesser extent large urban areas, was also identified as significant.

Second, I used linear mixed model analysis to examine broad scale trends in light exposure at nesting areas between 1993 and 2010 (Chapter 3). All five species had at least one MU with a significant increase in light exposure, and east Australian flatback turtles experienced the fastest

increase. MUs identified as the most light-exposed in Australia in Chapter 2 did not change, indicating those turtles have been potentially exposed to high light levels for at least two decades. Finer scale analysis indicated that significant light increases predominantly occurred for nesting areas located close to heavily industrialised coastal areas.

The detrimental impact of industrial light for Australian marine turtles was confirmed with a subsequent examination of flatback hatchling sea-finding ability at two nesting beaches located in regions of proposed or ongoing industrial development (Chapter 4). I assessed sea-finding using a combination and comparison of commonly-used methods for measuring hatchling orientation, and I recorded relative light levels at each site using a stellar photometer. Flatback hatchlings at a nesting beach with highly modified light horizons showed markedly reduced sea-finding ability compared to hatchlings in a region which is currently dark but earmarked for future development. My comparison and evaluation of methods suggested that explicitly described fan-based methods, in addition to strategically-placed arenas, would provide the best data for accurately assessing hatchling sea-finding ability in future studies.

These chapters demonstrate that management effort in Australia should be prioritised to focus on mitigation of lighting in existing or proposed developments' occurring close to marine turtle nesting areas at high latitudes along both the east and west coasts. The broad scale methods I developed in the former analyses, and the evaluation of methods I conducted in the latter, will also collectively benefit managers of marine turtles impacted by artificial lighting in other parts of the world.

My remaining data chapters (5, 6 and 7) examined the human dimension of effective lighting management in the nesting regions I had identified as vulnerable to light pollution. I first examined resident engagement with light reduction in a Queensland coastal community exposed to four years of light reduction campaigning (Chapter 5). Semi-structured questionnaires guided by an existing theoretical constraints framework determined that despite high levels of cognitive and affective engagement (knowledge and concern), community behavioural engagement (action) with light reduction was limited. I went on to explore specific community beliefs regarding light reduction for turtle conservation, using persuasive communication techniques based on the Theory of Planned Behaviour (Chapter 6). Despite limited behavioural engagement, I found residents had moderate-strong intentions to reduce light. Personal norms (morals) were a strong predictor of behavioural intention, and I found significant differences in the strength of salient beliefs held by campaign compliers and non-compliers. I therefore suggest that the strongest persuasion potential for future communications, as a means of increasing community behavioural engagement with light reduction, may result from targeting specific identified salient beliefs, in combination with an appeal to personal norms.

Next, I focused on industrial lighting in Western Australia. I conducted a qualitative, exploratory case study to examine the lighting management of a large industrial development located adjacent to flatback turtle nesting beaches (Chapter 7). Semi-structured interviews and annual reports were used to evaluate the 'success' of the lighting management. No conclusive lighting impacts on turtles had been found to date, and relevant stakeholder judgements of the lighting management were either positive or neutral. Overall I judged the lighting management to be successful, and thus recommend that current and future industrial developments emulate the lighting management in this example to minimise disruptive impacts. Based on emergent themes in the data, I went on to develop a conceptual framework to understand drivers behind the successful light management. The importance of effective and comprehensive regulation was highlighted; however this was determined to be dependent upon the existence of adequate scientific knowledge. Effective future management of light pollution impacts will therefore require increased management and regulatory focus on lighting impacts for marine turtles and other species.

Overall, my interdisciplinary thesis demonstrates the value of combining and synthesising several research methods for informing management of a complex environmental issue. Effective management of light pollution for marine turtles requires an understanding of how and where marine turtles are impacted, using ecological, biological, spatial and temporal information. Yet factors influencing human behaviour and motivations are extremely complex, and the methods required to effectively manage light-use in one instance may not achieve the same outcomes elsewhere. My findings have been incorporated into Government documents and should help direct future management of marine turtles in Australia by highlighting the areas where turtles face the greatest potential exposure to artificial light, whilst also providing managers with a better understanding of potential methods for tackling relevant human behaviour to reduce impacts.

Contents

List of Tables

List of Figures

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Chapter 1

General Introduction

"To light a candle is to cast a shadow."

- Ursula K. Le Guin (1968)

1.1 Artificial light as a biodiversity threat

Humanity has recognised the value of manipulating nighttime light levels for hundreds of years (Mosseri 2011). Yet, the invention of the electric light bulb in the late 19^{th} century (Fouquet and Pearson 2006) dramatically changed the way we illuminate the night (Hölker *et al.* 2010a). Modern humans exist in a "24-hour society" (Härmä and Ilmarinen 1999, p.610) where virtually all infrastructure is lit, or has the capacity to be lit, at night (Falchi *et al.* 2011), and levels of artificial lighting are estimated to be increasing at 6% per year (Hölker *et al.* 2010b). The scale of artificial light-use has effected a global environmental change, with nighttime environments across much of the globe facing radically altered levels of illumination (Cinzano *et al.* 2001a; Elvidge *et al.* 2007; Elvidge *et al.* 2011). We are gradually becoming aware that this drastic altering of nightscapes may have hazardous consequences. 'Light pollution', generally understood as an excess of non-natural light at night, may be responsible for serious physiological effects on human health (Davis *et al.* 2001; Navara and Nelson 2007; Stevens 2009; Lucas *et al.* 2014), as well as important costs to social well-being (Hölker *et al.* 2010a).

Light pollution is also increasingly gaining attention as a significant ecological threat (Gaston and Bennie 2014). Natural cycles of light and dark are one of the principle drivers of the biological world (Mills 2008; Bradshaw and Holzapfel 2010), and light is considered to be the strongest abiotic factor influencing both characteristics, and coordination, of organism activity rhythms (Kramer and Birney 2001). As a result, the widespread, recent, and rapid alteration of nighttime illumination has significant potential to disrupt environmental processes (Gaston *et al.* 2012; Gaston and Bennie 2014). Although only recognised as a key environmental threat within the last decade or so (Lyytimäki and Rinne 2013), a growing number of studies have shown that artificial lighting has negative implications for a wide variety of organisms, impacting vital biological processes such as physiology, behaviour, and reproduction (for reviews see Longcore and Rich 2004; Rich and Longcore 2006; Hölker *et al.* 2010b; Gaston *et al.* 2013; Gaston and Bennie 2014).

1.2 Marine turtles and light pollution

Marine turtles are particularly vulnerable to disruption from artificial lighting, due to certain life history and behavioural traits which evolved over millions of years (FitzSimmons *et al.* 1995). Although spending most of their lives in the ocean, marine turtles nest out of the water on sandy tropical and subtropical beaches, predominantly at night (Carr and Ogren 1960; Witherington and Martin 2000). Following approximately two months of incubation, hatchlings emerge from the nest, again predominantly at night (Mrosovsky 1968; Limpus 1985; Witherington *et al.* 1990; Gyuris 1993), and must rapidly reach the ocean (Salmon 2006). During the beach crawl, hatchlings are exposed to numerous predators (see Stancyk 1982 for a review), and estimations of hatchling survival under natural conditions are as low as only one egg per thousand surviving to adulthood (Frazer 1986). The dispersal of turtle hatchlings from the beach is characterised by rapid, frenzied movements (Witherington and Martin 2000), thought to have evolved as a mechanism to lessen mortality rates, by limiting exposure to predators (Dial 1987). Any delay in leaving the coast is therefore likely to have fatal consequences.

Artificial lighting close to nesting beaches can prevent or prolong sea-finding during the beach crawl because turtle hatchlings use visual environmental cues to locate the ocean (Mrosovsky and Shettleworth 1968; Mrosovsky 1977; Lohmann *et al.* 1997; Witherington and Martin 2000). Current consensus is that hatchlings locate the ocean using a combination of topographic and brightness cues, orienting towards the lower, brighter oceanic horizon, and away from elevated silhouettes of dunes and/or vegetation bordering the beach on the landward side (Limpus 1971; Salmon *et al.* 1992; Limpus and Kamrowski 2013). Bright artificial lighting can mask hatchling ability to perceive these natural light horizons (Tuxbury and Salmon 2005), and thousands of hatchlings die each year as a consequence of disorientation from artificial lights (Witherington and Martin 2000; Bertolotti and Salmon 2005).

Adult females also rely on visual cues to orient correctly on land (Ehrenfeld and Carr 1967; Ehrenfeld 1968; Mrosovsky and Shettleworth 1975), and there have been instances of females failing to find the ocean following oviposition on artificially lit beaches (Witherington and Martin 2000). In addition, females preferentially choose to nest on darker beaches, thus artificial lighting can deter females from emerging to nest (Talbert *et al.* 1980; Salmon *et al.* 1995). With continued coastal development and associated increasing levels of light at night, females will likely have fewer suitably dark beaches to nest on. In such a scenario, increased nest density on the remaining suitable beaches may constrain the future reproductive success of turtle populations (e.g. Mazaris *et al.* 2009). Beaches with higher density nesting face a greater likelihood of nest destruction by conspecifics (Bustard and Tognetti 1969), as well as likely increases in rates of hatchling predation (Pilcher *et al.* 2000; Wyneken *et al.* 2000).

Together these findings resulted in the IUCN Marine Turtle Specialist Group (MTSG)[1] classifying coastal development and associated light pollution as significant threats to marine turtle survival (Witherington 1999). Yet, despite extensive literature which focuses on the disruption that artificial lighting poses to marine turtles, effective management of the growing light pollution threat facing turtles may be hindered by important knowledge gaps.

[1] www.iucn-mtsg.org/

Lack of broad scale studies

The vast majority of research involving marine turtles and artificial lighting consists of laboratory studies, or field-based studies occurring at one beach, or in one region (e.g. Witherington 1991; Witherington and Bjorndal 1991a; Witherington and Bjorndal 1991b; Peters and Verhoeven 1994; Salmon *et al.* 2000; Bertolotti and Salmon 2005; Pendoley 2005; Stapput and Wiltschko 2005; Harewood and Horrocks 2008; Fritsches 2012). These studies have provided valuable information leading to recognition of lighting impacts, and management of lighting close to nesting beaches. However, implementation of conservation strategies typically involves allocation of limited financial and capacity resources (Fuentes *et al.* 2009), and managers are therefore required to prioritise management actions. Marine turtles are widely distributed animals (Blumenthal *et al.* 2006; Wallace *et al.* 2010), with species and populations often utilising nesting habitat over large spatial areas (Fuentes *et al.* 2013). Moreover, threats are unlikely to be equally distributed across such spatial scales (Wallace *et al.* 2011). Therefore successful management of lighting for marine turtles will require an understanding of the threat at ecologically-relevant scales e.g. at all nesting beaches used by a population, to allow effective prioritisation of conservation resources (e.g. Fuentes *et al.* 2011).

Limited number of well-studied populations and species

Research output for light pollution impacts on marine turtles has focused predominantly on a limited number of populations and species. To illustrate this, I performed a literature search in March 2011, and repeated the search again in April 2014, using Thomson Reuters Web of Science (formerly ISI Web of Science). I searched using the term ‘hatchling orientation’, which produced 69 entries in 2011, and 120 in 2014. Entries were reviewed and discarded unless they referred to single studies investigating orientation in marine turtles. In 2011, 30% of the 43 records considered marine turtle response to artificial light, compared to 49% of 70 records in 2014. Overall studies were dominated by research occurring in the Americas (Figure 1.1), and research involving loggerhead and green turtles (Figure 1.2). These studies have been used to infer behaviour in other populations and species. For example, in his biological review of Australian marine turtles, Limpus (2009) describes natural orientation mechanisms in loggerhead, green, hawksbill and flatback hatchlings, citing evidence arising from studies taking place outside Australia (Mrosovsky 1978; Lohmann 1991; Witherington and Bjorndal 1991a; Salmon and Wyneken 1994; Lohmann and Lohmann 2003) with only two exceptions (Limpus 1971; Limpus 1985). The lack of research involving hawksbill and flatback turtles is noted, and the presumption that these species orient in a similar way to other species is explicitly stated (Limpus 2009).

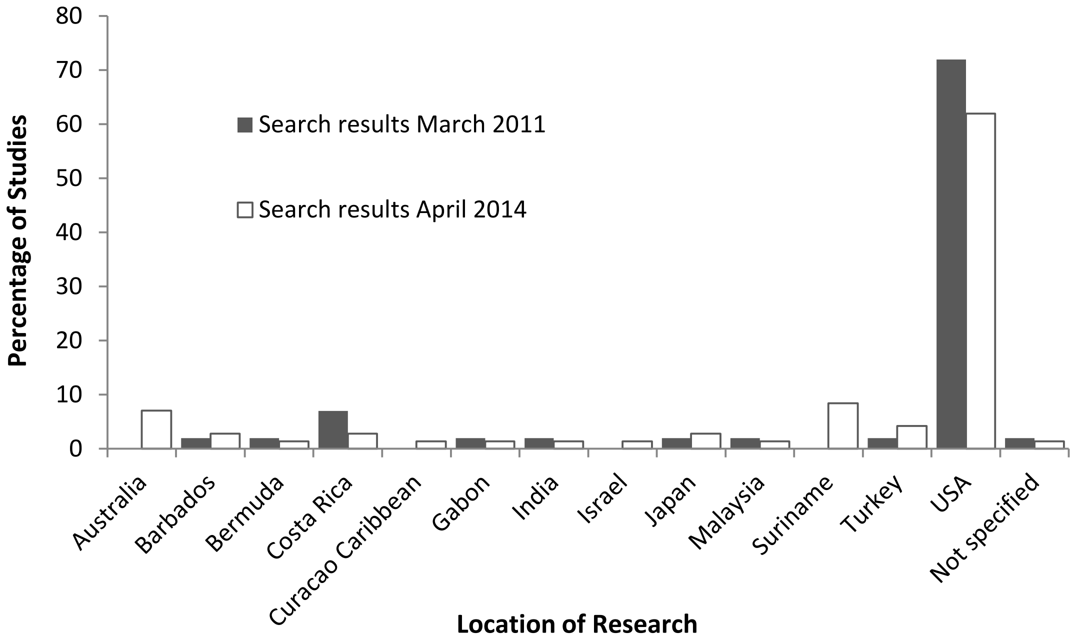

Figure 1.1 Results of a literature search using Thomson-Reuters Web of Science in March 2011, and April 2014, to find studies involving marine turtle hatchling orientation, classified according to research location.

Yet, the most effective management of light pollution for marine turtles requires population specific studies because behavioural differences may exist between well-studied populations and other populations and species. The existence of geographic variation in behavioural traits displayed by populations of the same species has been well-recognised (Foster and Endler 1999), and attributed to selective pressures imposed by potential environmental variations experienced by different populations (Bell 2005). Population behavioural differences are frequently observed in organisms which have migratory life history phases, with differences linked to migratory difficulty (Bernatchez and Dodson 1987); such as when separate populations have different distances to travel (Crossin *et al.* 2004; Pulido 2007). Marine turtles display migratory behaviour as hatchlings swimming away from near shore waters (Lohmann 1991; Musick and Limpus 1997), and the influence of geographic variation on population behavioural strategies was demonstrated in a laboratory study by Wyneken *et al*. (2008), where significant differences in early migratory activity levels were found between hatchlings from two distinct nesting groups within a single population of Florida loggerheads.

Moreover, the flatback turtle, which is only known to nest on Australian beaches (Limpus 2009), displays a different life history compared to other hard-shelled marine turtles (Salmon *et* *al.* 2009). Post-hatchlings remain within pelagic continental-shelf waters, making flatback turtles the only species without an oceanic phase (Walker and Parmenter 1990). Flatback hatchlings are also almost twice as large as other hard-shelled turtle hatchlings (Walker and Parmenter 1990; Van Buskirk and Crowder 1994), and they display a swimming strategy during offshore migration not seen in other species' (Salmon *et al.* 2009; Hamann *et al.* 2011; Pereira *et al.* 2011; Pereira *et al.* 2012). Thus in the absence of relevant studies, management of light pollution for marine turtle populations and species nesting outside the USA may be hindered by potential differences in the early orientation and dispersal mechanisms of hatchlings.

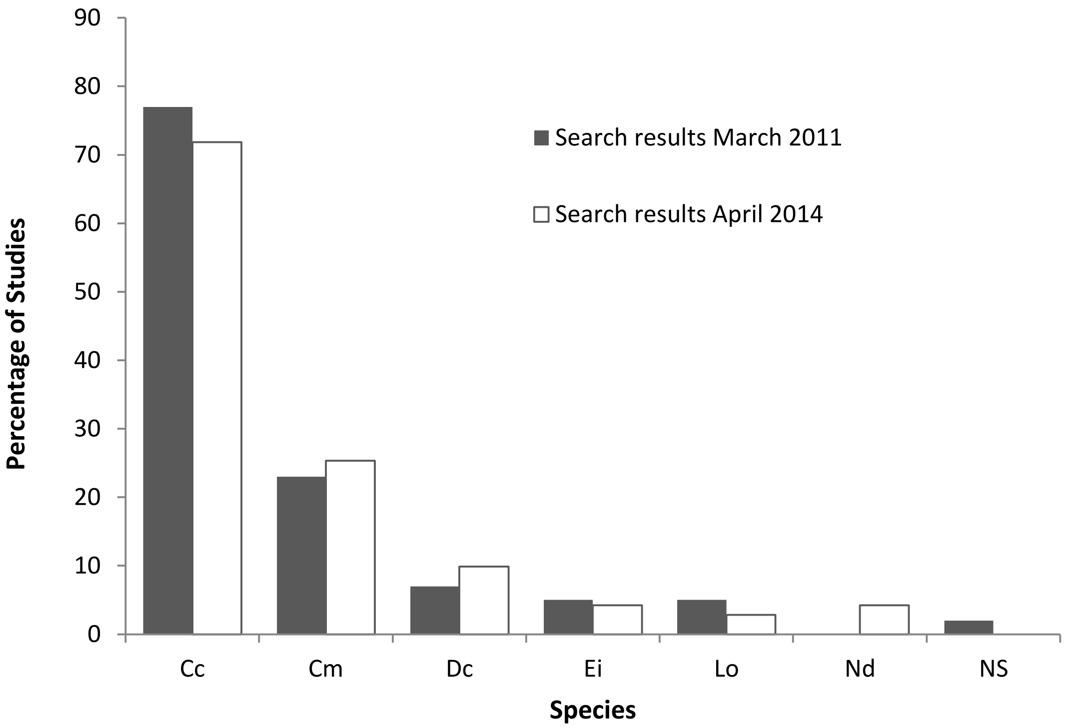

Figure 1.2 Results of a literature search Thomson-Reuters Web of Science in March 2011, and April 2014, to find studies involving marine turtle hatchling orientation, classified according to study species (Cc: *Caretta caretta*; Cm: *Chelonia mydas*; Dc: *Dermochelys coriacea*; Ei: *Eretmochelys imbricata*; Lo: *Lepidochelys olivacea*; Nd: *Natator depressus*; NS: Not specified).

The human factor

Anthropogenic activities are directly responsible for most of the environmental problems currently facing the planet (Vitousek *et al.* 1997; Stern 2000). Yet, management of environmental issues has traditionally been steered by a greater research emphasis on natural science knowledge, such as understanding underlying biological and ecological processes in affected species (Saunders 2003). However, despite extensive research output, management guided solely by natural science will unlikely lead to effective mitigation of environmental threats (Groffman *et al.* 2010; State of the Environment Committee 2011). For example, management of artificial lighting at turtle nesting beaches has typically favoured modifying existing light sources (Berthaume 2007), such as retro-fitting filters on lights to restrict the emittance of wavelengths below 530 nm (Florida Power and Light Company 2002), and the development of long wavelength ‘turtle-friendly’ lights (Halagar *et al.* 2008). This reflects a substantial body of research examining turtle behavioural and visual responses to lights of different wavelengths and intensities (e.g. Witherington and Bjorndal 1991b; Levenson *et al.* 2004; Pendoley 2005; Sella *et al.* 2006; Horch *et al.* 2008). However, a later test of such filters demonstrated that although filtered light reduced hatchling disorientation compared to standard street-lighting, hatchlings still oriented towards the filtered light (Sella *et al.* 2006). Furthermore, recent research has suggested that wavelengths that may be ‘turtle-friendly’ for one species or population, may not be for others (Fritsches 2012; Robertson 2013).

Effective management of lighting will require insights provided by the social sciences. Inarguably, the most valuable mitigation measure for preventing lighting impacts on turtles is turning lights off during the nesting season (e.g. Frazer 1992; Witherington and Martin 2000). This is both the easiest and the cheapest solution – however it is also the most difficult to implement (Witherington 1999). Artificial light at night is fundamentally important to today’s society, and recent research suggests that modern humans are so lacking in experience of non-light-polluted nighttime environments that we perceive excessive and/or extended use of light at night as ‘normal’, despite potentially significant environmental degradation (Lyytimäki 2013). This widely held perception can impede efforts to reduce light, with light reduction initiatives viewed as either ‘unimportant’ (Lyytimäki *et al.* 2012), or actively opposed because of unfavourable perceptions of natural, dark, nighttime environments as being unpleasant or dangerous (e.g. Bixler and Floyd 1997).

Since human activity is the fundamental driver of light pollution, widespread support of, and participation in light reduction initiatives will be critical to the success of lighting management efforts (Lyytimäki 2013; Lyytimäki and Rinne 2013). Research has recognised that pro-environmental actions are strongly correlated with a small number of human attributes, including attitude, personal responsibility and knowledge (Barney *et al.* 2005). Thus, understanding attitudes and perceptions towards light reduction initiatives is likely to be an essential step in the development of appropriate and effective light pollution management strategies (e.g. Stern 1993). Surprisingly, despite the wealth of literature concerning the threat artificial light poses to marine turtles, little attention has been paid to this ‘human factor’.

1.3 Light pollution and marine turtles in Australia

The northern half of Australia's coastline provides nesting habitat for large, globally significant populations of green, hawksbill, loggerhead, and flatback turtles, along with smaller nesting populations of olive ridley turtles (see Chapter 3, Figure 3.1), and sporadic nesting by leatherback turtles (see Limpus 2009 for detailed information regarding geographical location and range of nesting for each species). All six species are listed as threatened species in Australia under the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act) (Environment Australia 2003), and protected under both State and Commonwealth legislation (Limpus 2009). However, since the end of World War II, Australia's economy and population have been growing, exposing marine turtles to increasing anthropogenic pressures such as marine debris, boat strike, pollution, and habitat degradation (Environment Australia 2003).

At present, most nesting beaches in Australia are not exposed to the same level of coastal development that has occurred along nesting beaches elsewhere (Chatto and Baker 2008; Limpus 2009). In Florida, for example, unplanned development of the coast occurred for many years without recognition of the importance of the regions beaches for marine turtles (Salmon *et al.* 2000). In recent years, there have been high levels of interest in protecting Florida's turtle populations, described by some researchers as reactive, as opposed to proactive, management measures (Salmon *et al.* 2000), and this may go some way towards explaining the mass of literature centred on US turtle populations (Figure 1.1). However, coastal development within Australia is increasing. The southeast portion of Queensland, for instance, which has loggerhead, green and flatback turtle nesting areas (Limpus 2009) is undergoing the fastest urban growth within Australia, with a population increase of over one million people expected over the next two decades (SEQ Catchments 2010). The coastline is also facing rapid industrialisation, with extractive industry projects worth billions of dollars either proposed or in development (Ford *et al.* 2014). Similarly on Australia's west coast the light produced by existing industry projects in Western Australia is recognised as a significant pressure on marine turtles in the area (Pendoley 2005; Department of Environment and Conservation 2007; Environmental Protection Agency 2010).

Since we know how lighting from unplanned developments elsewhere, e.g. Florida, has detrimentally impacted marine turtles, we can anticipate likely impacts of increased artificial lighting on nesting turtle populations in Australia (Salmon *et al.* 2000). However, as shown in Figure 1.1, very little research has been published regarding natural hatchling orientation, or impacts of lighting on marine turtles, in Australia. The consequences of both increased coastal development, and lack of data on how Australian populations are affected by light pollution, means that management and policy-related solutions are primarily based on biological and ecological knowledge gained overseas. A study focused on light pollution and Australian marine turtles, which incorporates a critical understanding of the human dimension of mitigating lighting impacts, is both timely and valuable to form an empirical basis for managing current and future coastal development in relation to marine turtle conservation.

1.4 Thesis design and objectives

The overarching aim of this thesis is to provide new information to inform and guide effective marine turtle conservation strategies related to mitigation of light pollution impacts as coastal development continues. However, given the knowledge gaps I have identified, it is clear that one single approach will not be sufficient to address this aim.

Science has historically advanced via specialisation; yet the evolution of separate disciplines has produced knowledge which is often fragmented, lacking the synthesis necessary to enable examination and discussion of issues across broader contexts (Stern 1986; Brewer 1999). To solve global scale issues of human-induced environmental change, it is considered imperative that we move beyond this standard research paradigm (Brewer 1999). Management efforts require a better understanding of the complex links existing between society and nature (Davoudi and Pendlebury 2010), necessitating integrated contributions from several different disciplines (Skole 2004). Interdisciplinary research focuses on complex real-world issues to increase understanding of the specific problem through organisation and combination of knowledge obtained from multiple specialities. The resultant outcomes are often far more valuable than those generated from the individual separate contributions (Brewer 1999; Davoudi and Pendlebury 2010).

Light pollution is considered to be a significant global threat to the environment which requires transdisciplinary research to integrate disciplinary-focused outcomes (astronomical, medical, or ecological e.g. disruption of turtle nesting) with society's lighting requirements and preferences (Hölker *et al.* 2010a; Kyba *et al.* 2013; Lyytimäki and Rinne 2013). Therefore, to effectively contribute to the issue of light pollution mitigation for marine turtle conservation, I take an interdisciplinary approach to this thesis, with two discrete but linked objectives:

Objective 1: To provide a more comprehensive understanding of how and where coastal light pollution affects Australian marine turtles by: a) assessing the extent of the light pollution threat at broad, ecologically relevant scales (Chapters 2 and 3), and b) gathering on-land dispersal data (direction of movement after hatching) from flatback turtle hatchlings exposed to artificial lighting, to allow comparisons with other well-studied populations and species (Chapter 4).

Objective 2: To examine artificial light-use, and perceptions and attitudes towards light reduction initiatives for marine turtle conservation, in relevant stakeholder groups in Australia (based on objective 1 outcomes), as a means of informing targeted light mitigation strategies (Chapters 5, 6 and 7).

1.5 Thesis outline

This thesis is made up of eight chapters (Figure 1.3), with the six data chapters (Chapters 2-7) written with the intention of publication in internationally recognised journals.

At thesis submission, four chapters have been published (Chapters 2, 3, 5 and 6) and one chapter is under review (Chapter 4). As such, Chapters 2-7 are presented as independent papers, albeit with minor adjustments to ensure they are consistent in written style and linked together to improve flow and clarity. With this thesis structure, some repetition of text is unavoidable; however given the interdisciplinary nature of this project, and the disparate fields of study that it encompasses, I considered that the repetition may help to facilitate reader understanding of where and how each chapter fits into the thesis as a whole.

Chapter 1 provides a general introduction to this thesis, with a brief overview of the threat which light pollution poses to the environment, before focusing more specifically on how light pollution impacts marine turtles. I then identify key knowledge gaps related to light pollution and marine turtles, and outline the project framework and objectives.

In **Chapter 2** I use large scale nighttime light data collected by satellites to quantify the extent of light pollution exposure for marine turtles in Australia, and go on to identify where nesting turtles face the highest light pollution exposure across ecologically relevant scales. I wrote the chapter and carried out all of the data analysis. A. Prof Mark Hamann (JCU), Dr James Moloney (JCU) and Dr Col Limpus (DEHP) assisted with study development and design, interpretation of results and editing. James Moloney also assisted with the GIS analysis. Professor Peter Ridd (JCU) provided advice on the conversion of radiometric to photometric units of light.

- Kamrowski RL, Limpus CL, Moloney J & Hamann M (2012). Coastal light pollution and marine turtles: assessing the magnitude of the problem. *Endangered Species Research*, **19**: 85-98.

Chapter 3 assesses temporal changes in the light exposure of Australian marine turtle nesting areas, using large scale satellite nighttime light data in combination with linear mixed model analysis. I examine changes in light levels over time at broad, ecologically-relevant scales, as

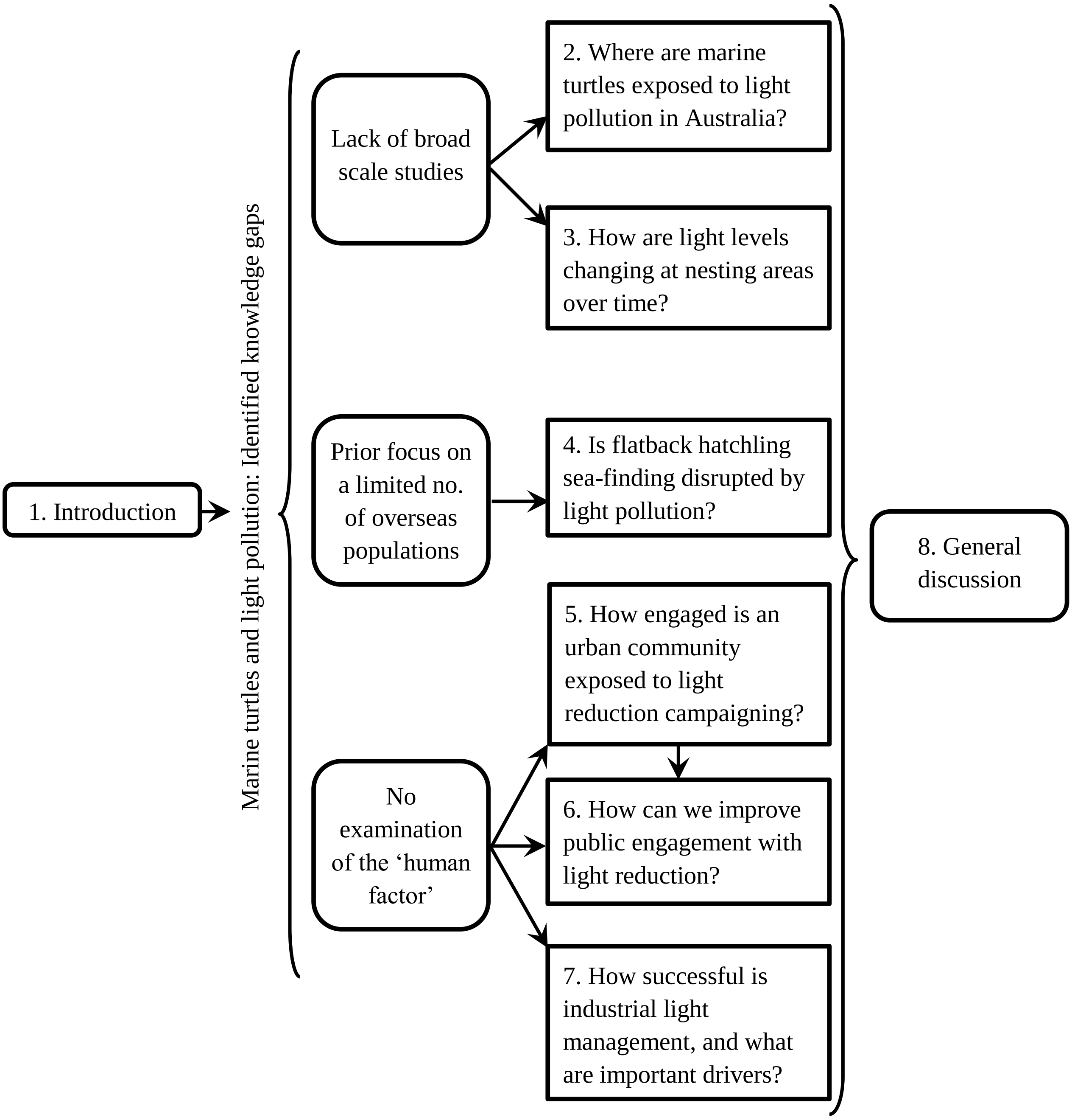

Figure 1.3 Thesis structure and outline, with chapters numbered appropriately.

well as at finer scales, to identify populations and areas experiencing the fastest changes in light over time. I wrote the chapter and carried out all of the data analysis. A. Prof Mark Hamann (JCU) and Dr Col Limpus (DEHP) assisted with study development and design, interpretation of results and editing. Professor Rhondda Jones (JCU) provided statistical advice, assisted with interpretation of results and editing. Dr Sharolyn Anderson (UniSA) provided advice on use of the satellite nighttime lights data, and edited the paper. Dr Chris Elvidge (NOAA) gave advice regarding inter-calibration of the satellite data, and also provided the necessary coefficients.

- Kamrowski RL, Limpus CL, Jones R, Anderson S & Hamann M (2014). Temporal changes in artificial light exposure of marine turtle nesting areas. *Global Change Biology*, **20**: 2437–2449.

Chapter 4 investigates the sea-finding ability of flatback turtle hatchlings in areas of planned or ongoing industrial development (see Figures 4.1 and 4.2), and determines previously undocumented time of nest emergence for east Australian flatback hatchlings. This chapter also evaluates methods frequently used for assessing the dispersal of marine turtle hatchlings to advance this field of knowledge. I collected all of the data, carried out all of the data analysis and wrote the chapter. A. Prof Mark Hamann (JCU) and Dr Col Limpus (DEHP) assisted with study development and design, interpretation of results and editing. Dr Kellie Pendoley (Pendoley Environmental) provided advice regarding light measurements, assisted with interpretation of results and editing. Dr Mike Salmon (FAU) provided advice at several stages of this work.

- Kamrowski RL, Limpus CL, Pendoley K & Hamann M (in review). Influence of industrial light pollution on the sea-finding behaviour of flatback turtle hatchlings. *Wildlife Research.*

In **Chapter 5** I use an existing theoretical constraints framework to explore public engagement, and constraints on engagement, with a light reduction campaign instigated to reduce light glow close to an important loggerhead turtle nesting beach in Queensland, Australia (see Figures 2.3 and 5.2). I collected all of the data, carried out all of the data analysis and wrote the chapter. A. Prof Mark Hamann (JCU) Dr Stephen Sutton (JCU) and Dr Renae Tobin (JCU) assisted with study development, questionnaire design, interpretation of results and editing.

- Kamrowski RL, Sutton SG, Tobin RC & Hamann M (2014). Balancing light at night with turtle conservation? Coastal community engagement with light-glow reduction. *Environmental Conservation*, http://dx.doi.org/10.1017/S0376892914000216.

Chapter 6 goes on to explore methods of increasing light reduction action in the same Queensland coastal community. Specifically, I evaluated the potential for using persuasive communication techniques underpinned by the Theory of Planned Behaviour in future campaign materials to increase community engagement. I collected all of the data, carried out all of the data analysis and wrote the chapter. A. Prof Mark Hamann (JCU) Dr Stephen Sutton (JCU) and Dr Renae Tobin (JCU) assisted with study development, questionnaire design, interpretation of results and editing.

- Kamrowski RL, Sutton SG, Tobin RC & Hamann M (2014). Potential applicability of persuasive communication to light-glow reduction efforts: A case study of marine turtle conservation. *Environmental Management*, **54**, 583-595.

Chapter 7 is a case study which examines light mitigation for turtle conservation in an industrial setting (Barrow Island, see Figure 2.2 for location). I evaluate the success of the implemented lighting management using multiple perspectives (the industry proponent, the industry workforce, the regulator, and other relevant experts), and drivers behind the program's success, or otherwise, are identified. I then develop a conceptual framework for understanding the drivers of successful light management in industry, to provide insights and guide future research efforts. I collected all of the data, fully transcribed all of the interviews, carried out all of the data analysis and wrote the chapter. Dr Stephen Sutton (JCU) and Dr Renae Tobin (JCU) assisted with study development, interview design, interpretation of results and editing. I will submit the framework I conceptualised in this chapter as a short communication:

- Kamrowski RL, Sutton SG, Tobin RC (in prep.) Drivers behind effective industrial light management for marine turtle conservation. To be submitted as a short communication to *Journal of Environmental Research and Development.*

Chapter 8 summarises and discusses the findings from the six data chapters (Chapters 2-7), and goes on to consider the implications of my findings for marine turtle management in Australia, and elsewhere, as coastal development and light pollution increase. I also highlight valuable directions for future research efforts.

Chapter 2

Coastal light pollution and marine turtles: Assessing the magnitude of the problem

In Chapter 1 I identified three knowledge gaps which may hinder management efforts to reduce artificial lighting impacts on marine turtles. The first of these was a lack of broad scale, ecologically relevant studies, precluding effective prioritisation of conservation resources. In this chapter, I address this knowledge gap using GIS analysis. I overlay nesting data onto nighttime light data collected by satellites to identify the marine turtle management units, and nesting regions, which face the greatest light pollution exposure within Australia.

Published manuscript:

Kamrowski RL, Limpus CL, Moloney J & Hamann M (2012) Coastal light pollution and marine turtles: assessing the magnitude of the problem. *Endangered Species Research*, **19**, 85-98.

http://www.int-res.com/abstracts/esr/v19/n1/p85-98/

2.1 ABSTRACT

Globally significant numbers of marine turtles nest on Australian beaches, and the human population of Australia is also heavily concentrated around coastal areas. Coastal development brings with it increases in artificial light. Since turtles are vulnerable to disorientation from artificial light adjacent to nesting areas, the mitigation of disruption caused by light pollution has become an important component of marine turtle conservation strategies in Australia. However, marine turtles are faced with a multitude of anthropogenic threats and managers need to prioritise impacts to ensure limited conservation resources can result in adequate protection of turtles. Knowledge of the extent to which nesting areas may be vulnerable to light pollution is essential to guide management strategies. I use geographical information system analysis to overlay turtle nesting data onto nighttime lights data produced by the NOAA National Geophysical Data Center, to assess the proportion of marine turtles in Australia potentially at risk from light pollution. I also identify the Australian nesting areas which may face the greatest threat from artificial light. My assessment indicates that the majority of nesting turtles appear to be at low risk, but population management units in Western Australia and Queensland are vulnerable to light pollution. The risk to turtles from light generated by industrial developments appears significantly higher than at any other location. Consequently, managers of turtle management units in regions of proposed or ongoing industrial development should anticipate potentially disrupted turtle behaviour due to light pollution. This methodology will be useful to managers of turtles elsewhere.

2.2 INTRODUCTION

Artificial lighting characterises modern human society; however, life on Earth evolved under distinct day-night cycles (Hölker *et al.* 2010a). Light is a principle determinant of organism activity in natural ecosystems (Mills 2008; Bradshaw and Holzapfel 2010), and consequently ecological impacts resulting from human use of light at night have received increasing attention in recent years (e.g. Longcore and Rich 2004; Rich and Longcore 2006; Gaston *et al.* 2013; Lyytimäki 2013). Light pollution causes disruption in multiple taxonomic groups, with nocturnal lights causing changes in critical animal behaviours including orientation, foraging, reproduction and communication (Rich and Longcore 2006). As a result, artificial light at night has been identified as a global environmental change (Lyytimäki 2013) significantly threatening biodiversity (Hölker *et al.* 2010b).

Marine turtles are arguably the best known example of an organism adversely affected by coastal lighting (Witherington and Martin 2000; Salmon 2003). As established in Chapter 1, dependence upon visual brightness cues for 'sea-finding', means the orientation of hatchling marine turtles is disrupted by artificial lighting close to the nesting beach (Witherington and Martin 2000; Tuxbury and Salmon 2005). This can have serious negative consequences for hatchling survival. Protracted periods spent crawling on the beach increase predation risk, as well as wasting the limited energy stores hatchlings possess from their yolk, which are necessary for crucial offshore migration (Salmon 2006; Hamann *et al.* 2007a; Booth and Evans 2011).

Coastal lighting has also been reported to discourage adult females from nesting on particular stretches of beach (Salmon *et al.* 2000). Many marine turtle nesting beaches are located adjacent to human populations, or to areas earmarked for development. As human population centres expand and light levels in coastal regions around the world increase, the availability of naturally dark beaches attractive to nesting females is likely to decrease. This may lead to higher concentrations of nests on beaches deemed dark enough for nesting purposes (Salmon 2006). However, beaches with higher density nesting face a greater likelihood of nest destruction by other nesting females (Bustard and Tognetti 1969) and potentially increased hatchling predation (Pilcher *et al.* 2000; Wyneken *et al.* 2000). In addition, shifts in nesting distribution may take hatchlings away from the oceanographic features which are most favourable for dispersal (Putman *et al.* 2010; Hamann *et al.* 2011).

Most studies concentrating on disruption to marine turtles as a result of artificial lights have been beach specific or limited to one region (e.g. Chapter 1; Witherington 1991; Peters and Verhoeven 1994; Salmon *et al.* 2000; Salmon 2003; Bertolotti and Salmon 2005; Pendoley 2005; Stapput and Wiltschko 2005; Harewood and Horrocks 2008). However, the extent of artificial light usage is visible from space. Global measurements of artificial light have been collected as part of the US Air Force Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) since 1992 (Elvidge *et al.* 2007). These data are freely available from the NOAA's National Geophysical Data Center (NGDC), and consist of cloud-free composites created from multiple nightly orbits by the DMSP satellites each year (Elvidge *et al.* 1997; Elvidge *et al.* 2001). The DMSP images have been employed for a diverse range of studies in recent years (e.g. Aubrecht *et al.* 2008; Nagatani 2010; Badarinath *et al.* 2011), yet few studies have utilised these global datasets with reference to nesting turtles (but see Salmon *et al.* 2000; Ziskin *et al.* 2008).

The wavelengths recorded by the OLS sensor are consistent with wavelengths disruptive to adult and hatchling marine turtles. Both adult and hatchling turtles have been shown to be responsive to wavelengths within the 440 to 700 nm range, with greatest sensitivity at longer wavelengths (approximately 580 nm) for adults (Levenson *et al.* 2004) and from 350 to 540 nm for hatchlings (Witherington and Bjorndal 1991b; Horch *et al.* 2008). The OLS possesses a broad spectral response from 440 to 940 nm, making these datasets a potentially useful tool for the assessment of light pollution impacts on turtle nesting areas (Magyar 2008).

The Australian coastline supports large and globally important marine turtle nesting aggregations (Limpus 2009). However, >80% of Australia's inhabitants live in coastal areas (Hennessy *et al.* 2007), and most of the current population growth, excluding capital cities, is occurring in coastal regions (Luck 2007). Currently, most beaches in northern Australia used by nesting turtles do not experience the same levels of human encroachment (and the associated impacts from light pollution) that have occurred in many other parts of the world (Chatto and Baker 2008; Limpus 2009). However, coastal development in northern Australia is increasing. For example, the southeast portion of Queensland and north Western Australia (WA), both of which support nesting by multiple turtle species (Limpus 2009), are each experiencing rapid urban growth and industrial development (SEQ Catchments 2010; Australian Bureau of Statistics 2012).

In Australia, all marine turtles are protected under the Australian and State Governments' conservation legislation (Limpus 2009), and the disruptive influence of light pollution is widely acknowledged (e.g. Department of Environment and Conservation 2007; Department of Environment and Conservation 2008). Management actions considered necessary to address this issue include the identification of priority areas affected by artificial light. Yet, implementing management strategies can be expensive and time intensive (Fuentes *et al.* 2009). Knowledge of areas at highest risk from light pollution is important to permit management resources to be allocated most effectively (e.g. Fuentes *et al.* 2011).

I used the 2006 Radiance Calibrated Lights dataset from the NGDC to address two specific aims. Firstly, I assessed the proportion of nesting marine turtles within Australia that are exposed to coastal light pollution as it is detected from space. This proportion was assessed at both a national and 'population management unit' scale, since it is important that the severity of threats to specific population units is determined so as to allow targeted management approaches, thereby ensuring that conservation strategies are as effective as possible (Dobbs *et al.* 1999; Wallace *et al.* 2010). Secondly, I identified those nesting areas in Australia which may face the greatest threat from artificial light. This is the first study of its kind. The results will be beneficial for both managers and scientists, since this method allows the identification of nesting locations vulnerable to coastal light pollution at ecologically relevant scales, which can be used in combination with existing on-the-ground data (see Chapter 4) to inform and guide conservation strategies or environmental impact assessments. The methods utilised in this chapter will also prove a useful tool for managers of marine turtles outside of Australia, in any location where limited resources require targeted conservation measures.

2.3 MATERIALS AND METHODS

Study species

Marine turtle nesting beaches occur across the entire northern coast of Australia, from northern New South Wales to Shark Bay in WA. Six of the 7 extant species of marine turtles (loggerhead *Caretta caretta*, green *Chelonia mydas*, hawksbill *Eretmochelys imbricata*, olive ridley *Lepidochelys olivacea*, flatback *Natator depressus*, leatherback turtles *Dermochelys coriacea)* nest in Australia, with only the Kemp's ridley turtle *L. kempii* absent. Nesting and hatchling emergence occur at different times of the year, depending on the species and population management unit (Limpus 2009). Due to the minor and sporadic nesting of leatherback turtles in Australia this species was not included in this analysis.

Data acquisition

I extracted the locations of nesting beaches for all turtle species within Australia from the QDERM (Queensland Department of Environment and Resource Management) turtle database, September 2003. These data consisted of geographical information system (GIS) point shapefiles, with a geographic position (latitude/longitude) for each nesting beach, as well as an estimate of the number of females breeding each year at the beach. The use of adult females, excluding adult males and immature turtles, is a commonly used metric for assessing population units of marine turtles (Heppell *et al.* 2003). The estimates used here are the results of numerous studies (see Limpus 2009 for a review), and are the best known data available. Gaps in the database were filled using expert opinion from Government or industry turtle project staff.

Population genetic structures for green, loggerhead, flatback and hawksbill turtles in Australia have been extensively investigated (Bowen *et al.* 1992; Broderick *et al.* 1994; Dobbs *et al.* 1999; Limpus *et al.* 2000; Dethmers *et al.* 2006; Conant *et al.* 2009; Limpus 2009). Only 1 discrete population management unit of olive ridley turtles was recognised in Australia at the time of this analysis. There are numerous terms in current usage within the scientific literature to describe population units of marine turtles. In this thesis I follow the terminology used by Dethmers *et al.* (2006), and refer to each population unit as a 'management unit'.

I obtained the 2006 DMSP-OLS raster image of radiance-calibrated nighttime light data from the NGDC archive (National Geophysical Data Centre 2006). These data were collected by Satellite F16 and are the most recent radiance-calibrated nighttime light products available. The DMSP satellite flies in a sun-synchronous low earth orbit (833 km mean altitude), and orbits the planet 14 times each day with a broad field of view (approximately 3000 km swath width), allowing complete coverage of the globe to be obtained in every 24 h period. The OLS sensor contains a photomultiplier tube, which intensifies the visible band signal at night, and captures 30 arc second resolution grids. This grid cell size corresponds to approximately 1 km^2 at the equator (Elvidge *et al.* 1997; Aubrecht *et al.* 2010). The nighttime pass occurs between 20:30 and 21:30 h each night (Elvidge *et al.* 2001). Turtle nesting and hatchling emergence occur throughout the night, with peak hatchling emergence occurring between 20:00 and 00:00 h (Limpus 1985; Gyuris 1993). Thus, this time period is suitable for assessing the risk to turtles from artificial lights.

Pre-assessment

The night-light data was obtained in a geographic coordinate system appropriate for global datasets (GCS_WGS_1984). Once the data pertaining to Australia had been extracted using ESRI ArcGIS 9.3.1 (Figure 2.1), the data were transformed into the relevant Australian coordinate system (GCS_GDA_1994), which matched the geographic coordinate system of the nesting data. For each management unit, nightlight and turtle nesting data were then further extracted and projected into the appropriate coordinate system (GDA_1994_MGA_Zone_49 to 56).

Pixel values within the radiance-calibrated lights product were converted into a measure of radiance (watts/m^2/steradian) using a conversion factor provided by the NGDC. The radiance data were converted into luminance data (cd/m^2) to permit a more intuitive measure of nighttime light concentrations, since radiance (a radiometric unit) describes all wavelengths of light emitted by a source, whereas luminance (a photometric unit) is a measure of the electromagnetic radiation detectable by an observer (Palmer 1999).

Converting between radiance and luminance is possible, but observers are not equally sensitive to all wavelengths (Narisada and Schreuder 2004). All photometry is based on the standard visibility curve (CIE 1932) designed for the photopic (light-adapted) vision of humans (Narisada and Schreuder 2004), which peaks at 555 nm. The design of artificial light sources is also related to this curve, since illumination levels generated by most light sources result in light-adapted vision (Zissis *et al.* 2007).

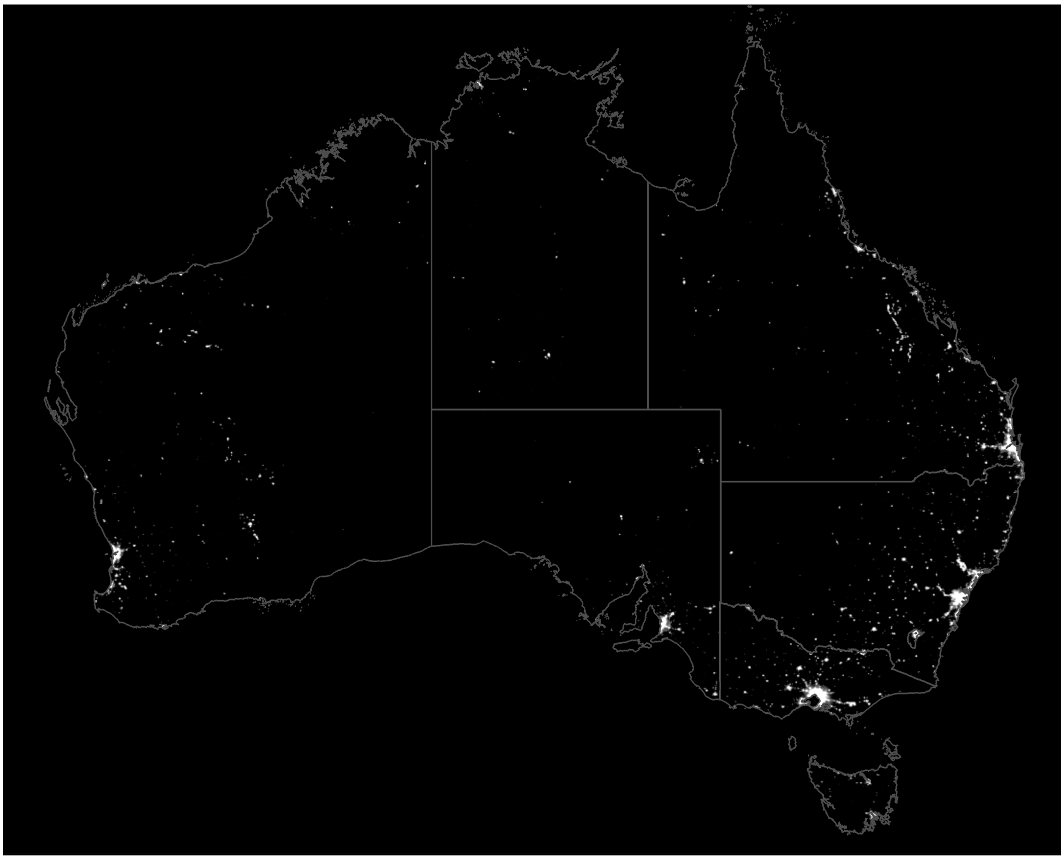

Figure 2.1 Nighttime lights of Australia. Image and data processing of night-light data by NOAA's National Geophysical Data Center. DMSP data collected by the US Air Force Weather Agency.

Recent research has discovered that the visual sensitivity of both adult and hatchling marine turtles show similarities to human vision. Both are sensitive to wavelengths in the visible part of the spectrum, with peak sensitivity found for green wavelengths at approximately 540 nm in hatchlings (Horch *et al.* 2008) and at approximately 580 nm in adults (Levenson *et al.* 2004). At present there is no luminosity function of photopic vision available for turtles; however, given the similarities in visual sensitivity and also the wavelengths recorded by the OLS sensor, for the purposes of the present analysis, it was considered sufficient to convert between the units using values from the spectral luminous efficiency for human photopic vision.

Radiance values were converted into luminance values using the following equation, which represents a weighting of the radiance spectral term for each wavelength in relation to the visual response at that wavelength (Palmer 1999):

$$X_v = K_m \int_0^\infty X\lambda V\lambda \, d\lambda$$

Where: X_V = the luminous intensity (cd/m^2)

K_m = the constant scaling factor (683 for photopic vision, Hentschel (1994))

X_λ = the corresponding radiant intensity (Watts/m^2/ster-nm)

V_λ = the curve for photopic vision

λ = wavelength

Each pixel could then be classified into a level corresponding to a ratio between artificial light and natural nighttime brightness below the atmosphere (Cinzano *et al.* 2001a) (Table 2.1). Natural nighttime brightness varies depending upon numerous factors, including geographical position, solar activity, time from sunset and sky area observed (Cinzano *et al.* 2001b). Since these details were not available for each nesting area, I followed the methodology of Cinzano *et al.* (2001a) and used an average natural nighttime brightness below the atmosphere of 2.52×10^{-4} cd/m^2 (Garstang 1986).

The International Astronomical Union (IAU) recommends that nighttime brightness should not be increased by >10% (approximately 200×10^{-6} cd/m^2) as a result of artificial lighting (Smith 1979). Consequently a 10% increase in night-sky brightness above natural levels is generally accepted as implying light pollution; this corresponds with category 2 shown in Table 2.1.

How bright a light appears to a turtle depends on several spectral characteristics of the light, i.e. light intensity, wavelength and turtle spectral sensitivity (Pendoley 2005). Marine turtle hatchlings are sensitive to very low light intensities across the visible spectrum (Witherington and Bjorndal 1991b), but particularly between violet and green wavelengths (400 to 500 nm). Since the satellite data I used include wavelengths within this range, I reasonably assume that light levels categorised as 'light pollution' in this chapter are visible to turtles. Moreover, given that very little light is necessary to disrupt the orientation of hatchlings (Witherington and Martin 2000), I believe that the threshold of light pollution utilised here is relevant to turtles.

Table 2.1 Quantification of light pollution, using ratios as per Cinzano *et al.* (2001a). The categories and risk values refer to this thesis.

Category (risk value)	Pixel value	Radiance value (watts/m^2/ster)	Luminance value (cd/m^2)	Ratio over natural brightness
1 (0)	0 – 0.6868	0 – $1.03x10^{-12}$	0 – $2.5x10^{-6}$	0 – 0.01
2 (0.01)	0.6868-0.7553	$1.03\ x10^{-12}$ – $1.14x10^{-11}$	$2.5x10^{-6}$ – $2.8x10^{-5}$	0.01 – 0.11
3 (0.11)	0.7553–0.9061	$1.14\ x10^{-11}$ – $3.43x10^{-11}$	$2.8x10^{-5}$ – $8.3x10^{-5}$	0.11 – 0.33
4 (0.33)	0.9061 – 1.36	$3.43\ x10^{-11}$ – $1.03x10^{-10}$	$8.3x10^{-5}$ - $2.5x10^{-4}$	0.33 – 1
5 (1)	1.36 – 2.734	$1.03\ x10^{-10}$ – $3.11x10^{-10}$	$2.5x10^{-4}$ – $7.6x10^{-4}$	1 – 3
6 (3)	2.734 – 6.842	$3.11\ x10^{-10}$ – $9.34x10^{-10}$	$7.6x10^{-4}$ – $2.3x10^{-3}$	3 – 9
7 (9)	6.842 – 19.167	$9.34\ x10^{-10}$ - $2x10^{-9}$	$2.3x10^{-3}$ – $6.8x10^{-3}$	9 – 27
8 (27)	> 19.167	> $2\ x10^{-9}$	> $6.8x10^{-3}$	> 27

Analysis of light proximity to nesting locations

Nesting beaches for each species were overlaid onto the night-light images, and a buffer was drawn around each nesting area. The data collected by the DMSP sensors corresponded to an area greater than that of actual light sources on the ground (Rodrigues *et al.* 2012) due to the phenomenon of 'skyglow', which refers to the dome of light projected upwards and outwards from urban areas at night (Chalkias *et al.* 2006). Skyglow is considered to contribute significantly to ecological impacts from light pollution (Rich and Longcore 2006; Kyba *et al.* 2011). For example, light generated by an aluminium refinery in Queensland, Australia, disrupted marine turtle orientation 18 km away (Hodge *et al.* 2007). Consequently, to take potential effects of skyglow from urban areas into account, but allowing for small location inaccuracies in overlaying transformed and projected data layers, I followed the methodology used by Aubrecht *et al.* (2008) and used a buffer with a radius of 25 km.

Given the low spatial resolution of the nighttime light data (Elvidge *et al.* 1997), as well as other factors which may influence the impact of artificial lights close to nesting beaches, such as barriers, cloud cover and moon phase (Salmon and Witherington 1995; Witherington and Martin 2000; Kyba *et al.* 2011), two measures were used to estimate the potential risk of light pollution faced by each species of nesting turtle - as a means of avoiding false precision. The buffer (25 km radius) surrounding each nesting area encompassed approximately 2400 pixels, each of which possessed a value corresponding to the amount of light emitted in that area. The mean and maximum pixel values within each buffer were calculated using the zonal statistics tool and Hawth's Tools extension (Beyer 2004) in ArcGIS. These values were then assigned into one of the light pollution categories (as per Cinzano *et al.* 2001a) using the values given in Table 2.1. This gave two potential risk values for each nesting area: 'mean light exposure' calculated from the mean pixel value and 'maximum light exposure' calculated from the maximum pixel value. Using the maximum pixel value provides an indication of the highest amount of light potentially visible to turtles at each site, and as such is the high-risk scenario. The mean pixel value was calculated across the entire area encompassed by each buffer, to effectively 'smooth out' the amount of artificial light emitted in that area (since light levels will be highest in areas where bright lights are located, decreasing as distance from the light source increases), hence providing a diffuse measure of light pollution within a particular buffer area. This was used to provide a secondary measure of risk given that nesting turtles may not be directly exposed to the highest levels of light present in the immediate area, but would still likely be susceptible to skyglow effects.

Next, to determine the nesting areas potentially at highest risk from light pollution for each species and management unit, I calculated the percentage nesting that occurred at each nesting location, both nationally and within each management unit. Then I weighted each location for potential risk, by multiplying the percentage nesting by the mean and maximum light exposure risk values, to give two potential measures of exposure to light pollution (presented as median values $\pm$ standard deviations).

Data analysis

Data were tested for normality using the Kolmogorov-Smirnoff test. Since data were not found to be normally distributed, comparisons of light exposure between population management units were assessed using the Mann-Whitney *U*-test and the Kruskall-Wallis test. Post hoc pairwise comparisons of the latter were carried out using Dunn-Bonferroni tests (Dunn 1964). All data were analysed using IBM SPSS 20 statistical software.

2.4 RESULTS

National light pollution exposure

Nesting areas for loggerhead, green, hawksbill and flatback turtles in Australia appear to be exposed to varying degrees of light pollution (Table 2.2). However, despite the broad geographic scale of impact, the majority of marine turtle nesting areas in Australia appear minimally affected by either level of light pollution exposure (Table 2.2).

Management unit light pollution exposure

The above analysis was repeated with the species nesting area data merged into management units (Bowen *et al.* 1992; Broderick *et al.* 1994; Dobbs *et al.* 1999; Limpus *et al.* 2000; Dethmers *et al*. 2006; Limpus 2009; Wallace *et al*. 2010).

Table 2.2 The proportion of nesting in Australia, by each species, potentially at risk from each category of light pollution, using the mean (mean light exposure) and maximum (maximum light exposure) pixel value from the radiance calibrated light data within a buffer of 25 km radius from each nesting area (Cc: loggerhead; Cm: green; Ei: hawksbill; Lo: olive ridley; Nd: flatback).

Ratio over natural brightness	Light pollution category	% Cc nesting		% Cm nesting		% Ei nesting		% Lo nesting		% Nd nesting	
		Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean
0 – 0.01	1	61.08	89.5	73.81	85.35	35.58	74.44	90.25	100	32.09	75.93
0.01 – 0.11	2	0	0	0	0	0	0	0	0	0	0.02
0.11 – 0.33	3	0	0	0	0.05	0	0	0	0	0	0.16
0.33 – 1	4	0	0.29	0	2.71	0	0.35	0	0	0	21.07
1 – 3	5	0	0.29	0	11.79	0	25.22	0	0	0	1.21
3 – 9	6	9.04	9.33	0.48	0.07	4.87	0	9.3	0	3.39	1.56
9 – 27	7	9.18	0.58	2.86	0.005	12.88	0	0.45	0	19.1	0.06
> 27	8	20.7	0	22.85	0	46.67	0	0	0	45.42	0
Total % exposed to light pollution		38.92	10.5	26.19	14.65	64.42	25.56	9.75	0	67.91	24.07

Loggerheads

There are 2 management units of loggerheads in Australia: the WA management unit, which occurs from Dirk Hartog Island to the Muiron Island region, and the eastern Australian management unit, which is concentrated on the mainland coast of southeast Queensland, the islands in the southern Great Barrier Reef (GBR) and minor nesting beaches in New Caledonia and Vanuatu (Limpus 2009).

Using the maximum light exposure values, I found more than a third of nesting WA loggerheads and 43.9% of the eastern Australian loggerheads were potentially exposed to light pollution (Table 2.3). Indeed a maximum light pollution weighting of 461.54 occurred for WA loggerheads (307.7 ± 217.6), which is significantly higher than the maximum weighted exposure for eastern Australian loggerheads (max. = 80.6; median = 8.06 ± 31.76; Mann-Whitney $U = <1$, $n_1 = 2$, $n_2 = 30$, $p < 0.05$).

However, when using the mean light exposure values, I found that, although the WA loggerheads appeared relatively unaffected by light pollution, 22% of the nesting areas for the eastern Australian management unit had a light pollution exposure weighting of 8.96 (2.7 ± 3.84); thus the beaches are potentially at risk from light pollution (Table 2.3).

Greens

There are 7 recognised green turtle management units in Australia (Dethmers *et al.* 2006). Only a small percentage of nesting areas for 3 of the management units were determined to be potentially at risk from light pollution (Table 2.3). The exception to this was the North West Shelf management unit in WA, which showed a large proportion of nesting beaches potentially at risk from both levels of light exposure (39% of the North West Shelf green turtle nesting areas highlighted using the mean light exposure values, and 68%, using the maximum light exposure values).

There was a statistically significant difference between the maximum light exposure of the 3 green turtle management units indicated as exposed to light pollution (Kruskal-Wallis $X^2(3, n = 40) = 23.07$, $p < 0.01$). Pair-wise comparisons indicated that risk of light pollution for nesting turtles on the North West Shelf (658.54; 197.6 ± 196.03) was significantly higher than for all other green turtle management units. Also, in eastern Australia, the risk of light pollution for green turtles nesting in the southern GBR stock (16.93; 1.69 ± 6.96) was significantly higher than for the northern GBR stock (0.33; 0.22 ± 0.15).

Using the mean light exposure values, green turtles nesting in the North West Shelf (24.39; 0 ± 8.1) were exposed to a significantly higher potential risk from light pollution compared to green turtles in the GBR (northern GBR: 0.11; 0.07 ± 0.05; southern GBR: 1.88; 0.19 ± 0.62) (Kruskal-Wallis $X^2(2, n = 13) = 7.67$, $p < 0.01$).

Table 2.3 The proportion of each management unit of marine turtle in Australia located in nesting areas potentially exposed to artificial lights brighter than the threshold level of light pollution i.e. light exposure of category 2 or above (see Table 2.1).

Species	Population management unit	Mean light exposure; % nesting above light pollution threshold, category 2 and higher (using mean pixel value)	Maximum light exposure; % nesting above light pollution threshold, category 2 and higher (using maximum pixel value)
Loggerhead	Western Australia	0	34.2
	Eastern Australia	21.5	43.9
Green	North West Shelf	39	68.3
	Scott Reef	0	0
	Ashmore Reef	0	0
	Gulf of Carpentaria	0	4.5
	Northern GBR	< 1	< 1
	Coral Sea	0	0
	Southern GBR	2.2	3.8
Hawksbill	Western Australia	54.5	99.8
	Gulf of Carpentaria	3.5	41.5
	Northern GBR & Torres Strait	0	31.4
Olive ridley	Northern Australia	0	9.8
Flatback	North West Shelf	59.06	87.4
	Western Northern Territory	0	0
	Gulf of Carpentaria & Torres Strait	< 1	61
	Eastern Australia	24.2	50.1

Hawksbills

Three hawksbill turtle management units are recognised in Australia (Broderick *et al.* 1994; Dobbs *et al.* 1999; Limpus *et al.* 2000). Using the maximum light exposure values, a large proportion of all 3 were potentially exposed to light pollution (Table 2.3). Most notable was hawksbill nesting in WA, for which 99.8% of nesting appeared to be exposed. The maximum light pollution weighting for hawksbills in WA (1225.42; 673.98 $\pm$ 636.75) was significantly higher than for hawksbills in the Gulf of Carpentaria (53.05; 17.68 $\pm$ 18.12), and for hawksbills in the Torres Strait and northern GBR (84.59; 0.85 $\pm$ 21.99) (Kruskal-Wallis $X^2(2, n = 46) = 23.88$, $p < 0.01$).

When employing the mean light exposure values, a large proportion of hawksbill nesting in WA remained highlighted as being at potential risk from light pollution, with an exposure weighting of 45.39 (4.54 $\pm$ 23.58), but the other management units were not determined to be at significant potential risk. The small sample size of affected locations precluded statistical analysis, but the medians indicated that the WA management unit remains at higher risk from light pollution than hawksbills nesting in northern Australia.

Olive ridleys

When this analysis was taking place, there was only one recognised management unit of olive ridley turtles in Australia (Limpus 2009). The nesting areas for this management unit appeared relatively unaffected by light pollution. The mean light exposure values indicated that none of the nesting areas appeared to be exposed to light pollution, and, using the maximum light exposure values, only 4 out of 25 nesting areas (9.8% of nesting olive ridleys) were potentially exposed to light pollution of categories 6 and 7 (Table 2.3).

Flatbacks

Four flatback turtle management units were recognised in Australia during this analysis (Limpus 2009). Flatback turtles which nest in the western Northern Territory appeared largely unexposed to light pollution (Table 2.3). However, for the other 3 management units when using the maximum light exposure values, large nesting proportions appeared potentially at risk from light pollution, whereas only the North West Shelf and eastern Australia management units were identified to be at potential risk when employing the mean light exposure values.

The maximum light exposure values gave a maximum weighting of 637.8 for flatback turtles on the North West Shelf (330 $\pm$ 294.3). This was significantly higher than exposure weightings obtained for flatback turtles nesting in either the Gulf of Carpentaria and Torres Strait (97.69; 1.51 $\pm$ 13.58) or eastern Australia (94.57; 4.73 $\pm$ 23). Eastern Australian locations appeared significantly more light-exposed than Gulf of Carpentaria and Torres Strait nesting areas (Kruskal-Wallis $X^2(2, n = 115) = 49.58$, $p < 0.01$). When using the mean light exposure values, flatback nesting areas on the North West Shelf appeared to be exposed to significantly more light pollution (23.62; 4.78 $\pm$ 9.46) than nesting areas in eastern Australia (5.25; 0.53 $\pm$ 1.98) (Mann-Whitney $U = 16$, $n_1 = 4$, $n_2 = 39$, $p < 0.01$).

Region

For each species with multiple management units within Australia, it was the management units nesting in WA that were exposed to the highest levels of light pollution (Table 2.4). In particular the Dampier Archipelago, Barrow Island, Montebello Islands and Cape Range Ningaloo were identified as potential high-risk nesting areas for >1 species (Figures 2.2 and 2.3).

Table 2.4 The top three marine turtle management units in Australia potentially exposed to light pollution, using the mean (mean light exposure) and maximum (maximum light exposure) pixel value.

Most light-exposed population management units	Mean light exposure	Maximum light exposure
1	North West Shelf flatback turtles	Western Australian hawksbill turtles
2	Western Australian hawksbill turtles	North West Shelf flatback turtles
3	North West Shelf green turtles	North West Shelf green turtles

2.5 DISCUSSION

Marine turtles spend 100% of their critical breeding life-history phase (egg laying, incubation and hatchling emergence) out of the water on beaches. Moreover, turtles migrate from dispersed foraging grounds to aggregate at these breeding sites (e.g. Limpus *et al.* 1992). Thus, effective, long-term conservation strategies require the protection of these developmental habitats (Troëng and Rankin 2005). Since successful turtle nesting is strongly hindered by the presence of artificial light (Witherington and Martin 2000) and the effective management of light pollution adjacent to turtle nesting areas may be both expensive and time-intensive (e.g. Fuentes *et al*. 2009), the identification of nesting areas at greatest risk from light pollution is crucial to ensure that limited conservation resources are allocated most effectively (e.g. Fuentes *et al*. 2011).

I used satellite imaging as a broad scale tool for the identification and comparison of nesting locations potentially vulnerable to coastal light pollution at ecologically relevant scales. An important caveat to this research, given the coarse spatial scale of the dataset utilised, is that beachfront lighting in an otherwise undeveloped area may not register in the satellite data, but would retain the potential to disrupt turtle nesting (Witherington and Martin 2000). However, lights from very small residential settlements (populations of < 300 people) in remote regions of Australia - including islands of the Torres Strait where no industry or commercial entities exist -

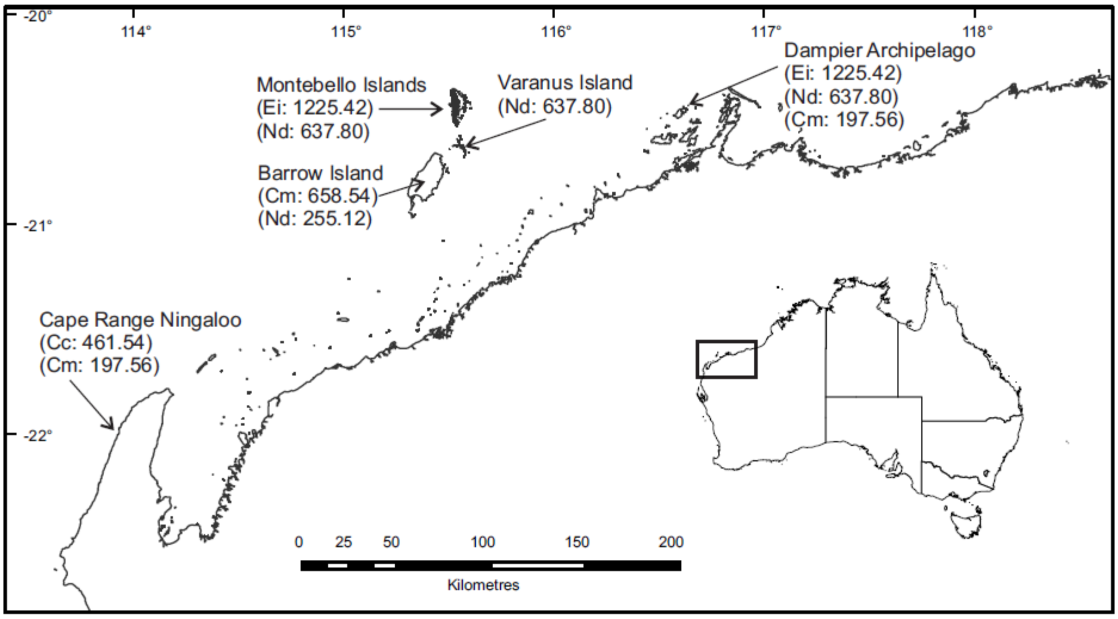

Figure 2.2 The 10 nesting areas (by species) in Australia potentially at highest risk from **maximum light exposure** (maximum pixel values), with light pollution exposure values (% nesting x risk value) in brackets. (Cc: loggerhead; Cm: green; Ei: hawksbill; Nd: flatback).

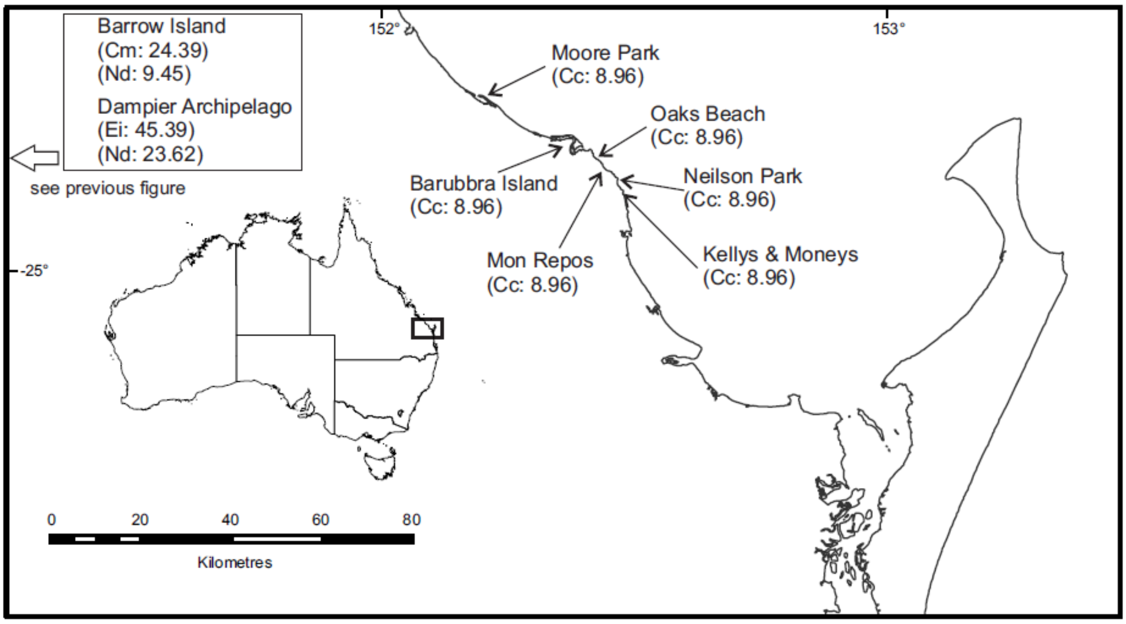

Figure 2.3 The 10 nesting locations (by species) in Australia potentially at highest risk from mean light exposure (mean pixel values), with light pollution exposure values (% nesting x risk value) in brackets. (Cc: loggerhead; Cm: green; Ei: hawksbill; Nd: flatback).

were picked up by the satellite data. Therefore, it is unlikely that significant sources of potentially disorienting light exist in Australia which were not identified here.

Furthermore, an examination of my data in light of evidence regarding the beach-scale impact of light pollution in Australia supports the value of my methodology. I determined that nesting areas on the North West Shelf of WA and along the Woongarra coast of Queensland were those facing the highest potential risk from light pollution Australia-wide, with nesting areas in northern Australia appearing to be minimally exposed to light pollution. In his comprehensive review of marine turtles within Australia, Limpus (2009) evaluated the threat of light pollution for each species of turtle, using data and observations from researchers working on-the-ground. Reflecting my data, Limpus (2009) found no evidence of turtles disrupted by artificial light in northern Australia, but highlighted the Woongarra coast of Queensland and the North West Shelf in WA as areas where disorientation of hatchlings regularly occurred due to the presence of artificial lights. Consequently, the method I have presented offers a useful means of highlighting particular regions, over a large spatial scale, where marine turtle nesting may be at risk from light pollution. My method also allows for the magnitude of potential light pollution risk to be compared across nesting areas. Once potentially high-risk nesting locations for management units have been identified, the next step for managers should be an on-the-ground assessment to confirm the risk identified by the broad scale analysis presented here, and to subsequently determine necessary beach-specific management actions.

Overall my findings indicate that there is large spatial variation in levels of coastal light pollution across Australia, which might be expected to cause disruption to marine turtles. Although the majority of marine turtle nesting in Australia appears to be minimally affected by light pollution, large proportions of nesting hawksbill, flatback, green and loggerhead turtles do appear to be exposed to light pollution, especially in WA and along the urban coast of Queensland. Moreover, turtles nesting at these locations are potentially exposed to light substantially brighter than natural nighttime brightness, with most affected nesting areas potentially exposed to light pollution of category 5 or higher (Table 2.1; > 1 to 3 times brighter than natural nighttime brightness). This is important because ecological and behavioural studies have found that hatchling disorientation can be caused by very low levels of artificial light (Witherington and Martin 2000). The pervasive levels of light pollution I found would be expected to disrupt turtle orientation in these locations.

Certain management units appear to face extreme potential risk, with 99.8% of hawksbill turtle nesting areas and 87.4% of flatback turtle nesting areas in WA determined to be at risk from light pollution. This is substantially higher than previous estimates of 12 and 42% for hawksbill and flatback turtles respectively, in the region of the Barrow, Lowendal and Montebello Islands of WA (Pendoley 2005). However, where I calculated exposure within an area 25 km in radius from the nesting beach, Pendoley (2005) considered the effect of lights within a radius of 1.5 km - a conservative radius considering the distance over which lights have been known to disrupt turtle behaviour on land (Hodge *et al*. 2007) and may potentially affect hatchling behaviour in the sea. Turtle hatchlings swim slowly, covering only 1.5 km/h or less (Frick 1976; Salmon and Wyneken 1987). However, swimming hatchlings show oriented swimming behaviour for longer than 24 h (Salmon and Wyneken 1987) and, in the absence of wave cues to guide them offshore, have been found to be more susceptible to disorientation from onshore light cues (Lorne and Salmon 2007). Consequently, in the absence of wave cues, artificial lights may influence the orientation of swimming hatchlings over distances >1.5 km. The high proportion of hawksbill and flatback turtle nesting areas in WA which I identify as being at potential risk highlights the need for management and policy approaches that consider synergistic and cumulative impact.

I found that within Australia a few nesting areas in WA, which support nesting by multiple species, appear to be the locations most vulnerable to light pollution - namely the Dampier Archipelago, the Montebello Islands, Varanus Island and Barrow Island. The presence of light pollution at these sites is well known. This is one of WA's, and indeed Australia's, most productive regions for resource extraction, processing and shipping, with 59% of WA's oil and 93% of WA's gas being produced on the North West Shelf (Department of Environment and Conservation 2007). Artificial lights and flares from hydrocarbon industrial plants have been categorised as a current major pressure on turtles in this region (Pendoley 2000; Environment Australia 2003; Department of Environment and Conservation 2007; Environmental Protection Agency 2010), and State Government legislation, plus industry-specific management plans, are in place to regulate the of use of appropriate lighting by existing and future industry (Department of Environment and Conservation 2007; Department of Environment and Conservation 2008; Chevron Australia 2009; Environmental Protection Agency 2010; BHP Billiton 2011).

Despite acknowledgement of the existence of light pollution in this region, I demonstrate that nesting area exposure to light pollution may be far higher in WA than elsewhere in Australia, and, collectively, it could impact turtles at ecological scales, since multiple nesting beaches appear affected within turtle management units. This indicates that rigorous light pollution management is vital, particularly given the importance of the turtle management units which nest here. The WA management units of hawksbill, green, loggerhead and flatback turtles are globally significant for their respective species (Seminoff 2002; Mortimer and Donnelly 2008). Moreover, my results are conservative due to use of light data from 2006; since that time development of the region has continued; and in the next chapter (Chapter 3) I explore the temporal change in exposure.

In one recent liquefied natural gas (LNG) development, the proponents were legally obliged under ministerial conditions attached to their Australian Government approval to develop management plans for marine turtles and develop and implement mitigation plans for light pollution (see Chapter 7). Under these plans, site-specific light pollution is audited annually (Chevron Australia 2009). Yet, although light pollution in this region seems to be being addressed by individual producers at site-specific scales (e.g. Spooner and Clifford 2008; Chevron Australia 2009; BHP Billiton 2011), the cumulative effect of extreme light levels over a small geographic region, or as it relates to specific turtle management units, is not addressed by State or Australian Government legislation or policy (Department of Environment and Conservation 2008).

I also found that nesting areas in eastern Australia appeared to be at high risk from light pollution, particularly in the case of loggerhead turtles along the Woongarra coast of southeast Queensland. Interestingly these nesting locations were only identified as being at high potential risk when using the mean light exposure values, i.e. the mean pixel value within the 25 km buffer. This suggests that light pollution in eastern Australia may be characterised by areas of widespread, moderate levels of light pollution from dispersed urban settlements, as opposed to small areas of high levels of localised light pollution from intense industrial development on an otherwise relatively unsettled coastline in WA. This has implications for management in that it may be more economically and logistically feasible to implement light mitigation in WA, by targeting small areas of high light pollution produced by a limited number of contributors, rather than targeting a larger area producing moderate levels of light pollution, with multiple contributors (e.g. Fuentes *et al.* 2011; see also Chapters 5, 6 and 7).

Industrial development is increasing along the eastern Australian coast, as well as in other turtle nesting locations worldwide, including Qatar (Tayab and Quiton 2003) and India (Fernandes 2008). Given my findings, which suggest that the amount of light pollution produced by similar existing industrial developments in WA may pose a very high risk to nesting marine turtles, the adequate management of light generated by proposed and ongoing industrial developments should be considered extremely important by managers and policy makers (Chapter 7). One of the challenges currently faced by industry, regulators and researchers involved with turtle conservation is the lack of monitoring tools to examine low, ecologically relevant, light levels, or tools to test the effects of skyglow (but see Pendoley *et al.* 2012).

By virtue of the collection method, only nighttime light levels on cloud-free nights are represented by the satellite data (Elvidge *et al.* 2001). However, cloud cover substantially increases skyglow, since unused light escaping upwards into the atmosphere is reflected back down to Earth by clouds (Kyba *et al.* 2011). Thus, light pollution levels, and the subsequent impacts of this light at turtle nesting beaches on cloudy nights, may be even higher than suggested by my findings.

2.6 CONCLUSIONS

Light pollution is an indisputable problem for marine turtles, and, given existing and continuing coastal development along many of the world's turtle nesting beaches, it is also likely to be a pervasive issue. Studies investigating the impacts of light pollution on marine turtles are numerous; yet, since most of this research is beach or region specific, understanding the risks posed to breeding marine turtles at a management unit scale, from light generated by different producers, has not been possible.

This study is the first of its kind. The methodology I present provides a useful first step for effectively managing the disruptive influence of light pollution on marine turtles, at an ecologically relevant scale. The large spatial scale used emphasises the significant risk that concentrated light produced by industrial developments, and diffuse light generated by urban complexes, may pose to nesting marine turtles. I also highlight the regions of Australia where turtle nesting appears to be at highest risk from light pollution, namely southern nesting areas on both the west and east coasts, with nesting beaches in northern Australia least affected. This knowledge will be invaluable for effectively prioritising conservation effort focused on mitigation of lighting impacts on marine turtles.

However, globally our use of artificial light is increasing (Elvidge *et al.* 2011; Pestalozzi *et al.* 2013), therefore understanding where marine turtles are exposed to artificial light is not fully sufficient for effective lighting management. We also need to understand how artificial light levels at nesting beaches are changing over time, and thus temporal changes in light levels close to nesting areas was the focus of the following chapter.

Chapter 3

Temporal changes in artificial light exposure of marine turtle nesting areas

Chapter 2 identified that all marine turtle species in Australia are vulnerable to light pollution, with turtles nesting on the North West Shelf in Western Australia, and along the Woongarra coast of Queensland, having the greatest potential exposure. However, the environment is not static. Natural processes and anthropogenic pressures are constantly evolving, and recent studies have shown that levels of artificial lighting have increased in most countries over the last two decades. Consequently, effective management requires more than an understanding of where turtles are exposed to light pollution. We also need to understand how light levels at nesting beaches are changing over time. This chapter examines temporal trends in artificial lighting close to Australian marine turtle nesting areas, and the broad, ecologically-relevant scale used here further addresses the knowledge gap identified in Chapter 1 relating to a lack of existing broad scale studies.

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3.1 ABSTRACT

Artificial light at night poses a significant threat to multiple taxa across the globe. In coastal regions, artificial lighting close to marine turtle nesting beaches is disruptive to their breeding success. Prioritising effective management of light pollution requires an understanding of how the light exposure of nesting areas changes over time in response to changing temporal and spatial distributions of coastal development. I analysed multi-temporal, satellite night-light data, in combination with linear mixed model analysis, to determine broad scale changes in artificial light exposure at Australian marine turtle nesting areas between 1993 and 2010. I found seven marine turtle management units (MU), from five species, have experienced significant increases in light exposure over time, with flatback turtles nesting in east Australia experiencing the fastest increases. The remaining 12 MUs showed no significant change in light exposure. Unchanging MUs included those previously identified as having high exposure to light pollution (located in Western Australia and southern Queensland), indicating that turtles in these areas have been potentially exposed to high light levels since at least the early nineties. At a finer geographic scale (within-MU), nine MUs contained nesting areas with significant increases in light exposure. These nesting areas predominantly occurred close to heavily industrialised coastal areas, thus emphasising the importance of rigorous light management in industry. Within all MUs, nesting areas existed where light levels were extremely low and/or had not significantly increased since 1993. With continued coastal development, nesting females may shift to these darker/unchanging ‘buffer’ areas in the future. This is valuable information which informs our understanding of the capacity and resilience of marine turtles faced with coastal development: an understanding that is essential for effective marine turtle conservation.

3.2 INTRODUCTION

As widely distributed and long-lived species, effective marine turtle conservation depends on an understanding of when and where threats occur, at broad, ecologically-relevant scales (Wallace *et al.* 2010; Wallace *et al.* 2011). Numerous studies document the disruptive impacts of artificial lighting on marine turtles, however as mentioned in Chapters 1 and 2, most of these have been beach- or region-specific (e.g. Peters and Verhoeven 1994; Bertolotti and Salmon 2005; Pendoley 2005; Tuxbury and Salmon 2005; Lorne and Salmon 2007; Harewood and Horrocks 2008). While these smaller scale studies are necessary, in Chapter 2 I demonstrated that remotely-sensed data could be used to quantify marine turtle nesting area exposure to light pollution, at broader spatial scales relevant to management (see also Mazor *et al.* 2013). Since conservation resources are often limited (Fuentes *et al.* 2009), such spatial knowledge of where marine turtles are likely to be exposed to light pollution is important for priority setting.

Yet, with ongoing and changing anthropogenic pressures and natural processes, the environment is in a state of constant evolution (Lyytimäki *et al.* 2012). Recent studies using nighttime satellite data have shown that levels of artificial lighting around the world have increased (sometimes dramatically so) in many countries over the past two decades (Elvidge *et al.* 2011; Pestalozzi *et al.* 2013). Furthermore, human population growth and urban expansion has occurred more rapidly in coastal regions than elsewhere (Nicholls 1995), and this trend is expected to continue across the globe (Turner *et al.* 1996), making coastlines extremely vulnerable to development and light pollution problems (Bird *et al.* 2004).

As described in the preceding chapters, the presence of artificial light adjacent to nesting beaches can disrupt hatchling sea-finding ability (Salmon 2006), and can also constrain nest site selection by adult females, with nesting density decreasing on beaches exposed to artificial lights (Witherington 1992; Salmon *et al.* 1995). With continued coastal development across the globe, there will likely be fewer suitable beaches dark enough to be attractive to nesting females. This is of serious concern in view of other major threats to turtle nesting grounds; first coastal modifications for industrial, residential, recreational and aesthetic (e.g. beach cleaning) purposes (Defeo *et al.* 2009) are likely to influence current and future nesting habitats, and second a changing climate is predicted to limit, or require a shift in, turtle nesting due to increased temperatures, cyclonic activity, sea-level rise, and altered oceanographic patterns (Hawkes *et al.* 2009; Fuentes *et al.* 2010; Witt *et al.* 2010; Fuentes *et al.* 2011; Hamann *et al.* 2011). Moreover, coastal development and climate change are not mutually exclusive – the sea level rise expected to occur as a result of climate change is likely to provoke an upsurge in coastal modifications through protective armouring, which in turn will impact beach erosion (Defeo *et al.* 2009). As such, an understanding of marine turtle exposure to the adverse consequences of coastal development is essential for effective conservation of marine turtle populations (Hamann *et al.* 2010).

Consequently, knowledge of *where* marine turtles are exposed to artificial light (Chapter 2) is not sufficient. An understanding of how artificial light levels at nesting beaches *change over time* is also necessary for investigating the capacity and resilience of marine turtles in the face of coastal development. In this chapter I examined temporal changes in artificial lighting at marine turtle nesting areas in Australia, using multi-temporal, nighttime light satellite data, freely available from NOAA's National Geophysical Data Center (NGDC) (Elvidge *et al.* 2007), and spanning the years 1992-2010.

I addressed two aims: firstly, I determined the temporal trend in artificial light exposure for all marine turtle species that nest in Australia, at a population management unit (MU) scale, to identify the turtle MUs within Australia with the greatest exposure to increasing light over time. Secondly, since marine turtles do not necessarily show absolute fidelity to individual nesting beaches, instead generally choosing to nest on beaches occurring within a particular region (Miller *et al.* 2003; Dethmers *et al.* 2006; Pfaller *et al.* 2009), each MU was examined at a finer scale to determine which nesting areas for each MU had the highest, and fastest changing exposure to artificial light, as well as those areas least exposed to artificial light. This information is useful since future coastal development may lead to nesting females shifting to these darker 'buffer' areas. As such, my methods and findings will permit more focused management and conservation actions aimed at protecting marine turtles around the world.

3.3 MATERIALS AND METHODS

Study area and species

As described in Chapter 2, five species of marine turtles (loggerhead *Caretta caretta*, green *Chelonia mydas*, hawksbill *Eretmochelys imbricata*, olive ridley *Lepidochelys olivacea*, and flatback *Natator depressus)* nest in abundance on Australia's tropical and/or subtropical beaches. In this chapter, I primarily follow the same MU groupings as in Chapter 2 (Table 3.1). However, while this chapter was being completed, more recent genetic analyses confirmed that olive ridleys consisted of two separate MUs (Jensen *et al.* 2013), and had also suggested that flatbacks nesting at Cape Domett in Western Australia may be a single breeding stock, separate from both the North West Shelf and western Northern Territory MUs (Commonwealth of Australia 2012). Nesting data for each species and MU was obtained from the Queensland Turtle Conservation Project database in September 2012.

Table 3.1 Change in artificial light exposure for marine turtle management units in Australia between 1993 and 2010. Management units where light levels changed significantly during this period are shown in bold.

Species	Management unit (MU)	Slope (light change over time)	Std error	Significant change
Loggerhead	**Western Australia**	**0.095**	**0.03**	**Yes (t_{16} = 3.18, p < 0.01)**
	East Australia	0.588	0.304	No (p = 0.071)
Green	North West Shelf	-0.272	0.3	No (p = 0.37)
	Scott Reef	0	-	No change
	Ashmore Reef	0	-	No change
	Gulf of Carpentaria	0.033	0.016	No (p = 0.06)
	Northern GBR	**0.102**	**0.05**	**Yes (t_{16} = 2.14, p < 0.05)**
	Coral Sea	0	-	No change
	Southern GBR	0.26	0.17	No (p = 0.15)
Hawksbill	Western Australia	-0.017	0.1	No (p = 0.87)
	Northern Territory and Gulf of Carpentaria	0.045	0.027	No (p = 0.12)
	Torres Strait and Northern GBR	**0.064**	**0.017**	**Yes (t_{16} = 3.78, p < 0.01)**
Olive ridley	**Northern Territory**	**0.007**	**0.002**	**Yes (t_{16} = 3.78, p < 0.01)**
	Northern Queensland	**0.02**	**0.0071**	**Yes (t_{16} = 2.74, p < 0.05)**
Flatback	North West Shelf	0.026	0.41	No (p = 0.95)
	Cape Domett	0	-	No change
	Western Northern Territory	0.0025 (from 2005 on)	0.002	No (p = 0.24)
	Gulf of Carpentaria	**0.14**	**0.033**	**Yes (t_{16} = 4.14, p < 0.001)**
	East Australia	**1.52**	**0.63**	**Yes (t_{16} = 2.4, p < 0.05)**

Nighttime light data

The version 4 time series of global Stable Lights, was obtained from the NGDC (collected as part of the US Air Force Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS), downloaded from: http://ngdc.noaa.gov/eog/download.html in September 2012). These data consist of large, grid-based GeoTIFF images of the Earth's surface at night, created annually from between 20 and 100 cloud-free observations, and showing the relative OLS visible band intensities of lit regions across the globe (Baugh *et al.* 2010). The image data have a spatial resolution of 30 arc seconds, giving a grid-cell size of approximately one square kilometre at the equator (Elvidge *et al.* 2011). The data have 6-bit quantization (Sutton *et al.* 1997), and the amount of light recorded in each pixel is given a digital number (DN) value between 0 and 63 (with 63 being the maximum amount of recorded light). The OLS is sensitive to wavelengths of light between 440 and 940 nm, and the typical nighttime satellite pass occurred between 20:30 and 21:30 h local time (Elvidge *et al.* 2001). As discussed in the previous chapter, since both adult and hatchling turtles respond to wavelengths between 440 and 700 nm (Witherington and Bjorndal 1991b; Levenson *et al.* 2004; Horch *et al.* 2008; Fritsches 2012), and both oviposition and hatchling emergence occur throughout the night (with hatchling emergence peaking between 20:00 h and midnight) (Limpus 1985; Gyuris 1993), these datasets are valuable for assessing marine turtle exposure to artificial light.

Data preparation

The global nighttime light datasets (1992-2010) were clipped to the Australia region using ESRI ArcGIS 10, transformed into the relevant Australian coordinate system (GCS_GDA_1994), and then the nighttime lights and the turtle nesting datasets were subsequently clipped and projected into the correct coordinate system (GDA_1994_MGA_Zone_49 to 56).

Turtle nesting areas were grouped according to MU for Aim 1 (see Limpus 2009) (Figure 3.1, solid and hatched circled areas). For Aim 2, nesting areas within MUs were grouped together either geographically or according to the importance of the area to the MU overall (Tables 3.2-3.6; Figure 3.1, black dots and arrows). Marine turtles have temperature-dependent sex determination (Yntema and Mrosovsky 1980; Miller and Limpus 1981), thus the sex ratio of produced hatchlings is strongly influenced by sand albedo (Hays *et al.* 2001). In Australia, mainland beaches are often characterised by darker sand than island beaches, thus mainland beaches tend to be warmer and female-producing (Limpus 1985) and island beaches tend to be cooler and male-producing (Poloczanska *et al.* 2009). Since marine turtle population viability depends upon recruitment of both sexes into the adult breeding population, which in turn is dependent upon the thermal environment existing at nesting areas within each MU, nesting area importance was based on the sex ratio of produced hatchlings, as well as the number of annual nesting females (Heppell *et al.* 2003). I primarily followed the within-MU nesting area groupings described in Limpus (2009) (see Tables 3.2-3.6).

Table 3.2 Change in artificial light exposure for **loggerhead** turtle nesting areas in Australia between 1993 and 2010. Nesting area groupings where light levels changed significantly during this period are shown in bold (*increase; ^decrease). Nesting area importance, in this and subsequent tables, was determined based on both the number of nesting females and the sex ratio of produced hatchlings.

Management unit (MU)	Nesting area grouping	Importance for MU	Light change equation	Std error: slope (intercept)	Significant slope	Relative amount of light
Western Australia	Dirk Hartog Island	major	NA: no light			
	Ashmore Reefs	minor	NA: no light			
	Mainland (inc. Ningaloo & Gnaraloo)	moderate	0.13 + 0.004x	0.003 (0.04)	No ($p = 0.12$)	Higher than zero ($t_{16} = 3.45$, $p < 0.01$)
	Dampier Archipelago	**minor**	**1.88 + 0.044x**	**0.02 (0.31)**	**Yes* ($t_{16} = 2.14$, $p < 0.05$)**	**Higher than Mainland ($t_{32} = 11.63$, $p < 0.001$)**
East Australia	Woongarra Coast	major	2.24 + 0.015x	0.02 (3.43)	No ($p = 0.52$)	Higher than at Wreck Rock ($t_{48} = 36.21$, $p < 0.001$)
	Capricorn-Bunker islands	major	NA: no light			
	Swain Reefs	major	NA: no light			
	Wreck Rock	**major**	**0.02 + 0.005x**	**0.001 (0.02)**	**Yes* ($t_{16} = 3.92$, $p < 0.01$)**	Not different to zero ($t_{16} = 1.04$, $p = 0.31$)
	Sunshine Coast-New South Wales	**minor**	**4.17 + 0.05x**	**0.01 (0.22)**	**Yes* ($t_{16} = 3.2$, $p < 0.01$)**	**Higher than other MU groupings ($t_{48} = 13.22$ to 36.32, $p < 0.001$)**

Table 3.3 Change in artificial light exposure for **green** turtle nesting areas in Australia between 1993 and 2010. Nesting area groupings where light levels changed significantly during this period are shown in bold (*increase; ^decrease).

Management unit (MU)	Nesting area grouping	Importance for MU	Light change equation	Std error: Slope (intercept)	Significant slope	Relative amount of light
North West Shelf	North West Shelf Islands	major	1.96 - 0.057x	0.56 (11.3)	No ($p = 0.22$)	Higher than Ningaloo Region ($t_{32} = -16.87$, $p < 0.001$)
	Lacepede Islands	major			NA: no light	
	Ningaloo region	major	0.144 + 0.005x	0.006 (0.79)	No ($p = 0.42$)	
Gulf of Carpentaria	Eastern Groote Eyland	moderate	0.008 + 0.0002x	0.0004 (0.006)	No ($p = 0.6$)	Higher than Eastern Arnhem land ($t_{32} = 3.04$, $p < 0.01$). Not different to zero ($t_{16} = 1.38$, $p = 0.19$)
	Wellesley Islands	moderate			NA: no light	
	Eastern Arnhem Land	moderate	0.0009 – 0.00002x	0.0001 (0.002)	No ($p = 0.83$)	Not different to zero ($t_{16} = 0.62$, $p = 0.54$)
Northern GBR	Major rookeries (Raine Island, Moulter Cay)	major			NA: no light	
	Major rookeries Sandbanks 7 & 8)	major			NA: no light	
	Minor rookeries	**minor**	**0.23 + 0.002x**	**0.0008 (0.11)**	**Yes* ($t_{16} = 2.14$, $p < 0.05$)**	
Southern GBR	Capricorn-Bunker Islands	major			NA: no light	
	Swain Reefs	major			NA: no light	
	Bushy Island & Percy Is. Group	moderate			NA: no light	
	Mainland south of Gladstone	minor	1.304 + 0.016x	0.014 (2.1)	No ($p = 0.26$)	Not different to zero ($t_{16} = 0.62$, $p = 0.54$)

Table 3.4 Change in artificial light exposure for **hawksbill** turtle nesting areas in Australia between 1993 and 2010. Nesting area groupings where light levels changed significantly during this period are shown in bold (*increase; ^decrease).

Management unit (MU)	Nesting area grouping	Importance for MU	Light change equation	Std error: slope (intercept)	Significant slope	Relative amount of light
Western Australia	Dampier Archipelago	major	1.41 + 0.035x	0.02 (0.27)	No ($p = 0.06$)	Lower than North West Shelf Islands in 1993, but higher by 2010 ($t_{48}= 2.96$, $p < 0.01$)
	Other North West Shelf Islands	**major**	**1.85 - 0.06x**	**0.01 (0.16)**	**Yes^ ($t_{16} = -5.24$, $p < 0.001$)**	**Higher than Mainland ($t_{48}= 21.1$, $p < 0.001$)**
	Mainland	minor	0.181 + 0.005x	0.01 (0.73)	No ($p = 0.68$)	Not different to zero ($t_{16} = 0.25$, $p = 0.81$)
Northern Territory & Gulf of Carpentaria	Outer Islands of English Company inc. Truant Island	moderate	NA: no light			
	Mainland & Bremer Island	**minor**	**0.427 + 0.0074x**	**0.003 (0.04)**	**Yes* ($t_{16} = 2.76$, $p < 0.05$)**	**Higher than Groote Eyland ($t_{32} = 16.17$, $p < 0.001$)**
	Groote Eyland (& associated Islands)	major	0.05 - 0.0002x	0.0007 (0.01)	No ($p = 0.75$)	
Torres Strait and Northern GBR	**Dayman, Long & Hawksbury Islands**	**major**	**0.121 + 0.0028x**	**0.0005 (0.01)**	**Yes* ($t_{16} = 5.48$, $p < 0.001$)**	**Higher than minor rookeries ($t_{32} = 11.41$, $p < 0.001$)**
	Minor Rookeries (dot on Fig 3.1c indicates the approx. centre of all rookeries which span latitude -9.8667 to -10.7400	minor	0.027 + 0.0005x	0.0003 (0.005)	No ($p = 0.11$)	

Table 3.5 Change in artificial light exposure for **olive ridley** turtle nesting areas in Australia between 1993 and 2010.

Management unit (MU)	Nesting area grouping	Importance for MU	Light change equation	Std error: slope (intercept)	Significant slope	Relative amount of light
Northern Territory	NA: All nesting areas of major or moderate nesting numbers registered either very low or no light					
Northern Queensland	Northwestern Cape York	major	0.06 + 0.002x	0.001 (0.016)	No ($p = 0.06$)	Higher than zero ($t_{16} = 4.01$, $p < 0.01$)

Table 3.6 Change in artificial light exposure for **flatback** turtle nesting areas in Australia between 1993 and 2010. Nesting area groupings where light levels changed significantly during this period are shown in bold (*increase; ^decrease).

Management unit (MU)	Nesting area grouping	Importance for MU	Light change equation	Std error: slope (intercept)	Significant slope	Relative amount of light
North West Shelf	North West Shelf Islands	major	2.32 - 0.067x	0.05 (18.4)	No ($p = 0.23$)	
	Mainland	**major**	**0.497 + 0.0501x**	**0.02 (4.2)**	**Yes* ($t_{16} = 2.23$, $p < 0.05$)**	**Higher than Mainland areas in 1993, but approx. same by 2010 ($t_{32} = 8.91$, $p < 0.001$)**
Gulf of Carpentaria	Crab & Deliverance Islands	major	0.002 + 0.00015x	0.0003 (0.0002)	No ($p = 0.57$)	Not different to zero ($t_{16} = 0.49$, $p = 0.63$)
	Wellesley Islands	moderate			NA: no light	
	East Gulf of Carpentaria	**major**	**0.062 + 0.0026x**	**0.0004 (0.01)**	**Yes* ($t_{16} = 6.14$, $p < 0.001$)**	**Higher than Crab & Deliverance ($t_{48} = 7.96$, $p < 0.001$). Higher than zero ($t_{16} = 6.14$, $p < 0.001$)**
	West Gulf of Carpentaria	moderate	0.0223 - 0.00002x	0.0003 (0.005)	No ($p = 0.95$)	Higher than Crab & Deliverance ($t_{48} = 5.69$, $p < 0.001$)
East Australia	Gladstone region	minor	3.78 + 0.037x	0.02 (0.27)	No ($p = 0.07$)	Higher than all other MU groupings (t_{64} = -42.9 to -22.7, $p < 0.001$)
	Peak, Wild Duck and Avoid Islands	**major**	**0.05 + 0.0018x**	**0.0007 (0.01)**	**Yes* ($t_{16} = 2.71$, $p < 0.05$)**	**Lower than all other MU groupings (t_{64} = 33.7 to 36.7, $p < 0.001$)**
	North of Rockhampton (inc Townsville & Mackay)	**minor**	**1.71 + 0.019x**	**0.007 (0.11)**	**Yes* ($t_{16} = 2.59$, $p < 0.05$)**	**No difference compared to areas South of Gladstone ($t_{64} = 1.17$, $p = 0.24$)**
	South of Gladstone (inc Woongarra)	minor	1.68 + 0.013x	0.02 (1.78)	No ($p = 0.46$)	

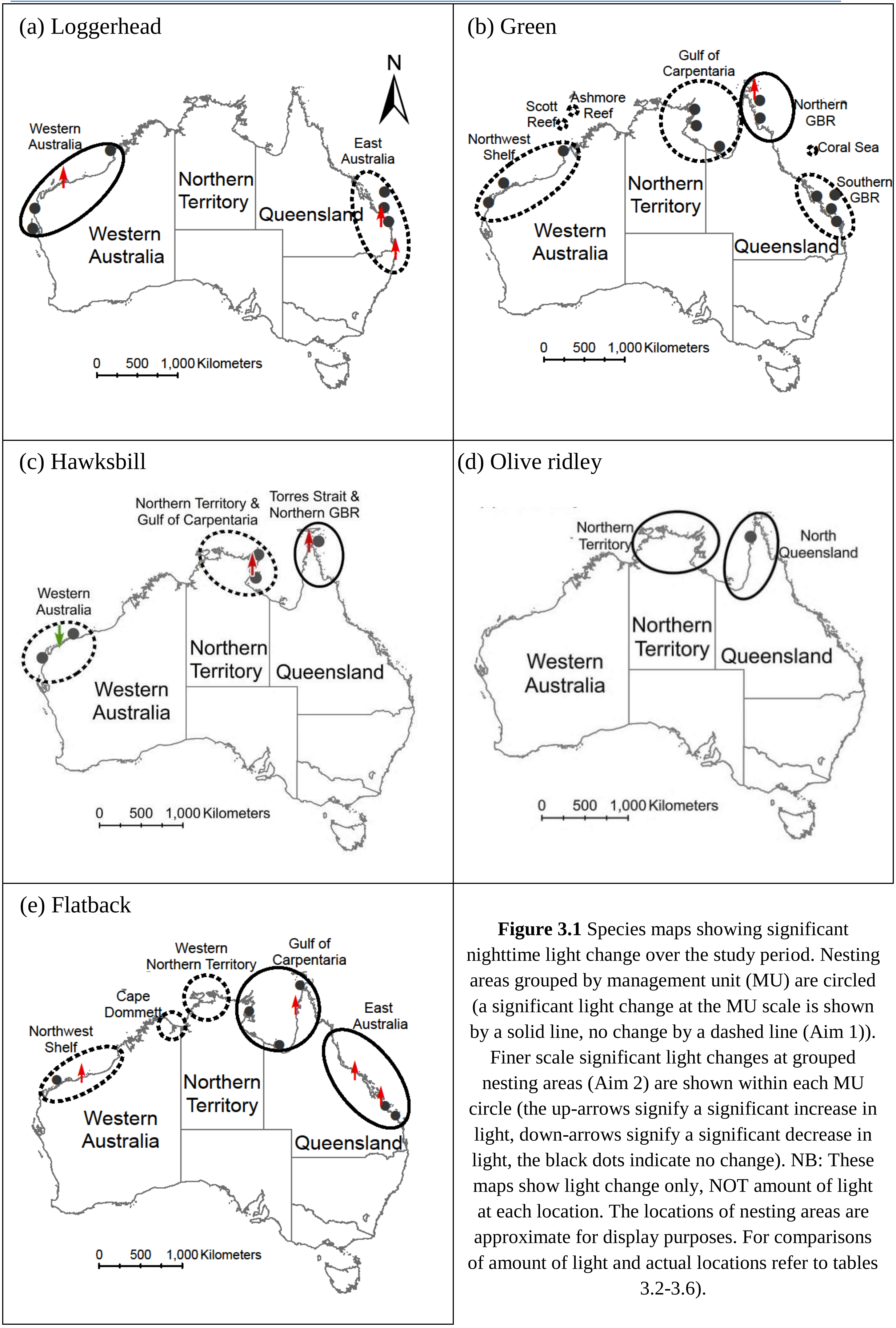

Figure 3.1 Species maps showing significant nighttime light change over the study period. Nesting areas grouped by management unit (MU) are circled (a significant light change at the MU scale is shown by a solid line, no change by a dashed line (Aim 1)). Finer scale significant light changes at grouped nesting areas (Aim 2) are shown within each MU circle (the up-arrows signify a significant increase in light, down-arrows signify a significant decrease in light, the black dots indicate no change). NB: These maps show light change only, NOT amount of light at each location. The locations of nesting areas are approximate for display purposes. For comparisons of amount of light and actual locations refer to tables 3.2-3.6).

Inter-calibration of nighttime lights imagery

The stable lights data were collected by six different satellites over 19 years. The OLS does not have an on-board calibration system (Elvidge *et al.* 2011), and sensor degradation occurs over time. Thus direct comparisons of light levels collected by different sensors and in different years are unreliable (Pestalozzi *et al.* 2013). However, since data from two satellites is available in most years, an inter-calibration procedure to reduce these yearly variations and sensor differences has been documented (Elvidge *et al.* 2009; Elvidge *et al.* 2011). This second-order regression model using coefficients provided by Christopher Elvidge at NOAA (C. Elvidge, personal communication) was applied.

Although the inter-calibration procedure substantially reduces inter-year variability, it does not completely remove it. This variability is largely due to spatial uncertainty and 'overglow' (Small and Elvidge 2011). I did not examine temporal changes in the spatial extent of light, but instead reduced light values for each nesting area to one value (mean) within a buffer area, thus I consider the inter-calibrated dataset suitable for describing broad scale changes in light levels at nesting areas over time. As a further measure to reduce variability, I also consulted with experts at NOAA to determine the optimum satellite data to use, after inter-calibration, for each year of the analysis (Appendix 1).

Light proximity to nest location

Nesting locations were overlaid onto each year's nighttime lights data, and a buffer of radius 25 km drawn around each (Chapter 2; Aubrecht *et al.* 2008). This buffer region contained approximately 2400 pixels, each with a DN value consistent with the amount of artificial light existing in that area. For Aim 1, I calculated the mean annual DN value occurring in each buffer zone using Geospatial Modelling Environment (Version 0.7.2.0) (Beyer 2012). I then summed the mean annual values for each nesting area (i.e. each of the buffer areas) within an MU to examine and compare trends in artificial light between MUs (Aim 1). For Aim 2, since I wanted to compare both trend in artificial light levels over time, as well as differences in the levels of light existing between nesting-area groupings within each MU, I calculated the mean DN and standard deviation of each nesting area's buffer zone (as above), then calculated weighted means, pooled variances and separate standard errors for each nesting-area grouping (Miloslav *et al.* 2012) to allow comparisons.

Estimation of rates of change in nighttime lights

For each MU, I used the slope of the linear regression of average light level against year, as a measure of the rate of increase in average light level for that MU over the study period (Aim 1).

However, slope estimation was complicated by the existence of significant autocorrelation between successive years in most MUs, and by the fact that 1992 was an outlier in all locations. I therefore omitted the 1992 data from the analyses and used a restricted maximum likelihood (REML) algorithm available in the lme package for SPlus 8.2 to fit the regression. This allowed incorporation of autocorrelation effects (AR(1)) in the model. With the inclusion of autocorrelation, residuals were homogeneous and normally distributed.

To examine differences in nighttime light trends between nesting area groupings within each MU (Aim 2), I re-analysed the whole data set using nesting area location as an additional fixed effect. This allowed comparisons of both slope (rate of change) and intercept (amount of light at the start of the study period) to be made. There appeared to be some heterogeneity of variance between nesting area locations, so the model was fitted with and without allowing for heterogeneity of variance between locations, with the optimum model (based on the Akaike Information Criteria (AIC)) (Ngo and Brand 1997) selected for use.

3.4 RESULTS

Management unit scale light change over time (Aim 1)

Artificial light levels increased significantly over the study period in at least one MU for each species of turtle (Table 3.1 in bold, Figure 3.1 solid circled areas). Namely, loggerhead turtles in Western Australia (WA), green turtles in the northern Great Barrier Reef (GBR), hawksbill turtles in the Torres Strait and northern GBR, all olive ridley turtles, and flatback turtles in east Australia and the Gulf of Carpentaria.

No light was recorded at green turtle Ashmore Reef or Coral Sea MU nesting areas, or for flatback turtles nesting at Cape Domett, across the entire study period. For green turtles nesting at Scott Reef, a small amount of light registered in 2008, but did not appear again in 2009 or 2010. In addition, no light registered in the flatback turtle western Northern Territory MU until 2005, and from 2005 onwards the low light levels did not change significantly. As a result these five MU's were deemed to have low exposure to artificial light and excluded from further analysis.

Comparisons between slopes of MUs with a significant change over time (Table 3.1 in bold, Figure 3.1 solid circled areas) indicated that the rate of light increase was significantly higher for flatbacks in eastern Australia than for any other MU in Australia (t_{112} = -3.52 to –3.97, $p < 0.001$). Olive ridley turtles had the lowest significant slope values of all the MUs, and further analysis showed that the light increase was significantly slower in the two olive ridley MUs compared to all other MUs with significantly changing light levels (Northern Territory: t_{112} =

2.35 to 4.55, $p < 0.05$; Northern Queensland: $t_{112} = -2.46$ to 3.93, $p < 0.05$). Light change was significantly slower for Northern Territory olive ridleys compared to olive ridleys in Northern Queensland ($t_{112} = -2.46$, $p < 0.001$), making Northern Territory olive ridleys the MU with the slowest increase in artificial light over the study period. There was no significant difference in the rate of light increase between flatbacks in the Gulf of Carpentaria and Western Australian loggerheads, northern GBR greens and Torres Strait and northern GBR hawksbills ($t_{112} = -0.7$ to -1.38, p = 0.17 to 0.48).

Finer scale light change over time (Aim 2)

Nighttime light changes in nesting area groupings (see arrow icons Figure 3.1), and comparisons between groupings are given for each species in Tables 3.2-3.6. Loggerhead, hawksbill, and flatback turtles all experienced significant light increases in nesting area groupings within multiple MUs (Tables 3.2, 3.4, 3.6). The fastest increase in nighttime lights over the study period occurred for North West Shelf flatback turtles which nest along the mainland in Western Australia (slope: 0.05), closely followed by east Australian loggerhead nesting along the southeast Queensland coast (Sunshine coast down to northern New South Wales: slope = 0.046), and Western Australian loggerhead nesting in the Dampier Archipelago (slope: 0.044).

However in every MU, light levels in at least half of the nesting area groupings were not found to have increased significantly between 1993 and 2010. Green turtles were the least exposed species to increasing light levels over time, with only minor rookeries in the northern GBR MU showing a significant increase in light during the study period. Olive ridley turtles were also found to have a low level of exposure to increasing light over time; indeed in the Northern Territory MU all nesting areas of major or moderate nesting numbers registered low levels or no light over the study period. Since exposure to artificial light in this MU appeared extremely low, no finer scale analysis was deemed necessary.

3.5 DISCUSSION

Global nighttime light pollution has dramatically increased in recent years (Cinzano *et al.* 2001a; Narisada and Schreuder 2004; Chalkias *et al.* 2006; Smith 2008; Hölker *et al.* 2010b); yet environmental management of this threat has lagged behind that of other pollutants (Hölker *et al.* 2010b). Knowledge of how artificial lighting is changing at marine turtle nesting beaches over time, at ecologically relevant scales, is vitally important to determine the resilience and adaptive capacity of marine turtles faced with coastal development, and thus inform and guide effective management efforts (e.g. Fuentes *et al.* 2013). In this chapter I used multi-temporal satellite data to examine trends in exposure of marine turtle nesting areas in Australia to artificial light levels, at broad, ecologically-relevant scales.

At a management unit scale, levels of artificial light increased significantly between 1993 and 2010 in at least one MU for each species of turtle (Table 3.1 bold, Figure 3.1 solid circles). The fastest increase in light occurred for flatbacks in east Australia, an increase which was significantly faster than for any other MU in Australia and thus warrants particular conservation attention from managers, particularly in light of the proposed industrial development of the Queensland coast (UNESCO 2012; Grech *et al.* 2013). In Chapter 2, I found that light pollution exposure at turtle nesting areas along the northern coast of Australia may be lower than at higher latitudes on both the west and east coasts. Yet data from this chapter suggest that at this broad scale, levels of artificial light are generally increasing faster at northern nesting areas (particularly in northern Queensland), and as such proactive management strategies should be considered in these areas to prevent light levels reaching potentially disruptive levels.

Artificial lighting did not change significantly over the study period for the majority of marine turtle MUs, despite the population of Australia growing by at least 1% every year (Heard 2013). At first glance this appears positive, however as discussed in Chapter 2, marine turtle exposure to light pollution was significantly higher at nesting areas in the North West Shelf of WA and southeast Queensland, than elsewhere in Australia. The fact that light levels in these regions have not changed significantly for most species over time indicates that these nesting turtles have likely been exposed to high levels of light pollution since at least 1993, and although the level of exposure to light pollution has not increased, neither has it decreased. As long-lived animals taking decades to reach maturity (Heppell *et al.* 2003), potential population-level impacts from sustained exposure to artificial lighting at nesting beaches, if present, will take several decades to become evident in the next generation (e.g. Mortimer 1989). Moreover determining the long-term impact of artificial light exposure for marine turtles in these areas is compounded by the fact that many MUs, particularly in northern and Western Australia, suffer from incomplete nesting population surveys and/or a lack of long-term census data (Limpus 2009) which will make assessing the long-term temporal impacts of artificial light on nesting populations difficult.

The lack of change in artificial lighting found in the present study supports the finding of Elvidge *et al*. (2011) that Australia is characterised by ‘stable lighting’ despite population and economic growth. This finding was attributed to the development of more efficient lighting and improved lighting design (Narisada and Schreuder 2004). However, advances in lighting technology are also expected to shift artificial lighting to shorter wavelength lights (e.g. LEDs) (Kyba *et al.* 2012). Since the OLS sensor is only responsive to wavelengths between 440 and

940 nm (Cinzano *et al*. 2001), it is possible that light has actually continued to increase around Australia, but the newer, shorter wavelength LED lights are not registering in the data. This is of particular concern with regards to impacts on marine turtles since hatchling turtles preferentially respond to shorter wavelength light from the near ultraviolet part of the spectrum (Witherington and Bjorndal 1991b; Pendoley 2005; Fritsches 2012). While the advantages posed by a satellite system capable of collecting multispectral nighttime lights data have been recognised (Elvidge *et al*. 2007), the technology is still under development (Elvidge *et al.* 2010). To the best of my knowledge, the nighttime lights data used here is the only large scale, multi-temporal dataset available for this region for the time period under consideration, and my findings thus provide a valuable baseline for future comparisons as sensor technology improves.

My second chapter aim was to determine trends in levels of artificial light at a finer geographic scale. Marine turtles show fidelity to natal regions, but not necessarily specific beaches (Miller *et al.* 2003). Thus nesting populations may shun beaches deemed too bright for nesting purposes in favour of other, darker beaches in the same region. Knowledge of where and how light levels have changed within an MU is important to allow predictions of where future shifts in nesting may occur. I determined that the regional nesting areas with the fastest changing light over time were those of flatback turtles along the mainland of the North West Shelf (WA), loggerhead turtles in the Dampier Archipelago (WA) and loggerhead turtles on the east coast of Australia from the Sunshine Coast south to New South Wales.

The mainland coast of the North West Shelf (particularly around Karratha and Port Hedland), and the Dampier Archipelago are both areas which support heavy industry (Drenth 2007). Industrial expansion is also likely to be the cause of the significant light increases in the nesting area groupings of more northern MUs. Significant light increases occurred for Gulf of Carpentaria hawksbill turtles at mainland and Bremer Island nesting areas, and for Gulf of Carpentaria flatback turtle major nesting areas. Light increases for these hawksbills are likely to be a result of light from mining operations and associated urban development, located nearby at Nhulunbuy in the Northern Territory, which is the site of a growing bauxite mine and alumina refinery (Northern Territory Government 2011). Similarly, the growth of the mining towns of Weipa and Napranum in far north Queensland accounted for much of the light growth for the major flatback nesting areas.

The significant change in light for the north Queensland MU of olive ridleys is also due in part to the growth of Weipa and Napranum. At a finer nesting scale this light change was not found to be significant (Table 3.5), and low levels of light exist in this area compared to other MUs, however the very small size of this olive ridley population (Jensen *et al*. 2013) indicates that proactive light management strategies may be warranted at the nesting beaches of this MU.

Within the MU with the fastest changing nighttime light levels (flatback turtles in east Australia), the significant change over time was found to occur at the major rookeries (primarily Peak Island) and at other minor rookeries north of Rockhampton. This is of concern because light levels at these nesting areas were found to be significantly lower than for nesting beaches in the Gladstone region, and although light levels at Gladstone were not found to have changed significantly between 1993 and 2010, substantial industrial expansion is planned for this area (Jones *et al.* 2005; Grech *et al.* 2013), including the construction of several liquefied natural gas (LNG) plants on Curtis Island, just offshore from Gladstone. Thus further increases in artificial light are likely within this MU, and should a shift in nesting away from the brightly lit Gladstone area occur, the areas with the least light at present (the major rookeries) have seen significant increases in light exposure (see Chapter 4).

Australia’s coastline is undergoing rapid industrialisation, particularly in Western Australia (WA) and Queensland (Condie 2007; Greenpeace Australia 2012). As such, the finding that industrial expansion and associated urban development can significantly increase light levels over a relatively short period, supports my conclusions in Chapter 2 that rigorous light management should be a crucial component of industrial environmental management, particularly when these developments occur in close proximity to marine turtle nesting areas (see also Chapter 7).

Surprisingly, light levels at nesting areas within MUs on the heavily industrialised islands of the North West Shelf in WA were either unchanged over the study period (green and flatback turtles) or had significantly decreased (hawksbill turtles). This might be due in part to the methodology I used here. The satellite data I used is characterised by spatial uncertainty (Small and Elvidge 2011), and thus I employed a buffer region around each nesting area of 25 km (see Aubrecht *et al.* 2008, and Chapter 2 for justification) and calculated one measure of light for each buffer region for each year of the analysis. I did not examine changes in the spatial extent of lights over time. As such the amount of light produced in the North West Shelf region as a whole may have increased without changes in light necessarily indicated within nesting-area buffer regions. However, the lack of change at these nesting areas may also be partly due to the individual industrial management plans implemented to address light pollution (e.g. Spooner and Clifford 2008; Chevron Australia 2009; BHP Billiton 2011), in recognition of the disruptive effect of light as a major pressure on turtles (Pendoley 2000; Department of Environment and Conservation 2007; Environmental Protection Agency 2010). This research does indicate that implementing mitigation measures may contribute towards successfully limiting levels of artificial light produced (see Chapter 7). However, as industry continues to grow in WA (Condie 2007), a continued decrease in light here is unlikely. Furthermore, it must be borne in mind that in Chapter 2, this region was found to be the most light-exposed portion of Australia for nesting turtles, and on the whole light levels here remained high for the entire period under examination.

Loggerhead nesting in southeast Queensland was also previously identified as having high levels of exposure to light pollution (Chapter 2). This analysis indicated that light levels along the Woongarra coast did not change significantly over the study period (Table 3.2). However, southeast Queensland is currently undergoing rapid urban growth (SEQ Catchments 2010; Australian Bureau of Statistics 2011), and thus light levels may increase in the near future. Two nesting regions within this MU (the Capricorn-Bunker Islands and the Swain Reefs) did not register any light for the duration of the study period, providing a large potential dark ‘buffer’ region, should nesting shift in response to high light levels. However, the finding that the highest and fastest increasing light levels in this MU occur at higher latitudes (along the Sunshine coast of Queensland and into northern New South Wales) is of concern. In a changing climate, nesting for loggerhead turtles in this MU is anticipated to potentially shift southwards into these areas (Hamann *et al.* 2007b). A combination of both climate change and artificial lighting may severely constrain nesting area selection for this MU in the future.

Finally, of all the species which nest in Australia, green turtles appear to be the species with the lowest exposure to changing light over time (Table 3.3). Moreover, all species and MUs were found to have nesting areas which registered very low light levels or had no light increases over the study period. With continued coastal development, nesting females may shift to these darker or unchanging ‘buffer’ areas in the future. This is valuable information which informs our understanding of the capacity and resilience of marine turtles faced with coastal development, and can be used by managers for effective priority setting and conservation planning.

Again, I must acknowledge the coarse spatial scale of the data used. Although it is unlikely that significant sources of potentially disorienting nighttime light exist without registering in the data (see Chapter 2 discussion), I am aware that no light was picked up for green and loggerhead turtles which nest in the Capricorn-Bunker Islands, despite disorientation of hatchlings being recorded due to lights at the small Heron Island and Lady Elliott Island resorts (C. Limpus personal communication). As such, whilst my data are useful for broad scale assessments, on-the-ground assessment should also be conducted to confirm the levels of exposure identified here, as well as to determine appropriate management strategies.

Future assessments of marine turtle light pollution exposure, as well as changes in light over time, will benefit from ongoing advances in satellite technology. Nighttime light data in 2012 was collected using a visible infrared imaging radiometer suite (VIIRS) satellite sensor

(Schueler *et al.* 2002). The VIIRS system offers several distinct advantages over data collected using DMSP-OLS, namely much higher spatial resolution and a sensitivity to much lower levels of light at night (Hillger *et al.* 2013). However, for assessing how light has already changed at marine turtle nesting areas, I demonstrate that the DMSP-OLS multi-temporal nighttime lights data is a valuable tool for informing the effective management of marine turtles potentially exposed to the disruptive influence of artificial lighting.

3.6 CONCLUSIONS

The biological world is primarily driven by light (Bradshaw and Holzapfel 2010), thus the increasingly widespread use of artificial light at night is considered a serious and significant global issue (Hölker *et al.* 2010b; Lyytimäki 2013). Marine turtle survival across the world is at risk from light pollution (Witherington 1999), and coastal development close to marine turtle nesting areas is likely to escalate as the human population continues to expand. Knowledge of where turtles are exposed to artificial lights, in combination with knowledge of how that lighting is changing over time, is necessary to enable an accurate evaluation of both the ecological consequences of artificial light, and the effectiveness of conservation responses (e.g. Iovanna and Vance 2007). My unique approach will therefore be of interest and value to managers worldwide who are concerned with disruptive impacts of artificial lighting.

Similar to Chapter 2, my findings in this chapter once again highlight the significant contribution of industrial lighting to the potential light exposure of Australian marine turtle nesting areas. Since I used remotely-sensed data in both chapters to reach this conclusion, an on-the-ground assessment was necessary to confirm the adverse impact of industrially-produced light exposure for Australian marine turtles. Therefore an assessment of hatchling sea-finding ability close to large scale industrial development was the focus of Chapter 4.

Chapter 4

Influence of industrial light pollution on the sea-finding behaviour of flatback turtle hatchlings

The second knowledge gap that my thesis aimed to address was the lack of population-specific studies which have focused on the orientation and sea-finding behaviour of Australian turtles, particularly in response to light pollution (Chapter 1). The broad scale analyses presented in Chapters 2 and 3 highlighted the significant contribution of industrial light to the increasing light exposure of nesting beaches across Australia, and Chapter 3 also demonstrated that light exposure increased significantly faster for east Australian flatbacks than any for any other Australian turtles. However on-the-ground assessments were deemed necessary to confirm the deleterious effect of this light exposure for marine turtles. Thus in this chapter I evaluated flatback hatchling sea-finding ability in areas of proposed or ongoing industrial development in Queensland.

The following submitted manuscript is based on this chapter:

Kamrowski RL, Limpus CL, Pendoley KL & Hamann M (in review) Influence of industrial light pollution on the sea-finding behaviour of flatback turtle hatchlings. *Wildlife Research.*

4.1 ABSTRACT

Numerous studies have demonstrated the disruptive influence of artificial light for sea-finding in marine turtle hatchlings, yet relatively few studies have examined sea-finding in flatback turtles. All known flatback nesting beaches occur within Australia: a country where coastal areas are undergoing rapid industrialisation. Given the large potential for disruption posed by industrial light adjacent to nesting beaches, this is a timely investigation into flatback hatchling sea-finding at two key Queensland rookeries in regions of proposed or ongoing industrial development. Sea-finding was assessed using a combination and comparison of fan and arena methods, and relative light levels at each site were measured using an Optec SSP-3 stellar photometer. Hatchling time of emergence was also assessed using a drift-fence and pit-trap system. There was no evidence of impaired hatchling orientation, and very low levels of light observed at Peak Island. However at Curtis Island, hatchlings displayed reduced sea-finding ability, with light horizons from the direction of nearby industry significantly brighter than other directions. Hatchling time of nest emergence was found to be later than reported for other populations and species. Skyglow produced by large scale industrial development appears detrimental to flatback hatchling sea-finding. As development continues around Australia's coastline, I strongly recommend rigorous management of industrial lighting, which considers cumulative light levels in regions of multiple light producers, as well as moon phase, moon-stage, cloud cover and hatchling time of emergence. All of these factors affect the likelihood of disrupted hatchling sea-finding behaviour at nesting beaches exposed to artificial light-glow, industrial or otherwise.

4.2 INTRODUCTION

Neonate marine turtles surfacing from underground nests must reach the ocean with minimal delays. This ability is dependent upon visual cues (Lohmann *et al.* 1997; Witherington and Martin 2000); hatchlings evaluate their surroundings by scanning the visible horizon and crawling towards areas of low horizon elevation and brighter light (Limpus 1971; Limpus and Kamrowski 2013), and away from areas of high, dark elevation (Salmon *et al.* 1992). Artificial lighting close to the nesting beach can mask a hatchling's ability to see natural light horizons and hence disrupt sea-finding (see Chapters 1 and 2; Witherington and Martin 2000; Tuxbury and Salmon 2005), with potentially severe consequences. A protracted period on the beach reduces the likelihood of hatchling survival due to predation or dehydration (Witherington and Martin 2000). Moreover, disrupted beach crawls may inhibit calibration of the turtles' internal magnetic compass or prevent correct compass calibration, resulting in hatchlings swimming in incorrect directions once they reach the sea (Lorne and Salmon 2007). Problematic light sources include those directly visible to hatchlings, such as streetlights (Sella *et al.* 2006), but skyglow from indirect sources of light can also influence hatchling behaviour (Salmon *et al.* 1995; Salmon 2006). As described previously, skyglow is considered to make a significant contribution to ecological light pollution (Rich and Longcore 2006; Kyba *et al.* 2011), and turtle orientation has been disrupted by light produced at distances of up to 18 km from the nesting beach (Hodge *et al.* 2007).

The disruption which artificial light poses to hatchlings has been well-studied in other parts of the world, yet although disrupted orientation has been reported in Australian hatchlings, little published data exists (Limpus 2009) (but see Limpus 1985; Pendoley 2000; Pendoley 2005; Berry *et al.* 2013). This is of concern, because as explained in Chapter 1, caution is necessary when using well-studied populations and species to extrapolate behaviour in other populations and species (Crossin *et al.* 2004; Pulido 2007). For example, loggerhead hatchlings from separate nesting groups within the same Florida sub-population, were found to significantly differ in initial offshore migratory activity (Wyneken *et al.* 2008). In addition, the initial 'frenzy' period of hatchling green turtles from Malaysia (Chung *et al.* 2009) appears to be almost double that found for green turtles from Florida (Wyneken and Salmon 1992; Salmon *et al.* 2009). As such, behavioural differences in the early orientation and dispersal mechanisms of Australian turtle hatchlings may exist, and indeed, a recent study indicates that crawling Australian turtle hatchings do not respond in the same way to certain wavelengths of artificial lights as their conspecifics in the US (Fritsches 2012).

The flatback turtle, *Natator depressus*, is a marine turtle species endemic to the Australian continental shelf, and all known nesting areas occur within Australia (Limpus 2009). The life history of the flatback turtle is markedly different to that of the other hard-shelled marine turtles (Salmon *et al.* 2009). It is the only species which lacks an oceanic phase in its life cycle (Walker and Parmenter 1990) with the post-hatchlings remaining within pelagic continental-shelf waters. Flatback hatchlings are almost twice as large as other hard-shelled turtle hatchlings (Walker and Parmenter 1990; Van Buskirk and Crowder 1994), and they display a swimming strategy during offshore migration which has not been seen in other species' (Salmon *et al.* 2009; Hamann *et al.* 2011; Pereira *et al.* 2011; Pereira *et al.* 2012). It is crucial that the early orientation behaviour of flatback hatchlings is documented to prevent management measures being based on behavioural knowledge extrapolated from different species and populations with potential differences in behaviour (Dryden *et al.* 2008).

Coastal development and the flatback turtle

At least four distinct population management units (MU) are currently recognised for flatback turtles within Australia (Limpus 2009; see also Chapters 2 and 3). The smallest population is the eastern Australian MU, where the largest rookeries support nesting by between 100 and 500 females annually (Limpus 2009). As with all marine turtles in Australia, flatbacks are protected under Federal and State Government conservation legislation, and are recognised as 'vulnerable' by both the Australian Commonwealth (EPBC Act 1999), and Queensland (Nature Conservation (Wildlife) Regulation 1994) Governments. Census data indicates that the size of the eastern Australian MU is stable at most of the index nesting areas, however one of the largest rookeries in east Australia (Peak Island) has shown a declining nesting population across several decades of tagging-recapture monitoring (Department of Environment and Heritage Protection 2013), despite a high level of habitat protection (GBRMPA 2008).

The cause of this localised decline in nesting is unclear; however disturbance linked to adjacent coastal development has been advanced as a possible contributing factor (Department of Environment and Heritage Protection 2013). Industrial development and urban areas are both growing rapidly in Australia, particularly along the Queensland coast (Australian Bureau of Statistics 2011; Grech *et al.* 2013), and in my previous chapters I demonstrated that levels of artificial light are both high (Chapter 2), and increasing significantly faster at nesting areas for eastern Australian flatback turtles than for any other turtle population in Australia (Chapter 3). Finer scale analysis showed that the significant change in light occurred at the major rookeries, but current light levels at the major rookeries remained significantly lower than for other nesting beaches in this MU (Chapter 3) which are located close to large, and expanding industrial centres (Jones *et al.* 2005; Grech *et al.* 2013).

The successful functioning of the eastern Australian flatback MU is therefore facing an increased risk of disrupted hatchling orientation from changing light horizons; both at nesting beaches close to industrial and urban development where light levels are already high, as well as at nesting beaches which have currently low, but rapidly increasing, levels of artificial light. Given the relative small size of this population, the lack of gene flow between MUs (Dutton *et al.* 2002), and the continuing decline in number of nesting females observed at one of its major rookeries (i.e. Peak Island), an examination of hatchling sea-finding behaviour in this population is imperative.

Flatback hatchling orientation behaviour was examined during dispersal from nests at two key east Australian rookeries to investigate impacts from artificial light glow generated as a result of large scale industrial development. A combination and comparison of hatchling fan and arena-based methods was used to provide insights into the optimum method for quantifying hatchling dispersal from the nest. In addition, since it was necessary to collect hatchlings for arena trials, I also documented hatchling time of nest emergence because no published data appears to exist regarding time of emergence for flatback hatchlings in east Australia.

4.3 MATERIALS AND METHODS

Study sites and context

Data collection occurred at two key east Australian flatback rookeries, where annual monitoring occurs - Peak Island and Curtis Island (Figure 4.1) (Limpus *et al.* 2006; Limpus 2009). Peak Island supports the largest flatback nesting population for the east Australian MU (Limpus 2009) and is located approximately 13 km offshore from the mainland in Keppel Bay. Nesting occurs along a 300 m stretch of west-facing beach (Figure 4.1i), by approximately 300 females annually (Parmenter and Limpus 1995). However the population is declining (Department of Environment and Heritage Protection 2013). Most nesting occurs in the northern half of the beach but does occur along the entire beach length. The island has a National Park (Scientific) designation, which is the highest level of habitat protection possible under the State Government's *Nature Conservation Act 1992*. The surrounding waters to a distance of 1 km are also protected to a high level, classified as Preservation Zone in the Great Barrier Reef Marine Park (GBRMP) zoning plan. This habitat management provides strong localised protection (GBRMPA 2008). However, inshore from Peak Island there is coastal urban and tourist development along the mainland coast of Keppel Bay, as well as proposed industrial developments within the adjacent Fitzroy River Delta. Xstrata Coal proposed the development of a coal export facility at Balaclava Island in the Fitzroy River Delta. Work on the Balaclava Island Coal Export Terminal (BICET) project began in 2009 and a draft Environmental Impact Statement (EIS) was developed before the project was suspended in May 2013 in response to economic concerns surrounding the then current Australian coal market. However, expansion of another coal export facility in the same area, the Fitzroy Terminal project, is still ongoing, with the EIS under development.

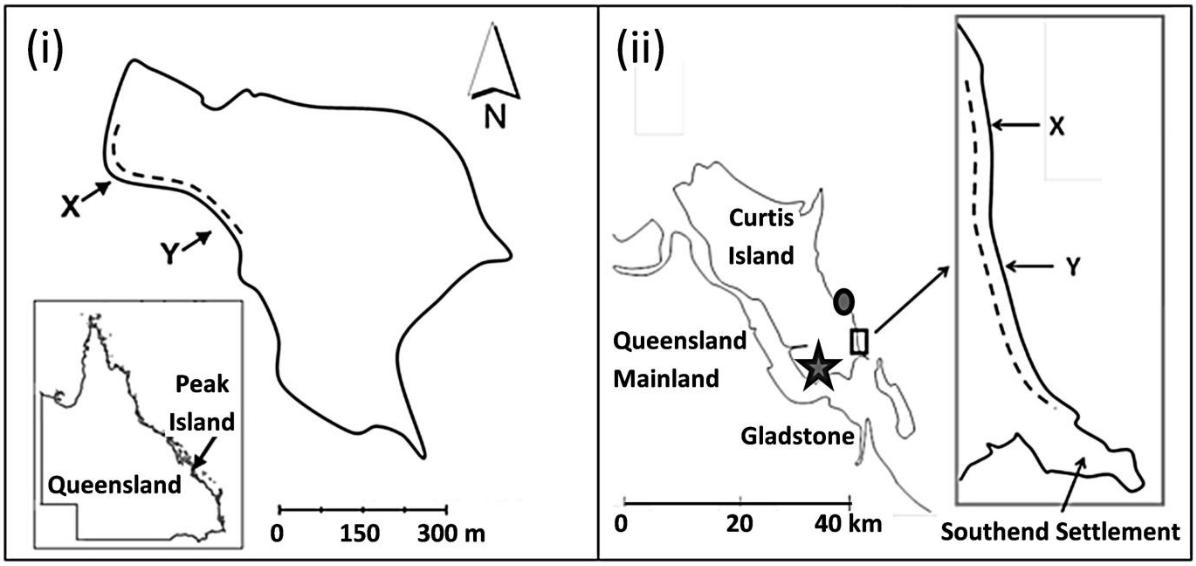

Figure 4.1 Study sites with dashed line indicating the nesting beach. (i) Peak Island: X denotes approximate location of arena 1 (S23°20.575, E150°56.006), Y denotes approximate location of arena 2 (S23°20.625, E150°56.108). Inset: location in Australia. (ii) Curtis Island and Gladstone. Inset: location of Southend Beach on Curtis Island. X denotes approximate location of arenas 1 and 3 (S23°43.155, E151°17.738), Y denotes approximate location of arena 2 (S23°43.926). Most nests naturally occurred between X and Y. Grey star indicates approximate location of LNG plants; grey circle denotes location of proposed tourist resort.

Curtis Island, which is part of the seaward margin to Port Curtis at Gladstone, Queensland, supports a moderate-sized flatback nesting population of 50 to 100 females each year (Limpus 2009). Nesting is mainly concentrated at the south-eastern end of the island at the 5 km long Southend Beach. The majority of clutches are laid at the northern end of the beach (between X and Y, Figure 4.1ii). At-risk clutches laid on the southern half of the beach, which is prone to substantial dune erosion, are often relocated further north. Significant industrial development of Port Curtis has occurred since the 1960s, and today the region contains more than 10000 ha of industrial land within the largest multi-commodity port in Queensland. It includes the State's largest power station, an aluminium refinery and smelter, a cement production works, chemical plants, and an international harbour (Duke *et al.* 2003). Industrial development of the port is ongoing (Danaher *et al.* 2005) and the region's urban population is also expected to rise over the next decade (Duke *et al.* 2003). More recently, three liquefied natural gas (LNG) plants are currently under construction on the south-western side of Curtis Island itself, with a fourth LNG development recently approved. These plants are located 8-12 km inland from the Southend nesting beach. In addition, a large tourist resort is planned for Turtle Street Beach, separated by 6 km of rocky shore north from the nesting beach at Southend. Light horizons were quantified in September 2011 during the new moon (Pendoley Environmental 2011) and showed a skyline highly modified by artificial lighting (e.g. Figure 4.2).

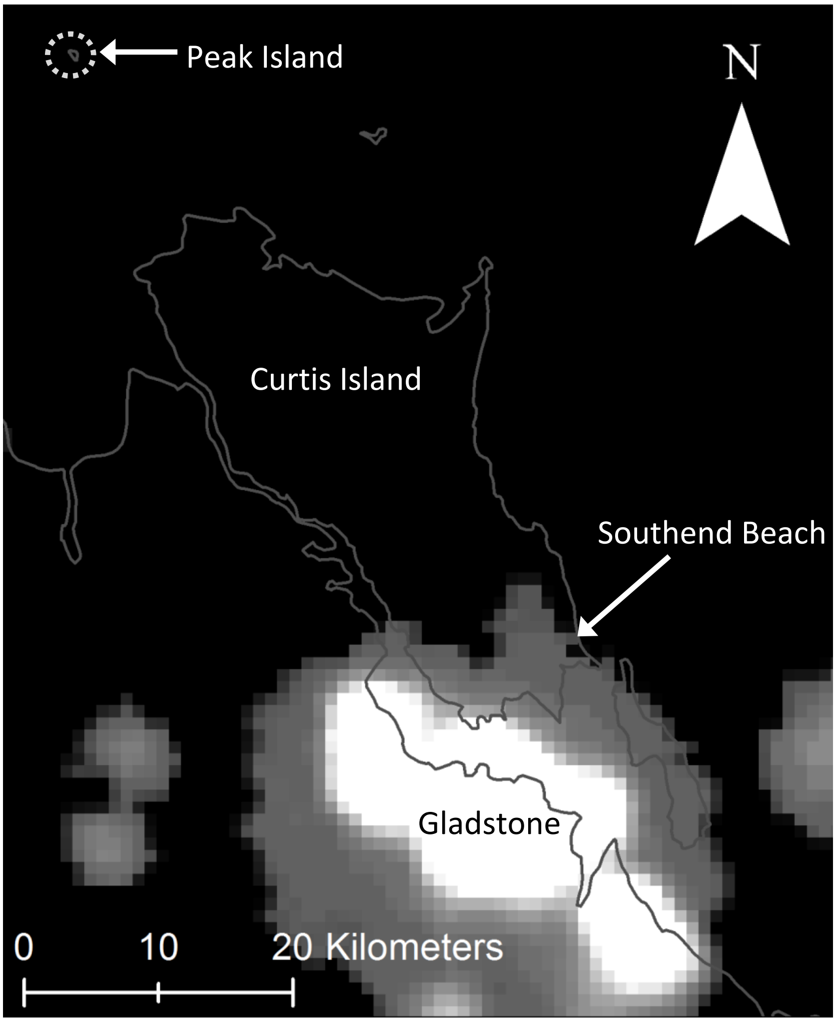

Figure 4.2 Nighttime lights of the study region in 2010, with location of Peak Island (circled) and Southend beach, Curtis Island shown in relation to Gladstone. Image and data processing of night light data by NOAA's National Geophysical Data Center. Defense Meteorological Satellite Program data collected by the US Air Force Weather Agency.

The relative brightness, and therefore potentially disorienting impact of artificial lighting fluctuates as a function of moon phase (Salmon and Witherington 1995; Pendoley 2005), with sea-finding disruption generally greatest during new moon or when the moon is not present in the sky, and much reduced when the moon is visible, particularly during the full moon (e.g. Salmon and Witherington 1995; Tuxbury and Salmon 2005; Berry *et al.* 2013). This is thought to be because moonlight reduces the directional light intensity gradients caused by artificial lighting, thereby allowing hatchlings to discern natural horizon elevation cues (Salmon and Witherington 1995; Limpus and Kamrowski 2013). Thus it is important that hatchling orientation data is collected during multiple phases of the moon, but particularly in the absence of moonlight, since this is when the impact of artificial lighting is likely to be strongest. Moon phase during data collection for this chapter is summarised in Table 4.1, with moon phase data obtained from www.timeanddate.com for Rockhampton, Queensland.

Table 4.1 Moon phase during data collection.

Location	Type of data collection	Date of data collection	Moon phase
Peak Island	Fan-mapping, arena trials, light measurements	January 23-February 2, 2012	New moon and 1st quarter
		January 31-February 14, 2013	Full moon and last quarter
Curtis Island	Fan-mapping, arena trials, light measurements	February 6-19, 2012	Full moon and last quarter
		January 8-23, 2013	New moon and 1st quarter
	Fan-mapping only	January 21-25, 2014	Last quarter

Hatchling fans

Emerging hatchlings leave tracks on the beach which fan out from the nest origin. Since the fan indicates the chosen travel direction of multiple hatchlings, it can be used for orientation measurements (Salmon and Witherington 1995; Pendoley 2005; Limpus and Kamrowski 2013). Fan-mapping techniques used in this chapter were based on the methodology of Pendoley (2005). Emergences with five or more clear hatchling tracks were examined at dawn for dispersal patterns using fan spread angle (i.e. A – B, where A and B are compass bearings from the nest along the outside edges of the track fan), and offset angle (the difference between the fan spread angle midpoint and a compass bearing along the shortest route to the ocean).

In 2012, the bearings of A, B and the shortest route to the ocean, were recorded at a distance of 2 m from the nest origin. This was closer to the nest than in previous studies which specified this distance (Salmon and Witherington 1995; Limpus and Kamrowski 2013), yet was necessary due to high nest and hatchling emergence density at Peak Island. In 2013, data at Peak Island was collected later in the season, following extreme weather. With the resultant reduced nest density, I was able to measure fan angles at 2 m and 5 m from the nest origin for a large proportion of nests. This permitted determination as to whether measurements differ depending upon the distance taken from the nest origin, whilst also allowing comparisons to be made between years at the study sites, and also with fan measurements taken in previous studies. Since track fans expand as hatchlings travel further from the nest, the difference between taking compass bearings at 2 m versus 5 m was predicted to be insignificant.

Arenas

Arena trials simulate the emergence of hatchlings from a nest, in a controlled, and staggered manner. In this chapter I followed the methodology of Bertolotti and Salmon (2005). At both locations, circles of 5 m diameter were created in the dry sand above the high water mark, where beach slope was minimal (to avoid hatchlings having slope as an seaward orientation cue (Salmon *et al.* 1992; Kawamura *et al.* 2009)). The sand was raked and cleared until smooth and free from debris and vegetation, and a small depression created in the centre.

Arenas were located in approximately the same locations in 2012 and 2013 (see Figure 4.1). At Peak Island, hatchlings were tested in arenas at both northern and southern ends of the beach, approximately 250 m apart. The northern arena was located in a section of the beach where the majority of nests naturally occurred. Both arenas were characterised by a high visible horizon in a landward direction, but the northern arena was located < 6 m from a large *Pandanus* tree. In 2012 the arena was located seaward of this tree, but in 2013, due to dune erosion, the arena had to be moved slightly further landward, with the tree being located adjacent to the arena, between 90° and 150° bearing from the arena centre.

At Curtis Island, the 2012 arenas were located at the northern (arena 1) and southern (arena 2) boundaries of most turtle nesting, approximately 2 km apart. The northern portion of the beach at Curtis was characterised by two rows of dunes running approximately parallel to the ocean with a prominent swale (trough) between them (Figure 4.3), and in 2013 an extra arena (3) was added at the base of this swale in the northern section of the beach behind arena 1.

For each trial, 20 hatchlings were selected at random from natural nest emergences and placed into a bucket containing a shallow layer of damp sand. The hatchlings were kept in the dark, open bucket until ready to be released (< 30 minutes). During trials, I released groups of five hatchlings in the arena's central depression and gave them three minutes to crawl to the edge. Any hatchlings remaining within the arena at the end of three minutes were excluded from the analysis. Two researchers, remaining out of sight of the hatchlings, were positioned landward and seaward of the arena. They collected hatchlings after they exited the circle and recorded the compass bearings from the centre of the arena to the exit point for each hatchling. Moon-stage (i.e. pre-moonrise, visible, post-moonset) during the trial was also recorded. The sand was then swept smooth and the procedure repeated with different hatchlings. No hatchling was tested more than once, and after each trial hatchlings were released at the high tide mark and all crawled to the ocean.

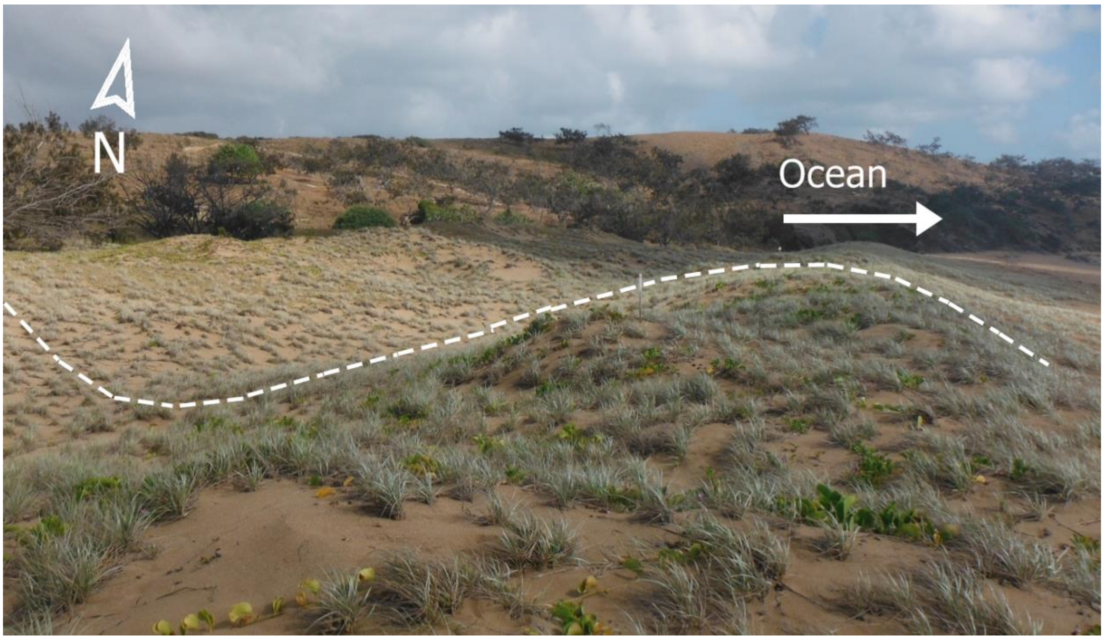

Figure 4.3 The northern portion of Southend Beach at Curtis Island. This section of beach is characterised by two rows of dunes (dashed line), with a prominent swale between them, running approximately parallel to the ocean.

Ambient light levels

Following methodology employed by Bertolotti and Salmon (2005), relative light levels were measured in each of the eight cardinal directions (N, NE, E, SE, S, SW, W, NW) using an Optec SSP-3 stellar photometer, with the V filter inserted (wavelength range 480-660 nm). The maximum sensitivity of this filter, at 540 nm, is close to peak flatback hatchling sensitivity to light. Flatback hatchlings appear to have a preference to light of around 500 nm, with a reduced sensitivity to shorter wavelengths of light compared to other species (Pendoley 2005). The photometer was attached to a tripod and positioned 0.5 m above the sand surface, just outside the arena boundary. The instrument was positioned at 15° elevation in the vertical plane (corresponding with light intensity just above the horizon line, but within the generally accepted 30° hatchling visual ‘cone of acceptance’ (Witherington 1997)), and measurements recorded as the tripod was rotated in 45° increments, through 360°. With an aperture of 0.002 inch diameter, the instrument has a very small cone of visibility, thus measurements taken in each direction did not overlap with brightness measurements of any other direction. Measurements were taken immediately after each arena trial and at regular intervals throughout the night (between 20:00 and 04:00 h), where possible. However, measurements taken when the photometer was pointed directly at the moon (during rising or setting) were excluded from further analysis since the very high light levels recorded skewed the overall results. Light values were converted into a $\log_{10}$ scale, and relative light levels drawn as radiance octagons, which spanned an intensity range of two log units. Each time light measurements were collected, cloud cover was recorded qualitatively in oktas (a standard meteorological measurement where one okta represents one eighth of the hemispherical sky being occupied by cloud) (Rogers and Yau 1989).

Although used in several studies for assessing lighting impacts on marine turtles (Salmon *et al.* 1992; Salmon *et al.* 1995; Salmon and Witherington 1995; Bertolotti and Salmon 2005; Sella *et al.* 2006), stellar photometers have several limitations. Firstly, there are different gain settings available, and the instrument set to a lower gain may show very little data variation despite possible light differences, whilst a higher setting may show large variations under the same atmospheric conditions. In addition, ambient temperature interacts with gain settings, with warmer conditions producing more electronic noise in the data (A. Verveer, Perth Observatory, personal communication). I used the stellar photometer in this chapter to record light levels using an identical gain setting for all measurements, as a means of supporting judgements of relative brightness made by researcher observations. However, since it was not possible to control for ambient temperature, I only made comparisons between light measurements taken over a very short time period. Thus I did not directly compare measurements between locations or across years of data collection. .

Time of hatchling emergence

Hatchling time of emergence was recorded at Peak Island for 14 24-hour periods between January 31 and February 16, 2013. A drift-fence and pit-trap system consisting of a plastic mesh fence (‘gutterguard’) and bucket (after Limpus 1985) was dug into the sand along 25 m of beach, above the high-water mark (located at approximately Figure 4.1i(X)). The square mesh formed a barrier 15 cm above the beach surface, and was laid in a ‘V’-shaped manner that intercepted hatchlings crossing the beach and directed them towards a bucket buried in the sand, located in the centre of the ‘V’. This trap was located in the section of beach where the highest density of nests occurred, to ensure a large sample size. The trap was checked at one hour intervals, or sooner, for the entire duration of deployment, and the number of individual hatchlings found in the bucket or along the fence recorded.

Analysis

Data were analysed using the statistical software programs: IBM SPSS 20 and Oriana 3 for Windows. All data were tested for normality, and non-parametric analyses or data-transformation used where appropriate. Standard circular descriptive statistics were calculated for arena data (Zar 2010), bimodal distributions were dealt with using an angle doubling procedure (Batschelet 1981) and the Rayleigh test used to determine whether hatchlings were significantly oriented. The V test, a variant of the Rayleigh test, was employed to compare mean hatchling arena escape angle with the shortest route to the ocean, and Watson U^2 tests used to compare hatchling orientation with, and without, a visible moon (Mardia and Jupp 2000).

4.4 RESULTS

Hatchling fans

Hatchling fan orientation indices are summarised in Table 4.2. At Peak Island in 2013, 51 fans had tracks which could be measured at both 2 m and 5 m distance from the nest origin. At Curtis Island, all 48 fans recorded in 2013 were measured at both 2 m and 5 m. Following $\log_{10}$ transformation of spread and offset angles measured at 2 m in 2012 and 2013, multivariate analysis of variance (MANOVA) was carried out with spread and offset angles as dependent variables, and year and location as independent variables. There was a significant multivariate effect of location ($p < 0.01$) for the orientation indices taken together, but no significant effect of year ($p = 0.11$). The interaction between year and location was also significant ($p < 0.05$).

Follow-up univariate analyses indicated a significant effect of location for both spread ($p < 0.001$) and offset angle ($p < 0.001$), with no significant effect of year for both spread ($p = 0.11$) and offset ($p = 0.1$). There was no significant interaction between year and location for offset angle ($p = 0.08$), indicating that offset angle did not differ significantly at either location between years, but was significantly higher for hatchlings at Curtis Island compared to Peak Island. There was a significant interaction between year and location for spread angle ($p < 0.05$). Further examination of the data indicated that spread angle was significantly higher for hatchlings at Curtis Island compared to Peak in 2012, but there was no significant difference in spread angle between Curtis and Peak hatchlings in 2013, and spread angle was significantly lower for Curtis Island hatchlings in 2013 compared to 2012.

At Curtis Island, across all years of data collection, more than 20% of fans had an offset bearing of > 90° from the most direct route to the ocean. In comparison, the maximum offset angle recorded across both years at Peak Island was 70°, i.e. zero clutches had an offset angle in excess of 90°. In 2014, although offset angle was reduced at Curtis Island, this was likely a result of extreme weather following data collection in 2013 modifying the nesting beach environment. Access to the swale between the dunes in 2012 and 2013 was via a gradual slope up the first dune. This had been replaced with an almost vertical erosion bank (height approximately 1.5 m) in 2014, which likely deterred females climbing and nesting over the top of the first dune (M. McLaren, personal communication, December 2013). In 2014, 91% of fans were located on the ocean-facing side or top of the first dune, rather than landward of the first dune; compared to 76% in 2013, and 37% in 2012.

Table 4.2 Hatchling fan orientation indices at Peak and Curtis Islands, 2012-2014

Location	Year	Measurement distance	Number of nests	Spread angle (°)		Offset angle (°)	
				Mean	SE	Mean	SE
Peak	2012	2 m	68	55.1	4.5	18.3	1.9
	2013	2 m	64	54.7	3.3	19.4	2.1
		5 m	51	41.1	3.1	18.3	2.4
Curtis	2012	2 m	19	126.3	18.5	66.4	15.1
	2013	2 m	48	91.2	11.2	46.3	7.8
		5 m	48	66.7	6.6	38.5	7.7
	2014	5 m	23	53	10.2	23	7.9

No significant difference was found between offset angle measured in 2013, at 2 m and 5 m from the nest origin (Wilcoxon Signed Ranks: Peak: $Z = -0.27$, $p = 0.79$; Curtis: $Z = -1.2$, $p = 0.23$), but spread angle was significantly larger when bearings were taken at 2 m compared to 5 m (Peak: $Z = -2.99$, $p < 0.01$; Curtis: $Z = -3.56$, $p < 0.001$).

Overall fan indices indicate that hatchlings at Peak Island were orienting correctly, whilst Curtis Island hatchlings showed a reduced sea-finding ability.

Arenas

At Peak Island 302 hatchlings from 19 clutches in 2012, and 98 hatchlings from 15 clutches in 2013 were tested in arenas. Two hatchlings each year failed to leave the arena within the allotted time and were thus excluded from the analysis. At Curtis Island, 87 hatchlings from 5 clutches were tested in 2012, and 213 hatchlings from 15 clutches in 2013 (Figure 4.4 and Appendix 2).

Qualitative examination of Figure 4.4 indicated that the distribution of hatchling exit points in the swale arena (3) at Curtis was bimodal, roughly 180° apart. Lack of unimodality was confirmed with the Kuipers test (von Mises $V = 3$, $p < 0.01$). The dominant modes were in the intervals 120-150° ($n = 30$), and 330-360° ($n = 28$).

Hatchlings in all arenas showed significant orientation (Rayleigh test: $p \leq 0.001$), and in every arena except the swale arena (3) at Curtis Island, hatchlings were significantly oriented in the direction of the ocean (V-test: $p < 0.001$). Although hatchlings tested in arenas where hatchlings had an unobstructed view of the ocean (1 and 2), at both locations, were significantly oriented towards the ocean, the circular standard deviation and angular dispersion (r) of hatchlings at Curtis Island were both higher than found at Peak (Figure 4.4). Hatchlings in the swale arena (3, with no view of the ocean) were also not significantly oriented towards the ocean. Thus, as was observed in the fan data, hatchlings at Peak appeared to be orienting correctly, whereas hatchlings at Curtis showed reduced sea-finding ability.

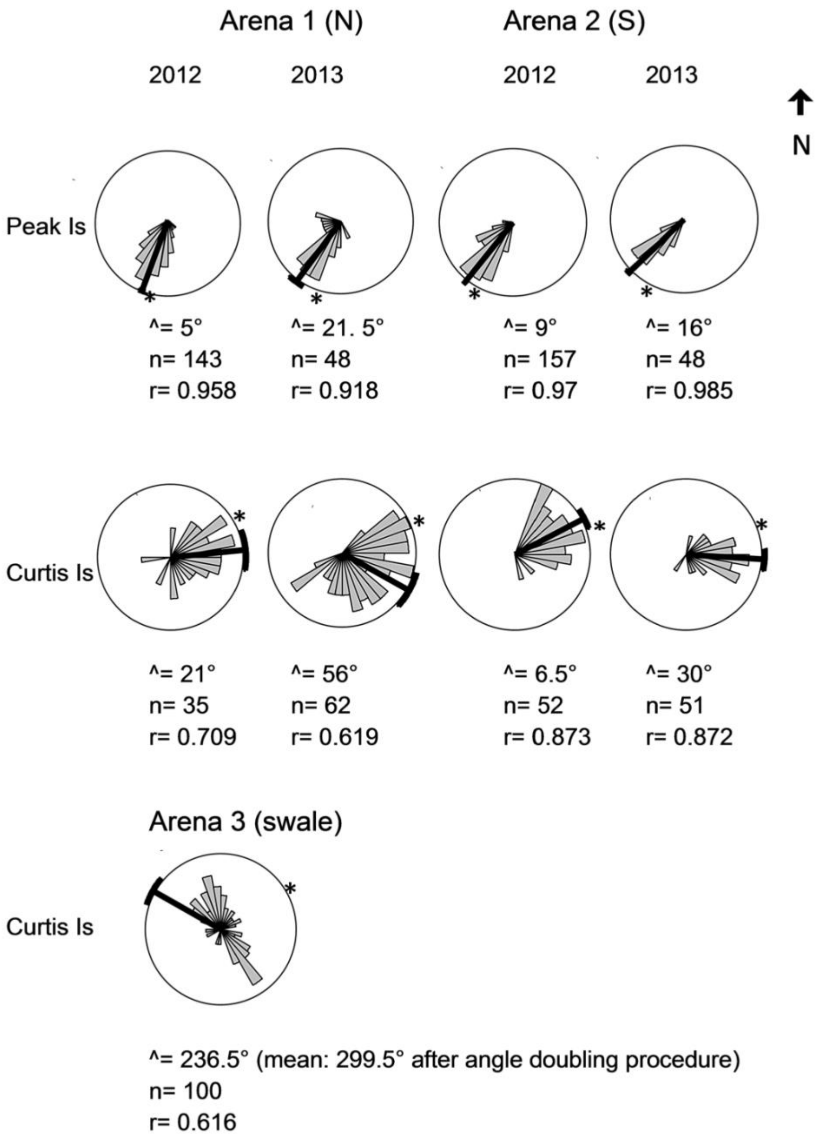

Figure 4.4 Rose diagrams showing flatback hatching dispersal during arena trials at Peak and Curtis Island in 2012 and 2013. Each grey wedge represents 10° of the total circular range and wedge area depicts the number of observations falling within that portion of the range. The straight black lines indicate mean bearing, with mean bearing for Curtis arena 3 shown following an angle-doubling procedure (Batschelet 1981). Curved black lines show 95% confidence intervals. The * symbol indicates the direction of the ocean. ^ indicates the difference between mean bearing and the ocean direction. r is a measure of angular dispersion where 0 = uniform dispersion, and 1 = concentrated in one direction.

Ambient light levels

Very little light was observed by researchers at Peak Island across all years of data collection. Light levels recorded by the stellar photometer indicated that there were no significant differences in the light visible in any direction from the nesting beach at Peak in 2012 (Kruskal-Wallis $H(7) = 1.69$, $p = 0.98$) or in 2013 (Kruskal-Wallis $H(7) = 10.41$, $p = 0.17$) (Figure 4.5).

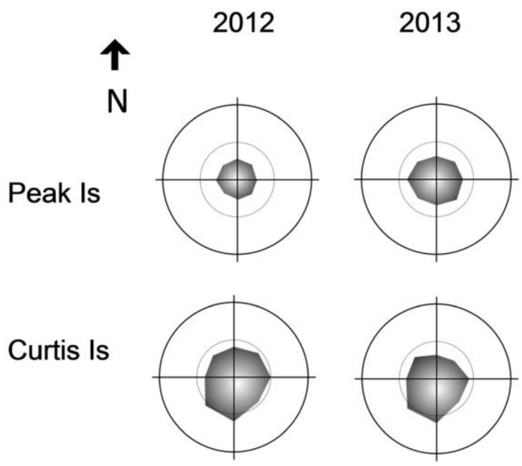

Figure 4.5 Mean light levels (shown as relative radiance octagons, with each concentric circle corresponding to one log unit) visible in all directions from the nesting beaches at Peak and Curtis Islands in 2012 and 2013.

In contrast, the field team observed light levels at Curtis Island which appeared visibly brighter than those observed at Peak, with light horizons from the south, southwest and east noticeably brighter than other directions. This was supported by the photometer data: light levels recorded in different directions were significantly different in both 2012 (Kruskal-Wallis $H(7) = 90.77$, $p < 0.001$) and 2013 (Kruskal-Wallis $H(7) = 232.2$, $p < 0.001$). In both years post-hoc comparisons using Dunn-Bonferroni tests indicated that light from the south was significantly brighter than all other directions except southwest. Light levels from the southwest were significantly higher than light in all directions other than south, southeast and east, and light from the east was significantly higher than light levels from the northwest, and north (Figure 4.5). Light from the east was attributed to the rising moon, as well as lights visible from ships anchored outside Gladstone Harbour. These ships extended to the southeast also. Light from the south and southwest was attributed to Gladstone Port and city (Figure 4.2; see also Pendoley Environmental 2011).

Given that moonlight is known to reduce the disorientating effects of artificial lighting for hatchlings (Salmon and Witherington 1995; Tuxbury and Salmon 2005), I also examined the Curtis Island arena data at different stages of the night, independent of moon phase: no moon visible in sky (pre-rise, post-rise or new) versus visible moon in sky (Figure 4.6).

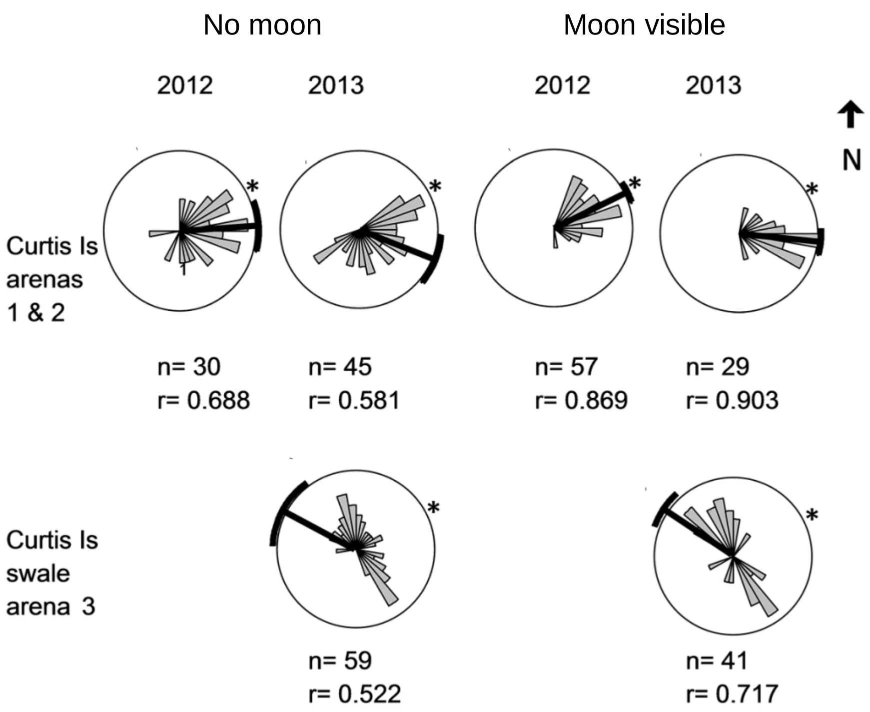

Figure 4.6 Hatchling dispersal during arena trials at Curtis Island with no moon and moon visible in 2012 and 2013 with data collected in the north and south arenas combined. Each grey wedge represents 10° of the total circular range and wedge area depicts the number of observations falling within that portion of the range. The straight black lines indicate mean bearing; curved black lines show 95% confidence intervals. The * symbol indicates the direction of the ocean, and r is a measure of angular dispersion where 0 = uniform dispersion, and 1 = concentrated in one direction.

Pooling the data from arenas 1 and 2 at Curtis Island (the northern and southern arenas where hatchlings had a view of the ocean), and examining the data with and without a visible moon indicated that in 2012 there was no significant difference in hatchling orientation in the presence or absence of moonlight ($U^2(30, 57) = 0.13$, $p > 0.1$), however the mean direction of travel when there was no moon was less ocean-oriented, in a more southern direction, than when the moon was visible, and dispersal was also greater in the no-moon condition (Figure 4.6). However, in 2013, hatchling orientation was significantly different with and without a visible moon ($U^2(29, 45) = 0.43$, $p < 0.001$), and once again the mean direction of travel in the no-moon condition was less ocean-oriented than when the moon was visible, in a more southern direction, and dispersal was also greater when there was no moon. Examining the swale arena (3) data at Curtis Island indicated that the hatchling exit point distribution remained bi-modal regardless of moon presence (Figure 4.6), and there was no significant difference between the two distributions ($U^2(29, 41) = 0.13$, $p > 0.1$).

Light levels and cloud cover

There was a significant positive correlation between light levels and cloud cover at Curtis Island in both 2012 ($r_s(47) = 0.66$, $p < 0.001$) and 2013 ($r_s(65) = 0.78$, $p < 0.01$), i.e. as cloud cover increased, so did horizon light levels. This indicates that at Curtis Island, the primary source of visible light was artificial, since this light is reflected back down to earth from clouds (see Kyba *et al*. 2011), with intensity levels increasing as cloud cover increases. In contrast, there was no significant correlation between light levels and cloud cover at Peak Island which is unsurprising given the low levels of horizon light recorded in this location. Moreover, in 2013 the data indicated a negative relationship between light levels and cloud cover, which just failed to reach significance possibly as a result of the small sample size of observations ($r_s(38) = -0.28$, $p = 0.09$). This suggests that the primary source of light recorded at Peak Island was celestial rather than artificial, since celestial light is obscured in the presence of clouds.

The Curtis Island data was analysed further in each year by splitting the cloud cover into three categories: low cover (0-2 oktas), medium cover (3-5 oktas) and high cover (6-8 oktas). Light levels differed significantly between the three levels of cloud cover in 2012 (Kruskal-Wallis $H(2) = 22.8$, $p < 0.001$) and 2013 (Kruskal-Wallis $H(2) = 7.9$, $p < 0.05$). In both years post-hoc analysis indicated that light levels were significantly higher when cloud cover was medium than when there was low cloud coverage, but there was no difference in light levels between medium and high cloud coverage.

Time of hatchling emergence

In total 774 hatchlings were recorded in the pit-fall trap at Peak Island, and of these 92% emerged between 20:00 and 04:00 h (Figure 4.7). The median time of hatchling emergence was 01:00 h, and 50% of hatchlings emerged between 23:00 and 02:00 h. Very few flatback hatchlings emerged during daylight hours (5.6% of total hatchlings recorded). Daylight emergences occurred during heavy rain and/or strong wind (> 20 knots).

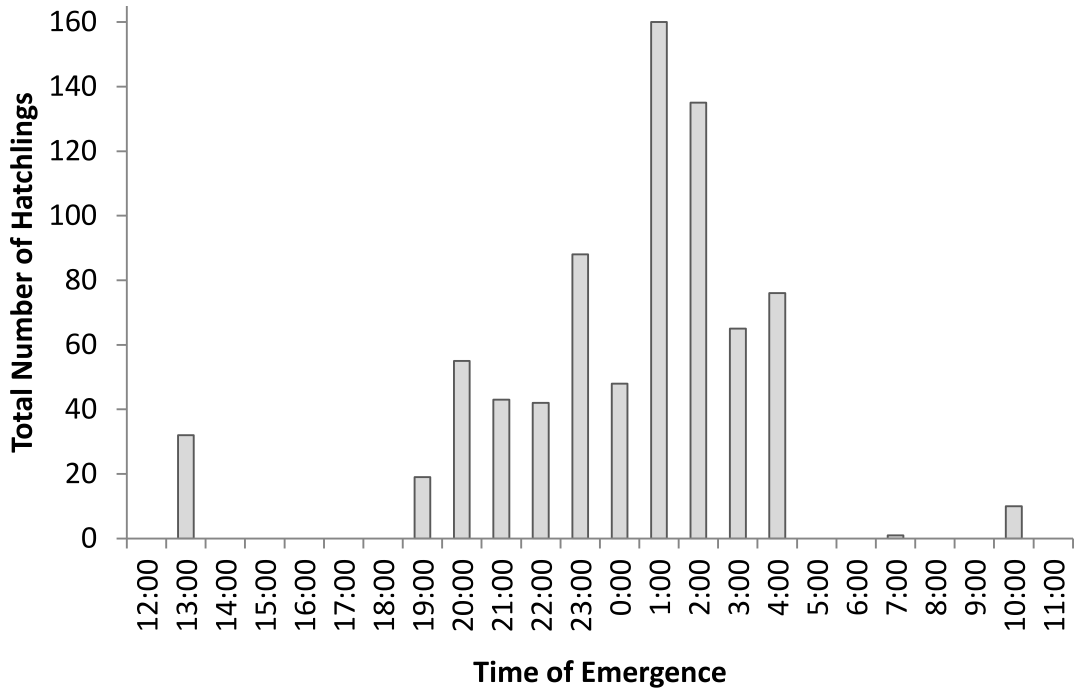

Figure 4.7 Total number of hatchlings emerging over 24 hours at Peak Island between 31.1.13 and 14.2.13 for each hour of the day. Median hatchling emergence was at 01:00 h, with the interquartile range of emergence occurring between 23:00 and 02:00 h.

4.5 DISCUSSION

This chapter examined flatback hatchling orientation behaviour during dispersal from the nest at two key east Australian rookeries, using a combination and comparison of hatchling fan and arena-based methods. Data collected at Curtis Island was used to determine the sea-finding behaviour of flatback turtles exposed to altered light horizons due to existing light-glow from a large industrial centre. Data collected at Peak Island was used as a reference site for Curtis Island, since very little anthropogenic light is currently visible at night from the beach at Peak Island. The Peak Island data also provides useful baseline data with respect to the proposed Fitzroy Terminal Project.

Hatchling orientation

Hatchling flatback turtles at Curtis Island showed reduced sea-finding ability compared to hatchlings at Peak Island. Fan measurements showed that both spread angle and offset angle were higher at Curtis Island. Following the ‘hatchling orientation index’ proposed by Witherington *et al*. (1996) in which offset angles of between 30-90° were classified as indicating moderate sea-finding disruption, and offset angles of more than 90° indicating severe sea-finding disruption, my findings indicate that hatchlings at Peak Island were not disrupted. However at Curtis Island, the offset angles of hatchlings in 2012 and 2013 demonstrate a moderate to severe disruption to sea-finding.

Previous studies involving fan indices to infer hatchling orientation (Salmon and Witherington 1995; Witherington *et al.* 1996; Pendoley 2005; Limpus and Kamrowski 2013), although similar in most respects, measured track bearings at different distances from the nest origin (i.e. 5 m, 10 m, to the high tide line, or to the point where the tracks disappear), or did not specify this distance. At Peak Island, nest density was very high, and as a result I found it necessary to measure fan angles at 2 m from the nest origin, since for most emerged nests, at greater distances the tracks became indistinguishable from those of adjacent nest emergences. In 2013, a reduced nest density allowed measurements to be taken at both 2 m and 5 m from the nest origin in a large number of instances, and comparisons of this data indicated that offset angle was not affected by the distance over which the bearings were taken. However spread angle was significantly larger when the bearings were taken closer to the nest origin, thus care must be taken when comparing fan spread measurements between studies, and this finding indicates that future studies must be clear in specifying measurement distance.

The arena data supports my conclusion that at Peak Island hatchling sea-finding was not disrupted. In both years the mean hatchling bearing was very close to the shortest route to the ocean with relatively small standard deviation from the mean, and hatchlings were significantly oriented towards the ocean. However it is worth noting that in the north arena (1) in 2013, hatchling travel direction shifted marginally around to the west compared to 2012, and the range of tracks increased. While subtle changes in the light spillage from the coastal development of Keppel Bay should not be discounted, I believe the change was due to the arena being located a few metres further landward in 2013, compared to 2012, due to dune erosion. The new arena placement resulted in the large *Pandanus* tree, which backed the arena in 2012, being located between 90° and 150° from the arena in 2013. The fact that the spread of hatchling tracks shifted westward supports previous findings that hatchlings orient away from high, dark silhouettes (Salmon and Wyneken 1994; Limpus and Kamrowski 2013).

At Curtis Island, data from arenas 1 and 2 indicated, in contrast to the fan data, that hatchling orientation was not significantly disrupted. Hatchlings in these arenas were found to be significantly oriented towards the ocean in both years. Yet, the standard deviation from the mean and the spread of tracks, were both higher than I found at Peak Island.

Artificial light-glow

Very little anthropogenic light was observed at Peak Island, and no differences were found in the amount of light recorded in different directions. In contrast, it was clear to observers that light originating from the direction of Gladstone had signficantly altered the light horizons of the nesting beach at Curtis Island (Pendoley Environmental 2011), and the light levels I recorded from the south and southwest were higher than in any other direction visible from the nesting beach. This light appeared to originate from Gladstone Port and city, since they lie south/southwest from the nesting beach (Figure 4.2).

While the light levels given in this chapter indicate relative, rather than absolute, levels of ambient light, absolute levels of light visible from the nesting beach at Curtis Island can be found in Pendoley Environmental (2011), and I strongly recommend that similar light measurements are made at Peak Island in the near future to provide valuable baseline data. However, the relative light measurements I recorded, examined in combination with hatchling dispersal data, did indicate that light produced from the Gladstone region contributes to a sea-finding disruption in flatback hatchlings at Curtis Island.

I also found that light levels were significantly higher at Curtis Island when cloud cover was present in both 2012 and 2013. This supports the findings of Kyba *et al* (2011), and indicates light mitigation measures may be more important on cloudy compared to clear nights. Further research is needed to determine whether hatchling disorientation increased as cloud cover increased, but given the disorienting effect of light on hatchlings, increased light levels due to cloud cover may be expected to increase the disorientation of hatchlings.

Although I did not examine the relationship between light levels, cloud cover and the presence/absence of moonlight, previous research has indicated that moonlight ‘smooth[s] out’ small variations in background light intensity (Salmon and Witherington 1995, p.937), reducing the disruptive influence of artificial lighting whilst also negating the effect of light reflected back down to Earth by cloud coverage. Comparing the orientation of hatchlings at Curtis Island in arena trials carried out with and without a visible moon in 2012, did not show that hatchlings were less able to find the ocean in the absence of moonlight; however this may have been related to the small sample sizes tested. Indeed, a visual examination of this data graphed (Figure 4.6), indicated that hatchlings were more dispersed around the circle and more likely to head in a southern direction in the absence of moonlight. In 2013, the same comparison with larger sample sizes did find this difference to be significant. Thus despite the fact that hatchlings at Curtis Island tested in arenas 1 and 2 were significantly oriented towards the ocean (Figure 4.4 and Appendix 2), in the absence of moonlight hatchlings had a reduced sea-finding ability, and were more oriented towards the altered light horizons to the south. My results therefore indicate that moonlight did moderate the disruptive influence of industrial light on flatback hatchling sea-finding, supporting previous research (Salmon and Witherington 1995; Tuxbury and Salmon 2005; Berry *et al.* 2013). However, I simply divided arena trials by either the ‘presence’ or ‘absence’ of moonlight, since I assumed that the presence of moonlight, irrespective of moon phase, would allow hatchlings to discern horizon cues thereby reducing sea-finding disruption (e.g. Limpus and Kamrowski 2013). Future work which assesses the relationship between hatchling orientation, cloud cover, and degree of lunar illumination, in relation to artificial lighting, would be valuable.

Other considerations

The beach topography of Peak and Curtis Islands is very different. The nesting beach at Peak is backed by a high peak of land, whereas at Curtis Island the landward horizon is relatively flat (Coffey Environments 2012a), and in addition, the nesting beach is characterised by a double row of dunes with a swale running between them in an approximately north-south direction, parallel to the ocean (Figure 4.3). Since hatchlings orient using both horizon elevation and brightness cues (Salmon and Wyneken 1994; Limpus and Kamrowski 2013), and because in 2012 most nests at Curtis naturally occurred landward of the first dune where the lowest horizon would not have been in a seaward direction, I hypothesised that the discrepancy in the amount of sea-finding disruption I found between the fan and arena methods may have been due to the placement of arenas at Curtis (the arenas were constructed on flattened sections of the first dune, giving hatchlings an unobstructed view of the ocean). Consequently, in 2013 I also tested hatchlings in an arena constructed at the base of the swale. Hatchling exit points from arena 3 followed a bimodal distribution which followed the direction of the swale i.e. in a direction approximately parallel to the ocean. This is strong evidence that hatchlings in this arena (3) were orienting as a result of elevation cues. As a result, when collecting hatchling orientation data using arenas I recommend placing arenas in a variety of beach locations where nests naturally occur, otherwise incomplete orientation conclusions may be drawn.

The influence of horizon elevation is also evident from the fan data. Mean offset angle in each year was greater when a greater proportion of nests had been laid landward of the first dune, where no view of the ocean existed, and the lowest horizon elevation was in a non-sea-finding direction. I thus propose that if choosing to use just one assessment method to assess hatchling sea-finding ability, then fan-monitoring is more practical than arena-based methods. Fan measurements also have additional benefits since they are easy to perform, relatively quick, and do not involve the time-consuming, logistical difficulties associated with maintenance of arenas and locating hatchlings for arena trials (Pendoley 2005). However, assessing light levels at the time of nest emergence is more difficult with fan-monitoring, and researchers should be careful to ensure that the fans examined reflect the total nesting environment, and not the areas' most convenient to find hatchling tracks. I thus suggest that fan-monitoring methods should be supplemented with strategically placed arenas to test specific topographic differences on the beach, under particular lighting conditions.

Unexpectedly, the mean direction of travel in the swale arena was in a north-western direction. Previous research has proposed that lowest horizon elevation functions as the principle cue in guiding hatchling orientation, but where multiple low horizons exist, brightness cues would be utilised (Limpus and Kamrowski 2013). Consequently, I expected hatchlings to orient parallel to the ocean along the swale, and towards the brighter, south-eastern direction. The reason hatchlings headed more frequently towards the northwest is unclear, but possibly the horizon elevation in that direction was marginally lower than in the opposing direction. This finding supports the recommendation of Limpus and Kamrowski (2013) that horizon elevation should be considered in any investigation into the sea-finding ability of hatchling turtles. Moreover, although the altered light horizons originating from industry located south of the nesting beach at Curtis Island influenced sea-finding in flatback hatchlings (greater fan spread angles, and more southern exit bearings and greater dispersal in arenas in the absence of moonlight), the topography of the beach also appeared to influence the reduced sea-finding ability of hatchlings at Curtis Island.

Multiple LNG plants were approved or were in the early stages of construction on Curtis Island at the time of data collection. In the absence of effective light management in these LNG plants, and during the associated port and city expansion, it is likely that light levels south and southwest of the nesting beach will increase further. As previously discussed, artificial light can mask hatchling ability to discern horizon cues (Limpus and Kamrowski 2013), and hatchlings also preferentially orient towards light of higher intensities (Mrosovsky 1972; Witherington and Bjorndal 1991a). The cumulative light emissions from all LNG plants and the proposed tourist resort, in addition to existing light from Gladstone Port and city, may thus result in anthropogenic light intensities high enough to cause an even greater disruption in the sea-finding ability of flatback hatchlings at Curtis Island. Moreover, reviewing the environmental impact assessments for the individual LNG plants indicates that whilst each operator recognises the need to minimise light emissions due to the nearby presence of nesting turtles, the plans do not address mitigation of potential cumulative impacts (URS Australia 2009; WorleyParsons 2010; QGC 2011; Coffey Environments 2012b). Continued monitoring of hatchling orientation at Curtis Island is therefore recommended.

Finally, I am the first to report time of emergence for flatback hatchlings from eastern Australia. Since hatchlings generally emerge at night (Mrosovsky 1968), knowledge of when hatchlings are likely to emerge will contribute to guiding more effective management of artificial lighting close to nesting beaches. Similar to studies with other populations and species, I found that the vast majority of hatchlings emerged during the night. However, unlike flatback hatchlings from northern Australia and green and loggerhead hatchlings from eastern Australia, for which core emergence occurs in the first part of the night (between 20:00 and 00:00 h) (Limpus 1985; Gyuris 1993; Koch *et al*. 2008), I found that eastern Australian flatback hatchling emergence predominantly occurred in the early hours of the morning. This may be a result of variation in sand or air temperatures existing between nesting beaches where emergence has been assessed, since the thermal environment of the nesting beach is known to influence hatchling emergence (e.g. Glen *et al.* 2005; Glen *et al*. 2006). Thus this finding would benefit from confirmation, and further investigation, in future studies and in different rookeries. However this information could also be utilised to guide light mitigation plans, both for industry in the Gladstone area, and further afield wherever artificial light may pose a problem for flatback turtles.

4.6 CONCLUSIONS

Flatback hatchlings at Peak Island appear unaffected by light pollution; however, flatback hatchlings at Southend Beach, Curtis Island, show evidence of impaired sea-finding ability. I conclude that this reduced sea-finding ability is the result of altered light horizons from light-glow produced by a large industrial centre, despite this light originating from approximately 15 km away, as well as beach topography.

Fan-based methods for assessing hatchling orientation appear more valid than arena-based methods. However the distance over which fan bearings are taken must be explicitly stated. I suggest that a combination of fan-based methods, in addition to strategically-placed arenas, would provide the best data for accurately assessing hatchling sea-finding ability.

Given that multiple LNG plants and a large tourist resort are either proposed or under development at Curtis Island, continued monitoring of hatchling orientation at this beach is strongly recommended. My findings also indicate that industrial development in the Fitzroy River Delta could potentially disrupt hatchling orientation at Peak Island in the future. Light management plans for industrial developments need to be comprehensive (see Chapter 7) and include consideration of moon phase, moon-stage, cloud cover and hatchling time of emergence; since all of these factors will affect the likelihood of hatchling disruption at nesting beaches exposed to large scale artificial light-glow.

Chapter 5

Balancing artificial light at night with turtle conservation? Coastal community engagement with light-glow reduction

The previous chapters have indicated that Australian marine turtles are vulnerable to light pollution (Chapter 2) which is increasing in many areas (Chapter 3), and may disrupt hatchling sea-finding behaviour (Chapter 4). Nesting beaches located close to urban areas along the Woongarra coast of Queensland were highlighted as potentially being some of the most light-exposed in Australia (Chapter 2).

In this chapter, I begin to address the third knowledge gap discussed in Chapter 1, namely a consideration of the 'human factor' in lighting management. I assess community engagement with light reduction initiatives instigated to protect local turtles along the Woongarra coast, using a theoretical constraints framework, which allowed an investigation of potential limits on engagement.

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5.1 ABSTRACT

Artificial lighting is a significant threat to biodiversity. Although efforts to reduce lighting are crucial for species' conservation efforts, management is challenging because light at night is integral to modern society and light-use is increasing with population and economic growth. The development and evaluation of appropriate light management strategies will require positive public support, and a comprehensive understanding of public engagement with light pollution. I present the first study to examine public engagement with reducing light at night for the protection of a threatened species. A community campaign to reduce artificial light-use was initiated in 2008 to protect marine turtles at a local, globally significant nesting beach. Semi-structured questionnaires assessed community engagement with light-glow reduction, using an existing theoretical constraints framework. Despite high levels of cognitive and affective engagement (knowledge and concern), behavioural engagement (action) with light reduction in this community was limited. Community perceptions of light reduction were dominated by 'uncertainty and scepticism' and 'externalising responsibility/blame', implying that behavioural engagement in this community may be increased by addressing these widely-held perceptions using modified campaign materials and/or strategic legislation. I also propose a refinement to the theoretical constraints framework to guide future empirical and conceptual research to improve understanding of public engagement with critical environmental issues.

5.2 INTRODUCTION

As a serious global pollutant, light has been neglected compared to other anthropogenic pressures (Falchi *et al.* 2011; Lyytimäki 2013). Modern humans lack experience of non-light-polluted nighttime environments and perceive extended use of light at night as 'normal' (Lyytimäki 2013). Efforts to reduce light may therefore be viewed as unimportant, or actively opposed due to negative perceptions of naturally dark environments (e.g. Bixler and Floyd 1997; Lyytimäki and Rinne 2013).

Since public support is integral to the success of conservation initiatives (Jacobson and McDuff 1998), effective management of light pollution will require the public to positively engage with the issue (Fischer and Young 2007; Lyytimäki and Rinne 2013). Lorenzoni *et al.* (2007 p. 446) define engagement as "a personal state of connection" with an environmental issue, comprised of cognitive, affective and behavioural elements. To be engaged, knowledge and awareness (the cognitive dimension) of the issue are necessary but insufficient in isolation. People need to also care about the issue (the affective dimension), and take action (the behavioural dimension) to address it. Although this definition was formulated to explore public engagement with climate change, which has been defined as an 'intangible' problem of global extent, characterised by possessing less urgency and certainty than other environmental problems (Moser 2010a), I believe the definition is also appropriate for an examination of public engagement with the issue of light pollution. Whilst individual actions to reduce light may be more tangible (for example the immediate reduction in lighting which can be seen after switching lights off), an individual's contribution to reducing larger-scale light pollution for reducing impacts on marine turtles is less tangible. Moreover, the global environmental change associated with artificial lighting is not widely recognised as an environmental concern, let alone one requiring urgent attention (Lyytimäki 2013).

Sutton and Tobin (2011) developed a framework to examine public engagement with environmental issues, which suggested that the three elements of engagement described by Lorenzoni *et al.* (2007) are related linearly (Figure 5.1). Under this framework, behavioural engagement is dependent upon the formation of a desire to engage, which depends upon affective engagement (i.e. concern), which in turn relies upon an individual processing any related knowledge they possess (i.e. cognitive engagement).

Sutton and Tobin's (2011) framework also incorporated a conceptualisation of behavioural constraints, based on the work of Tanner (1999), to investigate limits on engagement. Tanner (1999) argued that environmental behaviour is limited by situational and personal factors, independent of pro-environmental attitudes. She considered that external factors, termed 'objective constraints', may directly impede pro-environmental behaviour. However, because individuals also act based on their own "personal view of reality" (Tanner 1999 p. 147), internal factors, termed 'subjective constraints', are a second type of constraint which may limit desire for pro-environmental action. Sutton and Tobin (2011) suggested that subjective constraints act on the cognitive and affective elements of engagement, controlling the formation of a desire to engage; and objective constraints act to impede behavioural engagement in motivated individuals who have already formed a desire to engage. Overall this framework implies that a comprehensive understanding of existing cognitive, affective and behavioural engagement and related constraints will be fundamental to efforts to influence public engagement with environmental issues such as light-pollution.

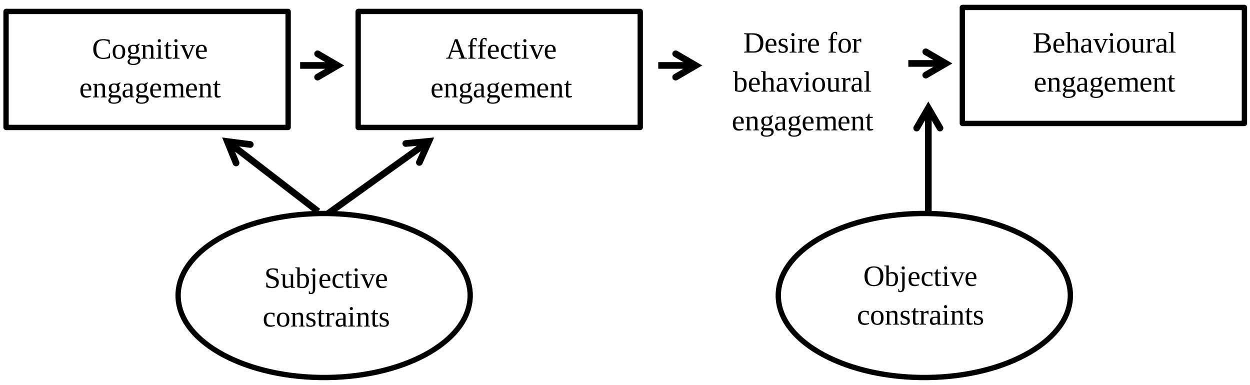

Figure 5.1 A hierarchical model of constraints on engagement (redrawn from Sutton and Tobin 2011)

Marine turtles are a species well-known to be disrupted by artificial lighting due to their dependence upon light-cues for orientation at the nesting beach (Witherington and Martin 2000; Salmon 2003). Light pollution has also been identified as a threat impacting marine turtles across large spatial scales (Chapters 2 and 3; Mazor *et al*. 2013). In this chapter, I examined community engagement with the issue of light reduction for turtle conservation near the globally important nesting beach of Mon Repos, on the Woongarra coast of Queensland: a region where marine turtles have been potentially exposed to significant levels of light pollution for many years (Figure 5.2) (Chapters 2 and 3; Limpus and Kamrowski 2013).

Located within a conservation park, Mon Repos beach is protected from coastal development. However, reports of emerging hatchlings crawling towards the conspicuous light-glow generated by the township of Bargara (census population of 6893 in 2011; Australian Bureau of Statistics 2013) located 2 km south of Mon Repos (Berry *et al.* 2013), led the Queensland Parks and Wildlife Service (QPWS) to launch the 'Cut the Glow to Help Turtles Go' campaign in

2008. Each year during the nesting season (November to March), local households and businesses have been provided with information and advice about reducing light usage: through leaflets, posters, community events and radio and print media. However, recent observations indicate that community light-glow remains problematic for local turtles (Berry *et al.* 2013) despite reported high levels of community campaign awareness (McDonald and Fielding 2010), suggesting insufficient community engagement with light reduction.

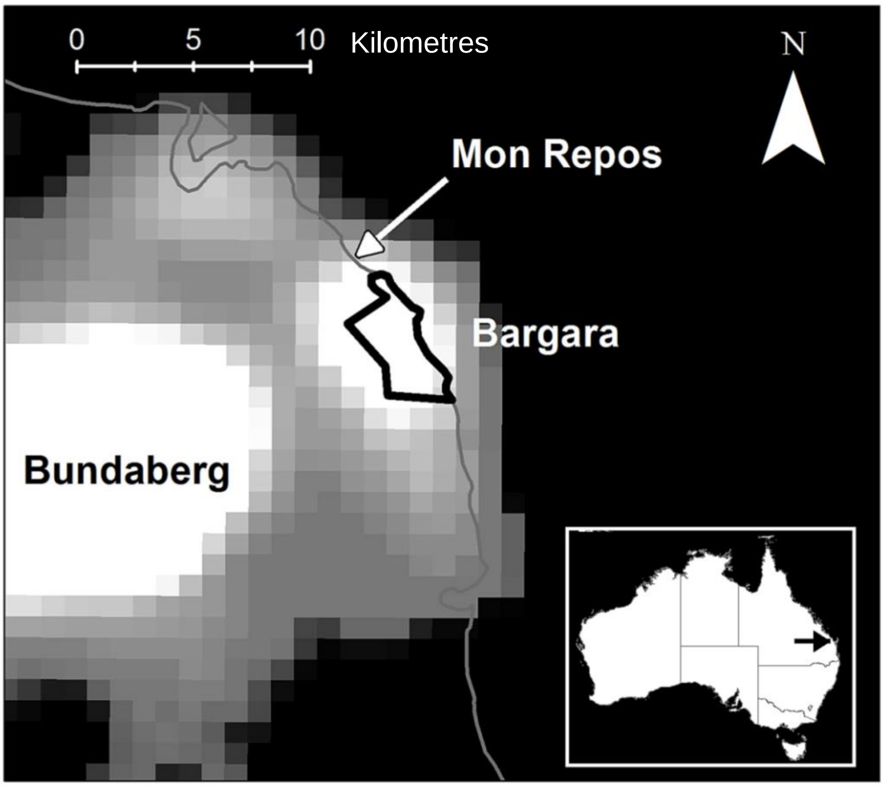

Figure 5.2 Nighttime lights of the study region with location of Mon Repos shown in relation to Bargara (inset: location within Australia). Image and data processing of night light data by NOAA's National Geophysical Data Center. Defense Meteorological Satellite Program data collected by the US Air Force Weather Agency.

I examined the times at which residents used artificial light, determined the proportion of the community who were cognitively, affectively and/or behaviourally engaged with the local light pollution issue, and identified specific constraints limiting engagement. I also evaluated the utility of the Sutton and Tobin (2011) constraints framework for understanding engagement with light reduction. My overarching objective was to provide information and conceptual development to facilitate public engagement with the issue of light pollution.

5.3 METHODS

Survey distribution

Questionnaires were distributed over 14 days in November 2012, at the start of the turtle nesting season when annual ‘Cut the Glow’ campaigning had commenced. The target population was adult residents of Bargara. Respondents were recruited using a stratified random door-knock sampling strategy, whereby 100 streets were selected from a map of Bargara, and houses on selected streets approached between 09:00 and 19:00 h each day. In total, 1010 houses on 96 streets were approached, with 494 doors answered. Once the door was answered, the researcher explained the survey aims and rationale. If the resident agreed to take part, the researcher arranged a time for survey collection (at least 24 hours later) rather than completing the questionnaire with each respondent. This method was used to avoid social desirability bias (where the presence of the researcher biases responses to those considered more ‘socially desirable’ (Paulhus 1984; Beckmann 2005)), whilst allowing more questionnaires to be distributed given time constraints. If there was no answer at the agreed upon collection time, the researcher left a card with a telephone number and requested the respondent call to rearrange collection. The researcher then made two further attempts to collect the survey. This procedure resulted in 352 completed surveys, giving a response rate of 71%.

Survey items

The questionnaire was confidential and self-administered (Appendix 3). It contained items to assess current light-use (“At what time do you generally turn your household lights off on weeknights (Sun-Thurs)/on weekends (Fri-Sat)?”), household size (“How many adults/children live in your residence?”), campaign awareness (“Are you aware of the ‘Cut the Glow to help Turtles Go’ campaign?”), and perceived importance of different light producers in disrupting local turtles, on a 7-point scale from 1 = disagree to 7 = agree (“I think the following light producers generate enough light at night to potentially affect local turtles: all residential properties/beachfront properties/properties located more than two streets back from the beachfront/bars, restaurants, takeaways/bowls club/shops/street lighting). The local lawn-bowls club offers flood-lit ‘night’ bowling, which was raised as a potentially significant contributor to the glow visible at Mon Repos during informal conversations with residents prior to study commencement. The Friedman test was used to analyse perceptual differences between light producers, and post-hoc analysis involved multiple Wilcoxon signed-rank tests with a Bonferroni correction applied. Items were also included to assess respondent experience with local turtles (“Have you ever visited Mon Repos or other beaches to observe turtles during the nesting season? If yes, how many times?”, and “Do you/have you ever volunteer(ed) with turtles at Mon Repos?”), as well as demographic information.

Items assessing engagement with the light glow/turtle issue were modified from Sutton and Tobin (2011). Level of cognitive engagement was measured by asking questions about the following beliefs on a 7-point scale: “How much of an effect does human activity have on sea turtle mortality?” (1 = no effect to 7 = major effect); “How much of a negative impact does artificial lighting have on local sea turtles?” (1 = no impact to 7 = major impact); “How necessary is it to reduce human use of light in areas where sea turtles nest?” (1 = not necessary to 7 = very necessary). Level of affective engagement was measured with the following items: “How concerned are you about the effects of artificial light on local sea turtles?” (1 = not concerned to 7 = very concerned); “If the local sea turtle population declined it would have serious consequences for me and my family” (1 = disagree to 7 = agree); “How interested are you in taking action to help reduce the impact of artificial light on local sea turtles?” (1 = not interested to 7 = very interested). The 7-point scale was collapsed into 4 categories for aiding the display of results and discussion (e.g. Sutton and Tobin 2011), as follows: Items scoring 2 or 3 were categorised as being considered of ‘minor’ importance by respondents (minor effect/minor impact/minor consequence etc.); items scoring 4 or 5 were categorised as of ‘moderate’ importance; and items scoring 6 or 7 as of ‘major’ importance (refined from Sutton and Tobin 2011). Spearman’s rank correlation was used to determine whether median scores from the items assessing cognitive engagement were correlated with scores from the items assessing affective engagement.

Respondents who indicated a moderate to strong interest (affect) in taking action to reduce impacts of artificial light on local turtles, by scoring 5 or higher (e.g. Sutton and Tobin 2011), were considered to have formed a desire to take light reduction action. Behavioural engagement was measured by asking “Since the campaign started in 2008, during the turtle nesting season (Nov-Mar) have you taken any deliberate action to help reduce the impact of light-glow on local sea turtles?”

Perceived ability to take action was measured by asking “Which of the following two statements best describes the extent to which you are currently helping to reduce the impact of light-glow on local nesting turtles? (a) I don't do as much as I would like to or (b) I don't want to do more than I am already doing”. This item, when considered in combination with the item measuring desire to take light reduction action, essentially divides respondents into those experiencing objective versus subjective constraints on engagement. According to Sutton and Tobin (2011), engagement in individuals with a desire to take action can be considered to be primarily limited by objective constraints if they select (a), and by subjective constraints if selecting (b). The hierarchical structure of the constraints framework further implies that the engagement of individuals without a desire to engage is principally limited by subjective constraints preventing a formation of desire, regardless of respondent selection of (a) or (b).

Thus, to confirm whether subjective or objective constraints were relevant to each category of respondent I asked the open-ended item "Please explain why you chose (a) or (b)". Responses to this question were grouped based on constraint categories identified by Lorenzoni *et al.* (2007) and also whether the limiting factors could be considered as internal (subjective) or external factors (objective) (Tanner 1999). Descriptive statistics were calculated for all measures and analyses appropriate for ordinal and normative data, as described within the results, were used for comparisons.

The questionnaire also contained items designed to assess community beliefs relating to three specific light reduction behaviours; however this will be detailed and discussed in the next chapter (Chapter 6)

5.4 RESULTS

Respondent profile and light-use

Respondents were aged from 16 to 87 years (mean = 50.1, SD = 16.2), 61% were female. Most respondents (65%) had previously visited Mon Repos to observe turtles, but the median number of visits to Mon Repos was low (2 visits, n = 210) relative to the mean length of residence in the area for these respondents (9.5 years). Only 0.04% of the respondents had ever volunteered with turtles at Mon Repos. In total, the survey recorded light usage of 990 residents (707 adults, 283 children), equating to 14.4% of Bargara residents, and 10% of the adult population (Australian Bureau of Statistics 2013).

The reported average time for lights out on weekdays was 21:30 h, and 87.5% of households reported household lights out by 22:30 h (Figure 5.3). Respondents reported leaving lights on slightly later on weekend days, with the average time for lights out being 21:55 h, and 89.3% of households having lights out by 23:00 h (Figure 5.3). All lights were reported to be out by 01:00 h each day.

Beliefs about light-glow contributions

Respondents' perceptions of the potential disruption of local turtles differed significantly across the various light producers (Friedman test: χ^2 (6) = 420.5, $p < 0.001$; Table 5.1). With a significance level set at $p < 0.0024$ following Bonferroni correction, respondents perceived 'beachfront properties' as the most disruptive light source, scoring it significantly higher than all other light-producers (Z = -6.69 to -12.02, $p < 0.001$). 'Local street lighting' was scored significantly higher than all other light producers (Z = -4.54 to -8.854, $p < 0.001$) with the exception of 'beachfront properties' and 'bars/restaurants/takeaways' (Z = -1.1, p = 0.27).

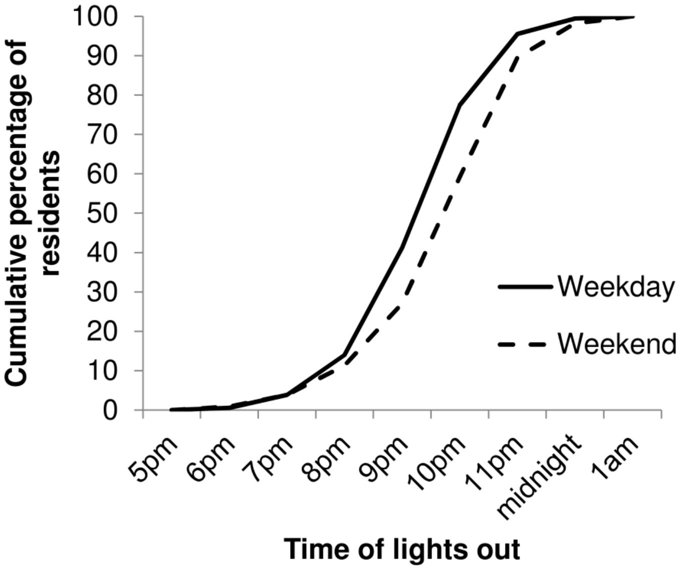

Figure 5.3.Artificial light-use at night reported by residents in Bargara.

Table 5.1 Respondent strength of agreement regarding whether each producer generated light potentially disruptive to local turtles (1: disagree, 7: agree), shown in descending order. Median ranked score (with each light producer ranked against all others) also shown.

Local light producers	n	Median score	Interquartile range	Rank score
Beachfront properties	345	7	6-7	5.5
Local street lighting	343	7	5-7	5
Bars/restaurants/takeaway shops	341	6	5-7	4.5
Retail shops	340	6	4-7	4
Properties more than two streets back from the beachfront	344	5	4-7	3.5
All residences	343	5	3-7	3
The local bowls club	341	5	3-7	3

In turn, ‘bars/restaurants/takeaways’ scored significantly higher than all remaining light-producers (Z = -7.008 to -9.557, $p < 0.001$). In contrast, ‘all residences’ scored significantly lower than all other light producers (Z = -12.02 to -5.73, $p < 0.001$) except the ‘bowls club’ (Z = -0.16, $p = 0.87$) and ‘properties more than two streets back from the beachfront’ (Z = -2.35, p = 0.019).

The median rank of responses, relative to each light source, indicated again that ‘beachfront properties’, followed by ‘local street lighting’ and ‘bars/restaurants/takeaways’, were considered to be the light-producers most likely to impact local turtles, with ‘all residences’ and the ‘bowls club’ ranked least likely (Table 5.1).

Awareness and engagement with light-glow reduction

Respondents were generally aware of the light reduction campaign (84%). Of those unaware of the campaign, a large proportion (36%) had lived in Bargara for less than 1 year, and because the campaign is seasonal, might not yet have been exposed to the message. However 12% of the long-term population (mean length of residence: 9.2 years), were unaware of the campaign.

Internal reliability for the three cognitive and three affective measures was adequate ($\alpha = 0.77$ and 0.75 respectively), and overall respondents showed high levels of cognitive and affective engagement with light-glow reduction (Figure 5.4). The majority of respondents believed that human activity has a major effect on local turtles (65.7%), believed that light-glow has a major impact on local turtles (66.2%), were highly concerned about impacts of light glow on local turtles (60%), and believed that reducing human activities that cause light-glow close to nesting beaches is a major necessity (78.3%). There was a highly significant correlation between cognitive and affective engagement ($r_s[352] = 0.536$, $p < 0.001$).

Despite the high levels of cognitive and affective engagement, 64.7% of respondents reported not taking any action in the past to reduce light. Yet, a large majority of respondents reported a desire to engage with light-glow reduction (75.3% score of >5, n = 259). Thus respondents desired to be behaviourally engaged, but generally were not behaviourally engaged at present. This finding was explored further by categorising respondents according to their desire to take light-glow reduction action and their perceived ability to take action at the desired level (Table 5.2). According to the framework developed by Sutton and Tobin (2011) individuals falling into boxes a, c, and d (Table 5.2) experienced subjective constraints on engagement (either having no desire to take action (Table 5.2, boxes c and d), or no desire to take further action (Table 5.2, box a)), whilst those in box b (Table 5.2) experienced objective constraints (they had a desire to take action, but something prevented them from doing so).

The largest proportion of respondents were individuals who expressed a desire to engage with light-glow reduction and were able to take action at the desired level (Table 5.2, box a). However there was no significant difference reported in past behaviour between these individuals and individuals who were able to take action at the desired level but reported no desire to engage (χ^2 (1) = 0.02, p = 0.89) (Table 5.2, box c).

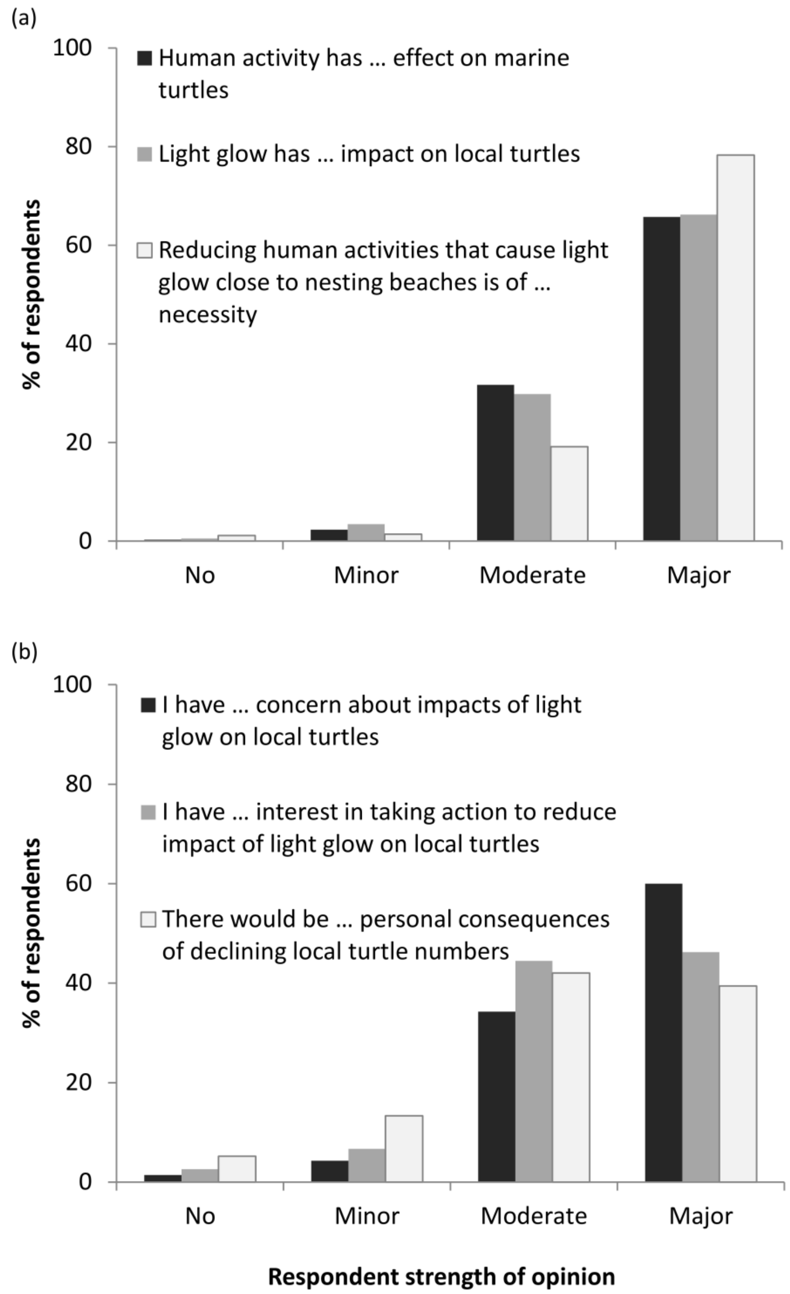

Figure 5.4 Responses to survey items measuring cognitive (a) and affective (b) engagement with light-glow reduction. Items were measured on a 7-point scale. Items scored with 1 (no effect/no impact/no consequence etc) are shown as ‘no’, items scoring 2 or 3 are shown as ‘minor’ (minor effect/minor impact/minor consequence etc.), items scoring 4 or 5 shown as ‘moderate’; and items scoring 6 or 7 shown as ‘major’.

Table 5.2 Respondents classified according to desire to engage in light-glow reduction and perceived ability to take action. Also shown are the percentages of respondents in each category who took past light-glow reduction action, and who indicated a moderate-high likelihood of future engagement with light-glow reduction.

		Able to take action at the desired level? Yes	No
Desire to take action?	Yes	**(Box a)** n = 124 Population proportion: 39.5% Likely future engagement: 44.4% Took action in past: 35.5%	**(Box b)** n = 116 Population proportion: 36.9% Likely future engagement: 81.9% Took action in past: 37.1%
	No	**(Box c)** n = 38 Population proportion: 12.1% Likely future engagement: 28.9% Took action in past: 34.2%	**(Box d)** n = 36 Population proportion: 11.5% Likely future engagement: 58.3% Took action in past: 22.2%

Of the individuals who reported a desire to engage with light-glow reduction, those who reported not being able to do as much as they would like (i.e., those experiencing objective constraints on engagement, Table 5.2, box b) were more likely to have taken light-glow reduction action in the past than individuals who experienced subjective constraints on engagement (Table 5.2, boxes a, c, d). Similarly, box b individuals were also more likely to believe they will engage with light-glow reduction for the rest of the nesting season, than were all other respondents. Individuals who felt no desire to engage and felt unable to take action at the desired level (Table 5.2, box d), although having the lowest likelihood of past action of all categories, also had a higher belief of future engagement than all individuals who reported an ability to take action (Table 5.2, boxes a and c).

To better understand the specific constraints affecting engagement, I performed a detailed examination of respondent responses (Tables 5.3 and 5.4). Respondents who felt able to take action (Table 5.2, boxes a and c) were dominated by subjective constraints (Table 5.4), as predicted by the Sutton and Tobin (2011) framework (mainly ‘externalising responsibility/blame’ for box a respondents, n = 30; mainly ‘uncertainty and scepticism’ and ‘externalising responsibility/blame’ for box c respondents, n = 18). However respondents who felt unable to take action at the desired level (Table 5.2, boxes b and d) were dominated by objective constraints regardless of reported ‘desire to engage’ (mainly ‘lack of knowledge’ and

Table 5.3 Reported constraints on engagement with light-glow reduction.

Type of constraint (Tanner 1999)	Constraint sub-categories (Based on Lorenzoni *et al*. 2007)	No. respondents	Example respondent quotes
Subjective	Uncertainty and scepticism	70	"We live away from the beach and so therefore don't believe that our lights would make a huge difference" (C8) "Turtles will lay their eggs wherever suitable, not only on Mon Repos" (M100)
	Externalising responsibility /blame – including the belief 'I am doing my part, it's up to others'	39	"I feel that we are doing what every household needs to do" (C95) "The main source of lighting in our street is the council lamp post which is so bright it causes issues at night to local residents. I would like to see council reduce wattage of lights to reduce glow" (E33)
	Helplessness / 'Drop in the ocean' feeling	20	"I don't believe there is any more we could do, other than sit in the dark!!" (M90) "there is very little I can do in our house to reduce the light pollution further" (E82)
	Reluctance to change lifestyle	11	"I am fairly lazy and believe my impact on the turtles is not negative" (M56)
	Distrust in information sources	1	"this idea is imposed by visitors not long term locals" (C61)
	Fatalism (no point)	1	"you can't shut the gate once the horse has bolted" (E81)
	Free rider effect	1	"it feels redundant when no one else does it" (E120)
	Total subjective	**140**	
Objective	Lack of knowledge	42	"I don't know what I can do to reduce the impact" (M85) "I was completely unaware the population has decreased so much" (E109)
	Importance of other priorities	27	"I would like to do more but am very busy" (E48) "it is true I could do more - but it's still not my priority in life when you're scraping to make ends meet" (C7)
	Other external factors	14	"We are vision impaired and need light to see" (C112) "our household is doing the most it can as we are renting and cannot change fixtures" (E51)
	Lack of enabling initiatives	8	"I would happily do more if directed on what would help" (C10) "If someone pointed out a fault I would try and change" (E26)
	Total objective	**91**	

Table 5.4 Respondent constraints categorised by desire and ability to engage.

		Able to take action at the desired level? Yes	No
Desire to take action?	Yes	**(Box a)** Subjective constraints: n = 86 (69.4%) Objective constraints: n = 15 (12.1%) Neither/missing: n = 23	**(Box b)** Subjective constraints: n = 27 (23.3%) Objective constraints: n = 52 (44.8%) Neither/missing: n = 37
	No	**(Box c)** Subjective constraints: n = 22 (57.9%) Objective constraints: n = 9 (23.7%) Neither/missing: n = 7	**(Box d)** Subjective constraints: n = 8 (22.2%) Objective constraints: n = 16 (44.4%) Neither/missing: n = 12

the related ‘lack of enabling initiatives’ for box b respondents, n = 31; and mainly ‘lack of knowledge’ and ‘importance of other priorities’ for box d respondents, n = 15).

Respondents who feel able to take action (boxes a and c) were dominated by subjective constraints, as predicted by the Sutton and Tobin (2011) framework (mainly ‘externalising responsibility/blame’ for box a respondents, n = 30; mainly ‘uncertainty and scepticism’ and ‘externalising responsibility/blame’ for box c respondents, n = 18). However respondents who feel unable to take action at the desired level (boxes b and d) were dominated by objective constraints regardless of reported ‘desire to engage’ (mainly ‘lack of knowledge’ and the related ‘lack of enabling initiatives’ for box b respondents, n = 31; and mainly ‘lack of knowledge’ and ‘importance of other priorities’ for box d respondents, n = 15).

5.5 DISCUSSION

Community light-use, engagement, and related constraints

I found high levels of cognitive and affective engagement with light reduction in my study community where a light reduction campaign was active. Thus the campaign had been effective at increasing community knowledge regarding impacts of artificial lighting on turtles, as well as promoting pro-environmental beliefs about artificial light-use (e.g. Sutton and Tobin 2011). However, despite a widespread reported desire to reduce light during the nesting season, community behavioural engagement with light reduction was limited. In addition, all household lights were reported to be turned out by 01:00 h each night, yet local hatchling emergence peaks between 20:00 h and midnight (Limpus 1985), highlighting the importance of widespread local light reduction.

There was a widely-held perception that the biggest contributors to light disruptive to local turtles were sources of light beyond residents' control, suggesting that community engagement may be limited primarily by internal factors acting to limit desire for pro-environmental action (Tanner 1999). Indeed, behavioural engagement with light reduction was principally limited by subjective constraints, mainly related to 'uncertainty and scepticism' and 'externalising responsibility/blame' (Lorenzoni *et al.* 2007). Dominant perceptions were that respondents lived too far from the beach for their lights to be an issue, or that respondents were already taking necessary action or did not produce contributing light (i.e. other lights were to blame). Similarly, in Finland, public perceptions of light pollution were dominated by feelings of resignation linked to citizens' lack of control over the most common light sources (Lyytimäki and Rinne 2013). Multiple studies have also found perceptions can limit engagement with pro-environmental activities (Tanner 1999; Lorenzoni *et al.* 2007; Sutton and Tobin 2011; Whitmarsh *et al.* 2011). Collectively, these results highlight the importance of understanding what individuals know and believe about environmental issues, and their potential solutions, for designing effective programs to motivate individuals to take action (see Chapter 6).

Applicability of the constraints framework

Groups of respondents who reported feeling unable to take action at the desired level (Table 5.2, boxes b and d) were also the two groups most likely to believe that they would engage in the future, and both were primarily limited by objective constraints. However, previous research has found the opposite i.e. individuals are more likely to engage in environmental behaviour when they believe they have the capability to help solve environmental problems (Trigg *et al.* 1976; Huebner and Lipsey 1981). Moreover, respondents falling into box d reported no desire to engage, and should have therefore been primarily influenced by subjective constraints according to the framework used. The Sutton and Tobin (2011) linear model of constraints may thus be too simple.

According to Tanner (1999), objective constraints prevent behaviour, independent of perceptions regarding the action, whereas subjective constraints prevent individuals from forming a desire to act, on the basis of perceptions of what is possible, permissible or pleasurable. Experiencing an objective constraint for a particular action (e.g. time constraints) may influence an individual's interest and therefore their reported 'desire' for action. Moreover, Tanner (1999) considers a lack of knowledge to be an objective constraint (dependent upon external factors). Since knowledge is a pre-requisite for cognitive engagement, and lack of knowledge was one of the most commonly reported constraints I found in this analysis, cognitive engagement with light reduction for turtle conservation may be considered at least partially limited by objective constraints; rather than solely limited by subjective constraints as implied by the framework I used. Yet, although adequate knowledge (cognitive engagement) is required in order to generate concern and interest (affective engagement) for an environmental issue (Macey and Schneider 2008; Sutton and Tobin 2011), having interest in a particular topic is also likely to increase motivation to seek out or be open to further topic-related information (e.g. Lorenzoni *et al.* 2007). Simply, a lack of knowledge may limit interest (affect) but conversely, a lack of interest may also limit knowledge. I found a highly significant correlation between respondent measures of cognitive and affective engagement. However, respondents both with and without a desire to take action (determined based on the strength of their interest (affect) in taking action) principally reported a 'lack of knowledge' to be the reason for their ability/inability to take action, indicating that affective engagement with light reduction may not be dependent upon cognitive engagement.

I propose a refinement to the framework developed by Sutton and Tobin (2011) (Figure 5.5) in which cognitive and affective engagement are considered reciprocally linked, i.e. either may influence the other.

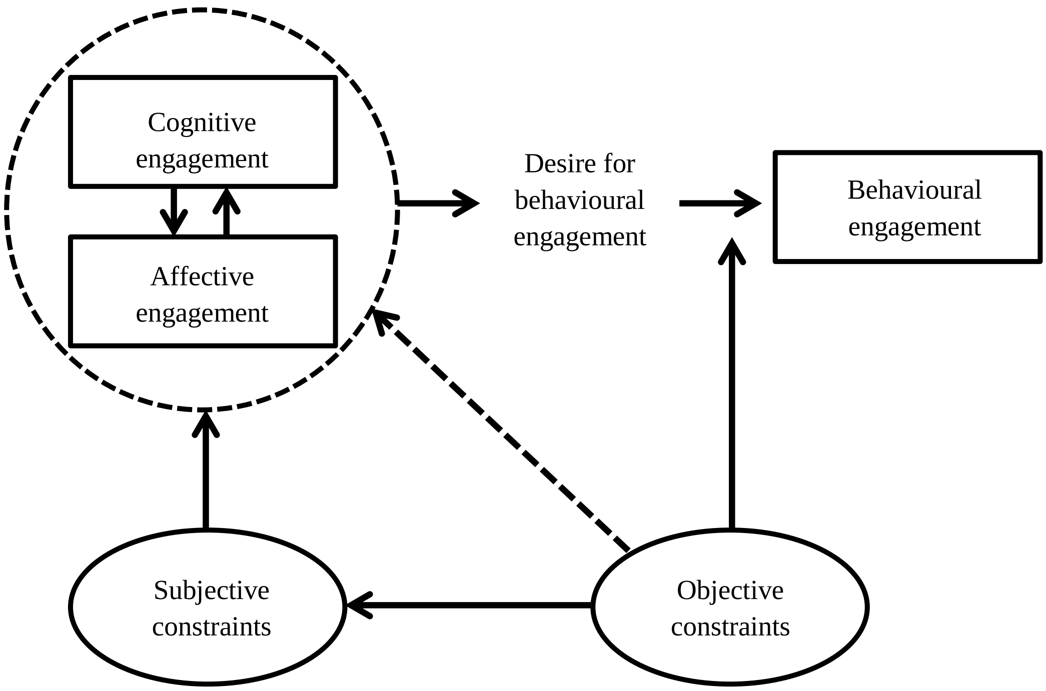

Figure 5.5 Proposed model of constraints on personal engagement with light-glow reduction for turtle conservation, adapted from Sutton and Tobin (2011). Arrows indicate direction of influence. The hatched arrow represents the fact that only certain objective constraints (e.g. lack of knowledge) may directly impact cognitive and affective engagement.

This ensures the model aligns with previous research which found cognitive influences on affect (Dolan and Holbrook 2001), as well as affective influences on cognition (e.g. Fischle 2000). Furthermore, I propose that objective constraints can lead to subjective constraints, because objective constraints can influence perceptions of what is possible and/or pleasurable, which in turn may limit cognitive and affective engagement necessary for the formation of a desire for action. Certain objective constraints may also directly limit cognitive and affective engagement, such as a lack of knowledge. Finally, objective constraints can still act at a later stage to prevent behavioural engagement with the pro-environmental issue, despite a desire for action.

I recognise that my proposed framework requires further research to test and refine the assumptions. For instance, my finding that affective engagement may not be dependent upon cognitive engagement may be related to the fact that light pollution is currently a relatively novel environmental issue (Lyytimäki 2013). Thus the framework would benefit from application to other, more widely recognised environmental behaviours. In addition, given that human behaviour is dependent upon a complex interaction of factors, such as normative influences (the behaviour and expectations of others) (Tucker 1999), and habits (Bamberg *et al.* 2003; Bamberg and Schmidt 2003), it is likely that a feedback loop exists between the different types of engagement. That is, performing the behaviour may have subsequent influences on what an individual thinks and/or feels about that behaviour (Ouellette and Wood 1998) and the desire (or not) for further or sustained performance. My data did not allow me to explore this link, but it would be a useful future research direction.

Recommendations

A range of methods exist which may facilitate engagement with environmental issues (Whitmarsh *et al.* 2011; Whitmarsh *et al.* 2013), and I recommend several strategies for increasing behavioural engagement in this community. First, there has been a recent call to impose legislative restrictions on light-use in this locality (Pudmenzky 2013), which emulates the widely used light reduction strategy in turtle nesting regions of the USA (e.g. Butler 1997). However, legislative restrictions on human light-use behaviours have been difficult to enforce and are extremely unpopular (Barschel *et al.* 2013). Given the widespread community perception that ‘local street lighting’ and ‘bars, restaurants and takeaways’ made significant contributions to light pollution, legislation imposed on commercial entities to reduce light, and to guide the replacement/installation of more ‘turtle-friendly’ street lighting, may be an effective way of reducing light without the need to legislate resident behaviour (I use the term ‘turtle-friendly cautiously here (Robertson 2013), referring only to positioning and shielding lights appropriately (Witherington and Martin 2000)). Such a scenario would reduce light directly by lessening light produced by these sources, but it might also indirectly reduce light by helping to address constraints perceived by residents. Two of the community constraints reported most frequently were subjective: 'uncertainty and scepticism' and 'externalising responsibility / blame'. Because the majority of residents were cognitively and affectively engaged with the issue of light reduction and also reported a desire to act, an obvious, and/or publicised reduction of light by other sources may result in a concomitant lessening of the widespread subjective constraint that the most disruptive light occurs outside of respondents own control, and help establish a community norm for a darker nighttime environment.

Thus, using technology and/or legislation to reduce light from other sources, as a means of altering the situation in which residents make decisions about engagement with light reduction behaviours, would likely be a valuable strategy for increasing behavioural engagement. However, should such an approach be implemented, communications to publicise actions taken by other actors must take care to avoid unwittingly deactivating norms by pointing out that some individuals or groups do not engage in light reduction efforts (McDonald *et al.* 2014).

Second, the existence of the small community proportion who engaged with light reduction without a desire to benefit turtle conservation (Table 5.2, box d) highlights the fact that pro-environmental behaviour is governed by complex interactions between psychological, social and environmental variables (Blake 1999; McKenzie-Mohr and Smith 1999; Stern 2000; Lorenzoni *et al.* 2007; Whitmarsh *et al.* 2013). Any public communication to increase pro-environmental engagement and stimulate desirable behaviours therefore needs to be 'psychologically smart' (Ockwell *et al.* 2009, p. 307). In particular, communication needs to recognise that different values, concerns, benefits, and barriers will exist between different audiences (Whitmarsh *et al.* 2013): thus audiences require their own specific messages. Targeted persuasive communication techniques underpinned by theories of behaviour change have been successfully used to influence human behaviour in specific instances of natural resource management (McKenzie-Mohr 2000a; Ham *et al.* 2008; Brown *et al.* 2010; Steckenreuter and Wolf 2013). Thus, persuasive communication insights used in future campaign materials, based on community beliefs about light reduction, may be a further method to increase behavioural engagement (see Chapter 6).

I examined engagement with light reduction initiatives specifically implemented to protect marine turtles, but I did not directly assess respondents' perceptions towards turtles. Visiting Mon Repos has been found to increase positive attitudes towards turtles as well as increasing desire for turtle conservation (Tisdell and Wilson 2001). Because the majority of respondents had visited Mon Repos, it is possible that light reduction behaviour was influenced by more positive perceptions to turtles than would be found in a similar community elsewhere. Yet, very few respondents had ever volunteered at Mon Repos, and generally visits to view local turtles were infrequent, thus I do not believe that my sample was biased towards people with a particular interest in marine turtles. However exploring the influence of direct experience with turtles, and perceptions of, and concern about, turtles for motivating light reduction action may be a useful avenue for future research (e.g. Ballantyne *et al.* 2011; Senko *et al.* 2011). Moreover, artificial lighting has detrimental impacts on multiple species, including humans (Rich and Longcore 2006; Stevens 2009). As recognition of these impacts increases, future work should assess whether community motivation to reduce light may be improved by widening the campaign focus from the single purpose of marine turtle conservation, and/or reframing the campaign to include other benefits of darker nights e.g. more pleasant lighting, cost savings related to energy use (Gallaway *et al.* 2010) or improved star-gazing opportunities (Willis *et al.* 2005; Hölker *et al.* 2010a).

I also recognise that although in this instance local community engagement is crucial for reducing light glow (given difficulties associated with legislating public behaviour close to nesting beaches (Barschel *et al.* 2013) and a current lack of non-disruptive lighting technologies (see Robertson 2013)), in different contexts different approaches to managing light will likely be required (e.g. Falchi *et al.* 2011; Cha *et al.* 2014). With continued research, methods to engage the public with light reduction initiatives will hopefully become part of a suite of management strategies which address detrimental impacts associated with this global environmental change.

5.6 CONCLUSIONS

Despite knowledge and awareness, light reduction action in this coastal community was limited; demonstrating that effectively managing public use of light at night for marine turtle conservation is a complex task which is unlikely to result from education campaigns alone. Yet, in this chapter I establish that a comprehensive understanding of public engagement with the light pollution issue, and identification of specific constraints on engagement, provide valuable insights for the development of appropriate and targeted light mitigation strategies. The refinements I propose to the Sutton and Tobin (2011) framework of constraints may also now be used and further developed to increase understanding of public engagement with critically important environmental issues.

In the following chapter, I continue my examination of light reduction behaviour in this Queensland community, to explore additional methods for increasing community engagement with reducing light for turtle conservation.

Chapter 6

Potential applicability of persuasive communication to light-glow reduction efforts close to turtle nesting beaches

Chapter 5 examined community engagement with light reduction along the Woongarra coast of Queensland, a region identified as potentially being one of the most light-exposed turtle nesting regions in Australia (Chapter 2). Although the community displayed high levels of knowledge and awareness regarding detrimental impacts of lighting for local turtles, behavioural engagement with light reduction initiatives was limited i.e. few community members were taking action. In this chapter I continue to address the identified knowledge gap related to the human dimension of effective lighting management (Chapter 1). I use a well-known explanatory model of human behaviour, the Theory of Planned Behaviour (Ajzen, 1991), to identify potential methods which may be used to increase engagement with light reduction in this coastal community.

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6.1 ABSTRACT

Artificial lighting along coastlines poses a significant threat to marine turtles due to the importance of light for their natural orientation at the nesting beach. Effective lighting management requires widespread support and participation, yet engaging the public with light reduction initiatives is difficult because benefits associated with artificial lighting are deeply entrenched within modern society. I present a case study from Queensland, Australia, where an active light-glow reduction campaign has been in place since 2008 to protect nesting turtles. Semi-structured questionnaires explored community beliefs about reducing light, and evaluated the potential for using persuasive communication techniques based on the Theory of Planned Behaviour (TPB) to increase engagement with light reduction. Respondents (n = 352) had moderate to strong intentions to reduce light. TPB variables explained a significant proportion of variance in intention (multiple regression: R^2 = 0.54-0.69, $p < 0.001$), but adding a personal norm variable improved the model (R^2 = 0.73-0.79, $p < 0.001$). Significant differences in belief strength between campaign compliers and non-compliers suggest that targeting the beliefs that reducing light leads to ‘increased protection of local turtles’ ($p < 0.01$) and/or ‘benefits to the local economy’ ($p < 0.05$), in combination with an appeal to personal norms, would produce the strongest persuasion potential for future communications. Selective legislation and commitment strategies may be further useful strategies to increase community light reduction. As artificial light continues to gain attention as a pollutant, my methods and findings will be of interest to anyone needing to manage public artificial lighting.

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6.2 INTRODUCTION

Artificial light at night, as a result of coastal development, is one of the major global threats facing marine turtle populations' worldwide (Eckert 1999; Witherington and Martin 2000); yet reducing use of light at night close to nesting beaches is challenging. As described in my preceding chapters, light-use is pervasive and increasing (Chapters 2 and 3), thus effective management of artificial lighting close to marine turtle nesting areas will require broad participation with light reduction efforts (e.g. Fischer and Young 2007; Lyytimäki and Rinne 2013). However, excessive and extended nighttime light-use is now so commonplace (Cinzano *et al.* 2001a) that most modern humans lack experience of naturally-dark nighttime environments and perceive an artificially-lit night to be 'normal' (Lyytimäki 2013). Moreover, since brightly lit areas are generally considered to be modern and safe (Morris 2002), whilst darkness has long been associated with poverty, danger, and evil (Packer *et al.* 2011; Lyytimäki and Rinne 2013), initiatives to reduce light are often publicly criticised and/or opposed (Lyytimäki 2013).

The first step in changing public behaviour is widespread positive engagement with the issue (O'Neill and Nicholson-Cole 2009). In Chapter 5, I applied a framework developed to understand public engagement and constraints on engagement with environmental issues (Sutton and Tobin 2011), within the context of coastal community engagement with light reduction for turtle conservation in Queensland, Australia. Despite high levels of knowledge and concern about the issue, individual light-glow reduction action was found to be limited. Therefore, in this chapter I go on to examine the underlying beliefs of this community regarding intention to engage with the light reduction recommendations, and evaluate the potential for these beliefs to be used via persuasive communication techniques, based on the Theory of Planned Behaviour (Ajzen 1991; Ham 2007; Ham *et al.* 2008; Powell and Ham 2008). These techniques may be useful in increasing engagement with light reduction behaviour during the turtle nesting season.

Study context & theoretical background

As discussed in the previous chapter, the south Pacific stock of loggerhead turtles predominantly nests along the Woongarra coast of Queensland, Australia with most of the mainland nesting occurring at Mon Repos beach (Limpus and Limpus 2003). Mon Repos is situated within a conservation park; however, located two kilometres south is the township of Bargara, a popular retirement and tourist destination (Australian Bureau of Statistics 2007a) which generates enough light at night to create a conspicuous skyglow (Figure 5.2; Chapters 2 and 3). The Queensland Parks and Wildlife Service (QPWS) launched the 'Cut the Glow to

Help Turtles Go' campaign in 2008, using predominantly non-sequential communication (e.g. leaflets, stickers, and posters) to raise awareness of the detrimental impact of community light on local turtles, and provide advice for community members about actions that could be taken to reduce light-glow.

Although successful in raising community awareness of the issue, the 'Cut the Glow' campaign was less successful in provoking actual light reduction action (Chapter 5). Extensive research indicates that knowledge does not necessarily translate into action (Owens 2000; Kollmuss and Agyeman 2002; Lorenzoni *et al.* 2007). The existence of this 'value-action gap' (Blake 1999) highlights an inherent difficulty in attempting to influence human behaviour: an individual's environmental behaviour depends upon complex interactions between psychological, social, economic and environmental factors (Frey 1999; McKenzie-Mohr and Smith 1999; Stern 2000; Lorenzoni *et al.* 2007), tends to be context-specific, and is thus contingent on specific benefits and barriers to action (Whitmarsh *et al.* 2011). As a result, any communication campaign aimed at promoting widespread behaviour change requires a sound basis in human psychology (Bator and Cialdini 2000), and thus, an investigation of specific community beliefs related to light reduction is essential for improving communication efforts to provoke increased light reduction action.

One theoretical framework which has been successfully used in communication research to motivate behaviour change in natural resource management (Ham *et al.* 2008; Brown *et al.* 2010) is the Theory of Planned Behaviour (TPB) (Ajzen 1991). In brief, the TPB states that an individual's actions are governed by three sets of beliefs; 1) Behavioural beliefs relate to the perceived consequences of a specific behaviour and the likelihood of each outcome, and lead to a positive or negative attitude towards the behaviour; 2) Normative beliefs give weight to the expectations of important reference individuals or groups, in combination with an individuals' motivation to comply with others' wishes, and thus lead to subjective norms regarding the behaviour; and 3) Control beliefs relate to a consideration of factors which may facilitate or impede action, in combination with an appraisal of the power of each to facilitate or impede action, leading to perceptions of behavioural control (PBC). The TPB assumes that an individual's intention to engage with a specific behaviour is formed based on these attitudes, subjective norms, and PBC, and furthermore, that these intentions can be used to accurately predict behaviour to the extent that the salient beliefs remain the same when the time comes to take action (Bamberg and Schmidt 2003). The TPB has been widely applied across numerous behavioural domains, and has received good empirical support (Ajzen 2001; Armitage and Conner 2001). TPB investigations of pro-environmental behaviours have included assessments of recycling intention (Tonglet *et al.* 2004), intention to use public transport (Heath and Gifford 2002) and intention to engage in environmental activism (Fielding *et al.* 2008).

In persuasive communication, the TPB is used to identify the three types of belief relating to a specific ‘target’ behaviour, since communications targeting the salient beliefs of the intended audience are more likely to influence behaviour than communications based on managers’ own beliefs, or guesswork (Brown *et al.* 2010). Identified beliefs are then examined to determine whether any have persuasive potential for use in a communication intervention. Persuasive potential relates to those beliefs which effectively differentiate individuals who already behave in the desired way (compliers), from individuals who do not (non-compliers). These beliefs can then be used in communications which strengthen compliance and weaken non-compliance with the target behaviour (Ham *et al.* 2008).

Although shown to be a useful model for predicting behaviours, there have been several attempts to improve the predictive power of the TPB framework in recent years, by including other potentially relevant behavioural antecedents (Whitmarsh and O'Neill 2010). Personal norms relate to an individual’s personal views about morally-correct behaviour i.e. the self-imposed obligation humans feel to act because ‘it’s the right thing to do’ (Schwartz 1977; Stern and Dietz 1994). The inclusion of a personal norm variable to the TPB model has been found to improve predictions of behavioural intentions, particularly when examining altruistic behaviours (Parker *et al.* 1995; Vermette and Godin 1996), including pro-environmental actions (Harland *et al.* 1999; Bamberg and Schmidt 2003; Corbett 2005; Brown *et al.* 2010). As far as I am aware, no study to date has assessed the inclusion of personal norms in the TPB framework, for investigating intention to reduce artificial lighting. Since light-use is increasing around the world, and light pollution is known to have detrimental effects on multiple species (Rich and Longcore 2006) including humans (Davis *et al.* 2001; Stevens 2009; Lucas *et al.* 2014), an examination of personals norms is extremely relevant to my assessment of community intentions to reduce light-use at night.

I elicited underlying beliefs of community intention to engage with light-glow reduction recommendations, and compared belief strength between people who took light reduction action and those who did not; as a means of determining belief persuasion potential for future campaign materials. I also evaluated the predictive benefit of including personal norms in the TPB framework, related to intention to take light reduction action. My primary objective was to explore methods of increasing light reduction behaviour in a community with high levels of knowledge and concern, but low levels of light reduction action (Chapter 5). As further detrimental impacts from artificial lighting are recognised worldwide (e.g. Lyytimäki 2013), this research will benefit future efforts to reduce light at night.

6.3 METHODS

Materials for the 'Cut the Glow' campaign suggest a number of actions community members may take to reduce light during the turtle nesting season. Following consultation with QPWS rangers to determine the light reduction behaviours deemed to be most effective for reducing visible light-glow, I selected three target behaviours (Ajzen 2002) to use in my assessment:

1) Turning off external lights more than usual during the nesting season (Nov-Mar)
2) Closing curtains and blinds when internal lights are on more than usual during the nesting season (Nov-Mar)
3) Using motion sensor lights instead of constant outdoor lighting during the nesting season (Nov-Mar)

(hereafter referred to as 'external lights', 'closing curtains', and 'motion sensors', respectively).

Following established procedures for measuring variables in the Theory of Planned Behaviour (TPB) framework, data collection occurred in several phases (Ajzen 2002; Francis *et al.* 2004):

Belief elicitation

I conducted semi-structured interviews with a sample of residents in Bargara over 6 days in October 2011, prior to the commencement of turtle nesting season and any 'Cut the Glow' campaigning that year, and following well-defined procedures (as detailed in Ham *et al*. (2008)) (see also Ajzen 1991; Middlestadt *et al.* 1996; Lackey and Ham 2003). I asked a series of open-ended questions based on the TPB framework, to identify salient attitudinal, normative and control beliefs about light-glow reduction behaviours. The interviews took no more than 30 minutes to complete and were conducted until theoretical saturation was achieved (i.e. the point at which additional interviews provide little further information (Guest *et al.* 2006)). Saturation was reached after 23 interviews, and there was a 0% refusal rate (see Appendix 4 for the interview recruitment information sheet).

All responses were transcribed verbatim and independently reviewed and reclassified by four coders into a smaller set of previously defined categories (see Ham *et al*. 2008). Only those responses which were coded into the same category by three or more coders (75% or higher agreement) were retained. These beliefs were reviewed for frequency, and any beliefs which appeared only once were excluded from further analysis. Beliefs which remained were examined for persuasive potential in a primarily non-sequential communication campaign e.g. vague or redundant beliefs were excluded (see Ham *et al*. (2008) for selection criteria), and thus 14 beliefs were chosen for further examination (Table 6.1; Appendix 5).

Three versions of a pilot questionnaire were constructed to assess respondent beliefs regarding one of the three specific light-glow reduction desired behaviours (‘external lights’, ‘closing curtains’ and ‘motion sensors’). These were presented to a professional peer-group, and completed by 16 Bargara residents during pilot testing, in September 2012. The questionnaires were modified following feedback to ensure clarity of questions and aims (see Appendix 3 for external lights version).

Table 6.1 The salient beliefs of residents in Bargara, regarding light reduction behaviour during the turtle nesting season, which were obtained during a qualitative study and taken forward for further examination in the quantitative questionnaires.

Type of belief	Belief	Incorporated into which quantitative questionnaire version?
positive behavioural belief	If I *do X*, I will be protecting the local turtles	All
	If I *do X*, I will be helping the local economy	
	If I *do X*, I will save money	
negative behavioural belief	If I *do X*, I will be harming the local economy	
	If I *do X*, crime will increase	
	If I *do X*, accidents will increase	
positive normative belief	Other local residents think I should *do X*	
	Local businesses think I should *do X*	
	The Mon Repos Rangers think I should *do X*	
positive control belief	Observing local turtles would make it easier for me to *do X*	
	Knowing other people are taking action would make it easier for me to *do X*	
	Legislation (regulations with penalties for non-compliance) to ensure X was done, would make it easier for me to *do X*	
positive control belief	Knowing where to buy motion sensor lights would make it easier for me to *do X*	‘Motion sensors’ only
negative control belief	The added cost would make it difficult for me to *do X*	

Questionnaire distribution

Each of the three versions of the questionnaire was preceded by identical items to assess community engagement with light reduction (Chapter 5), therefore my method of survey distribution is detailed in the method section of the preceding chapter (section 5.3). Previous research recommends a sample size of at least 80 respondents for TPB questionnaires (Francis *et al*. 2004), thus the objective of this chapter was to obtain 100 questionnaires for each of the three specific behaviours, to allow for partial questionnaire completion or missing data. All potential respondents were asked if they owned or rented the property, since it would be inappropriate to assess the specific ‘motion sensors’ behaviour in a rented property. The version of the survey given out at each property thus depended upon the status of the property, but the three versions were given out in rotation, with ‘motion sensor’ versions held back when renters answered and given out to the next home owners until equal numbers of each version had been distributed. In total 494 doors were answered from 1010 approached houses on 96 streets, resulting in 352 completed surveys (117 ‘external lights’, 121 ‘closing curtains’, 115 ‘motion sensors’), and a response rate of 71%.

Survey items

All items were measured on a 7-point scale. All three questionnaire versions contained two questions to assess compliance with the campaign and past behaviour (“Since the campaign began in 2008, have you *carried out X*?”; along with “Since 2008, during the nesting season (Nov-Mar), how often have you *done X*?” for the ‘external lights’/’closing curtains’ actions, or “If you answered Yes, please explain why you *did X*” for the ‘motion sensors’ action). Each version contained identical questions to assess respondent experience with local turtles (“Have you ever visited Mon Repos or other beaches to observe turtles during the nesting season? If yes, how many times?”, and “Do you/have you ever volunteer(ed) with turtles at Mon Repos?”), as well as demographic information.

Two items assessed each of the beliefs generated from the elicitation study (also referred to as indirect measures of TPB variables) (Table 6.1); one assessing belief strength and one assessing an evaluative component of the belief (‘outcome evaluation’ for behavioural beliefs, ‘motivation to comply’ for normative beliefs, and ‘power’ for control beliefs), following the recommendations of Ajzen (2002) and Francis *et al*. (2004). Recommended procedures also include an examination of direct measures of each TPB construct. Consequently, attitudes towards the specific behaviour were measured using items assessing both instrumental and experiential aspects of evaluation, as well as a measure of overall evaluation, with positive and negative endpoints counterbalanced to reduce potential response sets. Items assessing both injunctive (whether important referents approve or disapprove of the behaviour) and descriptive norms (whether important referents perform the behaviour themselves) were included to assess direct measures of subjective norm. Items assessing both self-efficacy and controllability were included to capture direct measures of perceived behavioural control (PBC). Personal norm was assessed using three measures “I feel a personal, moral obligation to *do X* during the turtle nesting season”, “It would be wrong of me to NOT *do X* during the turtle nesting season”, and “I feel that I should *do X* during the turtle nesting season”. Behavioural intention was assessed using four measures “I am willing to *do X*”, “I intend to *do X*”, “I plan to *do X*”, “I will *do X*” (Fishbein and Ajzen 2010). Items assessing different constructs were separated and dispersed through the questionnaire in a random order following recommended procedures.

Analysis

Descriptive statistics were calculated for all measures, and analyses appropriate for ordinal and normative data, as described within the results, were used for comparisons. Internal reliability of constructs was assessed by calculating Cronbach's alpha, and performing bivariate correlations between direct and indirect measures of the same construct, as well as correlations between each measure and intention (Francis *et al.* 2004) (Appendix 6). For the indirect measures of TPB constructs (beliefs; Table 6.1), belief strength was scored in both a unipolar (1 to 7) and bipolar (-3 to +3) fashion, whilst the evaluative measure was scored using a bipolar scale (-3 to +3) only. Following Ajzen (2002), the belief strength scoring scheme which gave the strongest correlation between indirect and direct measures of each construct was used (Appendix 6).

Bivariate correlation and multiple regression were used to assess the importance of TPB variables, personal norm, and past behaviour, in predicting behavioural intentions for the remainder of the nesting season. Belief strength was also calculated for compliers (respondents who either always perform the behaviour, or choose to perform it more during the nesting season) and non-compliers (respondents who do not always perform the behaviour and who choose not to perform the behaviour more than usual during the nesting season) (Ham *et al.* 2008; Brown *et al.* 2010). Belief strength scores were then multiplied by outcome evaluation scores to determine whether significant belief differences existed between the two groups following procedures detailed in Ham *et al*. (2008).

6.4 RESULTS

Determinants of specific behavioural intention

The profile of respondents is described in the preceding chapter (section 5.5). Overall participants had positive (moderate to strong) intentions to engage in behaviours to reduce light in the upcoming nesting season, with the strength of the intention marginally decreasing as the commitment to engage increased (from 'I am willing' to 'I will') (Table 6.2).

The mean, standard deviation, and correlation of intention with attitude, subjective norm and PBC items, as well as the Cronbach's alpha score for each construct, and correlations between direct and indirect measures of the same construct, are presented in Appendix 6. Attitudes towards taking light-glow reduction actions for turtles were positive overall (direct measures mean: 5.25-6.08, SD: 1.27-1.71). Using the indirect attitude measures, respondents showed weak to moderate positive attitudes towards light reduction action (Appendix 6).

Table 6.2 Respondent intentions to engage with the light-glow reduction behaviours.

Behaviour	n	Cronbach's alpha	Item	Mean (SD) scale range: 1 = disagree to 7 = agree
'External lights'	117	0.887	I am willing	6.46 (1.05)
			I intend	6.22 (1.23)
			I plan	6.13 (1.49)
			I will	6.16 (1.3)
			Overall	**6.24 (1.28)**
'Curtains and blinds'	110	0.970	I am willing	5.43 (1.93)
			I intend	5.18 (1.98)
			I plan	5.2 (2.03)
			I will	5.26 (2.0)
			Overall	**5.27 (1.98)**
'Motion sensors'	106	0.967	I am willing	5.19 (1.97)
			I intend	4.75 (2.2)
			I plan	4.53 (2.33)
			I will	4.54 (2.33)
			Overall	**4.75 (2.22)**

Overall direct measures of subjective norms were rated as moderately in favour of the light-glow reduction efforts for turtles i.e. in general respondents feel a moderate social pressure to reduce light during the nesting season (mean of direct measures for the three actions being: 4.25-5.29, SD: 1.79-1.96). Indirect measures indicated residents feel a very weak to weak social pressure towards taking light-glow reduction actions for turtles (Appendix 6). However, respondents had a moderately strong belief that other people important to them engaged with light-glow reduction behaviours frequently (descriptive norms) (mean: 4.42-5.52, SD: 1.63-1.9), and also had a weakly positive belief that other people important to them supported their engagement in light-glow reduction behaviours (injunctive norm) (mean: 3.99-4.12, SD: 1.63-1.9).

Overall direct measures of perceived behavioural control had low reliability (< 0.53), however removal of the question 'whether I *do X* is completely up to me' increased the reliability to an acceptable level (α = > 0.8) in all three versions of the survey. Therefore this question was removed from further analysis (Bryman 2004). Direct measures indicated that respondents reported moderate to strong control over their own ability to take light-glow reduction actions for turtles (mean: 5.33-6.38, SD: 1.11-2.03) i.e. the three light-glow reduction behaviours can be considered relatively easy. Respondents who were questioned about 'external lights' reported a greater feeling of control over light-glow reduction than respondents who were questioned about the other two behaviours. Indirect measures indicated that respondents experienced a very weak to weak positive level of personal control over light-glow reduction for turtles (Appendix 6).

Collectively, the three measures assessing personal norms (Table 6.3) were significantly correlated with intention and had high internal reliability for each of the three light-glow reduction behaviours. Respondents reported a positive (moderate to strong) personal norm to comply with the light-glow reduction recommendations.

Table 6.3 Measures of personal norm, and correlation to intention to engage with the light-glow reduction behaviours.

Behaviour	n	Cronbach's alpha	Item	Mean (SD)	Correlation with intention (*: p < 0.01)
'External lights'	117	0.837	'I feel a personal obligation to *do X*'	5.87 (1.42)	0.785*
			'It would be wrong to NOT *do X*'	5.98 (1.38)	0.679*
			'I feel that I should *do X'*	6.09 (1.51)	0.858*
			Overall	**5.98 (1.44)**	**0.855***
'Curtains and blinds'	110	0.922	'I feel a personal obligation to *do X*'	4.82 (2.06)	0.732*
			'It would be wrong to NOT *do X*'	5.29 (2.03)	0.735*
			'I feel that I should *do X'*	4.70 (2.09)	0.790*
			Overall	**4.94 (2.07)**	**0.810***
'Motion sensors'	105	0.908	'I feel a personal obligation to *do X*'	5.02 (1.89)	0.665*
			'It would be wrong to NOT *do X*'	4.93 (2.02)	0.699*
			'I feel that I should *do X'*	4.97 (2.04)	0.886*
			Overall	**4.97 (1.98)**	**0.821***

Bivariate correlations of direct measures and intention indicated that: attitudes ($p < 0.01$), subjective norms ($p < 0.001$), PBC ($p < 0.001$), personal norms ($p < 0.001$), and past behaviour

($p < 0.01$) were all significant predictors of intention to engage with all three specific light-glow reduction behaviours for the remainder of the turtle nesting season. Multiple regression analyses showed that the TPB variables (attitudes, subjective norms (SN), and PBC) explained a significant proportion of the variance in intention to engage with light-glow reduction: (‘external lights’: $R^2 = 0.54$ ($F = 36.6$, $p < 0.001$); ‘closing curtains’: $R^2 = 0.69$ ($F = 65.18$, $p < 0.001$); ‘motion sensors’: $R^2 = 0.64$ ($F = 53.18$, $p < 0.001$)), and all three variables were significant predictors of intention to engage with ‘external lights’ and ‘closing curtains’ (Attitude: $\beta = 0.24/0.38$, $p < 0.01$; SN: $\beta = 0.45/0.19$, $p < 0.05$; PBC: $\beta = 0.25/0.39$, $p < 0.01$). Subjective norm and PBC were significant predictors of intention to engage for ‘motion sensors’ (SN: $\beta = 0.34$, $p < 0.001$; PBC: $\beta = 0.54$, $p < 0.001$), but attitudes were not. The addition of personal norm improved the model, explaining a higher proportion of the variance in intention to engage (‘external lights’: $R^2 = 0.79$ ($F = 85.9$, $p < 0.001$); ‘closing curtains’: $R^2 = 0.74$ ($F = 61.3$, $p < 0.001$); ‘motion sensors’: $R^2 = 0.73$ ($F = 58.6$, $p < 0.001$)). For all three behaviours personal norm was a significant predictor of intention to engage (($\beta = 0.85/0.42/0.58$, $p < 0.001$).

Entering frequency of past behaviour as the final predictor variable based on bivariate correlations, did not significantly improve the model for ‘external lights’ or ‘closing curtains’ (‘external lights’: $R^2 = 0.78$ ($F = 61.7$, $p < 0.001$); ‘closing curtains’: $R^2 = 0.74$ ($F = 48.3$, $p < 0.001$)). However for ‘motion sensors’, adding past behaviour as the final predictor variable, significantly improved the model: $R^2 = 0.85$ ($F = 93.5$, $p < 0.001$). In this model, neither subjective norms ($\beta = 0.05$, $p = 0.5$) nor PBC ($\beta = 0.12$, $p = 0.08$) were significant predictors of intention to engage, however personal norm was still the strongest predictor of intention to engage ($\beta = 0.54$, $p < 0.001$) followed by past behaviour ($\beta = 0.42$, $p < 0.001$) and attitude ($\beta = -0.12$, $p < 0.05$).

Compliance with light reduction

Compliers with the ‘external lights’ and ‘closing curtains’ light-glow reduction recommendations were classified by either reporting ‘YES’ to ‘since 2008 have you performed the behaviour in question more than usual during the nesting season’ or those who reported ‘NO’, but then specified they always did the behaviour regardless (7 on the scale) (Table 6.4). For the behaviour ‘motion sensors’, compliers were considered those who responded ‘YES’ they had installed motion sensor lights since 2008 instead of external lights, as well as those who responded ‘NO’, but who already had motion sensor lights installed. For all three behaviours, people who responded ‘N/A’ since they had only recently moved to the area were excluded from further analysis.

Table 6.4 Percentage of compliers and non-compliers with the light-glow reduction recommendations.

Behaviour	n	Percentage compliers	Percentage non-compliers
Turn off external lights more than usual	111	67.6 (n = 75)	32.4 (n = 36)
Draw curtains and blinds more than usual	112	47.3 (n = 53)	52.7 (n = 59)
Replace external lights with motion sensors	113	43.4 (n = 49)	56.6 (n = 64)
Overall	336	52.7 (n = 177)	47.3 (n = 159)

The beliefs regarding the light-glow reduction recommendations which were found to significantly differ in strength between compliers and non-compliers are shown in Table 6.5. Refer to Appendix 7 for the comparisons for non-significant beliefs. Two behavioural beliefs and one normative belief differed significantly between compliers and non-compliers across all three specific light-glow reduction behaviours. However, there were no control beliefs that significantly differed across the three behaviours. Compliers in all three versions rated motivation to comply with the referent group 'Mon Repos rangers' more highly than non-compliers. Further examination indicated that across all three behaviours, 72.9% of compliers had visited Mon Repos, compared to only 53.2% of non-compliers. Analysis using the Chi-square test of association indicated that compliance with the 'Cut the Glow' campaign and having visited Mon Repos were related (χ^2 (1, 331) = 13.34, $p < 0.001$).

6.5 DISCUSSION

Recommendations for light reduction communications

Although public support and participation is vital for the success of conservation initiatives (e.g. Fischer and Young 2007; Lyytimäki and Rinne 2013), few studies provide specific insights into methods of increasing engagement with well-defined pro-environmental behavioural objectives, based on empirical research (Zint and Wolske 2014). In this chapter, I measured coastal community beliefs about light-glow reduction for turtle conservation to provide insights, which will be discussed below, into how managers may effectively communicate with members of the public to improve engagement with light reduction initiatives.

Using a framework based on the Theory of Planned Behaviour (TPB) (Ajzen 1991), I found that respondents had moderate to strong intentions to engage in three specific light-glow reduction actions during the turtle nesting season. Respondents overall had weak to moderate positive attitudes, experienced weak to moderate social pressure, and reported a weak to strong

Table 6.5 Salient community beliefs about light reduction which significantly differed in strength between compliers (C) and non-compliers (NC). Scoring scheme follows recommended procedures in Ajzen (2002).

Type of belief	Belief	Specific behaviour	Mean belief strength (-3 to +3 or 1 to 7)		Mean evaluation (behavioural) / Mean motivation to comply (normative) / Mean power (control) (-3 to +3)		Mean cross product (individual belief score multiplied by evaluation/motivation to comply/power score, then mean taken)		Difference between C and NC (**: p<.001 *: p<.01; ^:p<.05)
			C	NC	C	NC	C	NC	
Behavioural	Increased protection of turtles	'External lights'	2.32	1.77	2.91	2.46	6.92	4.86	2.06*
		'Curtains and blinds'	6.14	4.52	2.82	2.32	16.47	10.72	5.75**
		'Motion sensors'	2.3	0.83	2.76	2.62	6.58	2.3	4.28**
	Benefits to local economy	'External lights'	2.07	1.49	2.73	2.43	5.88	4.23	1.65^
		'Curtains and blinds'	5.51	4.24	2.63	2.32	14.83	10.19	4.64*
		'Motion sensors'	2.02	0.51	2.69	2.41	5.8	1.38	4.42**
	Saving money	'Motion sensors'	1.67	-0.02	2.46	2.07	4.64	0.18	4.46**
Normative	Mon Repos rangers	'External lights'	6.12	5.63	1.47	0.57	10	4.83	5.17^
		'Curtains and blinds'	6.35	5.4	1.43	0.34	9.47	3.31	6.16*
		'Motion sensors'	6.56	5.65	1.46	0.48	10.65	3.73	6.92*
	Other residents	'Curtains and blinds'	4.22	3.12	0.08	-0.84	2.76	-1.4	4.16*
	Local businesses		3.9	3.02	-0.41	-1.4	0.92	-2.33	3.25^
Control	Observing turtles	'External lights'	6.33	6.14	1.76	0.83	11.8	5.86	5.94*
		'Motion sensors'	2.43	2.18	1.1	-0.15	3.64	0.19	3.45*
	Other peoples actions	'Curtains and blinds'	3.98	3.54	0.51	-0.42	3.63	0.21	3.42^
	Legislation	'Motion sensors'	-0.81	-1.21	-0.26	-0.3	3.21	1.3	1.91*
	I know where to buy		2.5	1.72	0.81	-0.13	2.6	0.08	2.52^

control over their ability to take light-glow reduction actions during the nesting season. Although these are encouraging findings, there is significant scope for improvement and strengthening of these existing positive beliefs. I also found that TPB variables: attitudes, subjective norms, and perceived behavioural control (PBC), were important in predicting intention to engage with all three light reduction measures. Thus my findings add to the numerous studies which validate the TPB as a useful predictive model of behavioural intention, and also support my choice of framework for guiding a targeted communication strategy (see Foy *et al.* 2007; Ham *et al.* 2008; Brown *et al.* 2010; MacDonald 2011 for examples of effective persuasive communication interventions underpinned by the TPB)

The best TPB model obtained during my analyses accounted for 85% of the variance in behavioural intention, and incorporated personal norms and past behaviour antecedents. Although this is notably higher than variance in intention documented in previous studies, of between 41 and 50% (Morris *et al.* 2005), there remains a proportion of explainable variance which is unaccounted for. Previous studies have found that demographic variables may provide additional predictive capacity (e.g. Armitage *et al.* 2002; Morris *et al.* 2005; Lobb *et al.* 2007). Although I did not assess whether demographic variables influenced respondents beliefs and behavioural intentions with regards to light reduction, this could be assessed in future research.

Following established techniques in communications research (Ham *et al*. 2008; Brown *et al*. 2010), I elicited salient community beliefs about light reduction behaviour, and compared the strength of these beliefs between compliers and non-compliers. Overall I found 10 beliefs that significantly differed between individuals who complied with the light-glow reduction recommendations, and individuals who did not: three of which significantly differed across all three specific light reduction behaviours examined. This indicates that the salient beliefs about light reduction which exist in this community do have persuasion potential for use in targeted communication efforts. I would recommend that managers responsible for future ‘Cut the Glow’ campaign materials target the following beliefs: taking light reduction action will lead to ‘increased protection of local turtles’, ‘benefits to the local economy’, and that the ‘Mon Repos rangers approve of my taking light reduction action’, since these beliefs differed most strongly between compliers and non-compliers and therefore have the strongest persuasion potential.

I added the additional antecedent ‘personal norms’ to the TPB framework to determine whether it would provide increased predictive power related to intention to take light reduction action (e.g. Parker *et al.* 1995; Vermette and Godin 1996; Harland *et al.* 1999; Bamberg and Schmidt 2003; Corbett 2005; Brown *et al.* 2010). Indeed, I found personal norms to be the strongest predictor of behavioural intention across all three behaviours, and the inclusion of a personal norm variable in the TPB framework greatly improved predictions of intention to take light reduction action. Consequently I suggest that, in combination with the specific beliefs identified above, managers also utilise a personal norm appeal in future campaign materials. This combination of messages in a targeted communication (combining an identified behavioural belief with a personal norm appeal) has been used successfully in the past to significantly impact desired visitor behaviour in protected area management (Ham *et al.* 2008).

My results also suggest that further work may be necessary for effectively increasing engagement with the specific behaviour "using motion sensor lights instead of constant outdoor lights". Perceived behavioural control (PBC) was a strongly significant predictor of intention to engage in this specific behaviour, which only became non-significant when past behaviour was added into the model. Similarly, attitudes were only found to be a significant predictor of intention to engage with this behaviour after past behaviour was added into the model. Although intuitively obvious, this implies that once an individual has motion sensor lights, it is easier to engage with this light reduction action, thus people with pro-environmental attitudes would likely use motion sensor lights. However, for those individuals who do not have motion sensor lights, pro-environmental attitude is unlikely to result in engagement – rather it is an individual's perceived ability (PBC) to replace their lights that is crucial for intention to engage.

These findings indicate that my analysis would have likely benefitted from an examination of beliefs pertaining to the installation of motion sensor lights, rather than use of motion sensor lights, as a first step. Although I did not explore this directly, I did find a moderate to strong belief, held by both compliers and non-compliers, that motion sensor lights would cost them money. Non-compliers were also significantly less likely to know where to buy motion sensor lights than compliers, and were also significantly less likely to believe that using motion sensor lights would save them money. Knowledge of the existence of these beliefs can guide future efforts to increase community use of motion sensor lights, by providing a starting point for understanding the benefits and barriers associated with motion sensor installation.

Implications for legislative action

As discussed in the previous chapter, a recent parliamentary report (Pudmenzky 2013) called for State Government legislation to reduce light-glow in this region of Queensland, as a means of protecting the local turtle population. Legislation is currently used to regulate light-use close to turtle nesting beaches in the USA (Butler 1997); for example in Florida the Department of Environment, the agency responsible for marine turtle management, developed a model lighting ordinance to protect turtles from beachfront lighting. The model ordinance was founded on the *1973 Endangered Species Act* and the *1995 Florida Marine Turtle Protection Act*, which prohibit any 'take' of marine turtles, with 'take' defined as any activity which harasses or harms the animals (Butler 1997). The model ordinance has been adopted by 82 Florida local

Governments in whole or in part, however, using such legislation to enforce human behaviours pertaining to artificial light usage in Florida has been found to be unpopular and difficult to enforce (Barschel *et al.* 2013).

I found that residents who did not comply with light-glow reduction recommendations reported a positively-held belief about the beneficial existence of legislation to ensure light-glow reduction, but only for the behaviours ‘turning out external lights more than usual’ and ‘replacing external lights with motion sensors’. This indicates that legislation may be helpful in ensuring compliance with these two actions. Yet, for the action ‘using motion sensor lights instead of constant outdoor lighting during the nesting season’, perceived constraints related to cost and knowledge exist in this community (discussed above). Prior to imposing legislation to enforce compliance with using motion sensor lights, further work would first need to explore whether these perceptions are accurate or not (i.e. do respondents have a correct - or inflated - idea of potential costs involved?). Next the issue of cost would need to be addressed either through the use of offsets or subsidisation schemes (if cost perceptions are accurate) or through education regarding the real cost of motion sensor lights (if cost perceptions are inflated). Clear instructions of where to procure the required lights would also need to be given. Failing to adequately address these strongly held local beliefs would likely limit public acceptance of legislative measures (e.g. Stoll-Kleemann 2001).

Conversely, for the behaviour ‘turning off external lights more than usual during the nesting season’, both compliers and non-compliers had a moderate to strong positive belief that this light-glow reduction action would save them money. Thus legislation for this specific action may be more easily accepted by the local community, especially if the belief that there was a financial incentive to comply was reinforced when informing residents of the legislative measure.

Given that cost is a salient influence on resident light reduction behaviour, linking the existing light-glow reduction campaign with energy-efficiency initiatives may be a useful management strategy. The Federal Government’s Department of Social Services provides home energy-saving advice via a free helpline (Australian Government 2013), thus this information should be highlighted in future ‘Cut the Glow’ campaign materials. Moreover, although the State Government in Queensland provides energy saving incentives to businesses, currently there are no such incentives for residential energy use; however, these are being considered as part of the Queensland Energy Management Plan which will be implemented by 2020 (DEEDI 2011). Yet, residential energy-efficiency schemes are in place in other Australian states (namely New South Wales, Victoria, South Australia and the Australian Capital Territory) where energy suppliers are obligated to meet certain energy targets by establishing energy saving initiatives for households (Energy Action 2013). Should a similar initiative be implemented in Queensland in the near future, my findings indicate that by highlighting the financial incentives of reducing light, managers may increase light reduction behaviour in this community. This example also indicates how policy instruments may be integrated with public communications as a means of increasing desired pro-environmental behaviours such as reduced light-use (Ross and Dovers 2008).

Additional considerations and future avenues for research

I have identified specific beliefs which will be valuable to target in future campaign materials. However, the next step in communications research involves a consideration of the Elaboration Likelihood Model (ELM) (Petty and Cacioppo 1986). In basic terms, the amount of mental effort an audience gives a message is directly related to the enduring nature of any change in attitude. Thus the persuasive potential of any communication depends both on identifying target beliefs (as detailed in this chapter), but also presenting the target beliefs in such a way as to maximise elaboration or mental effort (by making the argument easy to understand and believable (Bator and Cialdini 2000)). Although outside the scope of this chapter, previous research has demonstrated the utility of using the TPB to identify message content, followed by the ELM to guide the communication strategy, to successfully motivate behaviour change in protected area management (e.g. Brown *et al*. 2010). Thus future work should consider the ELM when presenting the target beliefs I have identified here.

I did not take habitual behaviour into account. Previous studies have shown habit is likely to have a strong influence on future behaviour (e.g. Ouellette and Wood 1998), yet theoretical knowledge underpinning this relationship, and accepted methods of measuring the influence of habit on behaviour using survey research, are not well-developed at present (but see Bamberg and Schmidt 2003; Knussen and Yule 2008). Two of the behaviours I examined (‘turning off external lights’ and ‘closing curtains and blinds’) are likely to be habitual behaviours. Such behaviour is not always the result of conscious deliberation (Van Vliet *et al.* 2005), thus the value of using persuasive communication to influence these habitual behaviours may be questioned. Yet, research indicates that habitual behaviours pertaining to the environment may be open to influence, particularly through the use of personal norms (Thøgersen and Ölander 2006). Moreover, it has been argued that human behaviour is always regulated at some level, albeit possibly a low level, of cognitive effort, even when the behaviour is routine (Bamberg *et al*. 2003).

Related to the discussion of habit, it is possible to distinguish between three types of environmentally-friendly resource-use behaviours: investment, management and curtailment (McKenzie-Mohr 1994; McKenzie-Mohr 2000a). According to this theory, investment requires a once only change in behaviour, whereas repetitive actions (e.g. habits), require either management or curtailment, which in turn necessitate an initial behaviour change plus continued maintenance of that change. As such, changing repetitive behaviours and maintaining that change is considered more difficult than bringing about one-time-only actions. However repetitive actions are deemed susceptible to influence using certain social marketing strategies (McKenzie-Mohr 2000b). Of particular relevance to the research presented here is the use of commitment strategies (Pallak *et al.* 1980). Individuals who make a minor commitment to a certain behaviour are significantly more likely to engage in a more extensive commitment to the same behaviour later. This is due to a phenomenon termed 'cognitive dissonance' (Festinger 1962; Cialdini 1993) i.e. individuals prefer to both be, and be seen as, consistent in their behaviour. For example, offering residents a free 'I Cut the Glow to help Turtles Go' sticker and encouraging them to display it (e.g. Bator and Cialdini 2000), is likely to increase community commitment to light-glow reduction, despite the habitual nature of several of the desired light reduction behaviours, whilst also acting to advertise the issue via interpersonal communication.

I also found a significant association between compliance with the light-glow reduction actions and having visited Mon Repos beach to view local turtles. Given that compliers had a significantly stronger motivation to comply with the referent group 'Mon Repos rangers', this may imply that visiting Mon Repos increases the importance of the Mon Repos rangers as a normative influence on local people (which is important since it is the rangers who carry out the light-glow reduction campaign), subsequently leading to a greater motivation to comply with campaign recommendations. Alternatively, visiting Mon Repos may increase residents' connection to the turtles, making the consequences of their behaviour more 'real'. Thus a further strategy for increasing engagement with light-glow reduction would be to encourage local residents to visit Mon Repos for a 'turtle tour' during the nesting season, possibly using reduced ticket prices, or similar, for locals.

Future work could also assess tourist beliefs pertaining to light reduction behaviours since Bargara is a popular tourist destination (Pudmenzky 2013) and therefore light produced by visitors would likely contribute to the glow visible at Mon Repos. A large proportion of visitors to Bargara take part in 'turtle tours' at Mon Repos (Tisdell and Wilson 2005) and would thus be exposed to the 'Cut the Glow' message. Given my finding of a significant association between light reduction and visiting Mon Repos, an examination of visitor beliefs pertaining to light reduction would be an interesting and useful comparison.

Finally, I am basing my campaign-improving recommendations on behavioural intentions since measuring actual behaviour at a community scale would be logistically difficult and was not possible given the time constraints of this research. Although reviews of TPB across a variety of behaviours have indicated good predictive capacity in both behavioural intentions, and actual behaviour (Armitage and Conner 2001), future research would benefit from a long-term study to determine whether the recommendations I have made do translate into behaviour change.

6.6 CONCLUSIONS

Artificial lighting is a serious, but relatively unfamiliar, threat affecting marine turtles and many other species' around the world (Eckert 1999; Witherington and Martin 2000; Rich and Longcore 2006; Chepesiuk 2009; Lyytimäki 2013; Lucas *et al.* 2014). As recognition of this threat develops, methods for reducing public use of light at night will become more important to both managers and society. Yet, previous research has shown that educating individuals about negative impacts of artificial lighting is not sufficient (Chapter 5; Blake 1999; Owens 2000; Kollmuss and Agyeman 2002; Lorenzoni *et al*. 2007), and legislation to enforce light reduction behaviours in individuals is difficult to enforce and unpopular (Barschel *et al*. 2013).

I demonstrate that determining salient beliefs regarding light reduction in a community where light reduction is desirable provides useful information to increase the persuasion potential of public communications. I also show that utilising personal norms in such communications is likely to be a valuable strategy for increasing public light reduction behaviour.

However, in previous chapters I determined that both urban and industrial light contributes to the light exposure of Australian marine turtle nesting beaches (Chapters 2 and 3). While public support for, and participation in, light reduction initiatives may be improved by smart communication and a detailed understanding of community perceptions and beliefs about reducing light (Chapter 5 and this chapter), tackling light reduction within industry is more complex due to health and safety concerns, and associated legislation. As such, I go on to consider effective lighting management in an industrial setting as the focus of Chapter 7.

Chapter 7

Industrial light management for marine turtle conservation: A case study of the Gorgon Gas Development, Western Australia

Marine turtles nesting close to industrial developments on the North West Shelf in Western Australia had the highest potential light pollution exposure of all turtles nationally (Chapter 2). Since industry light was also shown to contribute to a sea-finding disruption in Australian turtle hatchlings (Chapter 4), effective management of lighting in industry is clearly important. However, management is challenging because industrial lighting must meet adequate, legislated health and safety standards. As a result communication efforts to reduce individual light-use (Chapters 5 and 6) will be of limited use for improving industrial lighting management. In this chapter, I present a case study which explores an instance of strict lighting management in a large industrial development located in close proximity to turtle nesting beaches in the North West Shelf. I focus on providing insights for improving management of light in industry, thereby addressing a different aspect of the identified 'human-factor' knowledge gap (Chapter 1).

Manuscript in preparation:

Kamrowski RL, Sutton SG & Tobin RC (in prep.) Drivers behind effective industrial light management for marine turtle conservation. The conceptual framework developed in this chapter will be submitted as a short communication to *Journal of Environmental Research and Development.*

7.1 ABSTRACT

Light generated by industrial activities significantly contributes to the increasing light exposure of Australian marine turtle nesting beaches. Since artificial light is a significant threat to marine turtle survival, effective management of industrial light in coastal regions is crucial. However, industrial lighting management is complicated by safety concerns, personal illumination preferences, and a widespread view of light at night as being normal. This qualitative, exploratory case study examined management of artificial light at a large industrial development located immediately adjacent to flatback turtle nesting beaches. Given the environmental importance of the location, the proponent has committed to strict lighting measures as part of their environmental approval. I evaluated the 'success' of the lighting management using turtle monitoring data, compliance with ministerial conditions and relevant stakeholder perceptions. Although compliance did not emerge as an adequate measure of success, no conclusive lighting impacts on turtles have occurred, and stakeholder perceptions related to lighting were either positive or neutral. Thus overall the lighting management was considered successful to date. Based on themes which emerged in the data, I developed a conceptual framework for understanding drivers behind this instance of successful industrial light management. The existence of regulation, and business growth emerged as primary drivers, but these were closely linked to secondary influences including culture, morals, particular individuals, external pressure and proponent ethos. Environmental significance directly influenced multiple drivers and was therefore another important contributing factor. This is the first study of its kind and the insights generated can be used to guide future research, management and policy development towards tackling the complex, growing problem of industrial light pollution for threatened species management.

7.2 INTRODUCTION

Artificial lighting is acknowledged as a threat to Australian marine turtles (Environment Australia 2003; Chapters 1 and 4), and light generated by industrial activities in Australia contributes significantly to the increasing light exposure of nesting beaches (Chapters 2 and 3). Given the ongoing industrialisation of the coastline (Greenpeace Australia 2012; Grech *et al.* 2013), establishment of effective industrial light management in regions close to nesting beaches is critical.

State Government policy and industrial site-specific management procedures have been developed to limit disruptive impacts of lighting on marine turtles (e.g. Department of Environment and Conservation 2007; Department of Environment and Conservation 2008; Chevron Australia 2009; Environmental Protection Agency 2010; BHP Billiton 2011). Yet, management of light in industry is complicated, being guided by factors including regulation, firm environmental commitment, engineering design, and safety considerations (Chevron Australia, personal communication). The latter is extremely important, particularly in extractive industries (O'Dea and Flin 2001). Inadequate lighting can lead to industrial accidents (Osterhaus 1993), and most countries have developed minimum lighting standards to safeguard employees working at night (Mills and Borg 1999). In Australia, lighting standards are governed by the *Workplace Health and Safety Act 1995*, and the *Workplace Health and Safety Regulation 2008*, which state that lighting must be sufficient to allow hazard identification and facilitate visual tasks, thereby creating a safe and comfortable visual environment (Rushworth *et al.* 2001; Workplace Health and Safety Queensland 2013).

Determinations of 'adequate' lighting also rely to an extent on value-based judgements (Lyytimäki 2013). Individuals may have different preferences for illumination levels (Mills and Borg 1999), and optimal levels of light for task performance do not always correlate with perceptions of 'comfortable' lighting levels (Smith and Rea 1980). Lighting judgements are also likely influenced by the ubiquity of artificial lighting in contemporary society. As described in preceding chapters, modern humans have so little experience of naturally-illuminated nighttime environments that the baseline we have for assessing changes in nighttime lighting away from true conditions has shifted (e.g. Kahn and Friedman 1995; Pauly 1995). We no longer consider dark nighttime environments to be 'normal' (Lyytimäki 2013; Lyytimäki and Rinne 2013), and we have less experience relying on non-visual senses from dusk until dawn (Kyba *et al.* 2014).

Further complicating the issue, effective management of environmental issues relies on adequate scientific knowledge regarding stressors and impacts (Sadler 1996). Yet despite a growing body of research centred on negatives associated with artificial light, there is currently limited recognition of light as a pollutant (Lyytimäki *et al.* 2012), and little attention appears to have been paid to evaluations of industrial lighting management for threatened species protection.

In this chapter, I examine the lighting management of an industrial development in close proximity to marine turtle nesting beaches in Western Australia (WA). Given the complexity of determining ‘adequate’ lighting (see above), I use a qualitative, exploratory case study design because case study research is considered appropriate when attempting to understand significant but complex social phenomena which cannot be separated from the context in which they occur (Kyle and Ross 1983; Yin 2009). Moreover, insights generated by case studies can be considered as speculative hypotheses which help to direct future research, and thereby advance knowledge of the field (Pryzwansky and Noblit 1990). In this case then, I aim to generate insights and recommendations as a first step to guide effective management and policy development related to industrial lighting impacts on marine turtles, as well as identify valuable avenues for future research as coastal development continues. There were two specific objectives:

I. To evaluate the success of measures employed to manage lighting in an industrial setting close to turtle nesting beaches, based on impacts to turtles, level of regulatory compliance and stakeholder perceptions

II. To understand why the lighting management in this case was successful or not, through identification and examination of the main drivers behind the lighting management

In this chapter, I use the term ‘success’ to mean a ‘favourable outcome’ (Chan and Chan 2004, p. 204), where organisational actions undertaken in the pursuit of identified goals (in this case effective management of lighting close to turtle nesting beaches) ensure achievement of those goals (Ambler and Kokkinaki 1997).

7.3 THE ‘CASE’

I present a single case, selected based on Yin’s (1994) recommendation that such a case be rare, unique, or an extreme example of the phenomenon under study. Barrow Island, located off the Pilbara coast of Western Australia (WA) (see Figure 2.2), is home to Australia’s largest operating onshore oilfield (Greenwood *et al.* 2009). It is also a Class ‘A’ Nature Reserve due to its unique ecology, endemic flora and fauna, and internationally renowned biodiversity values (Department of Environment and Conservation 2007): including large nesting populations of green and flatback turtles (Pendoley 2005; Pendoley *et al.* 2014). In 2001, the Gorgon Gas Project (hereafter referred to as 'Gorgon') was proposed with the intention of extracting and processing gas from Australia's largest undeveloped reserves: the Greater Gorgon gas fields. The proponents argued that Barrow Island was the only commercially viable location for the development despite the high conservation value of the island, and in-principle ministerial approval was given to the project in 2003 contingent on a statutory environmental impact assessment (EIA) (Pope 2007). Final approvals for the project were given in 2009 (Chevron Australia 2009), and the project is currently in construction. Gorgon is considered to be Australia's largest resource project ever, expecting to produce 40 trillion cubic feet of gas once construction is completed in mid-2015 (Government of Western Australia 2010). The project is a joint venture partnership between Chevron Australia, ExxonMobil, Shell, Osaka Gas, Tokyo Gas and Chubu Electric Power, with Chevron acting as the project operator (Flett *et al.* 2008).

Given the ecological value of Barrow Island, the development of Gorgon received significant stakeholder attention, as well as State and Federal Government supervision (Pope 2007). During the EIA process, the Gorgon partners designed a comprehensive strategy to protect the environment and meet the concerns of numerous stakeholders, including community groups, NGOs, other industry organisations, individual businesses, Government agencies, and members of the public. Subsequent ministerial approvals included comprehensive environmental conditions (Tibbett *et al.* 2011) considered to be some of the most stringent EIA conditions anywhere in the world (Sakmar 2013). The proponents are required to comply with more than 20 environmental management plans, including a specific long-term marine turtle management plan, which has comprehensive reference to managing detrimental impacts from artificial lighting, during both construction and operation (Chevron Australia 2009). Thus, Gorgon on Barrow Island is an extreme example of lighting management in industry (Chapters 2, 3 and 4).

Since this was an exploratory study conducted to judge the 'success' of the lighting management at Gorgon, as well as understand why the lighting management has been successful or not, I did not test specific hypotheses. However, according to Yin (2009) all case studies, including those with an exploratory focus, require assumptions or propositions derived from available theory to direct the exploration, and increase the external validity of the study by providing criteria against which the exploration may be judged. In the next section I provide a short overview of theory relevant to this chapter, which generated several assumptions to guide data collection.

Theoretical context and study assumptions

Since environmental practices can be very costly (Christmann 2000), theorists argue that corporate environmental actions are primarily driven by the influence of external stakeholders

(Freeman 1984; Clarkson 1995). Governments are widely considered to be the most important driving force behind environmental action (Harrison and Hoberg 1996; Newton and Harte 1997; Delmas 2002; Delmas and Toffel 2004), imposing coercive pressures on firms through environmental legislation and regulation (DiMaggio and Powell 1983). The stringency of regulations is considered important for encouraging corporate environmental responsiveness (Andrews 1998), and Kneller and Manderson (2010) found that tougher regulatory pressure resulted in higher levels of industrial environmental action. Given that Gorgon was selected as the 'case' for study in this chapter in virtue of the extreme regulatory conditions imposed on the project, including comprehensive lighting requirements to minimise impacts to marine turtles, I began this chapter with the following assumption:

- Regulation is likely to be a crucial driver of effective lighting management at Gorgon.

Yet, there have been instances where firms have adopted environmental management practices beyond regulatory requirements (Delmas and Toffel 2004), thus regulation cannot be the sole driver. Company environmental management practices are often influenced by the desire to improve or maintain relations with other stakeholders; for example, both customers and local community groups have been found to significantly influence corporate adoption of environmental management practices (Henriques and Sadorsky 1996). Institutional theorists also argue for the existence of mimetic pressures (DiMaggio and Powell 1983) - where firms are driven by competition and uncertainty to imitate profitable environmental strategies employed by other firms within the same industry (Escobar and Vredenburg 2011), and normative pressures - where internal, organisation-level values and norms govern the level of environmental action taken (Marcus and Nichols 1999; Ramus and Steger 2000).

Although the Gorgon Project generated significant stakeholder interest when it was proposed given the high conservation value of Barrow Island (Pope 2007), previous research has found that for large firms, non-regulatory external pressures do not seem to influence adoption of environmental initiatives (Qi *et al.* 2010). Moreover, as discussed earlier, most modern humans in developed societies do not recognise artificial light at night as a significant environmental threat, instead considering an artificially lit night to be normal and preferable to darkness (Lyytimäki 2013; Lyytimäki and Rinne 2013). Consequently, a second assumption guiding this chapter was:

- External and/or internal stakeholder pressures were unlikely to be important drivers behind the success, or otherwise, of the Gorgon lighting management.

7.4 METHODS

Data collection

In December 2012, interviews were conducted with 12 individuals. A variant of purposive sampling, known as criterion sampling (Palys 2008), was used to identify key informants so that the Gorgon lighting management was considered from multiple, informed points of view. This is an established method of data triangulation in qualitative research (Basit 1995). Interviewees were either affiliated with Chevron Australia on Barrow Island, or members (past or present) of the Marine Turtle Expert Panel[2] who are independent of Chevron Australia but have sufficient knowledge of Gorgon to provide informed perspectives (see Table 7.1).

Table 7.1 List of respondents interviewed, including the organisations they represent.

Interviewee	Identifying acronym	n	Viewpoint
Chevron Australia	CAM	2	Proponent
Onsite contract employee	COC	6	Barrow Island workforce
Marine turtle consultant	MTC	1	Marine turtle expert consulting to Chevron Australia to provide biological turtle monitoring data
State Government employee	SGR	1	Regulatory advice / compliance & assessment re. ministerial conditions
State Government employee	SGT	1	State Government marine turtle expert
Marine Turtle Expert Panel member	IPC	1	Independent expert

The small sample size was dictated based on the availability of individuals who had sufficient knowledge specifically related to the Gorgon lighting management implemented to protect marine turtles. However, it has been contended that in qualitative research ‘less is more’ (McCracken 1988), because a smaller sample allows a deeper, more in-depth understanding of a particular case than could be obtained from a larger sample within the same timeframe.

Interviews took between 30 and 90 minutes and were conducted face-to-face. Semi-structured schedules directed the interviews, which consisted of open-ended questions guided by the chapter objectives and assumptions (see Appendix 8 for core interview questions). However, given the nature of semi-structured interviewing, the question order, and addition of supplementary questions, was determined based on interviewee responses. All participants

[2] Chevron Australia were required to establish 3 expert panels (Marine Turtles, Dredging and Quarantine) to provide unbiased advice to both Chevron Australia and the Minister for the Environment regarding environmental management of the Gorgon Project under Ministerial Statement No. 800.

agreed to the interviews being recorded. Interviews were then transcribed verbatim and returned to respondents for verification prior to further analysis. Following recommendations, respondents also reviewed a draft of this chapter (the case study report (Yin 1994)).

I also obtained publicly available Chevron Australia annual reports to supplement the interview data. Ongoing environmental management and monitoring of the project is the responsibility of the proponent. The proponent is required to send publicly available reports to the Environmental Protection Agency[3] (EPA) each year as part of the ministerial commitments (Morrison-Saunders 1998). I reviewed environmental performance reports[4] produced in 2010, 2011 and 2012, as well as annual reports[5] from 2010, 2011 and 2013, addressing the status and compliance of the Gorgon Gas Development with State and Federal conditions during the previous 12 month period. There has been criticism over the use of company annual reports for analysing company practices, because documents may be biased to portray the proponent in a positive light (Escobar and Vredenburg 2011). However research has found that company reports are a valuable source of non-evaluative information, such as descriptions and frequencies of actions taken by the company (Abrahamson and Hambrick 1997; Duriau *et al.* 2007). I thus used annual reports, in combination with the interview data, as a further step of data triangulation, and also as an additional source of evidence to ensure this case study has sufficient 'construct validity' (Yin 1994).

Data analysis

When conducting research, conclusions are reached through either inductive or deductive reasoning. In inductive reasoning, conclusions are generated using patterns and themes which exist in the data; whereas deductive reasoning compares the data against existing knowledge (Patton 2002). In this chapter I use a combination of these approaches.

Objective 1

My first objective was to determine the success of the lighting management at Gorgon. Any evaluation requires outcomes to be compared against certain criteria (a deductive approach) (Conley and Moote 2003). Because Chevron Australia instigated lighting management at Gorgon to minimise impacts to marine turtles, the success of the lighting program may be reasonably judged using biological data from turtles monitored at Barrow Island to establish

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[3] A statutory authority within the State Government, responsible for assessing development proposals and recommending environmental conditions to the Minister. Also responsible for assessing proponent compliance with imposed conditions (State Government employee, personal communication).
[4] Gorgon Gas Development: Ministerial Implementation Statement No. 800, EPBC Reference: 2003/1294 (as amended) and EPBC Reference: 2008/4178 Environmental Performance Report 2010/2011/2012
[5] Gorgon Gas Development: Ministerial Implementation Statement No. 800 Compliance Report 2010/2011/2013 and Gorgon Gas Development: Ministerial Implementation Statement EPBC Reference: 2003/1294 (as amended) and EPBC Reference: 2008/4178 Compliance Report 2010/2011/2013.

whether lighting impacts have been managed and/or avoided (i.e. a 'favourable outcome' (Chan and Chan 2004)). Since the lighting actions were established in accordance with ministerial conditions, success may also be evaluated by determining Chevron's level of compliance with the conditions. However, determining the characteristics of adequate illumination is partly a value-based question that depends on individual perspectives (Lyytimäki 2013). The success of the lighting management was thus also evaluated based on whether relevant stakeholders[6] were satisfied with the process and outcomes. This required an inductive approach where the interview transcripts were analysed using thematic content analysis with QSR NVivo10 software. Transcripts were read carefully and data separated and grouped into distinct categories. Categories were then reviewed and revised as necessary depending upon associations between them (Strauss and Corbin 1998; Basit 2003; Weiss *et al.* 2012). Thus to meet objective one, I examined the proponent annual environmental performance and compliance reports, in combination with interview themes which emerged pertaining to success, turtles, compliance, and perceptions of the lighting actions taken (see Appendix 9 for my coding tree).

Objective 2

To meet my second objective: understanding why the lighting management had been successful or not, the data was examined for themes which emerged as important drivers behind the light management at Gorgon, following the inductive analysis described above (Appendix 9). Themes were only considered to be important drivers if they were generated as a result of responses from multiple respondents i.e. from multiple points of view. Identified drivers were then pattern-matched with predicted drivers from literature following Yin (2009). If the themes which emerged supported my initial assumptions, this would be considered an 'expected outcome'. However, through pattern-matching and considering potential rival, or competing, assumptions, the internal validity of the case study was increased (Yin 2009).

7.5 RESULTS AND DISCUSSION

Objective 1: Has the lighting management at Gorgon been successful?

Turtles

Lighting can disorient hatchling turtles reducing their sea-finding ability, and also can discourage female turtles from nesting (Witherington and Martin 2000; Salmon 2003). In 2010

[6] Since determining the success of the lighting management primarily concerns the point of view of the proponent implementing the actions, and the regulator ensuring actions are implemented, for this part of the analysis I concentrated on responses elicited from Chevron, on-the-ground contract employees working under the lighting regime, and the State Government employees.

and 2011, monitoring indicated that hatchling orientation and female nest site selection did not differ significantly at Gorgon in comparison to baseline studies. In 2012, the proportion of adult turtle nesting within 2 km of Gorgon again did not differ, but there were differences in hatchling orientation compared to baseline, with higher indices of orientation (i.e. potential mis- / dis-orientation) found at some locations compared to baseline. However, the findings were not conclusive, and as such, it was concluded there was limited evidence of lighting impact on marine turtles to date (Chevron Australia 2012, p.84). This was supported by the experts interviewed from outside Chevron Australia. For example, asking 'have there been lighting impacts on turtles?' produced the following responses:

> "No! None. So while there's been a lot of light…. [there has been] no detectable or measurable impact on the turtles" (MTC)
>
> "Well in terms of outcomes, you'd have to say the data's been successful, because the monitoring to date isn't showing any impact" (SGR)

In terms of limiting impacts to marine turtles, the lighting management at Gorgon thus appears to have been successful. However, there are a few necessary considerations. The 2010 environmental monitoring report (p. 74) states:

> "Monitoring hatchling orientation where there are no artificial light sources (i.e. Mundabullangana[7]) has been a useful comparison for Barrow Island. Terminal Beach recorded a higher offset angle[8] compared to all other Barrow Island beaches but Mundabullangana West beach recorded an even higher offset angle, indicating the high offset angle on Terminal was unlikely due to artificial light"

This conclusion is not necessarily valid. Hatchlings find the ocean using a combination of horizon elevation and brightness cues, with elevation cues dominating (Chapter 4; Limpus 1971; Salmon *et al.* 1992; Limpus and Kamrowski 2013). The beach profile and elevation cues available to hatchlings at Barrow Island may differ from those at the reference site, and although beach profiling is taking place on the nesting beaches of Barrow Island, this is being undertaken in response to coastal stability concerns, and it does not appear to have been used in the analysis of hatchling orientation indices to date. The importance of elevation cues was highlighted by one respondent during the interviews:

[7] Marine turtles are also monitored each year at Mundabullangana as a reference site for the turtle monitoring at Barrow Island.
[8] Fan indices including spread and offset angle are frequently used to assess orientation of marine turtle hatchlings as they leave the nest (e.g. Chapter 4; Berry 2010; Limpus and Kamrowski 2013; Pendoley 2005; Salmon and Witherington 1995)

> "The other factor that affects hatchlings is dune elevation. It's a big one. First year of working here … there was a huge amount of glow behind the beach … We were sure that we were going to have major issues with the hatchlings. Pfft, they all went to the ocean." (MTC)

Consequently, without a consideration of beach topography (i.e. measures of horizon elevation) and artificial lighting at both sites (Chapter 4), it is not possible to conclude that a larger offset angle at the reference site indicates that hatchlings at Barrow Island are unlikely being influenced by lighting.

Furthermore, studies were implemented in 2011 and 2012 to assess the influence of light from offshore structures on hatchlings swimming out from the beach (Chevron Australia 2009). In 2012, few hatchlings were observed in light spill around the MOF[9] relative to known emergences. This was suggested to be the result of hatchlings responding to wave-front cues rather than brightness cues, since wave-fronts are known to guide hatchlings during the offshore migration (Lohmann and Lohmann 1996). Other observations of swimming hatchlings congregating in lit areas offshore were considered likely due to either passive dispersal dictated by currents or active attraction to a light source. However, given limited sample sizes, Chevron acknowledged that further study is required (Chevron Australia 2012, p.98). The influence of industry lighting on the offshore behaviour of hatchlings has therefore not been conclusively determined. This was supported by expert opinion:

> "Once [hatchlings] get in the water, can they successfully get outside that light zone and then do their normal migration offshore? …One of the research strategies for Barrow was trying to come up with a reasonable program to track them at sea - that's very much in its infancy stages" (SGR)

> "If I felt that there's an area that we're gonna have to do more work on, it's probably the offshore lights and hatchlings" (CAM)

This is in part due to the well-recognised difficulties associated with measuring impacts of lighting on marine turtles at sea (e.g. Thums *et al.* 2013). However, the following observation from a contractor working onsite illuminates the danger of drawing any conclusion from the data on the influence of offshore light on turtles to date:

> "Marine-wise along the MOF, [the] only layer of monitoring has been to stand on the beach and look for hatchlings and if they're coming

[9] As part of the Gorgon Project a large, solid-structure causeway and materials offloading facility (MOF) was constructed on the east side of Barrow Island, extending approximately 2 km out to sea, perpendicular to the coastline, and located immediately between two of the important flatback nesting beaches; Terminal and Bivalve.

> against the MOF. So they haven't really looked, because of that there's no evidence of it"

Another pertinent issue that emerged during the interviews with regards to measuring the 'success' of the light mitigation program for turtles is time. Marine turtles take decades to reach maturity (Heppell *et al.* 2003), thus it is possible that impacts from sustained exposure to artificial lighting at nesting beaches will take many years to become apparent at a population level (e.g. Mortimer 1989; see also Chapter 3). Expert judgement indicates that with regards to hatchlings, impacts from artificial lighting on Barrow Island should already be visible. For example, when asked 'how confident can we be about how lights from industry are affecting turtles?' I received the following responses:

> "Really confident. Just doing the hatchling fan monitoring you know" (MTC)

> "It depends on your parameter. Something like hatchling orientation, if there was an impact you'd get an immediate [response]" (SGR)

> "There should be a fair indication in a few years, any impacts that have happened to those hatchlings" (SGT)

However, expert consensus is also that it will take a lot longer for impacts on nesting females to become evident:

> "The theory is that the old girls that have always been there will continue to go there. It's the new ones that will stop nesting. Do we get a shift away from those beaches[?] … the big issue is the timescales. That's going to be decades." (SGR)

> "Whether [adult females] are negatively impacted by selecting different beaches because there are lights[?]… that will probably take years to get around the natural variation that occurs. (SGT)"

Compliance

Following review of the proponent annual compliance reports, a compliance summary is provided in Appendix 10, which details compliance with specific commitments relevant to management of lighting at Gorgon. Although minor non-compliance issues with regards to the lighting management occurred, they were all identified and addressed. Supporting these reports, the proponent reported being satisfied with the compliance levels at Gorgon, and Chevron also seems to have a strong system in place to ensure compliance with commitments is being met:

> "[Ensuring compliance has] probably three or four levels. KJV[10] have effectively got responsibility for the site, and they have other contractors working for them… [The other contracted firms] have invariably got their own environmental staff, which is quite unusual… So there is an audit program: Chevron audits KJV, our expectation is KJV audits its contractors, and then [in those contracted firms] my expectation is that they would be going out to audit their works" (CAM)

> "We don't expect [the workforce] to know all [the commitments], but we made checklists for inspections that reflect [the commitments]. …Weekly we'd go around to each site … and we'd go, 'how are you doing this?' 'Look you're not doing this', and we'd mark them down on things and give them actions, make sure they're compliant" (COC)

It thus appears that with respect to compliance, the lighting mitigation program at Barrow Island has been successful. However, again there are certain issues which need to be considered. Firstly, addressing light pollution is an emerging field (Lyytimäki 2013). As such, the measures necessary for effective light mitigation are not yet well-established, and issues with the lighting commitments at Gorgon were identified:

> "It is tricky because some of these [lighting] commitments … have been written without knowing really what it's gonna be like… Some of them are almost impossible, or some of them were really loose and open … So we've slowly had to try and work out ways to make [it] practical" (COC)

> "I guess the frustrating thing from our point of view… [was that meeting the lighting commitments] did take a long time. Things take months and months… to get fixed. But… as they got to twelve months, and then 18 months, two years, …things have got better" (SGR)

Thus although compliance improved as the project progressed, lack of knowledge and time emerged as two issues which appear to affect the usefulness of 'compliance' as a measure of success. Additionally, as explained by one of the State Government employees, breaching environmental commitments is very serious for the proponent and therefore firms never want to be non-compliant:

> "During assessments… let's use a simple example of a gas plant emitting nitrous oxide. What they'll ask for in their license limit won't be …[the] mean [emission level], they'll want …[a limit above the

[10] The Kellogg Joint Venture (KJV) was contracted by Chevron Australia and partners to design, build, and manage the Gorgon Project on Barrow Island.

> maximum possible emission], because they never want to be non-compliant. None of us want non-compliance, so the limit gets set up there…" (SGR)

Indeed this view was supported by Chevron:

> "One of the things that Chevron has been very, very clear on is that we'll argue quite hard with the regulators … around ministerial conditions and management plans. So if we think that what's been asked of us is unreasonable or unworkable, or is not going to deliver the desired results … we will argue quite strongly for that. But when that management plan or those conditions are signed off - even if we disagree with some of the things in there … then we will absolutely comply with them" (CAM)

Thus using compliance as an indicator of environmental protection, especially in instances where reduction targets are not fixed (Ribeiro and Kruglianskas 2013) as is the case here[11], may not be appropriate at present. This is a concern given that compliance is the standard measure of success relating to environmental regulation, but the issue has been recognised by the regulator who is working to address it:

> "We don't want to give approval to impact more than what they necessarily need. It's an issue we're grappling with … part of that has been a policy response. [For example] with dredging now we have an environmental guideline that talks about not using extreme scenarios." (SGR)

Thus compliance may become a more useful measure of 'success' in environmental management in future assessments.

Lighting judgements

Relevant stakeholders all perceived both positives and negatives related to the lighting management at Gorgon, summarised in Table 7.2 (see also Appendix 11). For the proponent, the perception was that designing and implementing the lighting program incurred relatively minimal negatives in comparison to the overall Gorgon project, and such negatives were only to be expected given the large project scope. This is reinforced by the fact that although the lighting was assumed to have incurred a financial cost, the extent of this cost was unknown:

> "Everything costs money in terms of a build. What that cost is, I don't know. Is it a disadvantage? … It's all relative to the scheme of a big build" (CAM)

[11] Chevron Australia have committed to reduce light to as low as reasonably practicable (ALARP).

Table 7.2 Summary of stakeholder evaluations regarding the lighting management at Barrow Island (see also Appendix 11).

Stakeholder	Perceived positives of lighting management	Perceived negatives of lighting management	Overall perception of lighting management
Proponent	• The lighting management is meeting regulatory and ministerial commitments • It prevents the need to use the offset fund set aside to manage documented impacts on turtles • Avoiding impacts on turtles and meeting commitments is beneficial to the proponents reputation, and future business opportunities	• The lighting management has incurred a financial cost [albeit of unknown amount] • Managing the environment of Barrow Island, including impacts on turtles, is a significant control on the project, requiring extensive effort. • Given the itinerant workforce there is a need for continuous workforce education • It has reduced efficiency in certain work situations	• Neutral (neither positive nor negative) *“Compared to the [scope of the overall] project, some of the inefficiencies or additional controls we have in place about lighting, I think they're very small by comparison to [other] logistical challenges”*
Onsite workforce	• The reduced light is better for the environment • It is more pleasant working under reduced lighting at night • Less light allows better observations/experiences with nature	• Implementation difficulties: communication issues between work-crews, and effort to ensure lighting recommendations were practical in the workplace • Uneven responsibilities: Apparent differences in level of lighting response between contracted firms, and perceived unfairness with respect to compliance enforcement	• Positive (3/6 interviewees) “*I’m really happy with the permanent lighting …so far. The plant, when you look at it at night, it’s awesome*.” • Neutral (3/6 interviewees) “*There is adequate portable lighting … enough to see and for [my] needs*”
Regulator	• There have been no effects on turtles at Barrow Island to date • It provides an example for lighting management in similar projects	• The environmental importance of Barrow has negatively impacted regulator authority to impose conditions on new developments elsewhere • Implementation difficulties: it took a long time to meet the lighting commitments	• Positive for Barrow Island, but detrimental elsewhere “*The monitoring to date isn’t showing any impact. We’re happy with that…[But it] makes it harder to try and get good outcomes for other projects*”

> "We probably have incurred some costs … from getting all [our mobile light towers] modified – maybe we saved some costs by not hiring so many, I don't know… We haven't looked at it from the money side… back in the early days they would have costed it into the budget and then ok, that's what it is." (CAM)

Importantly, there were no safety concerns reported as a negative of the lighting management.

The positives from the proponent point of view were mainly related to meeting Chevron's ministerial commitments regarding lights and turtles, i.e. providing 'comfort' that the actions being taken were adequate, and preventing the need to use the 'offset fund'[12]. The fact that positives were mainly related to ministerial conditions was supported by one of the State Government employees:

> "If you work in the environment section of a big company like that, essentially your primary job is to get the approval through….not to protect the environment, that is a secondary role. That's not a criticism, that's just reality. Generally, they're trying to do the right thing… but they're constrained within the system they work in" (SGR)

This is one demonstration of the importance of regulation for industrial environmental management, which will be discussed further in a subsequent section. Overall the proponent view appeared to be that the lighting requirements were neither positive nor negative, but necessary.

Previous work has indicated that there may be negative perceptions of environmental conditions/actions by the workforce who are required to implement or work under those conditions (Qi *et al*. 2010). At Gorgon, there were early reports of resistance from the workforce:

> "I heard some [complaints about the light] very initially, and that's when we had a very small work-crew up here. And… a voice in that work-crew carries a lot of weight" (CAM)

> "There was initially a bit of push-back from workers [with] a couple of them … wearing a t-shirt that said 'Chevron cares more about the animals on the island than it does about the humans'" (IPC)

[12] If Gorgon has a demonstrated adverse impact on the flatback turtle population, the proponent has committed $5 million as a 'banked' offset to fund conservation actions to improve population recruitment (Middle 2008 p.7). This is a relatively small amount given the $150 million committed to other Gorgon-related conservation initiatives (Government of Western Australia 2010).

Although the onsite employees I interviewed reported a few minor initial annoyances with the lighting, once again no safety concerns related to the reduced lighting were reported. Overall perceptions were either neutral (3/6 interviewees) or positive (3/6 interviewees), with neutrality being solely related to the Gorgon lighting being adequate and becoming 'normal'. Although the sample size of onsite employees interviewed was small, this view was supported by insights from other interviewees:

> "When you've got 5000 people working up here and everyone else is like 'seems ok to me' the one or two people who complain are actually drowned out" (CAM)

This is a positive finding, contradicting the findings of Qi *et al*. (2010) and Shen and Tam (2002), and indicating that imposing strict lighting requirements on the activities of a large extractive project did not result in workforce discontent in this instance.

In contrast, the view of the regulator was that the positives of the lighting management had not outweighed the negatives. Although the environmental outcome so far has been good in this specific case (i.e. no detected impacts on the turtles) and the lighting guidelines have set a new benchmark for managing lighting impacts in industry, the lighting guidelines have not been implemented in any new developments:

> "Our hopes from Gorgon were that it'd help set a new best practice… but that hasn't been the case. You go … from Barrow down to Wheatstone [and] Chevron have said … 'no, we're not going to implement the light mitigation we did at Barrow. Barrow is a special case' …We're not even talking about a different company not implementing the actions. It's the same company." (SGR)

Moreover, the environmental significance of Barrow Island may have detrimentally affected the authority of the regulator in getting the environmental outcomes they want for new developments:

> "The first principle in environmental impact assessment is that you try to avoid the impact, so therefore you don't place large developments on high conservation areas. The EPA recommended against [Gorgon on Barrow Island] twice, and it was the Government who overturned it…. One of the downsides … is that when we're talking to other proponents about issues …a common response is 'look what's happening at Barrow and you're giving us a hard time'" (SGR)

Thus from a regulatory point of view, although the lighting guidelines have been successful for the environment at Barrow Island, the overall success of the lighting program has not been as hoped for.

Overall, outside Chevron, there was a shared view that lighting management at Gorgon has gone further than lighting management in other projects:

> "No-one has come up with any information, nor have I found any, which says 'here's a [lighting] model that is better'. I'm not aware of another model, let alone a better one" (IPC)
>
> "This is as close to best practice as there is at this point in time" (SGR)
>
> "I don't think you'll find anything like [the lighting management here] anywhere else in the world" (MTC)

Is this a successful example of lighting management?

To date, no conclusive lighting impacts have been found on the on-land orientation of hatchlings, or female nest site selection. However, given the importance of horizon elevation to the sea-finding ability of hatchlings (Limpus 1971; Salmon *et al.* 1992; Limpus and Kamrowski 2013; Chapter 4), the inclusion of elevation data in the hatchling orientation program may be warranted in the future. In addition, lighting impacts on hatchlings at sea, and future potential shifts in females nesting cannot be determined to date. Yet both Chevron Australia and the regulator are aware of these as important issues. Chevron is legally committed to reducing or avoiding impacts to marine turtles from lighting, using continual monitoring and research to fill knowledge gaps. Thus if or when impacts become apparent, Chevron will be required to take action to reduce these impacts. Furthermore, as techniques for gaining knowledge are developed they will also benefit marine turtle knowledge and conservation around the world. In terms of marine turtles, I conclude that the lighting management has been as successful as it can be with current knowledge and monitoring techniques. This is a view shared by the proponent, the State Government employees, and the consultant to industry (Table 7.2, Appendix 11).

In terms of compliance with ministerial conditions, the Gorgon light mitigation program does at first glance appear to be successful, with few instances of non-compliance all of which were addressed (Appendix 10), and a strong system in place to ensure compliance. However a deeper examination of 'compliance' reveals issues. Guidelines for lighting have been developed without a complete understanding of how to effectively manage light; an understanding which takes time to develop. In addition, compliance limits may be questionable due to an overwhelming preference for avoiding non-compliance. As such, I do not believe 'compliance' is an adequate measure of the success of the project.

In terms of lighting judgements, the proponent view of the lighting management was neutral overall given that it was a necessary condition of the operation taking place on Barrow Island. The workforce onsite also appeared satisfied with the lighting program, unlike other contractors faced with environmental conditions elsewhere (Shen and Tam 2002). Together these findings imply the lighting management has been successful, i.e. that it is possible to implement lighting at a large industrial plant that doesn't, at least in the short term, affect turtles, is not unpleasant or overly difficult to work within, and also crucially, doesn't lead to safety concerns (O'Dea and Flin 2001). Although the regulatory point of view was less positive due to increased enforcement difficulties associated with other projects, in terms of this specific case the regulator agreed the lighting management had been positive for the environment at Barrow Island after initial implementation difficulties.

Overall, the Gorgon lighting management can be considered successful to date; it also appears to be more substantial than lighting management in similar projects elsewhere. This analysis would have potentially benefitted from assigning ranks to the three criteria and weighting relative importance, however a more quantitative analysis was precluded by the necessarily small sample size. Yet, based on the insights generated here, future work should try to quantify success by using multiple criteria analysis, or similar, with a larger sample of respondents.

Here I only focused on lighting management, however because Chevron Australia are committed to multiple environmental actions at Barrow Island, future research would also benefit from an examination of whether other environmental commitments can also be judged as 'successful'. A comparison of the relative perceived 'success' of different actions would provide useful insights for managers and policy-makers in instances where said actions were required. For example, if the lighting management actions were more easily accepted and supported by the workforce compared to other environmental initiatives, this may indicate that despite the widespread view of light at night as 'normal' (Lyytimäki 2013), reduced lighting is something people accept relatively quickly. Alternatively, it may indicate that Chevron's environmental education of the workforce with respect to lighting may be superior to education efforts targeting other environmental actions. Further research to explore this finding would provide extremely useful knowledge for future efforts to reduce lighting in industrial settings.

Objective 2: Why has the lighting management at Gorgon been successful?

Thematic analysis of the interview transcripts produced seven main themes relating to drivers behind the success of the lighting management at Gorgon (Table 7.3).

a) Culture

The 'environmental culture of Barrow Island' was deemed important to the success of the Gorgon lighting management by most of the interviewees. Culture has been defined as a collection of ideas, values and practices that are typical of a particular identity group, which take time to develop and are marked by continuous evolution (Konrad *et al.* 1997). Schein (2004) defines organisational culture as a set of shared basic assumptions which are taught to new members as the correct way to do things. Chevron has had a long-term presence on Barrow Island[13], which has been recognised for outstanding environmental significance since the early twentieth century (Pope *et al.* 2005). It is likely that this long history has contributed to the development of the strong environmental culture on Barrow:

> "Chevron's been on Barrow Island … since the 60's. Over that time, the company and its people have built an environmental rapport with the island. ….[Chevron has] got a proud history of being associated with the island" (CAM)

> "[Chevron have] been operating here since 1965, knowing it was an A class nature reserve and that they had turtles and wildlife…. It's always been part of this operation" (MTC)

This has implications for the likelihood of successful light reduction initiatives elsewhere. As explained by one of the State Government employees, long-term, large scale industrial developments in areas of high environmental importance are not common. Thus there is a low likelihood of other industrial sites having an environmental culture developed to the same degree (e.g. Schein 1996).

Conversely, there is currently a large, temporary construction workforce onsite, who will leave Barrow Island once the project becomes operational. Migrating populations carry their culture with them into new situations and experiences (Levitt 1998), and this process of 'cultural diffusion' plays an important role in shaping the practices of the new host environments (e.g. Ashraf and Galor 2007). Although members of the workforce may not have the same level of influence over environmental initiatives as individuals in managerial roles (Drumwright 1994; Boiral *et al.* 2009), awareness of environmental issues in all employees has been considered a

[13] http://www.chevronaustralia.com/our-businesses/barrow-island

Table 7.3 Important drivers behind the success of the light management at Barrow Island, which emerged from thematic analysis of interview transcripts. Drivers are shown in the order they are discussed in the text.

Driver	Respondent	Example supporting quotes
1. Culture	Proponent	"Developing and maintaining a light culture, where people understand there're lighting requirements [and] people appreciate why lighting is as it is, [is] important … to put out into the environmental workforce"
	Onsite contract employee	"There's a culture of the animals come first" "I see a lot of people that are quite proud to be here. And I do see people say 'there's a bandicoot…just be careful fellas'" "It's not an attitude of 'it's gotta be off the road', It's an attitude of stop and pull up and 'gee that's a big perentie!'"
	State Government employee	"These guys aren't used to constructing things in such sensitive environments so they don't usually have to think about these sorts of things. But overall, yes there is a bit of a lighting culture. It's not perfect, but it would probably be naïve to think it would be"
	Independent expert	"We've visited and talked to people from 'the Boss' on the island, down to sub-contractors… and they've understood why [the lighting] is so important….and they were actively seeking to suggest additional things that they can do … in their little patch. So I think that's a demonstration of culture. Not just that they're doing what they're told, they're actively taking it further."
	Marine turtle consultant	"I think you'll find [managing the lighting is] not a big deal, it's just now what they do…it's all part of the culture on Barrow"
2.Moral responsibility	Proponent	"If the Government and the community have trusted us to put an LNG plant on Barrow Island, where there is flora and fauna that is important to us, then … they should expect that we perform at an extremely high level."
	Onsite contract employee	"People like Chevron … are the people that have to drive environmental issues" "If [humans] keep on fucking shit up, there won't be any more turtles"
	State Government employee	"if you want to build such a big project on a high conservation asset…they should have to [protect the environment]. So I don't pat them on the back … this is what [they] should be doing'"
	Marine turtle consultant	"they wanted to build this gas plant on Barrow Island … an A class nature reserve, it's one of the most important nature reserves…probably in the world… They knew that they were gonna have to [protect the environment] and do it well."
3. External pressures	Proponent	"there was a small but quite vocal and reasonably organised sector of the community [and] NGOs that opposed Gorgon on Barrow"

	Onsite contract employee	“[Compared to other firms I’ve worked for, the environmental management here is] probably a little better, but I don’t know if that’s just because it’s more in the spotlight. I mean, if there's an environmental disaster on Barrow Island then it will make the news”
	State Government employee	“The only other driver is… the risk to their reputation.”
	Independent expert	“There’s the distinct advantage in demonstrating good corporate citizenship. I think there's an advantage … in minimising if not eliminating, controversial, time-consuming, costly and damaging events that reach the public mind”
	Marine turtle consultant	“these big companies have global reputations that they're really keen to maintain, it’s just not worth their while to have a bad rep[utation]”
	State Government employee & marine turtle expert	“[an important driver] is public opinion, and [being seen as] good environmental citizens”
4. People	Proponent	“One of the things that really helped was [mine and our marine turtle contractor’s] prior experience on Thevenard Island, where we missed the opportunity [to get] baseline [data]. And we went through a lot of pain because of that.” “I'm not so sure [the lighting management] would have been successful if it had been a different contractor, and it might not have been successful if it had been a different … environmental lead [within Chevron]”
	Onsite contract employee	“It’s only because I give a shit that I will sit up late at night and think about it”
	State Government employee	“A lot of [the marine turtle management] was instigated through people [in environmental management in Chevron]. [Without those people] … it certainly wouldn’t have happened to the same degree.”
	Marine turtle consultant	“When the EPBC act was being drafted, I knew we couldn’t provide any info on turtles to meet the EPBC requirements. So when I was offered a voluntary redundancy I took it … and signed up for a PhD using the list of info we needed … to do our job managing marine turtles in an industrial zone.”
5. Proponent ethos	Proponent	“It’s part of our business. Its HES: health, environment, safety.”
	State Government employee	“I will say once [Chevron] decide to do something, they do it pretty well. Some of the turtle management is an example of that”
	Independent expert	“I hadn’t realised how important safety and environment was in [this] industry until I became exposed to it, [it’s a] major driver”
	Marine turtle consultant	“They’ve always set these high standards, with everything they do”
6. Increased business opportunities	Proponent	“Gorgon is probably the best example, certainly within Chevron … of how good environmental performance creates business opportunities. Chevron will undoubtedly use Gorgon as a way of demonstrating that we are a company that has strong environmental credentials, can be trusted, and if we say something, we will do it.”
	State Government employee	“People like myself grapple with the question of why the hell have they gone to Barrow? Potentially yeah, they have

		got interests [elsewhere], but some Chevron representatives have said to me, if we can demonstrate that we can build on a sensitive environment like Barrow, that maybe they'll get leverage to [build in sensitive environments elsewhere]"
	Independent expert	"There's also the distinct advantage of being seen to be a leader in this field. To be able to say in their public advertising, they're the best at this and here it is demonstrated. And I think big companies often are very keen to find ways of saying how good they are"
	Marine turtle consultant	"Chevron is stating now that … if they can build this plant and operate it on Barrow Island, it means they can operate in [other sensitive environments]. That's been spoken of publicly. Whether that was always.. one of the reasons? I don't know"
7. Regulation	Proponent	"We manage lights … to what we are committed to in the environmental commitments" "When that management plan …[is] signed off, even if we disagree with some of the things in there…we will absolutely comply"
	Onsite contract employee	"They do a lot of stuff that's best practice internally … [but] environmentally, not quite so much yet…And they're not going to, [unless] they have to…they're only going to do it cos they have to"
	State Government employee	"It's regulation which drives [environmental action]. I think it'd be wrong to say they would do nothing [without regulation], but they certainly wouldn't be doing what they're doing to the same degree, without the requirement to do it."
	Independent expert	"Environmental management is a very complex area, and the degree to which the effects of an industry on a particular species is mitigated, depends firstly on the capacity, the ability of a Government, usually the regulator, to understand the problem [and] to set realistic conditions."
	Marine turtle consultant	"[Regulation]'s important. It's really important. It's critical. If they're not required to, they won't."

critical success factor for firm environmental management systems (Zutshi and Sohal 2004), with industrial ecology argued to be reliant on bottom-up, rather than top-down approaches (Andrews 1999). Consequently, as the large temporary workforce disperses, they may assist in diffusing pro-environmental ideas about the importance of light mitigation into industrial developments elsewhere. This is of particular importance given that effective management of lighting will likely require shifts in human perceptions of how much light at night is necessary (Lyytimäki 2013). Although beyond the scope of the present analysis, further investigations into the magnitude of cultural influence on the lighting management and broader environmental appreciation of Barrow Island, as well as assessments of likely cultural diffusion of pro-environmental practices would be interesting and useful avenues for future research.

b & c). Morals and external pressures

Morals and external pressures both emerged as drivers behind the Gorgon lighting management. Doing 'the right thing', or moral responsibility, has previously been recognised as an important driver of organisational environmental action (Tutore 2013). This is linked to a discussion of culture, since an individual's perception of morally correct actions is influenced by the prevailing norms of that individual's culture (Husted 2005; Park *et al*. 2007). In Australia, marine turtles are very popular animals (Tisdell *et al.* 2004), thus a strong moral driver likely exists to protect marine turtles from development (see also Chapter 6). Given the environmental significance of Barrow Island, and the large, well-known turtle populations which occur there, the presence of a moral driver in this analysis is perhaps unsurprising.

Culture and moral responsibility also influence the views of external stakeholders (Tutore 2013), such as community groups and customers, and thus are linked to the coercive pressure these stakeholders exert on industry (DiMaggio and Powell 1983). As discussed earlier, when the development was proposed there was significant public opposition (Pope 2007). However, given the lack of awareness of light as a pollutant, external pressures were not expected to be a principle driver behind the success of the lighting management in this case. Indeed a search for recent media reports and other documents related to community opposition to Gorgon produced relatively little evidence of continued public opposition, despite a recently approved expansion of the project area in January 2014[14]. This lack of ongoing public opposition was confirmed by the interviewees:

> "We knew that [there] was the prospect of third party enquiries, but we all expected it to be in the form of conservation groups making public headlines … In fact we've had none of that which is quite

[14] http://au.news.yahoo.com/thewest/latest/a/20630790/gorgons-barrow-expansion-approved/

> astonishing…. I think they put their effort in at the beginning….But once that strategic decision had been made….I think [they have] other, bigger, more complex things to deal with" (IPC)

Indeed, subsequent to Gorgon, Woodside Petroleum proposed a large LNG precinct at James Price Point in the Kimberley region of WA (Grudnoff 2012). The project was scrapped in 2013 due to excessive costs; however during the proposal period, the project faced significant environmental opposition (Wall 2010) which may have directed limited conservation group resources away from Gorgon.

Alternatively, the lack of continued public pressure against Gorgon may be due to the remoteness of Barrow Island. Although support for protection of well-known conservation icons, such as the Great Barrier Reef, is often strong over large distances (e.g. the proposal of the Coral Sea Heritage Park by Pew Charitable Trust which is based in Philadelphia, USA (Pew 2008)), Morrison-Saunders and Bailey (2003) found that public pressure was generally weak for industrial projects located in remote WA locations. They attributed this to the sparse residential populations existing in these areas, and also to the fact that most inhabitants of remote areas close to industrial projects were likely to be involved with the industry in some way, and therefore be advocates for that project. This has implications for effecting more stringent lighting management in projects elsewhere, particularly where such projects occur in remote areas without well-known environmental icons. Yet, in more heavily populated areas – such as the Queensland coast of Australia which is located adjacent to the Great Barrier Reef, and is undergoing well-publicised industrialisation – providing that public awareness of harmful lighting impacts is recognised, external pressures may play a greater role in driving effective industrial lighting management.

d & e) People and proponent ethos

The importance of individuals was highlighted, with both environmental managers of Chevron, and environmental contractors working on Barrow Island, driving actions to manage lighting (Table 7.3). This supports previous work which has found that companies' environmental actions are often directed by employees (Buysse and Verbeke 2003; Boiral *et al.* 2009). In terms of implications for the likelihood of successful light reduction initiatives elsewhere, given the 'normal' view of light at night, it will be important to have recognition of light as a problem by individuals who are able to drive lighting management initiatives. Once again the discussion of the importance of 'people' is linked to the above discussion of moral responsibility and culture. Moral reasoning has been found to influence the decision-making of managers (Trevino *et al.*

1985; Trevino and Youngblood 1990), and individuals' 'values' have been attributed to cultural influences (Vinson *et al.* 1977).

Chevron's company ethos, which highlights the importance of the environment, was also indicated as an important driver of the lighting management success. Similar to above, 'proponent ethos' is intrinsically linked to the influence of people, morals, and culture, since it is the perceptions and interpretations of company individuals which sculpt organisational environmental practices (Anderson and Bateman 2000; Egri and Herman 2000; Bansal and Penner 2002). In addition, because most companies prefer to have a benign environmental image (Ketola 2004), it is likely that external pressures have influenced the environmental ethos of Chevron, and indeed this view was supported by the proponent:

> "If the … community has trusted us to put an LNG plant on Barrow Island, where there is flora and fauna that is important …then they should expect that we perform at an extremely high level. And that's the driver for it." (CAM)

In terms of implications for the likelihood of successful light reduction initiatives elsewhere, other large companies which develop facilities close to turtle nesting beaches, particularly in the extractive industries which seem to be dominating Australia's coastal development at present (Grech *et al.* 2013; Ford *et al.* 2014), will likely face similar external pressures (albeit depending upon visibility to population), and thus feel the need to present a positive environmental image. This suggests that proponents' may implement light reduction strategies if called for by individuals, morals or external pressure. However, the extent of light management will likely depend upon the environmental significance of the project location, and the types of environmental stressors likely to be affected, since certain species generate more public sympathy and concern than others (Leader-Williams and Dublin 2000).

Secondary influences on the success of the lighting management?

Given previous research, I began this case study with the assumption that regulation would likely be the crucial driver behind the success of the lighting management at Barrow Island. The five drivers discussed above all emerged as important influences for light management in this case, and it is clear that they are closely linked. These drivers therefore present a competing proposition for explaining the success of the light management, which would contradict my second assumption that pressures from external/internal stakeholders were unlikely to be critical drivers.

Yet, the extent of influence exerted by these drivers appears to be contingent on the environmental significance of Barrow Island. Following Gorgon, Chevron Australia began developing a project on the WA mainland called Wheatstone, but as mentioned earlier, the strict lighting practices in place at Gorgon were not transferred across to the new development. This was justified due to a perceived lessor environmental importance:

> "Each proponent … manages light differently, so taking a location that's well away from turtle beaches, you could argue why would you need to manage lighting?"
>
> "The EPA wanted Wheatstone to have the same lighting management plan as Barrow Island, and we said … why? What's the exposure, what's the risk?" (CAM)

Yet, marine turtles do nest close to the new development, albeit in lower numbers and at greater distances from the facility:

> "[On] the islands offshore, there is heaps of nesting, there're flatbacks near shore, greens further off, and collectively it's a pretty big rookery." (MTC)
>
> "The sensitive receptors [the turtles] are further offshore [at Wheatstone]. … they're probably 10 km … offshore." (CAM)

Marine turtle disruption attributed to light glow originating approximately 15 km away was described in Chapter 4. Disruption from artificial lighting has also been recorded in eastern Australia at distances of 18 km from large industry (Hodge *et al.* 2007). Yet, the potential influence of lighting at Wheatstone was not considered by proponents and stakeholders to be severe enough to warrant the same stringent lighting management as Gorgon. Given that in both cases the proponent ethos, the people involved, and the morals and culture were the same, as expected these drivers do not appear to be strong enough to influence strict lighting management in isolation, particularly in areas not deemed to be environmentally significant. This is once again likely linked to the shifting baseline identified by Lyytimäki (2013) – most people think light at night is normal, so why not start off with light and modify it based on the presence of sensitive receptors? This leads us to a discussion of the remaining two drivers identified as being important for the success of the lighting management.

f) Increased business opportunities

Increased business opportunities emerged as an important driver of the lighting management at Gorgon, which is perhaps unsurprisingly given that profitability is one of the fundamental goals of any business (Ittner and Larcker 2003). In this case, Barrow Island was considered to be the only economically viable location for Gorgon, with spending on environmental initiatives of approximately $150 million (Government of Western Australia 2010) significantly outweighed by predicted losses of approximately $11 billion if the project was located elsewhere (Pope 2007). The drive for increasing business value was therefore likely to be a very strong contributor to the success of the lighting management, because given the high environmental importance of Barrow Island (Class 'A' nature reserve (Department of Environment and Conservation 2007) it was in the proponent's best interest financially to ensure that environmental protection was accorded a high level of consideration.

The costs and benefits involved with implementing the program from an industry perspective (see Table 7.2) also indicate that future business opportunities depend upon the external perceptions of Chevron Australia as a firm that can demonstrate good environmental performance. In other words, it is dependent upon external pressures, people, and the associated culture and moral responsibility, which all link back to the environmental importance of Barrow Island, for example:

> "You've got to understand… all these companies exist on the stock market….their job is to make money for their shareholders… yes they'll do some things for the environment because that's a risk to their reputation, but it always comes back to 'how do we make more money for our shareholders?'" (SGR)

The fact that Chevron did not transfer the lighting regime to the new project site, Wheatstone, which was not located on a Class 'A' Nature Reserve, suggests that the importance of external pressures, people, and the associated culture and moral responsibility only become important drivers of successful light mitigation when they contribute to increasing business value.

Yet use of excess light also incurs a cost, and significant reductions in energy expenditure have been forecasted as a result of improving lighting technologies (Pimputkar *et al.* 2009). Thus reducing artificial lighting and improving lighting practices, such as those which have occurred at Gorgon, will likely reduce power costs over the long-term. This potential long-term financial saving does not appear to have been considered, for example when asked 'have there been any calculations or projections made as to whether the actions taken to mitigate light will incur a financial cost or saving over the life of the project?' I received the following responses:

> "I don't know the answer to that, sorry."
>
> "No, we haven't looked at it like that at all… We haven't looked at it from the money side." (CAM)

This supports previous work which suggests that potential economic advantages of environmental management practices do not become immediately apparent, or are not obvious (Epstein and Roy 2001), despite the fact that these practices may lead to significant cost savings over the long-term (Christmann 2000). This finding appears to align with 'myopic institutions theory' (Hansen and Hill 1991), which contends that firms will preferentially invest in activities leading to short-term gains. This hypothesis has not received much empirical support, particularly with regards to investments into product research and design (Hansen and Hill 1991). However, when the relationship between financial performance and corporate environmental responsibility was examined, Wahba (2008) found that investors were indeed oriented in the short-term. More recently, Cox and Wicks (2011) found that banks, mutual funds and insurance companies are likely driven by short-term benefits. Thus firms may give less thought and consideration to necessarily longer-term environmental strategies (Hart and Ahuja 1996), because external investments are driven by short-term outcomes. Future research focused on the applicability of 'myopic institutions theory' to environmental management in industry would therefore be valuable.

In this chapter, given the importance of increasing business value to the success of the lighting management, although cost savings associated with the reduced lighting may be minor compared to the overall project - should the savings be acknowledged or recognised in the future, it is possible that this might influence future business practices regarding lighting in other projects within Chevron. This is particularly relevant given that artificial lighting accounts for a significant proportion of all energy used globally (Kyba *et al*. 2014), and Chevron Australia have established a Global Technology Centre[15] in Perth, Australia, which aims to ensure that energy needs continue to be met in an emissions-constrained global environment (Krzywosinski 2013).

g) Regulation

I began this chapter with the assumption that regulation would be a critical driver behind the success of the lighting management at Barrow Island, and I found that multiple interviewees did consider the existence of regulation to be of overarching importance (Table 7.3). In WA, environmental regulation generally consists of strict environmental objectives set without specific details for how the objectives should be met (Morrison-Saunders *et al.* 2014). The WA environmental regulatory system is widely perceived as being both effective and comprehensive (Wood 1994). In fact, this style of flexible, outcome-based regulation matches the type of regulatory style deemed to be the most effective approach to environmental management

[15] http://www.chevronaustralia.com/our-businesses/technology-leadership-and-partnerships/global-technology-centre

(Nemetz 1986; Harrison 1998a), i.e. a combination of 'command and control' style regulation which ensures environmental outcomes (Harrison 1998b), with the flexibility necessary to reduce costs and encourage innovative solutions to environmental problems (e.g. Porter and Van der Linde 1995). Indeed, I found evidence suggesting that the existence of regulation had stimulated innovation with respect to lighting at Gorgon:

> "[the regulators said] 'it's up to you to work out what you can do and what's the lowest level of lighting you can safely work with'. We did a lot of work in our engineering offices [and] we have lighting in design requirements. Every piece of equipment that comes out of here… [has] a specific lighting plan …. We actually got the whole plant designed with our lighting requirements designed in" (CAM)

This aligns with previous research which found that the less prescriptive Australian regulatory approach has led to innovation in the oil and gas sector (Ford *et al*. 2014). However, despite innovation occurring, Chevron did not transfer the successful lighting regime across to Wheatstone, which had a reduced level of regulatory requirements:

> "I think the problem is [the regulators] assume that [Chevron are] gonna do best practice [with lighting] because they did it somewhere else ... And they're not going to …they're only going to do it because they have to." (COC)

This supports the findings of Ervin *et al.* (2013), who suggested that a firm is more likely to adopt environmental management initiatives when stronger regulatory pressures exist, thus regulatory threats are considered necessary for advancing environmental action.

Regulation has been considered as more important for environmental action when environmental issues are emerging and being defined (Post 1978). As discussed earlier, the perception of light as a pollutant is still gaining recognition (Lyytimäki *et al.* 2012) and I found a shared perception that light at night is not an issue in other circumstances (i.e. away from Gorgon):

> "Well the light's very different here [to other sites I've worked at]. It's obviously a lot duller... People actually care about where the lights get pointed, it's more of an issue… Inland, you don't really care" (COC)

> "Taking a location that's well away from turtle beaches, you could argue why would you need to manage lighting?" (CAM)

> "It's just a holdover from the old days when there was no reason to restrict [the lighting] and the whole attitude was 'if you've got it, let's light it up as much as you can'" (MTC)

Thus for the emerging problem of light pollution, it is perhaps unsurprising that regulation did indeed emerge to be of primary importance for the success of the Gorgon lighting management.

Links between drivers

Overall this exploratory study was concerned with generating insights and avenues for future research related to industrial lighting management. Thus I did not attempt to quantitatively determine the relative importance, or weight of the different drivers. However, it is clear that links exist between drivers and that certain drivers exerted a stronger influence than others. The existence of regulation was extremely important for driving the success of the lighting management, yet the secondary influences that were identified (i.e. culture, moral responsibility, people, external pressures, and proponent ethos) were likely to have influenced regulation. Tutore (2013) concluded that public pressure, based on moral and cultural influences, pushes regulators to enforce environmental management. Conversely, regulation is also likely to have influenced the other drivers: strict environmental regulation has been shown to raise public awareness and educate external stakeholders about environmental issues (Doran and Ryan 2012), as well as influencing the environmental attitudes and ethos of companies (Bond *et al.* 2014).

The lighting management at Gorgon was also strongly linked to business opportunities. Had it been possible, and more economically advantageous, to locate Gorgon in an area of lower environmental significance where environmental regulations would have been lower, the same level of lighting management may not have occurred (e.g. Wheatstone). Thus, the environmental importance of the site, although not directly emerging as a specific driver behind the lighting management in the interviews, was also important for the success of the lighting management, directly contributing to, and highlighting, the influence of both regulation and the secondary drivers described above. There are also links between regulation and increased business opportunities due to the innovative influence of regulation leading to competitive advantage (Porter 1991; Porter and Van der Linde 1995), and the economic advantage that comes with pre-empting additional regulations through development of comprehensive environmental initiatives (Raines and Prakash 2005).

As such I propose the framework shown in Figure 7.1 which attempts to model the relative importance of, and links between, identified drivers leading to the success of the lighting management at Gorgon.

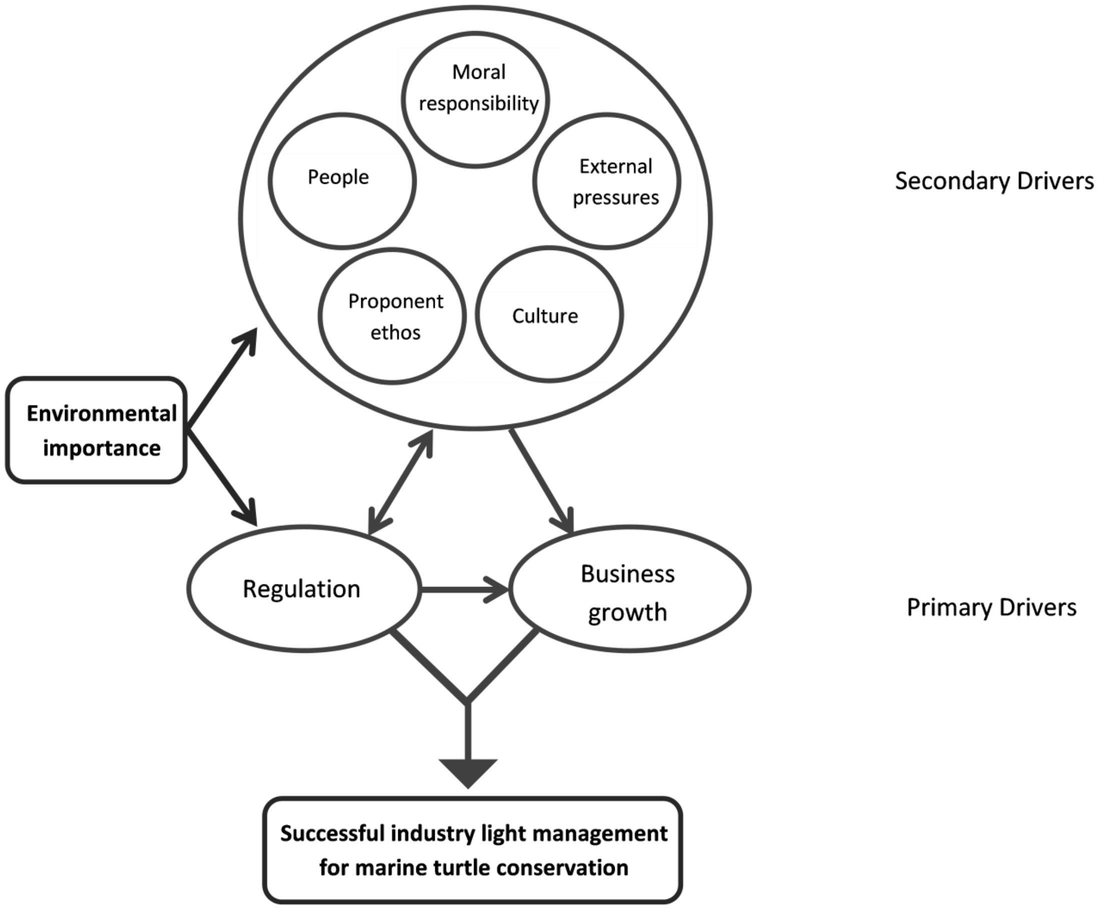

Figure 7.1 Drivers behind the successful light management for marine turtles at Barrow Island. Arrows indicate direction of influence.

7.6 CONCLUSIONS AND IMPLICATIONS

Coastal light pollution can disrupt marine turtle breeding success (Witherington and Martin 2000; Salmon 2003), and in Australia, industrial light is a significant contributor to the light exposure of nesting beaches (Chapters 2, 3 and 4; Pendoley 2005; Department of Environment and Conservation 2007; Department of Environment and Conservation 2008). In this exploratory case study, I focused on a single case of extreme industrial light management in a development located close to nesting beaches, to generate insights and avenues for future research regarding effective management of industry light for marine turtle conservation.

My findings suggest that the Gorgon Project is an example of successful lighting management in an industrial setting. This indicates that future or proposed industrial projects where lighting management is required, would benefit from seeking to emulate the Gorgon lighting model, particularly given that in this instance ‘successful’ lighting did not incur either prohibitive costs or workforce discontent. In addition, the lighting regime did not lead to reduced safety (perceived or otherwise) in the workplace: no safety concerns related to the lighting were mentioned by either the proponent or the onsite workforce. This is critical given the importance of occupational health and safety in the oil and gas industry (O'Dea and Flin 2001). Although I concluded that the lighting management had been 'successful' to date, and the interviewed experts shared the view that the lighting management at Gorgon had gone further than other projects, I did not evaluate whether it could be considered 'best practice' (defined as a set of repeatable procedures which are used to achieve a goal or task in the most efficient and effective way (Engle 2008)). Given the significant harm that extractive industrial operations pose to the environment (Ford *et al*. 2014), they have been hailed as a key sector for the development of best practices (Tutore 2013), as best practice is considered to be an effective way of promoting learning and innovation across a sector (Bulkeley 2006). Future research to evaluate whether Gorgon lighting management is indeed best practice, with the steps involved to warrant a 'best practice' designation explicitly identified, would thus provide additional, valuable information for both managers and policy makers.

Examining the main driving forces behind the lighting management supported my initial assumption that regulation was critical to the program's success. This is likely a result of the fact that lighting is not yet widely recognised as a pollutant (Lyytimäki *et al*. 2012; Lyytimäki 2013), therefore alternate drivers found to be important for other environmental initiatives, such as external stakeholder pressures, and internal values, were limited. Indeed, based on previous research, mimetic, or competitor, pressures may have been expected to appear as a driver in this instance (DiMaggio and Powell 1983), but this driver was notably absent. Recent research found sustainable development practices implemented in oil and gas multinational companies were unlikely to generate mimetic pressures, partly due to the lack of a clear financial benefit of implementing such strategies (Escobar and Vredenburg 2011). Since the proponent in this case did not appear to have considered long-term financial savings associated with reduced lighting over the life of the project (see section f) Increased business opportunities), it is perhaps unsurprising that competitors were unaware of potential financial benefits associated with the lighting regime. Yet, environmental practices may lead to significant cost savings over the long-term (Christmann 2000), thus should the financial benefits of reduced lighting be recognised at a later stage, this has implications for lighting management elsewhere. It is possible that future lighting practices may be influenced both within Chevron, but also in competing projects because firms tend to copy strategies perceived to be advantageous (Suchman 1995).

Marine turtles are a well-known species disrupted by artificial light (Salmon 2003), and are also currently listed as species' of national environmental significance in Australia (GBRMPA

2013a). Together this gives regulators power to impose lighting restrictions in regions close to marine turtle nesting beaches. However, artificial lighting has been found to adversely impact multiple other species and taxonomic groups (Rich and Longcore 2006; Le Tallec *et al.* 2013), yet these impacts are not widely recognised (Hölker *et al.* 2010b) potentially limiting regulatory influence. For example, as shown here, light management is viewed as less important away from turtle nesting beaches, and the severity of imposed environmental conditions is dependent upon the perceived presence of 'sensitive receptors'. In Western Australia, impact prediction during the EIA is dependent upon baseline data collection (Morrison-Saunders and Bailey 2003), yet the quality of science used for EIA assessment has been heavily criticised (e.g. Preston 1985; Fairweather 1989; Benkendorff 1999; Grech *et al.* 2013) with conservation managers in Australia found to regularly evaluate environmental issues based solely on their own experience (Cook *et al.* 2009). Rigorous science has been deemed as not wholly necessary for effective environmental management (Morrison-Saunders and Bailey 1999), because a subjective component exists for effective EIA based on values (e.g. Lemons and Brown 1990; Hellström and Jacob 1996). Morrison-Saunders and Bailey (2003) conclude that simply identifying environmental issues during the EIA process may have greater importance than impact prediction because it brings critical issues to managers' attention. Unfortunately, because light at night is viewed as normal (Lyytimäki 2013), a lack of rigorous baseline studies for informing appropriate lighting management is unlikely to be offset by identification of lighting impacts. This will be particularly true for species where research on lighting impacts is currently limited or absent. Thus regulator power to impose lighting restrictions is limited based on current scientific knowledge.

The importance of environmental management in industry is being increasingly recognised (e.g. Berry and Rondinelli 1998), and this has been attributed to a 'broadening of consciousness' related to current ecological threats, at both an individual and community level (Boiral *et al*. 2009). I conclude that a similar 'broadening of consciousness' is required to drive management measures designed to limit detrimental impacts of artificial light at night, as this will likely improve the effectiveness of regulation (which is currently of critical importance in lighting management), as well as strengthen other coercive and mimetic pressures. I thus support previous calls for active outreach efforts to overcome the widespread perception of an artificially lit night as being 'normal' (Lyytimäki 2013; Lyytimäki and Rinne 2013).

My research adds to the literature on driving influences behind environmental initiatives, indicating that relevant drivers of environmental action depend upon the specific action under examination. However, my study is limited by analysis of a single case and a limited sample of interviewees. Furthermore, given that recognition of the need for lighting management is increasing, the relative influences of the different drivers behind successful industrial lighting management may change. I thus recognise that the model requires testing and refinement for understanding drivers behind successful industrial lighting management in other instances and examples, and this would be an extremely valuable avenue for future research. Yet, until awareness of detrimental impacts associated with artificial light reaches adequate levels, my work to understand the drivers behind a demonstrated instance of successful industrial lighting management is a valuable first step for tackling the growing problem of light pollution.

Chapter 8

General Discussion

Following the invention of electric lighting, humans have rapidly and radically altered nighttime environments across the globe, with profound ecological consequences (Cinzano *et al.* 2001a; Hölker *et al.* 2010b; Gaston *et al.* 2013; Kyba *et al.* 2014). Excessive and increasing nighttime illumination has been particularly detrimental to the survival of marine turtles, given their reliance upon brightness cues for sea-finding whilst out of the ocean on beaches (Mrosovsky and Shettleworth 1968; Mrosovsky 1977; Lohmann *et al.* 1997; Witherington and Martin 2000; Salmon 2003).

Extensive research has ensured that the threat posed to marine turtles from light pollution is widely recognised (Witherington 1999). However, a review of relevant literature indicated that effective management of artificial lighting impacts on turtles may be impeded by several important knowledge gaps; namely a lack of broad scale studies, a knowledge base derived from a limited number of well-studied populations and species, and little to no consideration of the human dimension essential for widespread efforts to manage light (Chapter 1). Moreover, despite globally important nesting populations of marine turtles, published research which addresses light pollution impacts on Australian turtles is lacking (Chapter 1). Australian coastlines are currently facing rapid population growth and increasing industrial development (Australian Bureau of Statistics 2007b; SEQ Catchments 2010; Australian Bureau of Statistics 2011; Grech *et al.* 2013; Ford *et al.* 2014), thus increased management attention on mitigating likely light pollution impacts on marine turtles is currently warranted, and this was the focus of the present thesis.

8.1 Summary and synthesis of research findings

This thesis addressed identified knowledge gaps to provide an empirical base for more effective management of current and future light pollution impacts on marine turtles (Chapter 1). Meeting this overarching aim necessitated different approaches spanning several scientific disciplines. A schematic summary of this thesis, indicating the approaches used, is presented in Figure 8.1.

Objective 1

My first objective was to provide a more comprehensive understanding of how and where light pollution threatens marine turtles in Australia. To achieve this objective I used broad scale assessments of both nesting beach exposure to light pollution (Chapter 2) and temporal changes in artificial lighting (Chapter 3), as well as an ecological study to assess hatchling response to artificial lighting (Chapter 4).

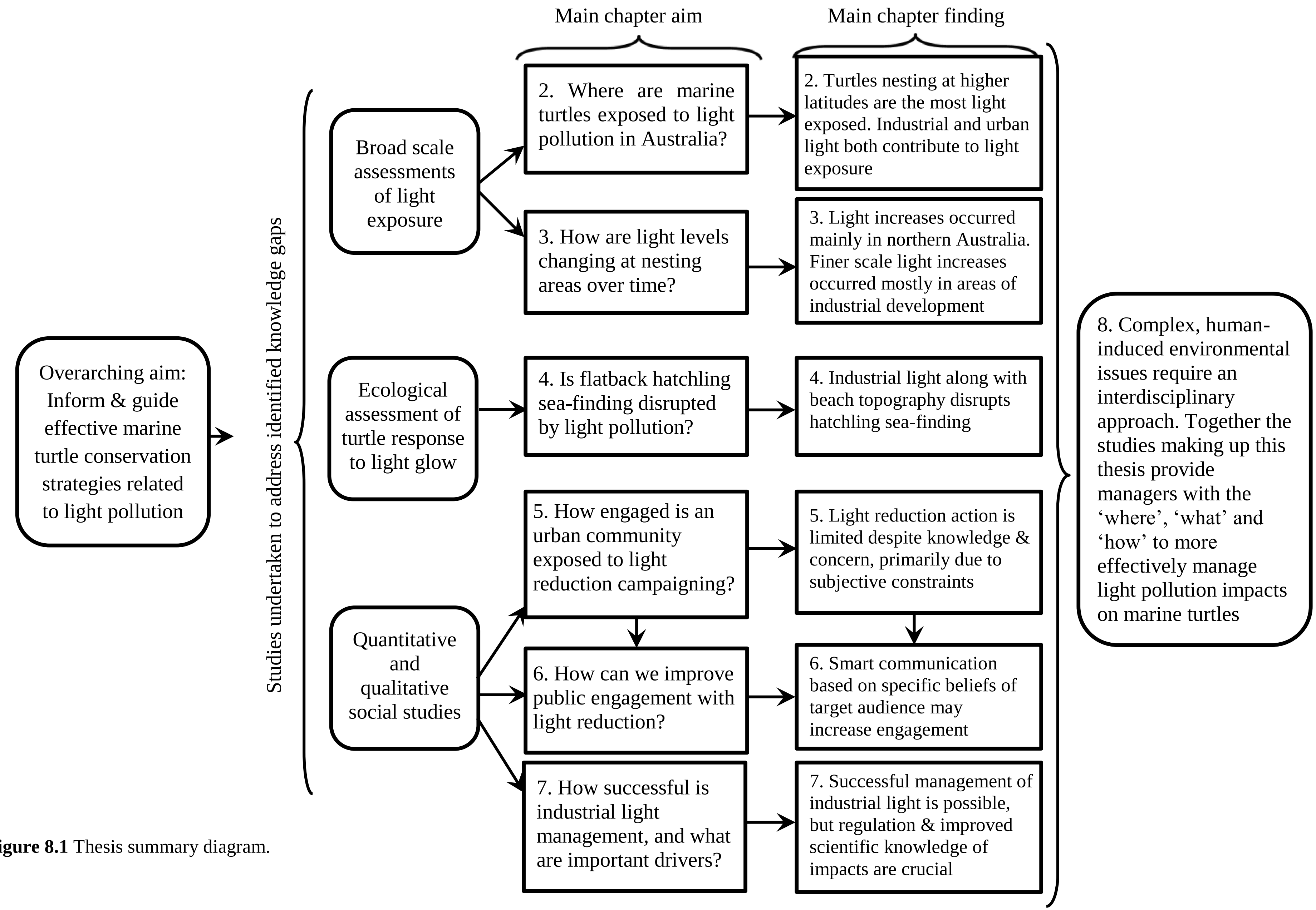

Figure 8.1 Thesis summary diagram.

The broad scale assessments I conducted in Chapters 2 and 3, using GIS analysis of nesting data overlaid onto nighttime lights data, demonstrated that all species of marine turtle in Australia are vulnerable to light pollution. Nesting areas in the North West Shelf of WA and along the Woongarra coast of Queensland were found to be potentially the most light-exposed nesting areas in Australia, and importantly, light levels in these regions have not changed since the early 1990's. Conversely, nesting areas further north were shown to be minimally exposed to light pollution, but in general light was found to be increasing more rapidly in these more northern nesting areas than for management units nesting further south. Both chapters also indicated the important contribution made by industry lighting, and to a lesser extent light from urban areas, to the increasing light exposure of Australian nesting beaches.

The detrimental impact of industrial lighting for marine turtle survival was confirmed in Chapter 4. Flatback hatchling sea-finding ability at a nesting beach in a currently undeveloped region was compared to sea-finding ability at a beach with light horizons highly modified by the presence of significant industrial development (Pendoley Environmental 2011). Skyglow produced by industry, in combination with beach topography, significantly disrupted hatchling sea-finding. By evaluating commonly used methods for assessing hatchling orientation to advance this field of knowledge, I demonstrated that combining fan-mapping techniques (Salmon and Witherington 1995; Pendoley 2005) with strategically placed arenas would provide optimal data for accurately measuring sea-finding ability, providing fan measurements are explicit. This was also the first study to document time of emergence from the nest for east Australian flatback hatchlings. Emergence peaked during the early hours of the morning, which is later than peak emergence for other Australian species and populations assessed (Limpus 1985; Gyuris 1993; Koch *et al.* 2008).

Objective 2

My second objective was to examine artificial light-use, and perceptions and attitudes towards reducing light for marine turtle conservation, in relevant stakeholder groups. Since marine turtles were found to be most vulnerable to light pollution impacts from industrial light in the North West Shelf of WA and from urban developments along the Woongarra coast of Queensland (Chapters 2 and 3), these were the stakeholder groups selected for study, to inform and guide targeted light mitigation strategies in the nesting regions of Australia where they are most necessary.

In Chapters 5 and 6, I surveyed residents on the Woongarra coast who had been exposed to four years of light reduction campaigning. I determined community light-use behaviour, in addition to engagement with, and salient beliefs about, light reduction for turtle conservation. I found all residential light was typically extinguished by 01:00 h each night. Using an existing theoretical constraints framework (Sutton and Tobin 2011), I found high levels of cognitive and affective engagement for light reduction i.e. the community knew and cared about the issue. Thus the existing campaign had been successful at educating the community. However, I found lower levels of community light reduction action. Subjective constraints, mainly related to 'uncertainty and scepticism' and 'externalising responsibility/blame', emerged as the primary cause of this limited behavioural engagement (Chapter 5), indicating that addressing these widely held beliefs would likely increase community action. I also proposed a refinement to the framework of constraints on personal engagement (Sutton and Tobin 2011), to guide future understanding of public engagement with light reduction initiatives (Figure 5.5).

I then further explored community beliefs related to light reduction (Chapter 6), and found that personal norms were the strongest predictor of intention to reduce light. I also identified three salient beliefs which significantly differed in strength between residents who take light reduction action, and residents who do not. Based on communication techniques underpinned by the Theory of Planned Behaviour (Ajzen 1991), this indicates persuasion potential exists for increasing light reduction behaviour in this community, which may be used to improve future campaign materials.

Management of lighting in industry is more challenging than managing individual light-use due to health and safety concerns and lighting standards. Therefore in Chapter 7, I used a qualitative case study approach which evaluated the success of light management in a large industrial development located on Barrow Island on the North West Shelf (WA). Using expert opinion and proponent annual reports related to impacts on turtles, compliance, and lighting judgements, I determined that the Gorgon Gas Development to date is an example of successful industrial lighting management implemented to protect marine turtles. Based on emergent themes, I developed a conceptual framework of drivers behind successful lighting management in industry (Figure 7.1). I identified that regulation and business growth were the principle drivers behind the successful lighting management, but secondary drivers such as external pressures, culture and moral responsibility, as well as the environmental importance of the development site, together exerted an important influence on the primary drivers.

8.2 Management implications

Australian marine turtles are threatened by multiple anthropogenic pressures (Environment Australia 2003) all of which demand management attention. My finding that all marine turtle species in Australia are vulnerable to light pollution (Chapter 2) demonstrates the importance of management effort focused on light mitigation close to nesting beaches, whilst also highlighting the management value of this thesis. In addressing the first identified knowledge gap and assessing the spatial and temporal scale of marine turtle exposure to light pollution, I have provided valuable information which will enable prioritisation of areas for management, and allow conservation resources to be allocated more effectively (e.g. Fuentes *et al.* 2011). Effort should be concentrated on management of lighting in existing or proposed industrial and urban developments at higher latitudes, and management attention should be given to coastal development in northern Australia to prevent increasing light reaching disruptive levels. In addition, the broad scale methods I used provide a useful first step towards managing lighting impacts for marine turtles at ecologically relevant scales (see also Mazor *et al.* 2013), and will be useful to managers of marine turtles and other species impacted by artificial light around the world, where conservation resources are limited (e.g. Fuentes 2009).

Since flatback turtles display a markedly different life-history to other hard-shelled marine turtles (Walker and Parmenter 1990; Salmon *et al.* 2009), I assessed flatback hatchling sea-finding to address the second identified knowledge gap and allow development of specific management approaches. My finding that flatback hatchlings were disrupted by the presence of artificial lighting during the beach crawl in an area of significant industrial development in Queensland, adds to the numerous studies which have demonstrated lighting impacts in other populations and species (e.g. Witherington 1991; Witherington and Bjorndal 1991a; Witherington and Bjorndal 1991b; Peters and Verhoeven 1994; Salmon *et al.* 2000; Bertolotti and Salmon 2005; Pendoley 2005; Stapput and Wiltschko 2005; Harewood and Horrocks 2008; Fritsches 2012). My findings confirm the detrimental impact of industrial light close to turtle nesting beaches which was highlighted in Chapters 2 and 3, and further emphasise the importance of industrial light monitoring and management close to turtle nesting beaches across Australia. The fact that flatback hatchling core time of emergence in east Australia was later than found in other populations and species can be used to guide more efficient and targeted lighting mitigation measures where necessary i.e. tasks where light at night is indispensable can be scheduled for outside peak emergence times. Furthermore, as coastal development and artificial lighting continue to increase in coastal regions around the world (Elvidge *et al.* 2009; Elvidge *et al.* 2011), my evaluation of methods typically used to measure hatchling orientation will aid identification of lighting impacts on hatchlings, as well as improve assessments of lighting management efficacy both within Australia and elsewhere.

Chapters 5, 6 and 7 addressed the third knowledge gap, which identified a lack of research focused on understanding human perceptions and behaviour when considering effective lighting management. The human dimension inherent in global issues of environmental change has been deemed the greatest challenge for current environmental research and management (Skole 2004).

Management of public light-use is particularly important in Queensland (Chapters 2 and 3), but I demonstrate that current light reduction initiatives instigated in 2008 by the Queensland Parks and Wildlife Service managers have not produced the desired behavioural response (Chapter 5). This supports extensive research showing that increased public awareness of an issue is not sufficient for stimulating environmental action (Owens 2000; Kollmuss and Agyeman 2002; Lorenzoni *et al.* 2007). Along the Woongarra coast, more targeted, psychologically smart communication should replace the existing light reduction campaign (Chapter 6). Future communications should focus on addressing the subjective constraints I identified, as well as appealing to personal norms and the salient beliefs I identified as having strong persuasion potential.

As coastal populations grow and continue to encroach on turtle nesting beaches in Australia, the techniques I employed should be used as a guide to identify relevant community beliefs and behaviours in other areas where light mitigation is deemed necessary, prior to instigating a light reduction campaign. This will save time and reduce costs involved, whilst also acting to limit public ‘fatigue’ with messages related to light reduction (e.g. Landers *et al.* 2006). This is particularly important in today’s society because multiple environmental ‘calls for action’ are potentially resulting in public apathy towards, or even backlash against, environmental initiatives (Kerr 2009).

Lighting management in industry is also crucial for limiting light pollution impacts on marine turtles (Chapter 4), particularly in the North West Shelf, Western Australia (Chapters 2 and 3); yet I demonstrate that a successful example of lighting management in a large industrial development exists in this region of Australia (Chapter 7). The lighting management employed in this case study did not incur excessive costs, nor did it stimulate workforce discontent. Thus current and future industrial developments, both in Australia and elsewhere where marine turtles are impacted by industrial lighting, would be well-advised to emulate the lighting model used in this instance. My examination of the drivers behind the successful lighting management highlighted the importance of effective and comprehensive regulation, mainly because recognition of light pollution as a significant biodiversity threat is still emerging (Lyytimäki *et al.* 2012; Lyytimäki 2013). Adequate scientific knowledge of lighting impacts was also found to be critical, thus effective management of light pollution impacts in the future will require increased management and regulatory focus on lighting impacts for both marine turtles and other species.

8.3 Management outcomes

The information presented in this thesis is directly relevant to the conservation goals, and related research needs of the Australian Commonwealth and State Governments, pertaining to management of marine turtles. Listed as species' of national environmental significance (GBRMPA 2013a), a *Recovery Plan for Marine Turtles in Australia* was implemented in July 2003 to guide marine turtle management efforts in accordance with the *Commonwealth Environmental Protection and Biodiversity Conservation Act 1999* (Environment Australia 2003). However, the Australian Government was required under legislation to update the plan by 2015, and the review process began in 2013. The broad scale threat assessments presented in Chapters 2 and 3 were used in the updated recovery plan (due to be released for public comment in Autumn 2014) to inform the level of conservation attention required for each Australian marine turtle management unit related to light pollution impacts (Department of the Environment 2014). My subsequent chapters also address or inform other research needs identified in the updated plan as vital for managing the light pollution threat, namely determining the impact of skyglow on turtle behaviour (Chapter 4), and developing guidelines for lighting management in coastal communities (Chapters 5 and 6) and industrial developments (Chapter 7).

My published work (Chapters 2 and 3) has also been used to inform two key documents produced by the Great Barrier Reef Marine Park Authority (Australian Government) 1) the Great Barrier Reef World Heritage Strategic Assessment which was prepared at the request of the United Nations (GBRMPA 2013b), and 2) the updated Great Barrier Reef Outlook Report, which is a report required under legislation every five years for submission to the Federal Government Minister for the Environment (GBRMPA 2011). The updated Great Barrier Reef Outlook Report is due for ministerial submission in June 2014, and public release soon after.

Similarly, my results have also contributed to the Ecosystem Research and Monitoring Program (ERMP) '*Gap analysis for monitoring of coastal sea turtles*' (Department of Environment and Heritage Protection 2013) instigated in the Port Curtis and Port Alma regions of Queensland to ensure recognition of potential environmental impacts as a result of industrial development practices.

8.4 Future research

Importance of interdisciplinary research

Efforts to solve important environmental problems have often lacked sufficient management focus and organisation of available knowledge (Brewer 1999; Lyytimäki *et al.* 2012).

Recognition of the critical need for environmental research which transcends single-disciplinary focus is growing (Kinzig 2001; Collins 2002), and environmental research linking human and natural systems is receiving increased attention (Skole 2004).

This thesis demonstrates the value of conducting interdisciplinary research when tackling significant environmental issues. Effective management of light pollution for marine turtles requires an understanding of how and where marine turtles are impacted, using ecological, biological, spatial and temporal information. Technological solutions may be useful in specific circumstances (Falchi *et al.* 2011; Kyba *et al.* 2014); however, since artificial lighting is almost exclusively a product of human preference and behaviour (McDonald *et al.* 2014), understanding the human dimension of lighting is fundamental to management efforts. Yet factors influencing human behaviour and personal motivations are extremely complex, and the methods required to effectively manage light-use in one instance may not achieve the same outcomes elsewhere. Therefore, only by understanding the human dimension specific to relevant stakeholders, in those areas where marine turtles face the greatest threat, can we begin to effectively address the problem of light pollution for marine turtles.

Light pollution is a complicated, global, social problem, for which the need for interdisciplinary research has been recognised (Hölker *et al.* 2010a; Lyytimäki *et al.* 2012; Lyytimäki 2013; Lyytimäki and Rinne 2013). Yet, marine turtles face numerous other significant and pervasive threats to their survival as a result of human activities. In addition to habitat degradation caused by coastal development - climate change, fisheries by-catch, and turtle harvest for meat and eggs are considered the major threats facing marine turtles in Australia (Department of the Environment 2014). Plastic pollution is also emerging as a significant threat to turtle survival in Australian waters (Schuyler *et al.* 2012; Schuyler *et al.* 2014). These pressures are all global in scope, and all stem from human behaviours considered undesirable from an environmental management perspective.

Crucial research focused on the social perceptions behind such human-induced environmental issues is increasing (e.g. Witherington and Frazer 2003; Davis *et al.* 2004; Campbell *et al.* 2007; Campbell *et al.* 2009; McDonald *et al.* 2009; Moore *et al.* 2010; Eagle *et al.* 2013; McDonald *et al.* 2014). However, effective threat management requires dialogue across disciplines, involving information on the scale of impact, biological and ecological implications of the threat, as well an understanding of relevant human responses (Kinzig 2001). Interdisciplinary assessments of environmental problems therefore, by necessity, require multiple studies to be conducted and synthesised (e.g. Nittrouer *et al.* 1991). Consequently, I support previous scholars in strongly advocating for better collaboration and communication between researchers and institutions (see Brewer 1999; Kinzig 2001; Campbell 2003; Skole 2004; Moser 2010b). Tackling environmental problems with an interdisciplinary approach will require a willingness to overcome potential disciplinary barriers, such as institutional traditions, funding bodies, and discipline-specific terminology (Brewer 1999; Moser 2010b), as well as increased acknowledgement of the value of interdisciplinary research and improved interdisciplinary training (Kinzig 2001). However, the potential benefits include informed and innovative solutions towards solving the critical and complex environmental issues facing the planet.

The PhD thesis is an ideal medium for tackling specific environmental issues with an interdisciplinary approach, because the thesis, defined as the 'scholarly analysis of a body of research' (Premaratne 2013, p.236), is typically comprised of multiple separate but related chapters (Davies and Rolfe 2009). PhD research also produces a significant proportion of all new scientific knowledge, whilst training and creating the next generation of researchers (Dowling *et al.* 2012). Increased undertaking of transdisciplinary PhD research projects would consequently fulfil the identified need for a greater number of adequately-trained individuals knowledgeable about interdisciplinary research methods (Moser 2010b). Therefore, increased student and academic focus on interdisciplinary studies during graduate training would be extremely valuable in the future.

Specific research suggestions

In terms of managing light pollution impacts on marine turtles, I identify the following as specific areas where future research effort would be valuable. Given the value of interdisciplinary research as discussed above, I suggest that the research avenues specified below should be integrated where possible, and involve all relevant stakeholders (including Government bodies, industry groups, community groups, non-governmental organisations and indigenous communities).

1. The broad scale threat assessments I presented in Chapters 2 and 3 are useful for management prioritisation, but given the coarse spatial scale of the data, it will be important to ground-truth the data by conducting on-the-ground assessments of the most light-exposed areas identified (e.g. Chapter 4). These local-scale assessments should include ecological assessments of lighting impacts, biologically-relevant measurements of artificial light levels (Pendoley *et al.* 2012), as well as identification of contributing light sources and relevant stakeholders, to permit targeted management responses. The satellite technology I used to collect the nighttime light data is continually improving, with recent sensor advances giving improved spatial resolution and increased light sensitivity compared to the satellite data used in this thesis (Hillger *et al.* 2013). Thus in time, the analyses I conducted would also benefit from replication using more up-to-date spatial night-light data.

2. Since light pollution impacts will increase and encroach on more nesting areas as coastal development increases, I recommend that increased research attention is directed towards determining the importance of topographic elevation cues in relation to brightness cues on nesting beaches. Limpus and Kamrowski (2013) provide evidence that low horizon elevation is the primary cue guiding marine turtles during sea-finding. However, this study would benefit from additional species-specific studies focused on the management utility of modifying beach horizon profiles in areas where marine turtles have a sea-finding problem, as well as research to assess adult female response to light pollution (both point source and skyglow) and horizon cues.

3. My assessment of flatback time of emergence from the nest warrants replication at other flatback rookeries, preferably taking account of nest thermal environment at each beach assessed (e.g. Glen *et al*. 2005; Glen *et al*. 2006). If emergence of flatback hatchlings at higher latitudes consistently peaks in the early hours of the morning, this would have implications for lighting management. For example, examination of light-use behaviours in my study community which was located close to a globally significant loggerhead turtle nesting beach (Chapters 5 and 6), demonstrated the need for community light reduction action because residents predominantly used light during peak local hatchling emergence (i.e. between 20:00 and 00:00 h) (Limpus 1985). However, all residential lights were reportedly extinguished by 01:00 h. Given that I found peak flatback hatchling emergence occurred in the early hours of the morning (Chapter 4), lighting management in residential developments located close to flatback nesting beaches in east Australia may not require the same level of stringency.

4. New research trialling hatchling response to advanced lighting technologies, specifically very narrow spectrum LED streetlight prototypes, is currently underway in Queensland, Australia by the State Government's Department of Environment and Heritage Protection (C. Limpus, personal communication). As these types of trials continue and lighting technologies continue to evolve, should lighting technologies be confirmed as 'turtle-friendly' for specific species and populations - future work should implement this lighting in the nesting regions I have identified as facing high light exposure.

5. In Chapters 5, 6, and 7, I found a lack of awareness of light as a serious environmental threat, despite recognition of the detrimental impacts of light for marine turtles. Given that excessive light at night is harmful for multiple species (Rich and Longcore 2006; Gaston and Bennie 2014), including humans (Davis *et al.* 2001; Stevens 2009; Lucas *et al.* 2014), I support the recent call for widespread and active outreach activities to better inform the

public, managers, and policy-makers about negative consequences of artificial lighting (Lyytimäki 2013). This will hopefully stimulate additional research focused on lighting impacts, which may facilitate public light reduction efforts (e.g. Chapters 5 and 6), and which is seemingly necessary to ensure adequate regulation to ensure effective light management in commercial and industrial developments (e.g. Chapter 7). Such research should include implementation of my recommended light reduction communications (Chapters 5 and 6) to determine their efficacy, as well as a determination of what constitutes 'best practice' for managing industrial lighting given that 'best practice' designations have proved valuable for promoting learning and innovation within industry (Bulkeley 2006). The contributions I made to theory, i.e. the refinements I proposed to the constraints on engagement framework (Figure 5.5) (adapted from Sutton and Tobin 2011) and the conceptual framework I developed to understand drivers behind successful light management in industry (Figure 7.1), would also benefit from replication and refinement. Together these theoretical contributions will help to advance our knowledge base, enabling more effective management of light-use behaviours in the multiple stakeholder groups who contribute to widespread use of light at night.

8.5 Concluding remarks

Artificial light at night has caused a global environmental change, significantly threatening the natural world. With continued population growth and increasing coastal development, negative impacts resulting from excessive lighting are likely to increase before recognition and effective management of lighting becomes widespread. My interdisciplinary thesis provides insights to improve management of lighting impacts for marine turtles, demonstrating the value of combining and synthesising several research methods for informing management of a complex environmental issue. This approach would be beneficial for understanding other global, pervasive threats impacting marine turtles, as well as tackling lighting impacts on other species as they become acknowledged.

The United Nations has proclaimed 2015 as the International Year of Light and Light-based Technologies (UN IYL), to celebrate the world-changing benefits we have gained as a result of artificial lighting (Kyba *et al.* 2014). Our ability to illuminate the night is a fundamental part of modern society, however this thesis adds to a growing number of studies which also recognise the value of darkness.

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Appendices

Appendix 1 Satellite data chosen for each year of analysis in Chapter 3, following expert opinion, for assessing temporal change in artificial light levels close to marine turtle nesting areas.

Year	Satellite data used
1992	F10
1993	F10
1994	F10
1995	F12
1996	F12
1997	F14
1998	F14
1999	F14
2000	F15
2001	F15
2002	F15
2003	F15
2004	F16
2005	F16
2006	F16
2007	F16
2008	F16
2009	F16
2010	F18

Appendix 2 Orientation indices of hatchlings released in arena assays at Peak and Curtis Island in 2012 and 2013 (Chapter 4).

	Peak Island arena				Curtis Island arena				
	North 2012	North 2013	South 2012	South 2013	North 2012	North 2013	South 2012	South 2013	Trough 2013
n	143	48	157	48	35	62	52	51	100
Direction of ocean	195	195	210	210	56	63	69	64	63
Mean exit bearing	200.2	216.5	218.8	226.3	84.2	119	62.5	93.6	299.5
Circular SD	16.8	23.8	14.1	9.9	47.6	56.1	29.9	30	56.4
r (angular dispersion: 0=uniform, 1=concentrated in one direction)	0.958	0.918	0.97	0.985	0.709	0.619	0.873	0.872	0.2 (after angle doubling: 0.616)
Rayleigh test	Z = 131, p < 0.001	Z = 40, p < 0.001	Z = 148, p < 0.001	Z = 47, p < 0.001	Z = 18, p < 0.001	Z = 24, p < 0.001	Z = 40, p < 0.001	Z = 39, p < 0.001	Z = 38, p < 0.001
Sig oriented?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
V test	u = 16.14, p < 0.001	u = 8.37, p < 0.001	u = 16.99, p < 0.001	u = 9.26, p < 0.001	u = 5.22, p < 0.001	u = 3.85, p < 0.001	u = 8.85, p < 0.001	u = 7.66, p < 0.001	u = -4.81, p = 1
Oriented toward ocean?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No

Appendix 3 One of three versions of the questionnaire distributed to Bargara residents (version: external lights) (Chapters 5 and 6).

How can we balance our use of artificial lights at night with effective sea turtle conservation?

The purpose of this questionnaire is to find out how you feel about reducing human use of light at night for sea turtle conservation purposes. There are no right or wrong answers. We need your honest opinions about your experiences, to help with future conservation efforts that don't discriminate against humans!

THE QUESTIONNAIRE WILL TAKE LESS THAN 15 MINUTES OF YOUR TIME.

First things first…..

1. How long have you been resident in Bargara? ________________________

2. How many people live in your residence? Adults: ________ Children: ________

3. At what time do you generally turn your household lights off on weeknights (Sun-Thurs)? ______________

4. At what time do you generally turn your household lights off on weekends (Fri-Sat)? ______________

5. Are you aware of the 'Cut the Glow to help Turtles Go' campaign? Yes / No

6. If you are aware of the campaign – how did you become aware? *(Tick all that apply)*

Posters/signs	☐	Visiting Mon Repos	☐	Community events	☐	Leaflets/flyers	☐
Radio/TV	☐	School activities	☐	Newspaper articles	☐	Stickers	☐

Other? (*Please specify*):____

We will begin by finding out what you think about possible disruptions to local turtles…
Please put an 'X' in the space where you think it fits best.

	Strength of opinion:		Neutral	
7.	**How much of an effect does human activity have on sea turtle mortality?**	No effect	____ : ____ : ____ : ____ : ____ : ____ : ____	Major effect
8.	**How much of a negative impact does artificial lighting have on local sea turtles?**	No impact	____ : ____ : ____ : ____ : ____ : ____ : ____	Major impact
9.	**How necessary is it to reduce human use of light in areas where sea turtles nest?**	Not necessary	____ : ____ : ____ : ____ : ____ : ____ : ____	Very necessary
10.	**How concerned are you about the effects of artificial light on local sea turtles?**	Not concerned	____ : ____ : ____ : ____ : ____ : ____ : ____	Very concerned

1

	Strength of opinion:					Neutral					
11.	**How interested are you in taking action to help reduce the impact of artificial light on local sea turtles?**	Not interested	___ :	___ :	___ :	___ :	___ :	___ :	___	Very interested
12.	**If the local sea turtle population declined, it would have serious consequences for me and my family**	Disagree	___ :	___ :	___ :	___ :	___ :	___ :	___	Agree

Since the 1970's the local population of loggerhead sea turtles has declined from approximately 3500 to 500 nesting females. One conservation effort put in place by the Queensland Parks and Wildlife Service to help protect the remaining turtles has been the 'Cut the Glow to help Turtles Go' campaign, started in 2008. Artificial lights can prevent female turtles from laying nests, and can disorient hatchling turtles by preventing them finding the ocean, so the aim of this campaign has been to help local communities reduce artificial light use at night because of the close proximity of sea turtle nesting beaches.

13. Since the campaign started in 2008, during the turtle nesting season (Nov-Mar) have you taken any deliberate action to help reduce the impact of light-glow on local sea turtles?

Yes / No

14. If you answered 'Yes' to Question 13, what action(s) have you taken to help reduce the impact of light-glow?

____
____
____

15. Which of the following two statements best describes the extent to which you are currently helping to reduce the impact of light-glow on local nesting turtles?

(a) I don't do as much as I would like to ☐ OR (b) I don't want to do more than I am already doing ☐

Please explain why you answered Question 15 in this way:

____
____
____

16.	**How likely are you to take action to reduce the amount of light-glow you produce for the remainder of this nesting season (until March)?**	Not likely	___ :	___ :	___ :	___ :	___ :	___ :	___	Very likely

The Queensland Parks and Wildlife Service believe that TURNING OFF EXTERIOR LIGHTS during the nesting season is an important action that community members can take to help reduce overall light glow

17. Since 2008, during the nesting season (Nov-Mar), have you TURNED OFF EXTERIOR LIGHTS <u>more than usual</u>?

Yes / No

18. If you answered YES to Question 17, please explain <u>WHY</u> you have turned your exterior lights off more than usual during the nesting season:____
____

2

19. **Since 2008, during the nesting season (Nov-Mar), how often have you TURNED OFF EXTERIOR LIGHTS?**	Never ___ : ___ : ___ : ___ : ___ : ___ : ___	Always

Now we would like to find out a little bit more detail about what you think about taking specific actions to reduce light-glow during the turtle nesting season. Some of the questions may appear similar, or obvious, but they are addressing slightly different things.

PLEASE ANSWER EVERY QUESTION, and READ EACH QUESTION CAREFULLY

20. I think turning off external lights more often than usual during the turtle nesting season is:

Bad	___ : ___ : ___ : ___ : ___ : ___ : ___	Good
Pleasant	___ : ___ : ___ : ___ : ___ : ___ : ___	Unpleasant
Unimportant	___ : ___ : ___ : ___ : ___ : ___ : ___	Important
Enjoyable	___ : ___ : ___ : ___ : ___ : ___ : ___	Not enjoyable

	Strength of opinion:		Neutral	
21	**I am confident I am capable of turning my external lights off more than usual during the turtle nesting season:**	False	___ : ___ : ___ : ___ : ___ : ___ : ___	True
22	**Most people like me would turn off external lights more often than usual during the nesting season:**	Disagree	___ : ___ : ___ : ___ : ___ : ___ : ___	Agree
23	**I feel a personal, moral obligation to turn my external lights off more than usual during the turtle nesting season:**	Disagree	___ : ___ : ___ : ___ : ___ : ___ : ___	Agree
24	**It would be wrong of me to NOT turn my external lights off more than usual during the turtle nesting season:**	Disagree	___ : ___ : ___ : ___ : ___ : ___ : ___	Agree
25	**The people in my life that I respect and admire think that I should turn off my external lights more often than usual during the turtle nesting season:**	False	___ : ___ : ___ : ___ : ___ : ___ : ___	True
26	**Whether or not I turn my external lights off more than usual during the turtle nesting season is completely up to me:**	Disagree	___ : ___ : ___ : ___ : ___ : ___ : ___	Agree
27	**<u>I intend</u> to turn off my external lights <u>more than usual</u> for the remainder of the turtle nesting season:**	Definitely not	___ : ___ : ___ : ___ : ___ : ___ : ___	Definitely

3

	Strength of opinion:		Neutral	
28	**For me, turning off my external lights more than usual during the turtle nesting season is:**	Difficult	___ : ___ : ___ : ___ : ___ : ___ : ___	Easy
29	**Most people whose opinions I value will turn off their external lights more often than usual during the turtle nesting season:**	Improbable	___ : ___ : ___ : ___ : ___ : ___ : ___	Probable
30	**I am willing to turn off my external lights more than usual for the remainder of the turtle nesting season:**	False	___ : ___ : ___ : ___ : ___ : ___ : ___	True
31	**Most people who are important to me think that I should turn off my external lights more often than usual during the turtle nesting season:**	False	___ : ___ : ___ : ___ : ___ : ___ : ___	True
32	**I will turn off my external lights more than usual for the remainder of the turtle nesting season:**	Unlikely	___ : ___ : ___ : ___ : ___ : ___ : ___	Likely
33	**I feel that I should turn my external lights off more than usual during the turtle nesting season:**	Disagree	___ : ___ : ___ : ___ : ___ : ___ : ___	Agree
34	**Most people I respect and admire will turn off their external lights more often than usual during the turtle nesting season:**	Unlikely	___ : ___ : ___ : ___ : ___ : ___ : ___	Likely
35	**I plan to turn off my external lights more than usual for the remainder of the turtle nesting season:**	Disagree	___ : ___ : ___ : ___ : ___ : ___ : ___	Agree
36	**Increased protection for local turtles is:**	Bad	___ : ___ : ___ : ___ : ___ : ___ : ___	Good
37	**If I turn off my external lights more than usual during the nesting season, local turtles will have increased protection:**	Unlikely	___ : ___ : ___ : ___ : ___ : ___ : ___	Likely
38	**Benefiting the local economy is:**	Bad	___ : ___ : ___ : ___ : ___ : ___ : ___	Good
39	**If I turn off my external lights more than usual during the nesting season, it will benefit the local economy:**	Unlikely	___ : ___ : ___ : ___ : ___ : ___ : ___	Likely
40	**I am able to visit local beaches to see nesting turtles during the nesting season:**	False	___ : ___ : ___ : ___ : ___ : ___ : ___	True

4

	Strength of opinion:	Neutral		
41	**Observing local nesting turtles would make it easier for me to turn my external lights off more than usual during the nesting season:**	Disagree	___ : ___ : ___ : ___ : ___ : ___ : ___	Agree
42	**Other people in this community turn their external lights off more than usual during the turtle nesting season:**	False	___ : ___ : ___ : ___ : ___ : ___ : ___	True
43	**Knowing that other people are taking action would make it easier for me to turn my external lights off more than usual during the turtle nesting season:**	Disagree	___ : ___ : ___ : ___ : ___ : ___ : ___	Agree
44	**Other local residents think that I should turn off my external lights more than usual during the turtle nesting season:**	Improbable	___ : ___ : ___ : ___ : ___ : ___ : ___	Probable
45	**Doing what other local residents think I should do is important to me:**	Disagree	___ : ___ : ___ : ___ : ___ : ___ : ___	Agree
46	**Legislation (regulations with penalties for non-compliance) exists to ensure external lights are turned off more than usual during the nesting season:**	False	___ : ___ : ___ : ___ : ___ : ___ : ___	True
47	**Legislation to ensure external lights are turned off more than usual during the nesting season, would make it easier for me to turn my external lights off more than usual during the nesting season:**	Disagree	___ : ___ : ___ : ___ : ___ : ___ : ___	Agree
48	**My saving money is:**	Bad	___ : ___ : ___ : ___ : ___ : ___ : ___	Good
49	**If I turn off my external lights more than usual during the nesting season, I will save money:**	Unlikely	___ : ___ : ___ : ___ : ___ : ___ : ___	Likely
50	**Local businesses think that I should turn off my external lights more than usual during the turtle nesting season:**	Improbable	___ : ___ : ___ : ___ : ___ : ___ : ___	Probable
51	**Doing what local businesses think I should do is important to me:**	Disagree	___ : ___ : ___ : ___ : ___ : ___ : ___	Agree
52	**Harming the local economy is:**	Bad	___ : ___ : ___ : ___ : ___ : ___ : ___	Good
53	**If I turn off my external lights more than usual during the nesting season, it will harm the local economy:**	Unlikely	___ : ___ : ___ : ___ : ___ : ___ : ___	Likely

5

	Strength of opinion:	Neutral	
54	Increases in crime are:	Bad ___ : ___ : ___ : ___ : ___ : ___ : ___	Good
55	If I turn off my external lights more than usual during the nesting season, crime will increase:	Unlikely ___ : ___ : ___ : ___ : ___ : ___ : ___	Likely
56	The Mon Repos rangers think that I should turn off my external lights more than usual during the turtle nesting season:	Improbable ___ : ___ : ___ : ___ : ___ : ___ : ___	Probable
57	Doing what the Mon Repos rangers think I should do is important to me:	Disagree ___ : ___ : ___ : ___ : ___ : ___ : ___	Agree
58	Increases in accidents are:	Bad ___ : ___ : ___ : ___ : ___ : ___ : ___	Good
59	If I turn off my external lights more than usual during the nesting season, accidents will increase:	Unlikely ___ : ___ : ___ : ___ : ___ : ___ : ___	Likely

60. I think the following light producers generate enough light at night to potentially affect local turtles:

All residential properties in the town	Disagree	___ : ___ : ___ : ___ : ___ : ___ : ___	Agree
Properties located along the beachfront	Disagree	___ : ___ : ___ : ___ : ___ : ___ : ___	Agree
Properties located more than two streets back from the beachfront	Disagree	___ : ___ : ___ : ___ : ___ : ___ : ___	Agree
Bars/Restaurants/Takeaways	Disagree	___ : ___ : ___ : ___ : ___ : ___ : ___	Agree
The local Bowls Club	Disagree	___ : ___ : ___ : ___ : ___ : ___ : ___	Agree
Shops	Disagree	___ : ___ : ___ : ___ : ___ : ___ : ___	Agree
Local street lighting	Disagree	___ : ___ : ___ : ___ : ___ : ___ : ___	Agree
Other: *(please specify)* _______________	Disagree	___ : ___ : ___ : ___ : ___ : ___ : ___	Agree

6

Finally we would like to know a little bit about you:

61. **Have you ever visited Mon Repos or other beaches to observe turtles during the nesting season?** Yes / No

    If yes, how many times? ________________________

62. **Do you/have you ever volunteer(ed) with turtles at Mon Repos?** Yes / No

    If yes, how many times? *(number of seasons)* ________________________

How old are you? __________

Are you: male / female

What is your occupation? ____

Which best describes the highest level of education you have completed? *(please circle one)*

Primary/Some Secondary / Completed Secondary / Completed Tertiary

Is there anything you would like to add?

Thank you for your time!!!

If you would like more information about this research please contact:

Ruth Kamrowski: 0488 535 923
ruth.kamrowski@my.jcu.edu.au

Appendix 4 Bargara resident interview recruitment information sheet (Chapter 6).

Tourism Queensland

How can we balance our use of artificial lights at night with effective sea turtle conservation?

Artificial light at night is extremely important for modern Western society, but these lights can also disrupt other organisms by interfering with natural behaviours.

Marine turtles are particularly susceptible to disruption from artificial lights close to nesting beaches, because of the importance of natural light cues in guiding their orientation behaviours.

www.webdesignerdepot.com

mrssmithworldphotography.com

What are we doing?

We want to find out how and why light is important to you. This is necessary to get the balance right between our needs and turtle needs.

Why are we doing it?

Turtles are pre-programmed to respond to light. They cannot change their reaction, so it is up to us to help reduce the effects of artificial light. However we understand that humans need light too! This research will allow the needs and concerns of all interested parties to be incorporated into the future management of artificial lighting close to marine turtle nesting beaches.

Interested?

If you would like to be interviewed as part of this project, please contact:
Ruth Kamrowski: 0488 535 923
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JAMES COOK UNIVERSITY
AUSTRALIA

Appendix 5 Frequency of the beliefs reported during the elicitation survey (Chapter 6), which were retained for further analysis following procedures detailed in Ham *et al*. (2008).

Type of belief	Elicitation questions	Response category	Response frequency: n (%)
Positive behavioural belief	1. What do you see as the advantages or good things that could result if you follow the Cut the Glow' campaign recommendations? 2. What is positive about the campaign? 3. What are the positives that would happen if everyone did follow the campaign?	It would protect the local turtles	19 (83%)
		It would be good for the local economy	5 (22%)
		Save money	6 (26%)
Negative behavioural belief	1. What do you see as the disadvantages or bad things that could result if you follow the Cut the Glow' campaign recommendations? 2. What is negative about the campaign? 3. What are the negatives that would happen if everyone did follow the campaign?	It would be bad for the local economy	5 (22%)
		Security concerns/increased crime	6 (26%)
		Safety concerns/increase in accidents	2 (9%)
Positive normative belief	1. Who (individuals or groups whose opinions you consider personally influential) do you think would support or approve if you reduced light during the nesting season?	Residents	3 (13%)
		Local businesses	3 (13%)
		Rangers/Park staff/DERM	4 (17%)
Positive control belief	1. What factors or circumstances enable or make it easy for you to follow the campaign recommendations? 2. What would help you to carry out the campaign steps?	More experience with turtles	3 (13%)
		Availability of correct lights	5 (22%)
		If I knew other people were following the campaign	2 (9%)
		Legislation	4 (17%)
Negative control belief	1. What factors or circumstances make it difficult for you to follow the campaign recommendations? 2. What would stop you from carrying out the campaign steps?	Cost	3 (13%)

Appendix 6 Descriptive statistics and internal reliability of direct and indirect measures of Theory of Planned Behaviour variables in Chapter 6. Indirect measures were scored in both a unipolar (1 to 7) (uni-bi) and bipolar (-3 to +3) (bi-bi) fashion. Following Ajzen (2002), the scoring scheme in which indirect and direct measures of each construct were most strongly correlated (shown in bold) was used in subsequent analyses.

Behaviour	Construct	n	Cronbach's alpha	Individual item scores	Mean (SD)	Correlation to indirect ([1]uni-bi [2]bi-bi)	Correlation to intention (*: p<.01; ^: p<.05)
'External lights'	Direct Attitude	96	0.738	Evaluation	6.61 (0.79)		0.515*
				Experiential	5.74 (1.44)		0.444*
				Instrumental	6.45 (0.98)		0.578*
				Experiential	5.53 (1.39)		0.431*
				Overall	6.08 (1.27)	10.398* 20.444*	0.568*
	Indirect Attitude	112	NA	Uni-bi (range: -126 to +126)	32.08 (20) weak +ve	NA	0.545*
				Bi-Bi (range: -54 to +54)	**30.51 (15.6)**	**NA**	**0.560***
	Direct Norm	117	0.815	Descriptive	5.46 (1.70)		0.494*
				Descriptive	5.55 (1.63)		0.559*
				Descriptive	5.55 (1.60)		0.489*
				Injunctive	5.00 (1.91)		0.500*
				Injunctive	4.89 (2.02)		0.362*
				Overall Norm	5.29	10.389*	0.552*

					(1.79)	20.240^	
	Indirect Norm	112	NA	**Uni-bi (range: -63 to +63)**	**10.22 (24.2)**	**NA**	**0.238^**
				Bi-Bi (range: -27 to +27)	7.47 (9.6)	NA	0.031
	Direct PBC	117	0.38 (removing Controllability item, brings it to 0.81)	Controllability	5.48 (1.93)		0.091
				Self-efficacy	6.38 (1.13)		0619*
				Self-efficacy	6.37 (1.10)		0.580*
				Overall (without controllability)	6.38 (1.11)	[1]0.375* [2]0.353*	0.685*
	Indirect PBC	114	NA	**Uni-bi (range: -63 to +63)**	**16.31 (24.1)**	**NA**	**0.459***
				Bi-Bi (range: -27 to +27)	7.29 (9.4)	NA	0.278*
'Curtains & Blinds'	Direct Attitude	93	0.865	Evaluation	5.59 (1.31)		0.705*
				Experiential	4.82 (1.79)		0.487*
				Instrumental	5.66 (1.61)		0.765*
				Experiential	4.58 (1.72)		0.524*
				Overall	5.25 (1.71)	[1]0.597* [2]0.549*	0.701*
	Indirect Attitude	109	NA	**Uni-bi (range: -126 to +126)**	**19.29 (19.4)**	**NA**	**0.580***
				Bi-Bi (range: -54 to +54)	22.19 (15.4)	NA	0.615*

	Direct Norm	109	0.939	Descriptive	4.39 (1.89)		0.591*
				Descriptive	4.51 (1.87)		0.593*
				Descriptive	4.38 (1.96)		0.622*
				Injunctive	3.98 (2.05)		0.564*
				Injunctive	4.01 (1.98)		0.588*
				Overall Norm	4.25 (1.96)	[1]0.595* [2]0.120	0.652*
	Indirect Norm	108	NA	**Uni-bi (range:-63 to +63)**	**5.69 (20.8)**	**NA**	**0.438***
				Bi-Bi (range: -27 to +27)	7.69 (7.9)	NA	0.141
	Direct PBC	110	0.334 (removing Controllability item, brings it to 0.823)	Controllability	5.41 (1.87)		-0.129
				Self-efficacy	5.27 (2.01)		0.725*
				Self-efficacy	5.38 (2.05)		0.692*
				Overall (no controllability)	5.33 (2.03)	[1]0.345* [2]0.100	0.769*
	Indirect PBC	106	NA	**Uni-bi (range:-63 to +63)**	**6.61 (23.8)**	**NA**	**0.441***
				Bi-Bi (range: -27 to +27)	7.82 (7.6)	NA	0.114
'Motion Sensors'	Direct Attitude	93	0.726	Evaluation	6.29 (1.24)		0.303*
				Experiential	5.55 (1.57)		0.312*
				Instrumental	6.22 (1.17)		0.327*
				Experiential	5.37 (1.54)		0.234^

				Overall	5.85 (1.44)	[1]0.422* [2]0.459*	0.316*
	Indirect Attitude	109	NA	Uni-bi (range: -126 to +126)	26.2 (20.4)	NA	0.553*
				Bi-Bi **(range: -54 to +54)**	**26.7** **(18.4)**	**NA**	**0.539***
	Direct Norm	104	0.916	Descriptive	4.74 (1.88)		0.515*
				Descriptive	4.37 (1.83)		0.589*
				Descriptive	4.19 (1.76)		0.724*
				Injunctive	4.13 (2.04)		0.620*
				Injunctive	4.12 (1.86)		0.598*
				Overall Norm	4.31 (1.88)	[1]0.320* [2]0.105	0.688*
	Indirect Norm	107	NA	**Uni-bi** **(range: -63 to +63)**	**2.69** **(20.1)**	**NA**	**0.372***
				Bi-Bi (range: -27 to +27)	5.46 (8.1)	NA	0.186
	Direct PBC	106	0.529 (removing Controllability item, brings it to 0.834)	Controllability	5.53 (1.80)		0.147
				Self-efficacy	5.73 (1.86)		0.656*
				Self-efficacy	5.30 (1.87)		0.783*
				Overall (no controllability)	5.51 (1.87)	[1]0.243^ [2]0.321*	0.816*
	Indirect PBC	106	NA	Uni-bi (range: -105 to +105)	7.27 (35.9)	NA	0.365*
				Bi-Bi **(range: -45 to +45)**	**9.86** **(14.6)**	**NA**	**0.389***

Appendix 7 Salient community beliefs about light reduction in Chapter 6, which did not significantly differ in strength between compliers (C) and non-compliers (NC).

Type of belief	Belief	Specific behaviour	Mean belief strength		Mean evaluation		Mean cross product		Difference between C and NC
			C	NC	C	NC	C	NC	
Behavioural	Saving money	‘External lights’	1.95	1.89	2.43	2.47	5.41	5.06	0.35
		‘Curtains and blinds’	3.16	2.4	2.1	1.77	6.77	4.02	2.75
	Harming the local economy	‘External lights’	-1.67	-2.09	-2.28	-2.23	4.04	5.4	-1.36
		‘Curtains and blinds’	1.94	2.02	-2.7	-2.1	-4.6	-3.66	-0.94
		‘Motion sensors’	-1.57	-1.89	-2.49	-2.23	4.28	4.48	-0.2
	Increased crime	‘External lights’	-1.41	-1.14	-2.7	-2.37	4.04	2.86	-1.18
		‘Curtains & blinds’	1.72	1.95	-2.57	-2.6	-4.26	-4.71	-0.45
		‘Motion sensors’	-2.18	-2.02	-2.57	-2.6	6.04	5.52	0.52
	Increased accidents	‘External lights’	-2.05	-1.71	-2.65	-2.46	5.57	4.49	-1.08
		‘Curtains & blinds’	1.59	1.56	-2.8	-2.5	-3.68	-3.43	-0.25
		‘Motion sensors’	-2.42	-2.16	-2.56	-2.56	6.46	5.92	0.54
Normative	Other residents	‘External lights’	4.6	4.43	0.03	0.09	1.37	2.94	-1.57
		‘Motion sensors’	4.62	3.35	-0.32	-0.78	-0.19	-2.27	2.08
	Local businesses	‘External lights’	4.37	4.11	-0.36	-0.43	0.36	0.83	-0.47
		‘Motion sensors’	4.91	3.52	-0.64	-1.23	-2.28	-2.74	0.46
Control	Observing turtles	‘Curtains & blinds’	6.38	6.05	0.72	0.07	6.20	1.44	4.76
	Other peoples actions	‘External lights’	4.58	4.35	0.99	0.97	5.91	5.32	0.59
		‘Motion sensors’	0.91	0.05	0.43	-0.38	0.87	-0.05	0.92
	Legislation	‘External lights’	3.03	3.74	-0.05	0.37	1.13	3.34	-2.21
		‘Curtains & blinds’	2.82	2.05	-0.37	-1.32	1.38	-0.66	2.04
	Cost money	‘Motion sensors’	-1.67	-0.2	-2	-0.52	5.29	3.75	1.54

Appendix 8 Interview guide and core questions for interviews with experts regarding the lighting management of the Gorgon Gas Development, Western Australia (Chapter 7).

Lighting management at Gorgon:

- Can you describe the artificial lighting used at Gorgon?
- Has light-use been reduced at Gorgon as much as is possible? How?
- How is light generally used in oil and gas plants? How does the lighting at Gorgon compare?
- Has Chevron gone further in terms of light mitigation actions than other oil/gas companies in the region?

Drivers:

- Why have the lighting actions been taken?
- Have the light mitigation measures put in place at Gorgon been transferred to other plants run by Chevron? Why/why not?
- How do the ministerial commitments related to lighting at the Gorgon site compare to other oil and gas installations in the region?
- How flexible are the regulatory requirements/ministerial conditions?
- Have any of the light mitigation actions taken by Chevron at the Gorgon site, gone beyond what might be expected? Why do you think that is?

Turtles:

- Have there been any impacts from lights on the turtles?
- In terms of determining impacts to turtles from artificial light, what parameters are being measured / documented?
- How confident can we be about how lights from Gorgon are affecting / not affecting turtles?
- What else (if anything) needs to be done to mitigate effects of Gorgon light on local turtles?

Perceptions regarding the lighting management:

- How successful would you say the lighting management has been?
- How much of that potential success is due to the strict regulatory requirements?
- How do you feel about the lighting management?
- In your opinion, what (if any) have been the advantages/benefits of the actions taken to mitigate light at Gorgon?
- What do you think have been the disadvantages/costs of the light management?
- Over the life of the project, are you aware of any calculations or projections made as to whether actions taken to mitigate light will incur a financial cost or saving?
- Do you think the advantages have outweighed the disadvantages or vice versa?
- How does the environmental management of Barrow Island compare to other industrial involvement you have had?
- How would you describe the relationship between Chevron and the environment?

Appendix 9 Coding theme summary employed during analysis of interview transcripts in Chapter 7.

- Success
  - Turtles
    - Benefits to turtles, impacts to turtles, unknowns/confidence, timescales
  - Compliance
    - Meeting commitments, unknowns/confidence, timescales
  - Perceptions of lighting
    - Light reduction: benefits and costs, view of light as a pollutant, education, team effort

- Drivers behind successful lighting management
  - Culture
    - History, timescales, environmental importance, pride
  - Moral responsibility
    - Pride, 'the right thing to do', environmental importance, turtle importance, values
  - External pressures
    - Public perception, opposition, environmental importance, turtle importance, values, reputation
  - Importance of Individuals
    - view of light as a pollutant, team effort, values, pride, environmental importance
  - Proponent ethos
    - reputation, values , pride, environmental importance, turtle importance, safety
  - Increased business opportunities
    - Profitability, costs, new business, environmental performance, reputation, environmental importance
  - Regulation
    - Responsibility, flexibility, innovation, emergent issue, Wheatstone, view of light as a pollutant, compliance, unknowns/confidence

Appendix 10 Summary of compliance with light mitigation commitments established at Barrow Island for the Gorgon project in 2010, 2011 and 2013[16] (Chapter 7). Evidence sources included where possible.

Relevant commitment	Year	Level of compliance with specific commitment (this does not represent compliance or non-compliance with the marine turtle management plan[17] as a whole)
Specify design features, management measures and operating controls to manage, and where practicable, avoid adverse impacts to marine turtles, with specific reference to reducing light and noise emissions as far as practicable	2010	Satisfactory during this period
	2011	Compliant
	2013	Compliant - Long-term Marine Turtle Management Plan Revision 0 (G1-NT-PLNX0000296) - Submission letter from Chevron Australia to the Minister for Environment, dated 4 September 2009 (G1-CO-LTR-CVXPH-MEYPH-0000005) - Approval letter from the Minister for Environment, dated 10 September 2009 (G1-CO-LTR-MEYPH- CVXPH-0000005)
Annually audit and review the effectiveness of lighting design features, management measures and operating controls and if reasonably practicable, propose and implement improvements to any of those lighting design features, management measures or operating controls	2010	Satisfactory at this stage - Review of Effectiveness of Lighting Design Features, Management Measures and Operating Controls dated August 2010 (G1NT-REPX0003220)
	2011	Compliant - Review of Effectiveness of Lighting Design Features, Management Measures and Operating Controls dated August 2011 (G1NT-REPX0004020)
	2013	Compliant - Review of Effectiveness of Lighting Design Features, Management Measures and Operating Controls dated, 11 October 2012 (G1-NT-REPX0004958)
Proponent shall implement the long term marine turtle management plan	2010	Compliant (in terms of lighting commitments)
	2011	Non-compliant • Two yellow fluorescent lights mounted above the chemical dosing facility at the Reverse Osmosis Plant were not shielded and were visible from Bivalve beach. Corrective actions taken: • Action 1: Operation of the facility to cease in July 2011 and demobilisation of the facility to commence in August 2011

[16] Gorgon Gas Development: Ministerial Implementation Statement No. 800 Compliance Report 2010/2011/2013 and Gorgon Gas Development: Ministerial Implementation Statement EPBC Reference: 2003/1294 (as amended) and EPBC Reference: 2008/4178 Compliance Report 2010/2011/2013

[17] Chevron Australia (2009) *Gorgon Gas Development and Jansz Feed Gas Pipeline Long-term Marine Turtle Management Plan*, Document No: G1-NT-PLNX0000296. Chevron Australia Pty Ltd.

		(Completed) • Action 2: Site environment team to conduct site demobilisation inspections in September 2011 to confirm that all machinery and equipment (including lighting) associated with the Town Point Reverse Osmosis plant have been removed (Completed) - Letter from Chevron Australia to the General Manager OEPA dated 12 September 2011 (G1-CO-LTR-CVXPHEPAPH-0000068)
	2013	Non-compliant • Revision 1 of the Long-term Marine Turtle Management Plan requires light screening techniques to be implemented. During the night lighting inspection, three of 12 lighting towers sighted at Chicago Bridge and Iron (CBI) worksite required adjustment to direct the light downwards and one of 12 lighting towers required adjustment to direct the light away from a reflective surface. The Night Works Plan did not outline the requirement to conduct an inspection of the lighting towers at dusk, or to document this inspection. • Revision 1 of the Long-term Marine Turtle Management Plan requires an Artificial Lighting Management Procedure to be developed and included in Contractor management plans, where relevant. The Lighting Management Plans for two of 11 vessels for the Domestic Gas Pipeline installation fleet had not been approved for 'work to proceed' (Code 1) at the time of the audit. Corrective actions taken: • Action 1: Review existing processes to include documenting nightly light inspections. (Completed) • Action 2: Review the Lighting Management Plans (LMPs) of the two *identified contract companies* and issue reviewed LMPs to the Contractor to ensure the LMPs are resubmitted for approval. (Completed)

Appendix 11 Summary of respondent quotes pertaining to positive and negative evaluations of the lighting mitigation program in place at Barrow Island (Chapter 7).

Perceived positives associated with the light mitigation program	Perceived negatives associated with the light mitigation program
• *Meeting commitments* “The conditions are centred around managing marine turtles and what it means for marine turtles…the key advantage for us is that we’re not seeing an effect on hatchling orientation. Nor are we seeing, an effect on adult nesting to date. The two life stages affected by lighting. Are we having an impact from lighting? The answer at the moment – no. “That gives [us] comfort … in that we’re doing the right thing. It gives senior management in Chevron the level of comfort that what’s being done for lighting is the right approach” “There’s an offsets program that considers if we are having an impact to the turtles then a certain amount of money has been put aside to manage those impacts. So you could argue, we don’t need to look at using that money” • *Reputation and business benefits* “Gorgon is probably the best example, certainly within Chevron, and probably in industry, of how good environmental performance creates business opportunities. Chevron will undoubtedly use Gorgon as a way of demonstrating that we are a company that has strong environmental credentials, can be trusted, and if we say something, we will do it.” • *Better for the environment* “it has made people more aware, it definitely has its advantages energy-wise as well” “Artificial light does actually upset the … you know bats and birds. And there would be a huge energy saving. So here I think it’s good” • *More pleasant work environment* “It is peaceful onsite at night. It is nice not having lights blaring everywhere” “I think it is better practice and … a lot of lighting is just over the top and not necessary”	• *Financial* “There’s been a cost … implementing lighting, everything costs money in terms of a build. What that cost is, I don’t know” “[It’s] probably a little bit more expensive… all the light towers. For example, when you go out at night, you’ll see they're all sodium. The standard if you go on the mainland, they're all metal halide or bright white. They’ve [also] all got shutters on them, and they get moved every time the work phase moves. [They get] reposition[ed], or re-orientated. So there is a significant cost from that side of it.” • *Effort* “you wouldn’t propose [this project on Barrow Island] unless it was, you know, really the only place that you can do it. There's no doubt that quarantine, turtles, CO_2 management, land clearing, you know, our footprint. All those things are significant controls on this project” • *The need for workforce education* “The complexity is that you’ve got an itinerant workforce at the moment. They’ll be there for a month, a few months, and then they leave. So you get fresh people come on board all the time. There’s always a turn-over that we have to manage as well” “some people are a bit challenged early on, to understand why we’ve got so low lights, but … one of the things that we do, is…a lot of [workforce] education” • *Inefficiency* “I think it probably does increase a degree of… inefficiency at the workface. There are a lot of lighting controls and so it is a specific workface that is lit up, rather than general lighting. So that often has to change … on a nightly basis, depending on where people work.”

"I love it out there. It's nice and dark. It's beautiful." "I think some places they overdo the lighting. Obviously they've got to have some lighting for safety, but in general at night, if there's no one there, I don't see the point of having [light] there" "I wouldn't want to [work at] a site that was lit up like a Christmas tree, just for the sake of putting the lights on" • *Allows for better observations/experiences with nature* "The star-gazing's awesome and a lot of people comment on the stars" "I see more [animals] out where there's no lighting" "you can definitely see the stars very well" • *Turtles* "Well in terms of outcomes, you'd have to say the data's been successful, it doesn't appear to show any effects on orientation at this point." • *Provides an example for other projects* "[It's] something we can point to: 'this is what we consider best practice, and [it] has been successfully implemented'. An issue that always comes up when you try to suggest new things is, 'oh it's too hard, we can't do it, it's too costly' so, it certainly helps when we can point to this." [Researcher: 'if a comparable project was proposed would it make it easier to impose conditions?'] "Oh without doubt. Yep."	• *Implementation issues* "Sometimes out the front of some sheds, there're issues between day and night shifters as to whether they leave the lights on for us, but that's probably been the only real issue" "It is tricky cos some of these [lighting] commitments, have been written without knowing really what it is gonna be like….. And some of them are not practical so we've slowly had to try and work out ways to make that practical" • *Uneven responsibilities* "What definitely upsets people is that our facilities are so dull and dark, it really is like UFO-style dark lighting, and then you have the marine side with gigantic lights, or TEES, out on the LNG plant with gigantic lights. That annoys people a lot. Especially when [our lights are] not even near the beach and there isn't much chance of glow. It's kind of a pain in the arse then." "We got a bit antsy for a while there when they were coming down hard on us for something – the light was left on at the old airport, and you look at the MOF and look back at Barrow Island, and its lit up like a Christmas Tree, and you're thinking 'you can't even see the sea from our…[area]'. So it seems to be [uneven]" • *Negative influence on new proposals* "When we're talking to other proponents about issues…a common response is 'look what's happening at Barrow and you're giving us a hard time about this" • *Implementation difficulties* "I guess the frustrating thing from our point of view, we were on the island, I was up there in the very early days, um it did take a long time"