Sherry Du
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"Lights, Ocean, Action!": The Effects of Light Pollution on Sea Turtles' Nesting and Hatching Behaviours

A wise sea turtle once said, "Oh, it's awesome, Jellyman. The little dudes are just eggs, we leave 'em on a beach to hatch, and then, coo-coo-cachoo, they find their way back to the big ol' blue" (Fig. 1) (Stanton 2003). This quote, from *Finding Nemo*'s Crush, perfectly describes the general process of sea turtle nesting and hatching behaviours in coastal environments (Stanton 2003). To reiterate, female sea turtles lay their eggs on a beach and their hatched offspring will make the treacherous journey back to the water (Hirth 1980, Lutz et al. 2013). It seems quite simple, right? Yet, with the introduction of a new anthropogenic factor, the nesting and hatching behaviours of sea turtles no longer seem to be the same (Longcore and Rich 2004, Oliver de la Esperanza et al. 2017).

Background Information on Sea Turtles

What has four flippers and carries its own house? Sea turtles are large thick-skinned reptiles that reside in the tropics (Lutz et al. 2013). These ancient reptiles are comprised of seven different species; some examples include the leatherback sea turtle (*Dermochelys coriacea*), loggerhead sea turtle (*Caretta caretta*), and green sea turtle (*Chelonia mydas*) (Lutz et al. 2013). According to The IUCN Red List of Threatened Species, these species range from being vulnerable to critically endangered (Wallace et al. 2013, Wibbels and Bevan 2019). Characterized by their paddle-resembling forelimbs and sleek bodies, they have been able to migrate expansive distances across many oceans (Lutz et al. 2013). However, they are not strictly confined to aquatic environments (Hirth 1980, Lutz et al. 2013). Sea turtles can still be found in terrestrial environments during a particular time of year (Hirth 1980, Lutz et al. 2013).

During a warm summer night, female sea turtles emerge out of the water to find a perfect nesting spot on sandy beach shores (Hirth 1980). They prefer specific beaches over others due to differences in sand softness, lagoon presence, and much more (Kikukawa et al. 1999). The mother then kicks her rear-flippers to dig a nest for her eggs (Fig. 2) (Lutz et al. 2013). After laying her eggs, the mother crawls back into the ocean and allows the eggs to incubate in the hot sand (Lutz et al. 2013). Around 2 months later, baby turtles will hatch and follow the moon-reflected water to their new homes (Fig. 3) (Lutz et al. 2013). However, this nocturnal journey is not without any natural hazards. The hatchlings are a vital food source and may be snatched by seagulls, predatory fish, and much more (Butler et al. 2020). Clearly, the risk of predation during such a vulnerable stage may threaten the recruitment of sea turtles (Butler et al. 2020).

Speaking of food, the diet of sea turtles varies depending on the species and life stage (Lutz et al. 2013). For example, adult green sea turtles primarily munch on seagrass (Lutz et al. 2013, Pilcher et al. 2020). These primary consumers help maintain the health of seagrass beds by removing the aboveground biomass of seagrasses to stimulate their growth (Christianen et al. 2012). In contrast, leatherback sea turtles are gelatinivores, which means that they consume invertebrates like jellyfish (Davenport 2017). Leatherback sea turtles can eat approximately ¾ of their body mass in jellyfish if the prey is found in high densities (Heaslip et al. 2012, Fossette et al. 2012). They use their sharp beaks and reversed spikes in their mouth and throat to capitalize on this otherwise undesirable snack (Heaslip et al. 2012). Overall, sea turtles play a vital role in stabilizing food webs by maintaining predation pressures on unpalatable prey or overcrowded plants (Luschi et al. 2006, Heaslip et al. 2012, Lutz et al. 2013, Davenport 2017, Pilcher et al. 2020).

Lights as a New Anthropogenic Factor

Lights serve many useful purposes for humans. They brighten people's homes, enable increased vision while driving at night, beautify shop displays, and much more. It's clear that lights increase visibility or may solely be used for aesthetic reasons. Yet, increasing urbanization has fueled the need for lights at night (Rodríguez et al. 2020). As a result, lights have emerged as a major cause for concern (Longcore and Rich 2004, Hernández et al. 2007, Stone et al. 2015, Falchi et al. 2016, Pilcher et al. 2020).

Light pollution is a sensory pollutant caused by humans (Falchi et al. 2016). This pollution often affects organism behaviour, predator-prey interactions, and ecosystem processes (Stone et al. 2015, Falchi et al. 2016, Pilcher et al. 2020). One of the main sources of light pollution is artificial light at night (ALAN) (Falchi et al. 2016). ALAN can be emitted from street lamps, people's homes, or commercial light sources (Falchi et al. 2016). Light pollution occurs when light sources trespass their intended area (Fig. 4) (Drake 2019). If the light is not directed correctly, then it may cast unwanted glare, skywards light, reflected light, and skyglow (Drake 2019).

The effects of light pollution on sea turtles are well-studied (Longcore and Rich 2004, Hernández et al. 2007, Kamrowski et al. 2013, Silva et al. 2017). One prominent consequence is that lights disorientate hatchlings (Longcore and Rich 2004). Simply put, water reflects the glow of the moon. Hatchlings rely on these moonlight cues to direct themselves to the water and away from dark terrestrial areas (Longcore and Rich 2004, Kamrowski et al. 2013). However, instead of chasing the saltwater finish line, newly hatched sea turtles have started to dash towards glitzy neon signs or buildings (Kamrowski et al. 2013). An Australian study conducted by Kamrowski et al. (2013) found that light from industrial sites posed a significantly higher risk to sea turtles than light from other sites (Kamrowski et al. 2013). Likewise, predation risks may increase under ALAN as predators may be able to spot hatchlings more easily (Silva et al. 2017). It is evident that encroaching new urban developments along once secluded shores may attract hatchlings into oncoming traffic and increase susceptibility to predation (Kamrowski et al. 2013, Silva et al. 2017). Inevitably, light pollution could limit hatchling survival and recruitment (Kamrowski et al. 2013, Dimitriadis et al. 2018).

Light pollution also affects another life stage activity: sea turtle nesting (Kikukawa et al. 1999, Hernández et al. 2007, Kamrowski et al. 2013, Mazor et al. 2013, Silva et al. 2017). Through satellite-based imagery, Mazor et al. (2013) discovered that ALAN intensity was negatively correlated with the nesting activity of green and loggerhead sea turtles (Mazor et al. 2013). Similarly, Silva et al. (2017) found that loggerhead sea turtles preferred to nest on unlit beach areas instead of brightly lit areas in Boa Vista (Silva et al. 2017). In addition, the researchers also found that females had an increased nest search time and trouble finding their way back to the ocean (Silva et al. 2017). These two studies suggest that female sea turtles seem to be highly receptive to human disturbances, especially under yellow or orange lights (Mazor et al. 2013, Silva et al. 2017). As of right now, there are no clear explanations as to why sea turtles dislike nesting on lit beaches. However, Silva et al. (2017) hypothesized that illuminated beaches may deter females from nesting due to the turtle's increased ability to assess the risk of predation (Silva et al. 2017). All in all, light pollution may also inhibit population growth as the mothers may die of exhaustion in the search for a perfect nesting spot (Silva et al. 2017).

This issue is important because different sea turtles serve as keystone species in their respective ecosystems (Luschi et al. 2006). If a specific species is removed or depleted, it could potentially have detrimental consequences on marine biodiversity (Luschi et al. 2006). With the rise in warming annual temperatures, dissolved oxygen (DO) levels have started to decrease in many marine systems (Shoji et al. 2005). In a study conducted by Shoji et al. (2005), it has been suggested that moon jellyfish (*Aurelia aurita*) may outcompete other predators in low DO environments due to their low metabolic costs (Shoji et al. 2005). Unsurprisingly, moon jellyfish are preyed upon by leatherback sea turtles (Heaslip et al. 2012). Since light pollution may be hindering leatherback sea turtle recruitment by misguiding hatchlings away from the ocean or reducing nesting activity, the growing jellyfish population may remain unchecked (Luschi et al. 2006, Bourgeois et al. 2009). In turn, the populations of jellyfish prey or competitors may be depleted, which could lead to a food web collapse (Shoji et al. 2005, Luschi et al. 2006). This is just one of the many ecological complications that could occur. Therefore, we must provide measures to counteract light pollution on and near beaches before it is too late.

Solutions to Light Pollution

As lights are vital to humans, it may be hard to tell urban populations to discontinue using ALAN sources entirely. One way to mitigate light pollution would be to use shielded dim lights. A study found that sea turtle nests tend to be clustered in areas with lower light pollution (Vandersteen et al. 2020). This suggests that sea turtles may be able to handle light pollution at lower intensities (Vandersteen et al. 2020). Also, Bertolotti and Salmon (2005) demonstrated that road-embedded lights decreased disorientation of hatchlings in comparison to unshielded streetlamps (Fig. 5) (Bertolotti and Salmon 2005). Evidently, high or unshielded lights may increase skyglow or light trespass. As a result, using a combination of short, shielded lights with low wattage light bulbs may be a good compromise for both humans and sea turtles.

Furthermore, the colour of light also matters. White, yellow, and orange visible light appear to be the most detrimental to sea turtles and other organisms (Silva et al. 2017, Davies and Smyth 2018). However, red lights could potentially mitigate these issues (Fig. 6). Silva et al. (2017) revealed that orange and yellow lights had significant effects on predation risk, nesting behaviour, or disorientation in loggerhead sea turtles, while red lights did not (Silva et al. 2017). A similar study conducted by Robertson et al. (2016) also found that red lights were less disorientating to sea turtles than amber lights (Robertson et al. 2016). This suggests that longer wavelengths ($\geq$640 nm) in the visible light spectrum may be less disruptive (Robertson et al. 2016, Silva et al. 2017). Therefore, red light bulbs could potentially be used in designated sea turtle nesting sites where ALAN cannot be avoided (Silva et al. 2017). Red light sources have already been adopted as "turtle-friendly" by the Florida Fish and Wildlife Conservation Commission (FWC) (Florida Fish and Wildlife Conservation Commission 2018).

In summary, artificial light at night disrupts nesting behaviour, disorientates hatchlings, and increases predation risk (Kamrowski et al. 2013, Mazor et al. 2013, Silva et al. 2017). Other unintended ecological consequences could be decreased biodiversity since sea turtles are regarded as a keystone species in maintaining overgrowth of jellyfish and other marine organism populations (Shoji et al. 2005, Fossette et al. 2012). Since nesting and hatching are critical to population recruitment and sustainability, preventative measures such as red, shielded, dim lights should be implemented in coastal areas where sea turtle presence is prevalent. If we don't put an end to this issue, then many sea turtles won't be finding their way to the big ol' blue any time soon.

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APPENDIX

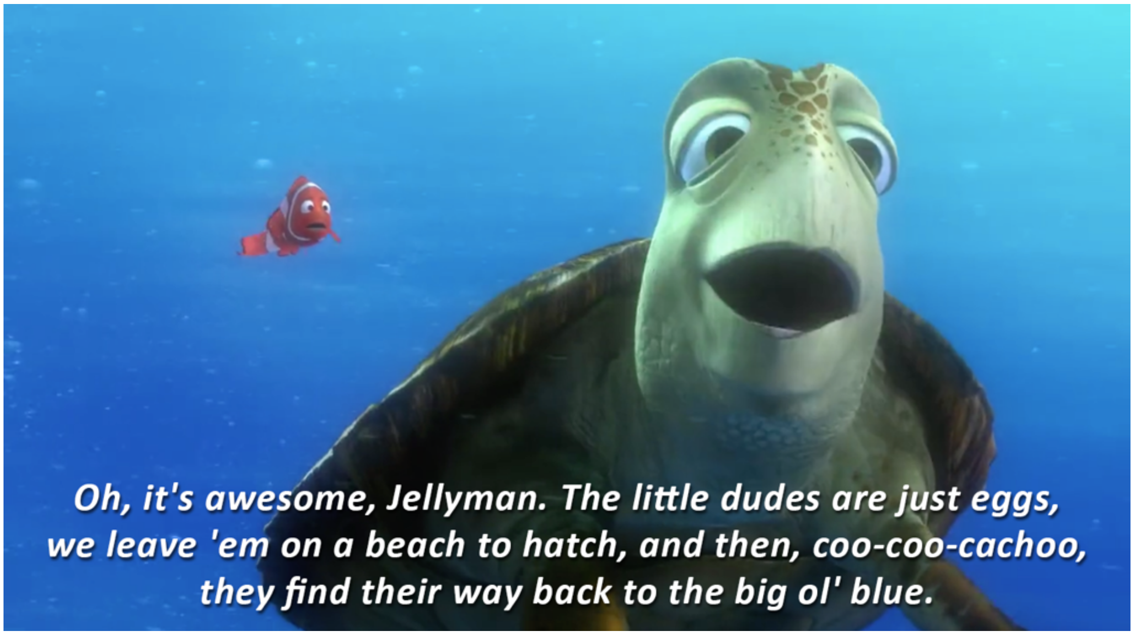

Figure 1. A screenshot from the 2003 animated film, *Finding Nemo*, by Andrew Stanton (Stanton 2003). The screenshot depicts Marlin, a clownfish, and Crush, a sea turtle, as they discuss the general process of sea turtle nesting and hatching (Stanton 2003).

Figure 2. A female leatherback sea turtle (*Dermochelys coriacea*) laying eggs on a beach (Waldstein 2020).

Figure 3. Baby leatherback sea turtles (*Dermochelys coriacea*) hatching out of their nests as they begin their crawl towards the ocean (Waldstein 2020).

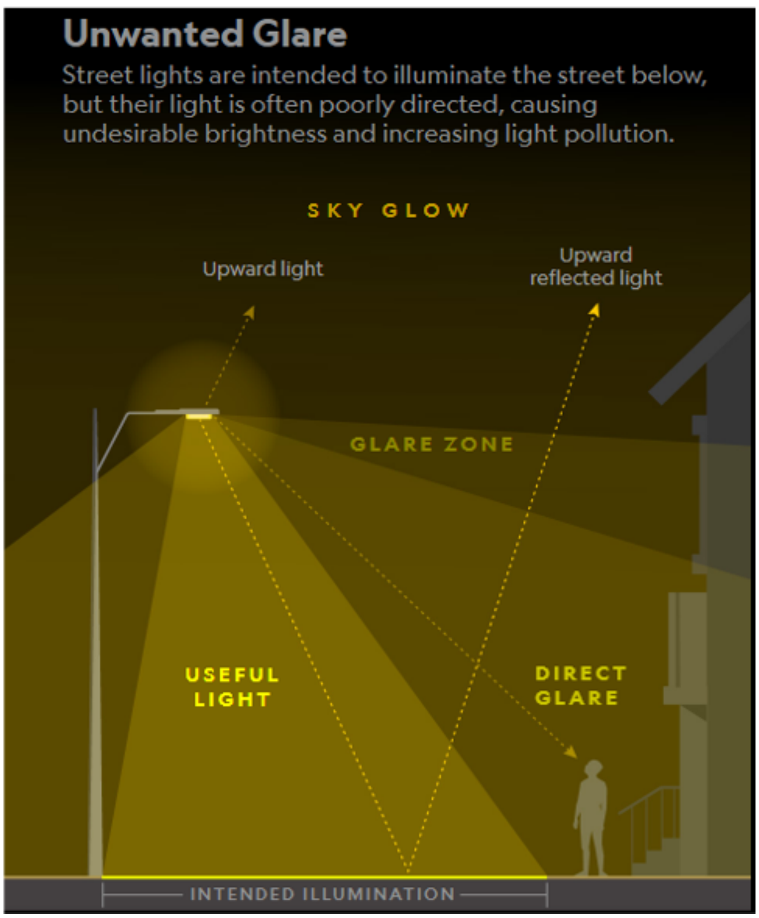

Figure 4. A graphical representation of the unintended consequences in relation to misdirected light (i.e., light pollution) (Drake 2019).

Figure 5. A comparison between unshielded streetlamps (top) and embedded road lights (bottom) from Bertolotti and Salmon (2005). Unshielded streetlamps cast a high amount of unnecessary light around a greater surface area. In addition, they also cast upwards light and contribute to sky glow. On the other hand, embedded road lights are low to the ground and cast enough light to dimly light areas where needed (Bertolotti and Salmon 2005).

Figure 6. An example of an appropriate turtle-friendly light source provided by the FWC (Florida Fish and Wildlife Conservation Commission 2018). The light is shielded, dim, and contains a red-light bulb.