Journal of Environmental Economics and Management 77 (2016) 95–116

Contents lists available at ScienceDirect

Journal of Environmental Economics and Management

journal homepage: www.elsevier.com/locate/jeem

Environmental pollution and biodiversity: Light pollution and sea turtles in the Caribbean

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ARTICLE INFO

Article history:
Received 19 May 2014
Available online 3 March 2016

JEL classification:
Q57

Keywords:
Biodiversity
Pollution
Sea turtles

ABSTRACT

We examine the impact of pollution on biodiversity by studying the effect of coastal light pollution on the sea turtle population in the Caribbean. To this end we assemble a panel data set of sea turtle nesting activity and satellite-derived measures of nighttime light. Controlling for the surveyor effort, the local economic infrastructure, and spatial spillovers, we find that nighttime light significantly reduces the number of sea turtle nests. According to data on replacement costs for sea turtles raised in captivity, our result suggests that the increase in lighting over the last two decades has resulted in the loss of close to 1800 sea turtles in the Caribbean, worth up to $288 million. Incorporating our empirical estimates into a stage-structured population model, we discover that the dynamic effect of nighttime light on future generations of sea turtles is likely to be much larger, with a cost of approximately $2.8 billion for Guadeloupe alone. More generally, our study provides a new approach to valuing the cost of environmental pollution associated with species extinction.

Introduction

Over the last few decades, coastal areas have witnessed considerable growth in economic activity (UNEP, 2008). Inevitably, such growth has also been accompanied by significant increases in environmental pollution that potentially threatens the rich biodiversity that is characteristic of the world's coastlines (Jackson et al., 2001; Myers and Worm, 2003). One important aspect of the biodiversity debate is the protection of species from extinction, since any disappearance of species will reduce biodiversity (Polasky et al., 2005). More recently, the impact of increased lighting on biodiversity because of local economic development has been the focus of attention (Navara and Nelson, 2012; Gaston et al., 2013; Kyba and Holker, 2013). While a number of studies have already demonstrated that some marine species are particularly sensitive to light pollution (Bustard, 1967; Witherington and Martin, 1996; Bird et al., 2004), the impact of rising coastal illumination has gone largely unexplored (Hill, 2006; Rich and Longcore, 2006; USC, 2008). In this study, we investigate how light pollution in Caribbean coastal areas may have affected the critically endangered sea turtle

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http://dx.doi.org/10.1016/j.jeem.2016.02.003

population (IUCN, 2001).[1] As Nicholas (2001) points out, light pollution in the Caribbean is already thought to be an important threat to the three indigenous turtle species. Hence, in this paper we provide a quantitative estimate of the impact of light pollution on Caribbean sea turtle populations in both the short and long term.

In the natural sciences, considerable attention is given to the preservation of biodiversity and species extinction. Economists are also concerned with similar issues but have tended to concentrate on the design and implementation of conservation policies subject to resource constraints. Examples of different studies on this broader topic include harvesting (Clarks, 1973; Costello et al., 2008), habitat change (Polasky et al., 2004; Hanley et al., 2009), and the general problem of measuring biodiversity (Solow et al., 1993; Weitzman, 1992, 1998). Important related research includes studies on natural capital and sustainability (see Helm and Hepburn, 2014, for a recent survey).[2] In terms of pollution more generally, Polasky et al. (2005), Spangenberg (2007), and UNEP (2012) emphasise the detrimental role that pollution may play in loss of biodiversity or species extinction. Indeed, pollution is widely recognised as one of the key threats to biodiversity.[3] Moreover, biodiversity conservation is often the subject of public discourse in response to major pollution incidences such as the Deepwater Horizon oil spill.[4] Polasky et al. (2005) argue that an understanding of how human actions impact biodiversity and how this relationship changes over time is a major remaining challenge for the economics of biodiversity.

A number of papers in the natural science literature note that the presence of nighttime light is likely to interfere with sea turtle behaviour in several ways. Artificial nighttime light tends to deter sea turtle adults from nesting (Raymond, 1984; Hirth and Samson, 1987; Witherington, 1992; Johnson et al., 1996). It also reduces the ability of sea turtle hatchlings to find their way from the beach where they hatch to the sea, thus resulting in higher mortality rates due to exhaustion, dehydration, and predation (Bustard, 1967; Tuxbury and Salmon, 2005; Lorne and Salmon, 2007). However, the quantitative effect of nighttime light on sea turtle nesting and population levels has not yet been investigated statistically or has been limited to case studies of particular beaches (Kaska et al., 2003; Witherington and Frazer, 2003). The only exception is the study by Mazor et al. (2013), who investigated the effects of satellite-measured nighttime light on sea turtle nesting in coastal areas of Israel. However, although their descriptive statistics suggest a negative correlation between nighttime light and nesting activity, the authors find that the relationship between nighttime light and nesting is positive according to regression analysis.[5] Importantly, however, they did not control for either surveyor effort or potential spatial spillovers between beaches. Moreover, they did not, as we do here, interpret their quantitative estimates in terms of either the short- or long-term impact.

Our paper contributes to the existing literature in a number of ways. First, we provide a quantitative assessment of how a potentially important type of pollution affects an endangered species. More specifically, we estimate the impact of nighttime light pollution on sea turtle populations in Guadeloupe by combining data for satellite-derived nighttime light images, the location of nesting sites, nesting activity, local economic activity, and surveyor effort. From a methodological perspective, we explicitly take into account the spatial effects of nighttime light pollution on sea turtle nesting in the context of a count data model. We then apply our estimates to a population model that enables us to capture the dynamic implications of nighttime light on the sea turtle population. To this end, we incorporate our estimates into a simulation of sea turtle population dynamics for Guadeloupe using a stage-structured population model first described by Crouse et al. (1987) and Crowder et al. (1994). Our approach follows Crowder et al. (1994), who investigated how turtle excluder devices in trawl fisheries affect the sea turtle population in the Southeastern United States. However, in contrast to Crowder et al. (1994), we estimate rather than assume the impact of our factor of interest on the population dynamics.

To briefly summarise our main findings, we show that after controlling for local economic activity and the effort made in nest counting in the econometric analysis, there is a significant negative impact of coastal nighttime light on the nesting activity of sea turtles in Guadeloupe. Other things being equal, we provide evidence that an increase of 1 unit in nighttime illumination reduces the number of nests by approximately 4. Extending our estimate of the marginal effect of nighttime light to the whole Caribbean, we benchmark against the cost of rearing sea turtles in captivity and find that the replacement cost for the nearly 1800 sea turtles estimated as lost due to greater nighttime illumination since 1992 may be as high as $288 million. With respect to the impact of nighttime illumination on future generations of sea turtles, we conclude from our calibrated population model for Guadeloupe that the fertility drop caused by photopollution appears to substantially accelerate the extinction of sea turtles. For hawksbill and green turtles, coastal nighttime light decreases the time to extinction from 164 and 154 years to 130 and 139 years, respectively. This impact is even greater for leatherback turtles, which, under current light conditions, would disappear in 514 years, but without

[1] In this paper we consider three different species of turtle. Of those, both the green turtle (*Chelonia mydas*) and the leatherback turtle (*Dermochelys coriacea*) were classified as endangered in 1996, while the hawksbill turtle (*Eretmochelys imbricata*) was listed as endangered in 1986 before being changed to critically endangered in 1996.

[2] As observed above, species extinction is a key component of the biodiversity debate (Solow et al., 1993). Mace (2014) notes that conservation biologists, nature conservationists, and wildlife managers care explicitly about endangered species and extinction. Moreover, Polasky et al. (2005) distinguish between two categories of biodiversity measures: measures based on relative abundance and measures based on joint dissimilarity. It is the latter category that tends to be most frequently used in the economic literature when there is a focus on extinction (Weitzman, 1992).

[3] See the Convention on biological diversity at http://www.cbd.int for details.

[4] The report of the Center for Biodiversity (April 2011) showed that more than 82,000 birds, 6,000 sea turtles, 26,000 marine mammals, and an unknown large number of fish and invertebrates may have been harmed by the oil spill and its aftermath.

[5] See Figure 3 and Tables 2 and 3 of their paper. It is noteworthy that in an earlier study, Aubrecht et al. (2010) also found a positive relationship between nighttime light intensity and sea turtle nesting activity in Florida from a simple plot of their data. However, as the authors argue, this counterintuitive finding may have been a result of legislation in the mid-1980s that imposed regulations on beachfront lighting for protection of sea turtles on beaches that were more brightly lit.