Biological Conservation 159 (2013) 127–136

Contents lists available at SciVerse ScienceDirect

Biological Conservation

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

An index of risk of co-occurrence between marine mammals and watercraft: Example of the Florida manatee

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ARTICLE INFO

Article history:
Received 14 July 2012
Received in revised form 22 October 2012
Accepted 27 October 2012
Available online 21 January 2013

Keywords:
Aerial surveys
Boats
Environmental/temporal covariates
Predictive models
Risk of collisions
Occupancy models

ABSTRACT

Collisions between wildlife and vehicles represent a large source of mortality for many species. To implement effective protection zones, it is important to identify areas in which wildlife–vehicle collisions are likely to occur. We used statistical models to derive an index of risk of co-occurrence between manatees and boats. Our statistical models were used to predict the distribution of both manatees and boats, while accounting for observer-specific detection probabilities. Models used aerial survey data and we found that both environmental and temporal covariates influenced manatee and boat distributions. Moreover, the probability of detecting manatees varied substantially with the weather and among observers. To our knowledge, this is the first time that manatee distribution is modeled as a function of key environmental and seasonal covariates, while accounting for imperfect detection of manatees. We computed an index of risk of co-occurrence by multiplying the probability of manatee occupancy by the expected boat density and occupancy to identify areas where manatee–boat collisions are likely to occur. This analytical framework emphasizes the importance of accounting for imperfect detection, and how modeling distribution of both organisms and vehicles as a function of key covariates can help improve predictions of risk of collisions. Risk of collision metrics can then be used in designing protection zones.

1. Introduction

Wildlife–vehicle collisions can have a large effect on animal populations. Car collisions for terrestrial species have been well documented (Forman and Alexander, 1998) and are a large source of mortality for many mammals (Allen and McCullough, 1976; Gunson and Clevenger, 2003; Hell et al., 2005), birds (Hell et al., 2005), reptiles (Langen et al., 2009), amphibians (Puky, 2006; Langen et al., 2009) and insects (Rao and Girish, 2007). Many large marine animals, such as manatees (Aipanjiguly et al., 2003; Calleson and Kipp Frohlich, 2007), dugongs (Maitland et al., 2006), North Atlantic right whales (Kraus, 1990; Ward-Geiger et al., 2005; Fonnesbeck et al., 2008; Vanderlaan et al., 2008) and some dolphins (Wells and Scott, 1997; Stone and Yoshinaga, 2000), as well as green turtles (Hazel et al., 2007), suffer from strikes from both commercial and recreational watercraft. In the case of the Florida manatee (*Trichechus manatus latirostris*), collisions with boats are a primary source of mortality (Runge et al., 2007).

Protected areas with prohibited access or restrictions on vehicular speed can reduce wildlife–vehicle collisions and decrease their impact on wild animal populations (Allen and McCullough, 1976; Calleson and Kipp Frohlich, 2007; Hazel et al., 2007). It has been suggested that for manatees, boat speed limits in high-use areas tend to reduce the risk of deadly collisions by providing the boat operator and the manatee more time to avoid the collision, and by reducing the severity of injuries when a collision does occur (Calleson and Kipp Frohlich, 2007). Management policies regulating vehicle accesses and speeds can be controversial (e.g., because of the burden imposed on boaters, Aipanjiguly et al., 2003); therefore, to most effectively determine where to create protection zones, it is important to identify areas where wildlife and vehicles are most likely to collide.

One approach to identify areas with the highest risk of collisions has been to develop statistical models that use covariates to predict the distribution of the species of interest, and determine the risk of co-occurrence with the observed distribution of vehicles. For example, Fonnesbeck et al. (2008) developed a predictive model for whale distribution and used shipping traffic to evaluate the

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http://dx.doi.org/10.1016/j.biocon.2012.10.031

risk of vessel strikes under alternative routes. Here, we extend this approach by developing models using covariates for both manatees and boats to predict their distribution and compute the risk of co-occurrence between them, with the ultimate goal of improving the design of protection zones for wildlife. There are several benefits to modeling distribution of manatees and boats, instead of simply plotting observed locations of both. Firstly, scientific hypotheses about the effect of environmental covariates or habitat characteristics can be evaluated. This information can then be used to better identify areas of high risk by linking them to specific risk factors (e.g., presence of seagrass, or other important habitat characteristics). Secondly, this approach can be helpful in making predictions about areas that have not been surveyed, and thus help prioritize survey areas.

We used sightings of Florida manatees recorded from aerial surveys flown in Collier County, Florida, USA, to construct an occupancy model (Royle and Kéry, 2007; Kéry, 2010). Similar surveys were conducted over the same area to record boat sightings and were used to construct abundance and occupancy models for boats (Martin et al., 2005; Kéry, 2010). We accounted for detection probability in the manatee occupancy model. Although survey designs that do not account for detection probability are cheaper, they can lead to an underestimation of the probability of occupancy and to spurious inference (Yoccoz et al., 2001; MacKenzie et al., 2002; Kéry, 2010).

Environmental features and conditions can play a large role in determining manatee distribution. Several studies (Axis-Arroyo et al., 1998; Jiménez, 2005; Olivera-Gómez and Mellink, 2005) have reported an effect of bathymetry on apparent occupancy (i.e., detection probability was not included) by manatees, and they indicated that manatees were more likely to be seen near seagrass, which is their main food resource. Axis-Arroyo et al. (1998) and Jiménez (2005) also found a positive relationship between manatee occupancy and water temperature. We quantified the effects of the environment by using environmental and temporal covariates in our manatee and boat models. We evaluated the influence of the environment on manatee and boat distribution, as well as its influence on manatee detection. We then calculated an index of risk of co-occurrence between manatees and boats to identify areas in which relative risk was high (Fonnesbeck et al., 2008; Vanderlaan et al., 2008). The information about risk of co-occurrence could ultimately be incorporated into a decision theoretical framework to help design manatee protection zones. Historically, manatee speed zones have been put in place with the expectation that it will likely be 10 years or more before the zones are re-evaluated. Therefore, in most cases, the establishment of speed zones can be viewed as a one time step decision process. Nevertheless, if zones need to be revised, our analytical framework would still be relevant but would likely require additional monitoring data.

2. Methods

2.1. Manatee distribution

2.1.1. Manatee aerial surveys

The Florida Fish and Wildlife Conservation Commission (FWC) conducted nine manatee aerial surveys (where GPS tracks were recorded) along the southwest coast of Collier County between July 2007 and May 2008 (Fig. 1). Flights were conducted from a high-winged Cessna 172 at an altitude of 250 m. Dual observers (two observers working independently to detect animals) recorded the location and the number of manatees they sighted within a 600-m distance from the right side of the aircraft (Pollock et al., 2006; Langtimm et al., 2011). In addition, information about survey conditions were recorded from the Automated Surface Observing Systems (ASOS) obtained from local airports. The plane followed a standardized path over the survey area, and a GPS was used to record the exact flight path. Data from nine of these surveys were used in the analyses because no GPS track was recorded for the other surveys. GPS tracks were necessary to rigorously evaluate the effects of key covariates on manatee distribution.

2.1.2. Manatee data analysis

Non-detection of the species of interest during a survey does not necessarily imply that the species is absent. An individual can go undetected by an observer because it is not available to be seen (e.g., a manatee resting on the bottom in turbid water); alternatively, an individual can be present and available to be detected by the observer, but for other reasons, is not observed (Pollock et al., 2006; Edwards et al., 2007; Fonnesbeck et al., 2009; Langtimm et al., 2011). Occupancy models can be used to estimate the probability of occurrence (ψ) of a species while accounting for detection probability (p) (MacKenzie et al., 2003, 2006). In the context of our study, ψ_{it} is the probability that site i is occupied by at least one manatee during survey t, whereas p_{it} is the probability that at least one manatee is detected at site i during survey t, given that it is present and available for detection. The input data to estimate ψ_{it} and p_{it} consist of vectors of 0s and 1s (or encounter histories) for each site, where 1 indicates that at least one manatee was detected and 0 indicates that no manatees were detected. If multiple visits are conducted, it is possible to simultaneously estimate ψ_{it} and p_{it}, in this case p_{it} also accounts for availability. The key assumption in estimating ψ_{it} and p_{it} is that the time between visits is sufficiently short to assume that the state of occupancy remains the same between visits (i.e., the site is assumed to be "closed"). Hereafter, we refer to these short visits as *passes*, and in our protocol the time between passes was less than 30 min. We also conducted multiple surveys at each site; the time between these surveys was more than 10 days (sites are not assumed to be "closed" among surveys). This protocol corresponds to a typical multiseason survey design (MacKenzie et al., 2006). Thus, repeat passes were used to estimate p_{it}, whereas repeat surveys were used to model ψ_{it} as a function of temporal covariates. Because this was a pilot study, there were not enough repeated passes to accurately estimate p_{it}; instead, we used observations from the first pass from both observers in lieu of observations from two different passes. This approach allowed us to estimate the probability of detection associated with each observer, given that manatees were available for detection. To create site encounter histories, we overlaid a grid (cell size, 1000 m $\times$ 1000 m) (Fig. 1) onto the survey area, defined each cell as a site, and assigned each cell a 1 if at least one manatee was detected by the observer at a site; otherwise 0 was assigned. For instance, for site i during survey t, the encounter history "01", meant that the first observer did not detect any manatees, and the second observer detected at least one manatee.

2.1.3. Manatee occupancy covariates

We modeled manatee occupancy as a function of key environmental covariates: bathymetry, distance to seagrass, distance to developed areas, and seasons.

Bathymetry is believed to influence manatee distribution (Axis-Arroyo et al., 1998; Jiménez, 2005; Olivera-Gómez and Mellink, 2005). Using a GIS (ESRI ArcGIS version 9.3.1.), we partitioned bathymetric data (NOAA National Geophysical Data Center, U.S. Coastal Relief Model; http://www.ngdc.noaa.gov/mgg/coastal/crm.html) into 1-m depth bin categories. The mean depth value of each category was used in our models; tidal fluctuation was not taken into account, which has the potential to fluctuate up to 1 m from high tide to low tide in Southwest Florida. The bathymetric data that we used generally correspond to mean lower low