Biological Conservation 227 (2018) 133–140

Contents lists available at ScienceDirect

Biological Conservation

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

One step ahead to predict potential poaching hotspots: Modeling occupancy and detectability of poachers in a neotropical rainforest

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ARTICLE INFO

Keywords:
Atlantic forest
Conservation measures
Game species
Illegal hunting
Species management

ABSTRACT

Poaching is a common threat to vertebrates even within protected areas, yet it is difficult to predict and prevent due to a lack of information on its spatial distribution. We apply occupancy modeling to produce a spatially-explicit diagnostic of potential poaching areas in a protected area of the Atlantic Forest biodiversity hotspot, in Brazil. We used camera trapping along a 13-month period (April 2013 to May 2014) on 39 sampling sites selected using a systematic random design stratified by vegetation type. Using a single-species, single-season occupancy model, we evaluated seven covariates that might influence occupancy and detectability, to identify and compare sites selected by poachers. A total of 7020 trap-days was conducted during the study. Occupancy by poachers was higher near water resources and forest edges. Detectability of poachers was higher near water resources, forest edges and human settlements, in areas with higher abundance of game species, and in periods of higher lunar light intensity. Occupancy-based estimates of poaching matched well historical poaching records in the Reserve, and indicated that poaching pressure is not homogeneous across the Reserve; rather, there are clear poaching hotspots in areas with higher accessibility to poachers. Our results provide subsidies for increasing knowledge about this illegal practice, and points out for future strategies of conservation and management of game species. In addition, our methodological approach may be used in other Reserves to identify poaching hotspots, thus assisting managers in predicting and avoiding this illegal activity.

1. Introduction

Wild animal hunting, widely spread in tropical forests, has great nutritional, economic, social and cultural importance for local communities (Bennett and Robinson, 2000). However, when there is no adequate management of the exploited set of species, it can become a consistent predatory activity (Redford, 1992). Illegal hunting, hereafter referred to as poaching, also feeds the international traffic of wild animals (RENCTAS, 2001). Each year, 5–20 billion dollars are moved through the illegal trade of fauna and flora (Rosen and Smith, 2010). Importantly, in addition to direct impacts caused by the removal of specimens from natural environments, poaching has caused the emergence and spread of diseases and facilitated biological invasions, threatening the health of humans, native species, and agricultural activities (Karesh et al., 2005; Rosen and Smith, 2010). Because it is a widely disseminated and highly relevant activity for tropical forest conservation, poaching has attracted the attention of researchers in recent decades (Redford, 1992; Bodmer et al., 1997; Peres, 2000; Fa et al., 2002; Brashares et al., 2004; Corlett, 2007; Parry et al., 2009; Parry and Peres, 2015; Sousa and Srbek-Araujo, 2017).

Populations of animals can be affected by poaching in different ways, including population size reduction (Peres, 1996; Peres and Nascimento, 2006; de Souza and Alves, 2014) and changes in behavior (Ferreguetti et al., 2017). Local extinctions of vertebrates caused by both subsistence hunting and habitat loss and fragmentation have already been reported in the literature (Bodmer et al., 1997). Mammals, which have a relatively longer life span, lower population growth rate, and long generation time, tend to be highly susceptible to local extinction by poaching (Bodmer et al., 1997). Species such as the lowland tapir (*Tapirus terrestris*) and the white-lipped peccary (*Tayassu pecari*), for example, were locally extinct in areas of Mexico, Panama, and Brazil, both in the Amazon region and in the Atlantic Forest (Peres, 2001). In 101 areas of the Brazilian Amazon, populations of vertebrates moderately or intensely exploited by hunting had their densities reduced by about 90% (Peres, 2000; Peres and Palacios, 2007; Wilkie et al., 2011). In the Brazilian Atlantic Forest, the abundance of medium

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https://doi.org/10.1016/j.biocon.2018.09.009
Received 3 May 2018; Received in revised form 26 August 2018; Accepted 6 September 2018

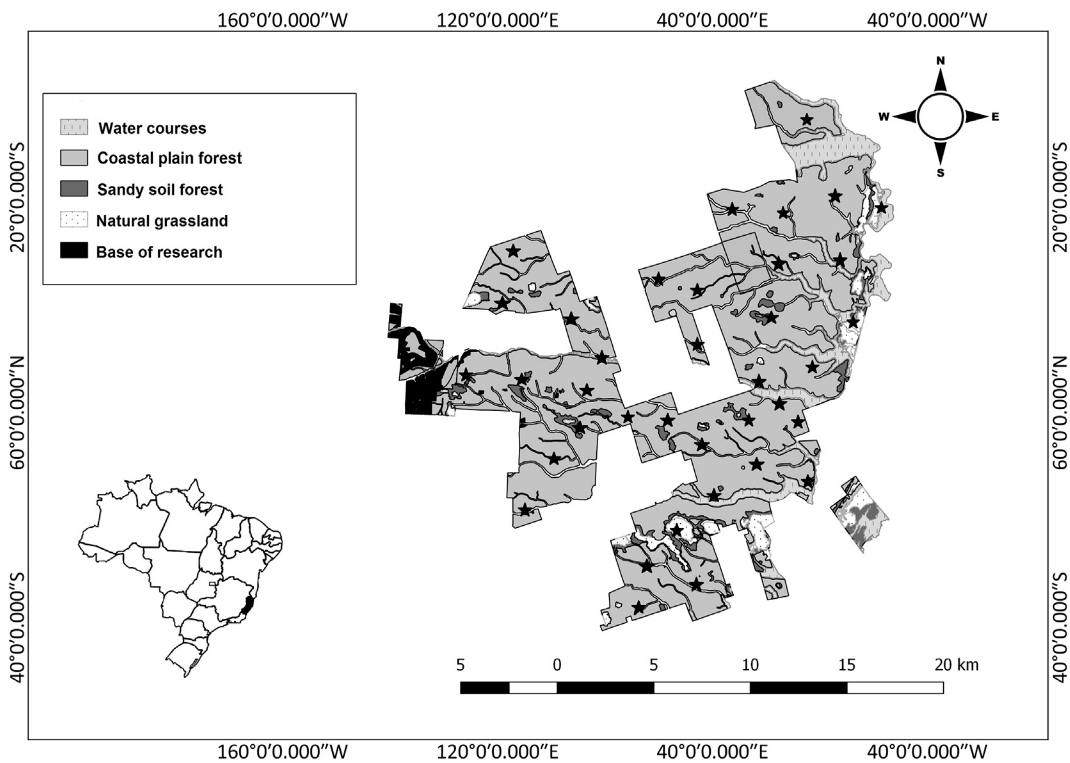

Fig. 1. Habitat mosaic inside the Vale Natural Reserve, Espírito Santo, Brazil. Black stars represent the location of the 39 camera traps.

and large vertebrates was on average 37% lower in intensely hunted areas compared to lightly hunted areas (Cullen et al., 2000). Vertebrate defaunation caused by hunting, poaching and illegal trade in tropical forests has even been considered comparatively more harmful than deforestation (Fa et al., 2002). Through cascading effects, the abrupt decline or even extinction of populations probably have had pervasive impacts on ecosystems structure and dynamics (Dirzo et al., 2014).

The rapid and continuous increase in human population density nearby forest ecosystems, especially in tropical regions, have increased access and facilitated harvesting, hunting and poaching activities (Peres and Lake, 2003; Laurance and Vasconcelos, 2009). In Congo's forests, for example, human population growth as a result of the setting up of logging companies and the expansion of highways, have further boosted the extraction and sale of wild animal meat in the region's markets (Wilkie et al., 2000). Due to its long history of occupation and destruction after European colonization (Dean, 1996), the remaining fragments and the few Reserves in the Atlantic Forest biodiversity hotspot become easily accessible by poachers. Indeed, 73% of the remaining Atlantic forests are located < 250 m from non-forest areas (Ribeiro et al., 2009).

Unfortunately, poaching is still widespread even within protected areas (Cullen et al., 2000; Sousa and Srbek-Araujo, 2017), partly due to the high cost of monitoring and combating poaching over large areas. To better focus conservation efforts within protected areas, it is still necessary a better understanding of the spatial distribution of poaching activities. The scarceness of quantitative information on poaching distribution is partly explained by the fact that poaching activities occur under the forest canopy, which hampers its monitoring by conventional remote sensing techniques (Peres et al., 2006; Ahmed et al., 2014). Instead, investigation of poaching patterns often requires in situ techniques that can compromise both the spatial extent and the number of survey repetitions (Parry and Peres, 2015), as well as result in an increased cost of the research activity. Therefore, studies are urgently needed to predict potential poaching areas and to identify the set of conditions that favor this activity, to maximize the efficiency of surveillance efforts and to better support the decision-making process aiming at wildlife protection.

In this study, we show how occupancy modeling may be applied to produce a spatially-explicit diagnostic of poaching in protected areas. Occupancy modeling provides an approach for estimating the probability of occupancy of a site by an organism of interest (in our case, poachers) while accounting for imperfect detection, based on data collected at repeated visits to multiple sites (Bailey et al., 2014; MacKenzie et al., 2002). Given the difficulties of obtaining abundance estimates of a given species from count- or detection/non-detection data, researchers often avoid using density estimation altogether, adopting occupancy (i.e. the probability that a site is occupied by a species), in combination with detectability (i.e. the probability that a species is detected given that it is present), as alternative parameters of interest (Burton et al., 2015). Occupancy modeling is considered to be a more cost-effective alternative for the monitoring of populations in comparison with other methods (Gerber et al., 2014; Gray et al., 2010, 2014) but has not been applied yet to estimate poacher's occupancy. Here, we show that occupancy modeling may be useful to estimate poaching hotspots in protected areas, and to determine how different covariates could affect poacher's occupancy and detectability, which reflect poacher's occurrence and abundance, respectively. Detectability is treated as a proxy for intensity of poachers (i.e. poachers will be more easily detected in places they go more often). We tested the general hypothesis that poaching occurrence and intensity is higher in sites with higher accessibility by poachers. We predicted that poacher occupancy and detectability would be higher in sites closer to Reserve edges, human settlements, trails, roads and water resources. We also predicted that poacher detectability would be higher in nights with higher lunar light intensity, which would facilitate poacher's movement, and in sites with higher frequency of prey. The innovative methodological approach used here, as well as the findings of our empirical study, may advance understanding and combating poaching activities in different protected areas.