Applied Geography 64 (2015) 35–45

Contents lists available at ScienceDirect

Applied Geography

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

Influence of protected areas on malaria prevalence in Sub-Saharan Africa

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A R T I C L E I N F O

Article history:
Received 28 April 2015
Received in revised form
8 September 2015
Accepted 8 September 2015
Available online 22 September 2015

Keywords:
Malaria
Plasmodium falciparum
Random forests
Epidemiology
Geospatial health
Infectious disease

A B S T R A C T

Introduction: Despite exponential growth in the number and extent of protected areas globally, their role within disease dynamics remains unclear. Protected areas shape many biophysical and social factors related to malaria prevalence such as land use-land cover, biodiversity, socioeconomic conditions, and human behavior. This work examines the extent to which protected areas influence *Plasmodium falciparum* malaria prevalence within surrounding human populations throughout Sub-Saharan Africa..
Methods: Using malaria prevalence data from 2008 to 2012, we tested for differences in mean malaria prevalence at survey locations according to the IUCN classification of the nearest protected area. We also used dual logistic regression and Random Forest approaches to model malaria burdens at survey locations using a variety of known biophysical determinants of malaria in addition to protected area related covariates.
Results: We found that malaria prevalence differed by IUCN class, with survey locations near IUCN classes Ia and III exhibiting significantly higher prevalence values than all other classes. Additionally, distance to the nearest protected area emerged as an important predictor of malaria prevalence in the logistic regression model, with lower malaria prevalence at locations closer to protected areas (OR: 1.14; 95% CI: 1.10–1.17). Distance was of moderate importance in the Random Forest models; however, the relationship between distance and prevalence was nonlinear..
Conclusions: We show that, at a continental scale, malaria prevalence was lower for populations closer to protected areas in Africa, compared to farther away. However, we also found evidence of spatially complex relationships, both around individual protected areas, and across protected areas at this geographic extent, reinforcing the need for additional, small-scale case studies. Ultimately, by showing a link between protected areas and disease presence, this work helps improve understanding of the complex, multiscalar drivers of malaria..

1. Introduction

In 2013, the most recent year for which estimates are available, a total of 3.3 billion people globally lived in areas at risk of *Plasmodium falciparum* (*Pf*) malaria and more than 500,000 deaths were directly attributable to malaria. Of these, more than 90% occurred in Africa (Gething et al., 2011; World Health Organization, 2014). Despite decades of efforts and billions of dollars aimed at preventing and controlling malaria, it remains one of the greatest vector borne disease burdens (Stratton, O'Neill, Kruk, & Bell, 2008). Ecological factors such as vector presence, abundance, and behavior (e.g. biting rates), biophysical factors such as temperature, precipitation and land cover, and socioeconomic factors such as education and development status all influence malaria prevalence to varying degrees (Gosoniu, Msengwa, Lengeler, & Vounatsou, 2012; Paaijmans, Read, & Thomas, 2009; Patz & Olson, 2006; Vittor et al., 2006). Although we now possess a greater understanding of the socio-ecological determinants of malaria and significant advances have been made towards eliminating malaria, large knowledge gaps remain as shown by the persistence of the disease (Stratton et al., 2008; World Health Organization, 2014).

The modern definition and categorization of protected areas (PAs) arises from the International Union for Conservation of Nature (IUCN), established in 1948. The IUCN currently recognizes

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http://dx.doi.org/10.1016/j.apgeog.2015.09.001
0143-6228/

seven PA categorizations, ranging from "strict nature reserves" managed mainly for science to "managed resource protection areas" managed mainly for the sustainable use of natural ecosystems (Chape, Spalding, & Jenkins, 2008). The varied nature of current PA classification reflects the diverse motivating factors for PA establishment and management. A variety of research on the various risk factors, determinants, and correlates of malaria prevalence suggests that PA existence and management may shape malaria prevalence in the surrounding landscape. However, a lack of direct, empirical evidence supporting this linkage and conflicting reports about potential relationships between protected areas and malaria prevalence necessitates further research. For example, Valle and Clark (2013) found higher malaria prevalence in areas closer to forested PAs, while Olson, Gangnon, Silveira, and Patz (2010) found higher malaria prevalence in recently deforested, unprotected areas. However, both of these studies were conducted in the Amazon, limiting their generalizability to other regions. We attempt to resolve the discrepancy introduced by these studies while also testing for relationships in a different geographic region. Here, we ask whether PAs shape malaria prevalence in nearby human populations in Sub-Saharan Africa. Specifically, we predict that:

1. Malaria prevalence differs by the IUCN status of the nearest PA and that PAs with IUCN classifications reflecting greater human interaction with the PA will correspond with higher malaria prevalence in the surrounding communities.
2. Malaria prevalence will be lower in areas near PAs and higher in areas further away from PAs.

In contrast to earlier studies, we use logistic regression and Random Forest models to explore relationships between malaria prevalence and PAs and determine whether the determinants of malaria prevalence differ and operate at finer spatial scales when malaria is present.

Protected areas influence many of the biophysical, ecological, and social determinants and correlates of malaria burdens such as land-use/land-cover, biodiversity, socioeconomic conditions, and human behavior (Hansen & DeFries, 2007). However, the role of PAs within malaria dynamics is unclear and largely unexamined. With exponential growth in the number and extent of PAs globally (IUCN & UNEP, 2014), and a weak shift from more utilized PAs to strictly managed PAs in the last decades of the 20th century in Africa (Zimmerer, Galt, & Buck, 2004), the importance of understanding potential links between PAs and malaria prevalence becomes apparent.

Protected areas often represent relatively intact ecosystems, relative to the surrounding landscape, and thus shape land use-land cover within the PA and the surrounding landscape. As a result, PAs influence the environments that could serve as potential habitat for malaria vectors at relatively broad scales. In fact, recent work suggests that proximity to forest cover may increase malaria risk (Ernst et al., 2009; Haque et al., 2011; Valle & Clark, 2013) while another study found increased forest cover was associated with decreased malaria incidence (Krefis et al., 2011). However, *Anopheles* species' habitat preferences vary by species and can even change seasonally, and mosquito species' preferences primarily depend upon the egg laying behavior and larval development of the mosquitos (Munga et al., 2009; Yasuoka & Levins, 2007). As a result, forested PAs in particular may shape malaria prevalence, although the nature of the relationship is complex and remains to be determined.

The classification and management of PAs also has potentially important implications for malaria prevalence by influencing the degree to which people may come in contact with environmental niches favored by some malaria vector species. Although IUCN classification does not directly correspond with management practices, it is a convenient, if imperfect, proxy for management because the various IUCN categories generally reflect a PA's management objectives. Strict nature reserves or wilderness areas that limit human access and PAs with 'hard' borders typically limit resource use, habitation, and even human movement through the area (Miller, Minteer, & Malan, 2011). Such restrictions place important limitations on the physical presence of humans and thus, their exposure to some species of malaria vectors. For example, individuals engaged in timber harvesting may work alongside microhabitats favored by malaria mosquito vector species (Vittor et al., 2009). Therefore, PAs may drive patterns in malaria prevalence by influencing vector presence and abundance and by controlling human exposure to malaria vectors. Here, we build upon national level studies of malaria prevalence by conducting a continental scale analysis with point records of malaria prevalence. While this study does not examine fine scale variability in malaria prevalence, we predict that undertaking a continental scale analysis may reveal broad patterns and general trends in relationships between the landscapes surrounding PAs and malaria. Examination of these broad constraints on PA-influenced landscape factors may help explain conflicting reports at finer spatial scales.

2. Methods

To test the prediction that IUCN PA classification and distance to the nearest PA are important predictors of malaria prevalence, we modeled malaria prevalence at survey locations as a function of biophysical and PA-related variables.

We acquired malaria prevalence data for point locations throughout Sub-Saharan Africa. The Malaria Atlas Project (MAP) maintains a database of more than 22,000 malaria prevalence survey records collected from published, peer reviewed articles, reports and unpublished sources such as research groups and aid agencies. Survey records represent individual sites and dates; and all records include latitude and longitude, the date the survey was conducted, the number of people tested for malaria and the number of people that tested positive for malaria (Moyes, Temperley, Henry, Burgert, & Hay, 2013). We calculated the binomial response variable, *Pf* prevalence, as the number of people that tested positive for the parasite *P. falciparum* divided by the total number of people tested. Prevalence data from 2008 to 2012 (the most recent year for which data were available) were downloaded from the MAP Data Explorer to acquire spatial data coverage for a substantial portion of Sub-Saharan Africa while also minimizing the number of years to control for changes in environmental conditions and malaria prevalence from year to year. The majority of the MAP data for 2008–2012 originally came from the US-AID Demographic and Health Surveys (DHS) database of Malaria Indicator Surveys (MIS), developed by the Monitoring and Evaluation Working Group of Roll Back Malaria (US-AID., 2014). These MAP data points were missing geospatial information because DHS requires authorization to access the spatial coordinates of their survey locations due to privacy concerns. Therefore, DHS Geographic Datasets were downloaded for the countries and years covered by the MAP dataset and matched to the MAP records using unique DHS ID numbers common to both datasets in order to acquire the spatial coordinates for these records.

Protected area locations in Sub-Saharan Africa, including IUCN classification and area, were acquired in shapefile format (IUCN & UNEP, 2014). These data are produced by the World Database on Protected Areas (WDPA), a joint project of the IUCN and the United Nations Environment Programme. Only those PAs which have been officially designated (dates of PA establishment ranged from 1905