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Malaria parasite mobility in Mozambique estimated using mobile phone records

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Abstract. Malaria is one of the primary causes of death in Mozambique, responsible for an estimated 15,000 deaths in 2017. Human-mediated parasite movement combined with spatial and seasonal changes in transmission threatens the success of malaria interventions by reintroducing parasites to areas targeted for elimination. In this study we used pseudonymized and aggregated call detail records from a sample of over 8.5 million subscribers of a mobile phone operator in Mozambique to quantify human movements for four months in 2017. We calculated parasite importation and exportation rates to identify potential net sinks and sources of malaria across districts. We used a community structure algorithm to explore the connectedness of provinces in Mozambique, and we calculated parasite mobility between urban and rural areas. This work will help provide evidence to inform malaria elimination strategies regionally.

1 BACKGROUND

Despite large reductions in burden, malaria remains one of the primary causes of death in Mozambique, responsible for an estimated 10 million cases and 15,000 deaths in 2017 [1]. Malaria is transmitted by a vector typically associated with specific types of habitat, meaning malaria transmission varies spatially and temporally across landscapes and the populations that reside in them [2]. A variety of interventions exist that can help eliminate malaria within targeted areas, but human mobility threatens the success of these interventions, as long-distance human-mediated parasite travel could reintroduce it in areas where it was previously eliminated [3]. This is a particular concern in southern Africa, where there is a regional effort to eliminate malaria transmission (Elimination8) and relatively high transmission in Mozambique poses a challenge for the low-transmission countries nearby. Call detail records (CDRs) provide a unique insight into human movements in real time and have previously been used to identify sinks and sources of malaria in other countries [3–5], ultimately providing evidence to help national control programs more efficiently target efforts to control malaria.

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2 METHODS

In this study we used pseudonymized and aggregated call detail records (CDRs) from a sample of over 8.5 million subscribers of a mobile operator in Mozambique to quantify human movements for four months between February and May of 2017. Because the most important malaria vectors in this region (the mosquito species *Anopheles gambiae, funestus and arabiansis* [6]) primarily bite at night, we used the last known location of the day to make an assumption about where a subscriber spent the night.

We used gridded human population data at 100m resolution from the WorldPop project [7] to obtain estimates of the number of people residing in each district of Mozambique and compared these to the number of geolocated subscribers in each district. We divided the WorldPop estimate of population in each district by the number of subscribers in each district to obtain scaling factors, then used these to scale estimates of people moving in between districts to estimate actual population movements. We then generated mobility matrices for daily movements at a province and district level and combined these with high-resolution malaria prevalence maps [8] to calculate parasite importation and exportation rates and to identify potential net sinks and sources of malaria across 139 districts.

We used a community structure algorithm [9] to explore the connectedness of provinces and districts in Mozambique through both overall human mobility and human-mediated parasite mobility. Lastly, we used a high-resolution map [10] of rural and urban areas in Mozambique overlaid with the mobility matrices to estimate human movements and human-mediated parasite movements between urban and rural areas.

3 RESULTS

Our work revealed four novel findings that are valuable to inform malaria elimination strategies. First, we identified seasonal differences in parasite mobility between the months, with parasite exportation and importation rates varying in certain districts from month to month. Notably, districts with the highest prevalence of malaria were not necessarily the districts with the highest human-mediated parasite movement.

Second, we discovered that the districts in southern Mozambique are more connected to each other through human mobility than to districts in northern Mozambique, suggesting that current efforts to eliminate malaria from the southernmost provinces of Mozambique by 2020 could have lasting effects on reducing the risk of cross-border exports into neighbouring countries.

Furthermore, analysis of community structure at the province level suggested differing structures for human movements and human-mediated parasite movements: human movements overall were best modelled with a two-community structure with a clear north-south divide, while human-mediated parasite movements showed a three-community structure, also with a north-south divide, best described the flow of parasites (Figure 1).

Lastly, we compared all human movements to human-mediated parasite movements between urban and rural areas. We saw that while the majority (96%) of both types of movements are rural to rural, the proportion of human-mediated parasite movements from rural to urban areas was 2.3 times higher than the proportion of all human movements in this direction. We also observed that parasites are more often carried from rural to urban districts (2.986% of movements) than vice versa (0.009% of movements).

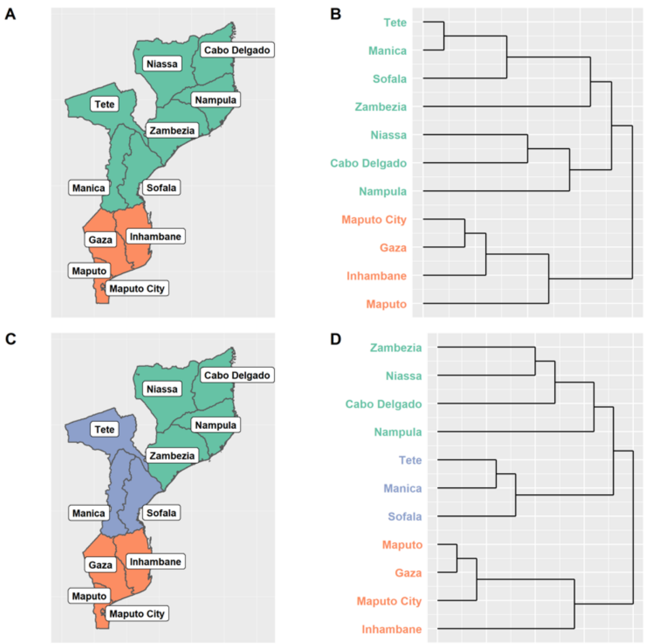

Figure 1. **A** Two-community structure from human movements between provinces in Mozambique. **B** Dendrogram of connections between provinces through all human movements between provinces. **C** Three-community structure from human-mediated parasite movements between provinces in Mozambique. **D** Dendrogram of connections between provinces through human-mediated parasite movements between provinces.

4 CONCLUSIONS

Our findings will help provide evidence to inform malaria elimination strategies regionally. Controlling malaria at parasite sources would benefit both the populations living in the source areas and the populations that suffer from malaria exported from those areas. Our results on community structures within Mozambique could help allocation of resources by identifying regions where the movements of parasites are relatively contained.

In future work we plan to use pseudonymized and aggregated CDRs from a whole year to further explore the effects of seasonality on parasite movement in Mozambique. We will also combine these data from other sources to validate estimates and to extend their utility, which will include sources such as rainfall data, travel history surveys and migration data to predict cross-border movement from Mozambique into eSwatini and South Africa. We believe in the power of data-driven approaches to help tackle malaria eradication.

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