UNDERSTANDING MALARIA TRANSMISSION IN BIOKO

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HUMAN POPULATION DISTRIBUTION

For operational purposes, Bioko island is divided into a 1x1 km grid of uniquely coded map *areas* that allow the identification of all houses and individuals inhabiting them. Each area is in turn divided into 100 *sectors* of 100x100 m each. To reduce computational requirements during simulations, we have summarized population and MIS point level data to the *area* level. Figure 1 shows the distribution of the human population across the 194 populated areas. Based on Hay *et al*. 2005 we classified these areas according to population density. Those with >1000 people were defined as *urban*, between 250 and 1000 people defined as *peri-urban*, <250 and >=100 people as *rural-1* and <100 people defined as *rural-2*. Human population on Bioko island is mainly concentrated around the country capital, Malabo. According to the 2015 population census, 34 (17.5%) areas accounted for 88.2% of the island population (199,326 of the total 225,950 individuals), mostly in and around Malabo.

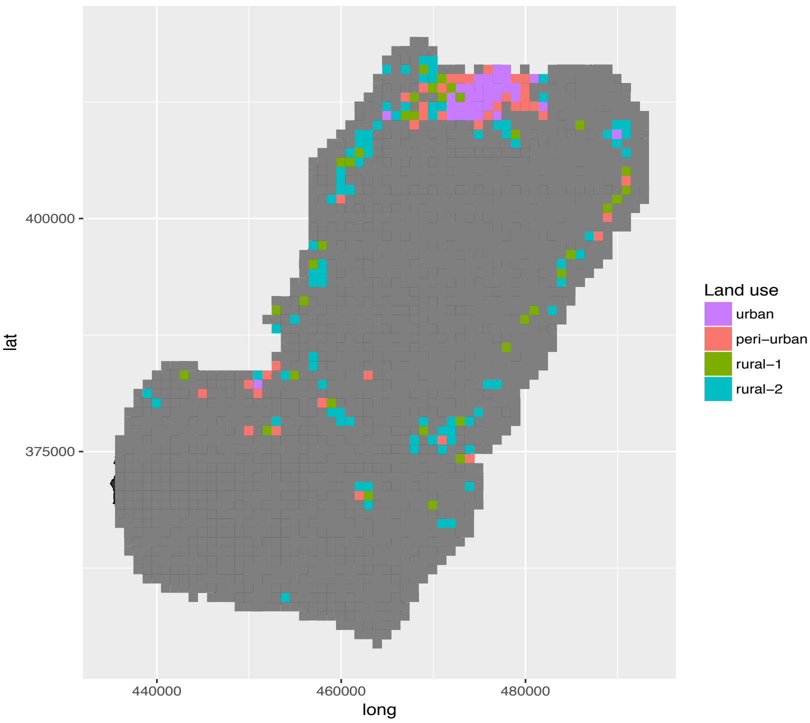

Figure 1. Populated areas in Bioko classified according to population density. Areas in grey are unpopulated by humans.

MALARIA PREVALENCE AND URBANIZATION

The mean of the sector-level smoothed *Pf*PR is shown by area in Figure 2. No clear pattern is immediately evident from this map apart from a relatively lower prevalence along the east coast compared to the west. Figure 3 plots population density against *Pf*PR at sector level and suggests some relationship between both. Looking into the raw *Pf*PR data, during the 2016 MIS, 14,922 were tested for malaria across 180 different areas. Eight of these areas were not classified as populated according to the 2015 population census. Among the remaining 172 areas surveyed, 34 were urban, 39 were peri-urban, 36 rural-1 and 63 rural-2 areas. Among all individuals tested, 76.6% were urban dwellers, 12.9% lived in peri-urban areas and 10.5% were rural dwellers (6.7% from areas classified as rural-1 and 3.8% from rural-2 areas). Urban areas are generally less attractive to malaria anopheline vectors and, therefore, transmission intensity is expected to be relatively lower in urban than rural areas. However, no such relationship is evident from the MIS 2016 data from Bioko, with no significant differences between transmission intensity as measured by *Pf*PR among urban, peri-urban and rural areas (Figure 4). A similar lack of relationship is observed when using smoothed *Pf*PR (not shown).

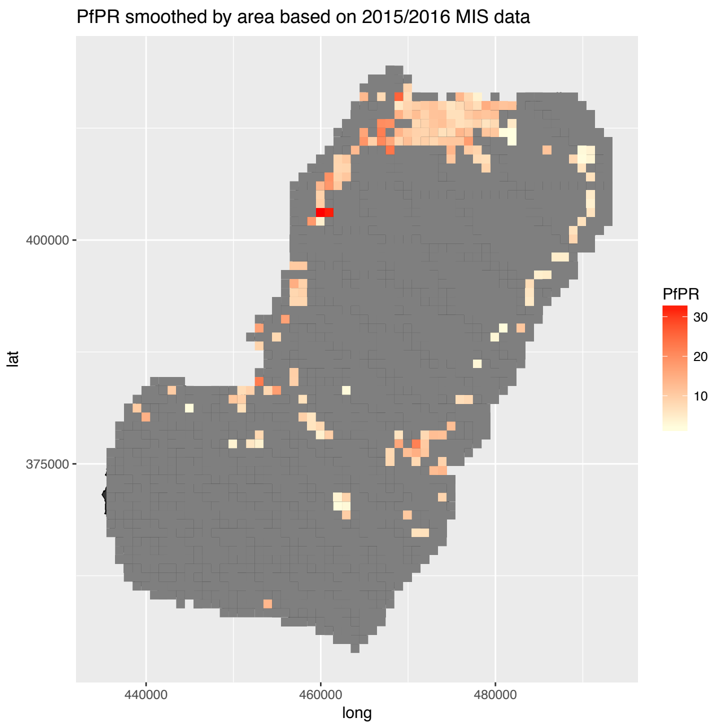

Figure 2. Mean smoothed *Pf*PR for 2015 and 2016 MIS by area.

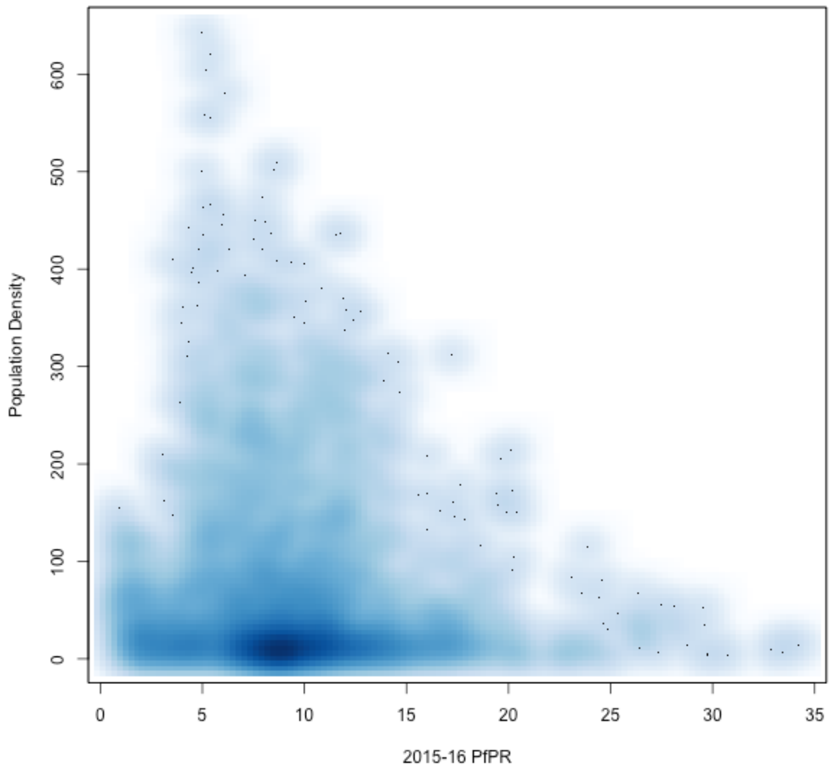

Figure 3. Mean population density against smoothed *Pf*PR (2015 and 2016) at sector level.

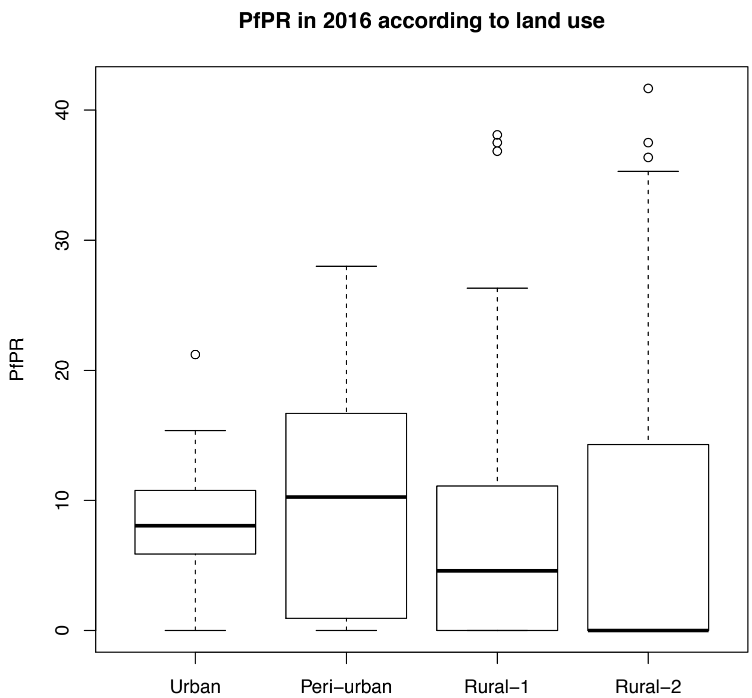

Figure 4. Mean observed 2016 *Pf*PR by area according to land use.

VECTOR POPULATIONS AND ENTOMOLOGICAL INOCULATION RATES

Prior to the BIMCP, malaria transmission in Bioko was sustained by three anopheline species: *Anopeles gambiae* s.s., *An. melas* and *An. funestus.* The latter was the main contributor to annual EIR in some areas of Bioko. Populations of *An. funestus*, however, dropped dramatically after the third round of IRS and the vector has since not been identified in entomological surveys (Overgaard et al. 2012). Vector monitoring is undertaken through light trap and human landing catches across sentinel sites. The anopheline species composition is summarized in Figure 5 based on data from the last eight years of entomological surveillance (from 2009 to 2016). Both *An. gambiae* and *An. melas* were recorded. Notably, *An. melas* was almost ubiquitous across sentinel sites, although there was high variability over the years.

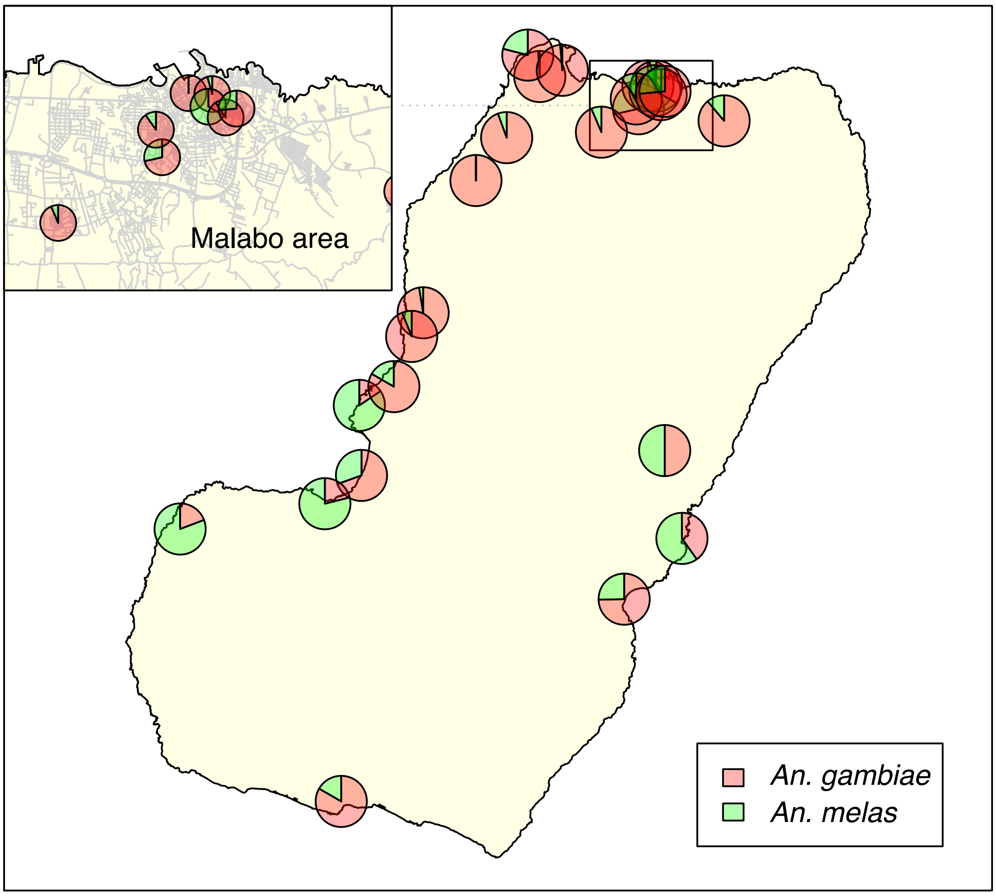

Figure 5. Anopheline species composition in sentinel sites. The pie graphs illustrate the proportional composition of *An. gambiae s.s.* and *An. melas* according to entomological surveillance between 2009 and 2016. The map inset gives higher detail of the Malabo area.

Vector surveillance has included human biting and sporozoite rates estimation for the determination of entomological inoculation rates (EIR). Some of the highest EIR estimates ever recorded in malaria endemic areas have been reported in Bioko. In 2009, for instance, an EIR of ~1200 infected bites per person per year was estimated in Mongola, on north western Punta Europa, based on outdoor catches over a month, although the average annual estimate for indoor and outdoor biting over that year was 840 bites per person (Oveergard et al. 2012). In recent years, however, a dramatic drop in EIR has been observed across Bioko (Figure 6).

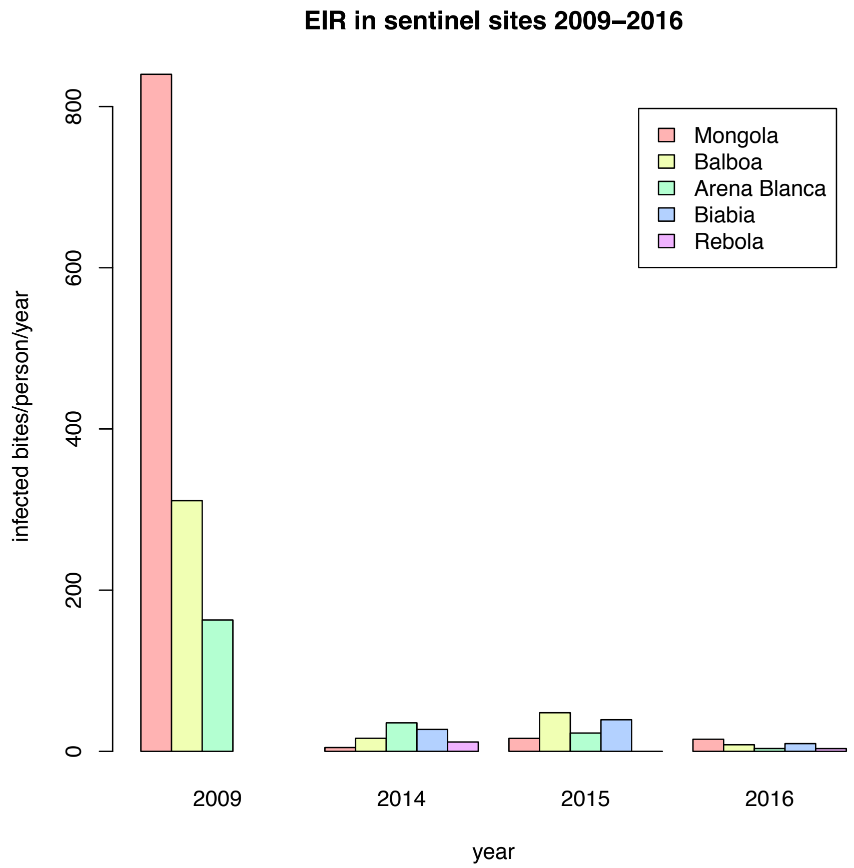

Figure 6. Comparison of EIR estimates across the same sentinel sites surveyed in Bioko in 2009 and during the period 2014-2016.

Figure 7 illustrates the estimated EIR in sentinel sites and the contribution of both anopheline species to these estimates. In 2014 and 2015 EIR were highest in Arena Blanca (west coast) and Balboa (east coast), respectively, with 35.4 and 47.9 infected bites per person per year. In 2016, EIR were generally lower, with the highest estimate in Mongola at 15 infectious bites per person per year. *Anopheles melas* contributed to a significant fraction of the EIR, especially in Arena Blanca.

To determine the relationship between EIR and *Pf*PR in Bioko, we used the parasite prevalence measured during the 2015 and 2016 MIS at the areas corresponding to the entomological monitoring sentinel sites during the same years. Despite a weak correlation between EIR and *Pf*PR

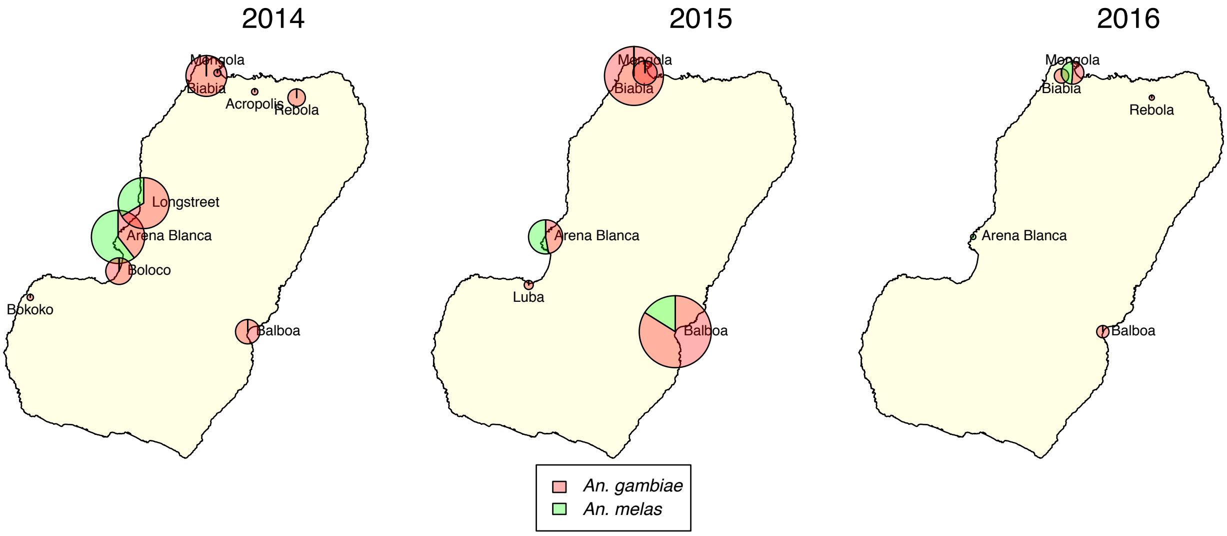

Figure 7. EIR by species measured in sentinel sites between 2014 and 2016.

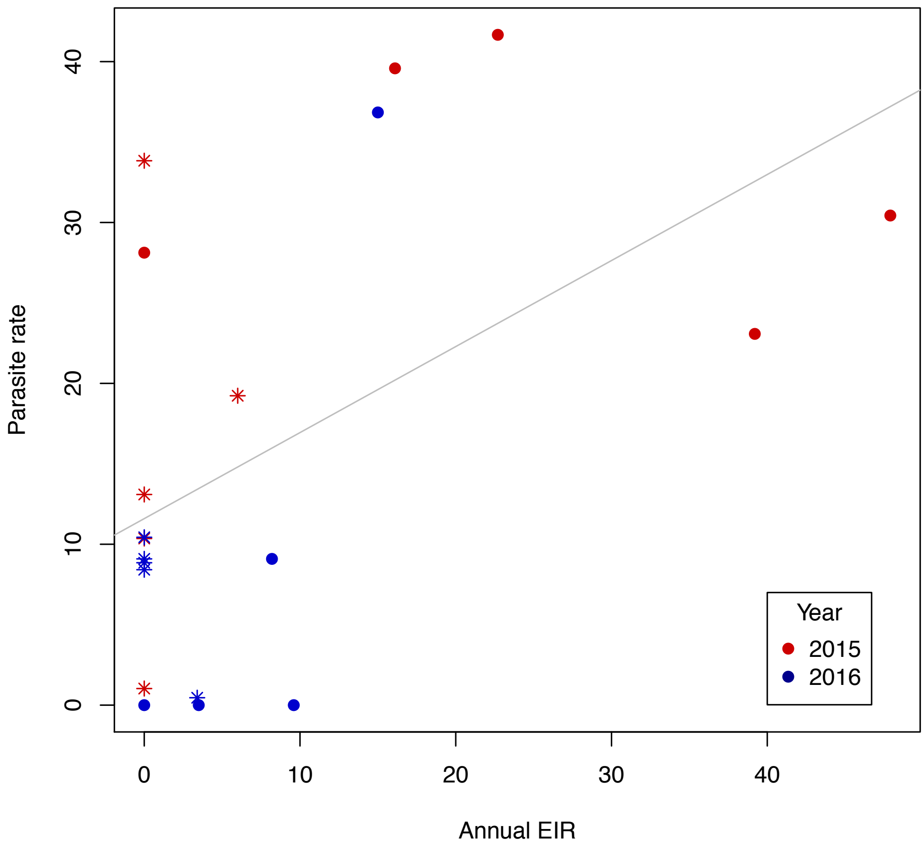

Figure 8. The relationship between measured *Pf*PR summarized at the area level and EIR estimated at sentinel sites for 2015 and 2016. Stars indicate sentinel sites falling in areas defined as “urban”.

was found (r^2=0.26, Figure 8), even though EIR was zero in eight out of 10 observations conducted in urban areas, their corresponding *Pf*PR measurements were all above 0 and over 10% in 5 of these instances.

MALARIA TRANSMISSION AND HUMAN MOVEMENT

One plausible explanation for the lack of association between measured *Pf*PR, EIR and urbanization is human movement. Because people move around Bioko and the distances are relatively short, it is likely that urban dwellers acquire their infections in high transmission areas outside of urban areas. It is not possible to test this confounding factor with the current data, however. The MIS included questions about travel within the island. In 2016, 9.9% of respondents (1,478 of 14,922) travelled within Bioko in the 8 weeks prior to the survey. Most of these travelers were urban and peri-urban dwellers (42.2 and 27.9%, respectively). Unfortunately, their destination was recorded at the district level (second administrative unit), making it impossible to determine the actual transmission intensity of their final destination with any degree of certainty and, hence, to infer what might be the actual impact of their travel on the lack of association between malaria transmission and urbanization.