# Micro-Stratification for Malaria Transmission Risk in a High Burden Area of Honduras

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## Abstract

# Background

As Malaria cases are continuously reported across the globe, epidemiological and integral approaches should be considered for an optimal stratification on endemic areas for elimination goal. In Central America, a 75% reduction in malaria incidence has been reported between 2000 and 2015, similarly, in Honduras, more than 75% of total cases in 2016 were concentrated in 7 municipalities, mainly in Gracias Dios department. Achieve malaria elimination in Honduras demands the implementation of strategies to identify main hotspots.

# Methods

Based on WHO guidelines, local malaria epidemiological data from case-based surveillance system of the Ministry of Health between January and December 2016 were analysed. Furthermore, on field evaluations were carried out in Puerto Lempira municipality, Gracias a Dios department to an analysis validation. Finally, a set of epidemiological components were generated and proposed together with risk-factor description and proposed actions for health system improvement.

# Results

On 2016, Gracias a Dios reported 61% of total malaria cases in Honduras; based on our analysis, 12 micro-areas were identified, including epidemiological, entomological, and socio-demographic information from local technicians.

# Conclusions

Malaria elimination in endemic areas urges implementation of different strategies, here we show the on-field micro-stratification process of 12 “micro-areas” carried out in one endemic department of Honduras. This information provides a more targeted strategy for diagnosis, treatment, and vector control interventions for malaria elimination goal in Honduras.


## Background

Over the last decade, calls for malaria elimination have increased with the World Health Organization (WHO) making it one of its priority in the Global Technical Strategy 2016–2030, aiming to eliminate malaria from 35 countries by 2030. (1, 2) In 2019, 229 million cases of malaria and 409 000 deaths were due to malaria worldwide. However, this scenario is particularly different in Central America, where all countries achieved more than 75% decline in malaria incidence between 2000 to 2015, and malaria elimination is considered as a near possibility. (2–5) As a result of the achievements of the countries in Central America in malaria reduction; considering previous achievements in elimination of other diseases, the existing political will, improvement of surveillance systems and the focalized transmission, on 2013, the Council of Ministers of Health of Central America and the Dominican Republic (SE-COMISCA) adopted the goal of eliminating malaria by 2020, reorienting national malaria control programmes towards malaria elimination (6, 7) Currently, El Salvador has had more than 3 years since the last autochthonous case was reported and Belize reported the last indigenous case in 2018. Both countries are part of the E-2020 initiative of WHO, an effort aimed at reaching the organization’s GTS target for malaria elimination.(5)

Malaria interventions have historically been implemented based on an epidemiological and entomological risk factor analysis. Since 2000, this has ranged from analysis at the first-level administrative division, equivalent to states or provinces, to a more focused approach at the level of houses, although limited to small study settings. With declining prevalence across the world, the epidemiological landscape of malaria has changed considerably. Consequently, WHO has updated the stratification strategy and the recommended methodology for better optimization and delivering of available resources. (2, 8)

In order to identify populations most likely to be infected with malaria, WHO recommends stratifying an area according to population risk, based on ecological determinants, population mobilization and epidemiological factors. (9–11) The basic aim of this type of analysis is to identify the receptivity and vulnerability of a particular setting. Vulnerability is considered as a major characteristic for malaria transmission and re-establishment on endemic areas. According to WHO, malaria vulnerability is considered as the probability or incidence of imported cases, or infected anophelines mosquitos from a specific area to another, or also, to be estimated by the population flow between endemic areas. (8, 12, 13)

Between 2014–2016, 9 out of the 25 high burden malaria districts / municipalities in Central America were from Honduras.(14) The department of Gracias a Dios in Honduras had a majority of malaria cases nationally (58% in 2016). However, since 2000 there had been considerable case reduction in the country (85% between 2000 to 2015) and malaria cases were concentrated to certain areas in particular – more than 75% of all cases were in 7 of the 298 municipalities in Honduras in 2016. (15, 16)

From 2000 onwards, the MoH in Honduras has used several strategies for prioritizing malaria interventions across endemic areas. Initially, the proportion of cases at the level of state was used followed by a transition to Annual Parasite Incidence (API) at the municipality level from 2008 onwards.(17) As malaria began to decrease, cumulative data over 3 years were used to stratify each municipality according to API from 2013. Nevertheless, as malaria cases concentrated to a group of municipalities, API at municipality level became less useful, and identification of each malaria foci was required. An effort to investigate each locality as a malaria focus was undertaken in Honduras but it showed that it was unlikely to be logistically feasible to do it once, let alone be repeated on an annual basis given that more than 180 localities had reported malaria cases in 2016. (18) Moreover, the shared risk between two adjoining localities made it unlikely that a locality could be considered as a discrete focus. While the use of the API at municipality level had become less useful, and identification of each malaria foci was still not feasible, a stratification strategy that would bridge the gap in the interim was required.(7, 15, 19)

In 2017, given the epidemiological situation, a new stratification strategy was needed and based on the WHO recommendation for tailored and surveillance guided interventions, the implementation of foci characterization was considered. This work aimed at adopting the current global strategy for malaria elimination and apply it in an on-field based approach with locally available data from the Ministry of Health and provide these results as input for strategic planning in the preparation of the National Strategic Plan for Malaria elimination in Honduras, raising the possibility of replicating this exercise in other countries.

## Methods

## Study site

Several activities were separately carried out between September 2016 to July 2017 in Honduras, Central America. The initial desk-based analysis included all localities where malaria cases were reported from January to December from 2016. Fieldwork validation was carried out in Puerto Lempira municipality of Gracias a Dios department, in the north-east coast of the country. This municipality alone reported 50% of *Plasmodium falciparum* cases of the country and the highest API. (20) The activities were carried out along with personnel from the national offices of the Ministry of Health of Honduras (MOH), Tegucigalpa (capital of Honduras), local personnel from Puerto Lempira, Gracias a Dios department and was supported by experts of the Pan American Health Organization / World Health Organization (PAHO/WHO), Global Communities – Principal Recipient of the Global Fund grant and the Clinton Health Access Initiative (CHAI).

## Data collection

Based on the principles of the Global Technical Strategy for Malaria 2016–2030 (2), main variables were consolidated in a practical operational guideline for assessment. The initial process consisted on collection and analysis of i) local epidemiological data from a case-based surveillance system (Information System based on Localities – SISLOC Acronym in Spanish) at the national level for the year 2016. Parameters included for each case were local health centre, method of diagnosis, type of parasites and presence of their sexual stages, place of residence, place the person was 2 weeks ago, treatment scheme, sex and age. Additionally, ii) entomological data from sentinel sites (Human Landing Catches) and insecticide resistance data, iii) health and malaria diagnosis network coverage and access to it, iv) social and economic situation in each locality, and v) movement routes and modes between localities of people were collated. These data were obtained both from the national and local levels of MOH and through technical group discussions. (21)

Data were initially consolidated and analysed with Excel® and Tableau® at MOH, Tegucigalpa with support from health personnel at department level. Maps included were elaborated with software Epi Info™ version 7.2 (https://www.cdc.gov/epiinfo/).

## Desk-Review of data at national level

A desk review of the data was conducted in a workshop wherein data collected was analysed. Maps of malaria incidence at locality level, population by locality, human movement and malaria diagnosis posts were assessed. Localities were grouped based on shared characteristics into micro-areas.

## Characterization of malaria transmission dynamics in situ

On-field evaluation in selected areas of Puerto Lempira municipality were subsequently carried out between 24–28 July 2017 to validate the draft analysis. Analysis of each micro-area was subsequently presented and discussed with local health personnel. Briefly, each visit consisted of comparing the data obtained through SISLOC versus local data present in 4 local health centres (Tansing, Yahurabila, Dapat and Tailibila), also criteria for active case detection, number of sites diagnosing malaria (as a proxy for surveillance coverage), proportion of *P. falciparum* cases with gametocytes (as a proxy for access to diagnosis and treatment), vector control response and LLIN use was analysed and discussed. During the visit, the patient attention in each health centre was made observed, including the detection, diagnosis, and treatment process. Finally, a couple of community health workers selected through a convenience selection process were visited in each site to assess the response at that level and compare the surveillance records between the community health worker and the local health centre. All findings were summarised, and further analysis was carried out together with inputs from local and national malaria working group.

To establish a comprehensive systemwide response, an initial risk factor analysis was carried out integrating epidemiological, entomological, and socio-demographic information to ascertain the reasons or a hypothesis for continued transmission in each micro-area. Gaps in the health system response and malaria community diagnosis and treatment network were central to the gap analysis used to develop a “micro-plan”. Weekly trend of cases for each micro-area were graphed and studied with seasonal variation of risk factors, especially occupational risk, rainfall and vector density, movement of people, human behaviour with respect to use of LLINs and housing characteristics.

## Ethical considerations

The information included in this study was collected from national surveillance databases. Patient data sourced were used without identifiers and only in aggregate form for the aim of the present study. Thus, the approval of an ethics committee was not deemed necessary.

### Results

Based on initial analysis, 10 out of the 18 departments reported 4,097 new malaria infections in Honduras in 2016. Gracias a Dios reported 61% of these infections. Of the total reported cases, 84% (n = 3446) were geo-referenced using the locality the person was residing as a proxy for place of infection (where available), otherwise the place of residence of patient was used. This information is asked for at the time of case notification in Honduras. Case investigation data was not available at the time of analysis. Within Gracias a Dios, the highest proportion of malaria cases were reported in Puerto Lempira municipality (78%). A total of 181 localities reported cases in Gracias a Dios, and of these, 120 localities reported more than 3 cases during the calendar year 2016. It was assumed that localities with 3 or less cases in a year were not likely to have active transmission and were excluded from the analysis. Cases in those localities were assumed to be either relapses or infected elsewhere. (Fig. 1)

## Microstratification

Localities were initially grouped based on geographical proximity evident on a map. This was then refined based on movement routes, ecological characteristics, and social dynamics. The mode of transportation between each of the localities as a proxy for intensity of movement, the size of the populations of the localities and the quality of surveillance, adjudged based on access to a malaria diagnosis and treatment post, was also used. The proportion of *P. falciparum* infections with gametocytes was also used as a proxy for access to health services, although its use was limited as that species was concentrated in some of the micro-areas. (18) The initial desk-review analysis led to identification of 8 “micro-areas” with active transmission located across the 6 municipalities of the Gracias a Dios department, which subsequently increased to 12 micro-areas after the field visit wherein a more detailed analysis was feasible. (Fig. 2) It is important to note that in this exercise, administrative boundaries of municipalities were not considered for grouping localities as micro-areas.

Agriculture and fishing are the principal economic activities in the department. Most of the malaria cases were in an ethnic population called “Miskito”. The whole of Gracias a Dios state is considered highly receptive for malaria given the tropical ecosystem with multiple lagoons, swamps and rivers, and multiple riverine routes that are present across it which provide a propitious environment for the vector.

Daily movement is carried out in small boats with capacity for 20–40 passengers along with some part of the territory which is accessible by dirt roads.

To assess vulnerability, movement of people due to economic, cultural, or social reasons was used as a close proxy. The transportation routes, intensity of movement and time taken to move between each locality were approximated and mapped based on knowledge and experience of local MOH personnel (Fig. 3). This showed a higher movement both towards and from the Kaukira sector on the Atlantic Coast and Puerto Lempira town centre both in Puerto Lempira municipality. Also, considerable movement between Nicaragua, the neighbouring country, and localities along the river that forms the international border was observed, although mostly through identifiable routes.

# Characterization of micro-areas

This analysis across micro-areas showed that movement between localities was the main factor associated with variations in malaria transmission across the micro-areas, along with economic activities which expose population during peak biting hours (e.g. jellyfish fishing) in some of those micro-areas. Table 1 (Additional file 1)

Coverage of access to malaria diagnosis and treatment was analysed by mapping all active microscopy and Rapid Diagnosis Test (RDT) posts (Fig. 4). Additionally, contextual factors that determine availability of diagnosis and treatment were also analysed for each micro-area, especially working hours of health centres, stock outs, availability of electricity for microscopy, security situation and its effect on working hours and access of MoH personnel to the locality and even the human factor like performance of health personnel.

The entomological analysis included data from 11 sentinel sites across the country. Each carries out routine surveillance activities to determine the distribution, seasonality, and bionomics of anophelines. In the case of Gracias a Dios department, the entomological sentinel site in Yahurabila, Puerto Lempira municipality, shows a predominance of *Anopheles albimanus* as the principal malaria vector across the year. Also, higher outdoor biting rates have been routinely reported.(22) Considering the homogeneous eco-system of the department, the current data was assumed to be representative for the rest of the localities of the department. Vector control interventions largely include the mass distribution of Long-Lasting Insecticidal Nets (LLIN) and Indoor Residual Spraying (IRS), with 82,000 LLINs delivered, most of them in Gracias a Dios. Additionally, of the 51,000 houses sprayed in 9 states, 2,224 houses were covered by two rounds of IRS in Gracias a Dios in 2016.

As a final part of this operational investigation, gaps were detailed to the lowest level possible and documented. An in-depth discussion of the findings, gaps and responses were carried out with the involvement of the local health personnel. A detailed response plan was thus consolidated and collated in a 'micro-plan' for each micro-area focussing on modifying the health response tailored to local risk factors such that it improves access to diagnosis and treatment and use of preventive interventions. Table 2 (Additional file 2) These micro-plans support the National Strategic Plan for Malaria 2017–2020 and were used as a basis for funding requests from donors like the Global Fund.

# Discussion

The Global Technical Strategy for Malaria advocates for "*Malaria surveillance as a core intervention*"; here we describe an effort of using the available data from the malaria surveillance system triangulated with other contextual information to analyse, characterize, and provide a response tailored to the malaria transmission dynamics at a very local level.

Over the past few years, pressure has been laid on the identification of epidemiological hotspots and tailoring of interventions.(23, 24) Several groups have explored potential approaches to stratify using high resolution risk maps created by using a comprehensive set of information. Use of these would have further improved the identification of hotspots in our work and to that end a risk map was developed in 2014 but could not be repeated annually. (25)We considered that the microstratification methodology should be replicable at least annually and by the local health staff; thus, tools available at their disposal were considered for our work. Additionally, there is considerable lack of information to guide tailored malaria interventions in an elimination setting.

In 2018, the WHO recommended a framework for stratifying malaria risk based on receptivity, vulnerability, epidemiological determinants, and interventions.(8). Cohen et al, suggest that optimal operational planning requires use of more than one aspect of risk assessment such as incidence. (26) Our work employed the use of all the factors recommended by WHO by operationalizing available information for risk stratification and tailoring interventions, albeit at a micro level, and moving away from use of a single aspect of risk

– annual parasite incidence, as was done in previous years. It also shows how to employ the operative knowledge of MOH health personnel at the national and local level to develop a bottom-up response plan. (2)

A key aspect evidenced here is the increasing availability of malaria detection through RDT posts or microscopy in each micro-area. Given the socio-demographic characteristics, medical attention in Honduras is largely through rural health centres and a few tertiary level institutions. (15) The voluntary collaborator (ColVol, acronym in Spanish) network for malaria came into being in the late 20th century in Honduras and these were trained in attending patients and taking blood slides to be subsequently revised by the microscopist and treatment administered by the ColVol. Since 2014, they have been trained in using RDTs to ensure prompt diagnosis and treatment, especially in Gracias a Dios department (27). The ColVol network has been used by the country for other interventions like active case detection, distribution of LLINs and IRS, information, and education, among others. Our work provides information for better placement and orientation of this network to malaria endemic areas as malaria incidence declines.

The detailed study of health system factors at each locality and micro-area was vital for operational planning. Management of health systems is the Achille's heel of all disease elimination programmes and the major reason for failures or exceptional delays.(28) Our approach takes the health system into account as vital parameter, analyses deficiencies, proposes solutions and local operational plans for their implementation.

Nonetheless the micro-stratification and the resulting operational planning is but an initial step towards improving response, the final goal. We consider that microstratification must be dynamic exercise that changes as determinants vary and should be revised and update by the local health personnel, preferably annually. This requires capacity development at the local level to both conduct as well as update the micro-stratification and micro-planification plan, and thus requires the methodology to be both simple yet encompassing the most important factors using information available to the local health staff.

Together with biological factors related to vector and parasites, human behaviour is considered key in the process of transmission on malaria-endemic settings across the world. (8, 29, 30) The correlation between infection risk and the human movement patterns is well established and several studies have tried to use information like census tracts, mobile phone use among other methods to understand this. However, given the low amount of data available at the granularity needed, this aspect is highly limited in low transmission malaria dynamics settings. (10, 25, 31–33) The use of local knowledge was an innovative way in our study to determine patterns of human movement and use it in conjunction with known malaria risk areas to determine vulnerability at the locality level. Undocumented migration both to and from Nicaragua as well as drug trafficking other than local socio-economic activities were also considered. However, it did not capture variations by seasons and other ad-hoc reasons like festivals, sports, or religious activities. Tools to measure vulnerability and temporal changes therein at the level of each locality are required.(34)

Among the limitations of this study are the availability and quality of data, and inherent biases in its generation. It is recognized that the national malaria program of Honduras has achieved tremendous advances on its pathway to elimination, as is demonstrated through the expansion of its diagnosis and treatment network via community health posts using RDTs and sustaining passive case detection by microscopy over the last ten years, case based surveillance and improving malaria case investigation capacity across the country.(4, 6, 7, 35) However, coverage of surveillance measured through number of suspected cases detected by geographical area and time was available at the level of locality was available for previous years but not for 2016. Geographical availability of diagnosis and treatment was used as a proxy for surveillance coverage. Nonetheless, we consider that highlighting this gap and demonstrating its need is a product of our approach. Need of more data or improvement in its quality should be a product of and not a pre-requisite for its use and analysis. Deficient information on site of infection, inability of mapping 15% of confirmed cases, combination of data from both passive and active case detection were also substantial limitations. These and other potential deficiencies of the national malaria surveillance system need be rectified for malaria elimination in Honduras. (2, 8, 9)

A limitation of this exercise was the lack of operational methods for receptivity characterization at the level of each locality. Receptivity was used as binary variable of being present or absent in our work. Data for adult entomological indicators were available from only one sentinel site in Gracias a Dios but information on breeding spots and larval density was available from most localities. The historic use of environmental methods for malaria control in Central America have led to extensive larval surveillance capacities and their implementation, further strengthened by various projects like the DDT/GEF project in 2004–2007.(36) However, no clear correlation between larval density or presence of breeding sites and the receptivity grade within a place currently exist. Further tools are required for the use of this information as well generally to establish receptivity gradient of a locality based on routine entomological surveillance information.

Data from the sentinel site in Puerto Lempira shows *An. albimanus* as the major malaria vector. This is are consistent with Escobar et al. who reported *An albimanus* as the most abundant and widespread anopheline specie in the country. (37) This, together with insecticide susceptibility surveillance data form Gracias a Dios, support the current national vector control strategy against major based on use of IRS and LLINS using mostly pyrethroids. (38, 39) Insect populations generally response as community individual, the basis of sentinel site surveillance. However, several studies have shown that some characteristics like insecticide resistance can be developed as a local event shaped by environmental variations. (40) This is a common characteristic found in African anophelines but not well studied on neotropical anophelines. (40, 41) As we get closer to elimination, improvement in coverage of entomological surveillance will be required to provide more evidence based tailored interventions. (8, 9, 38)

Our results show the viability of delimitation of micro areas in malaria-endemic areas of Honduras. Even when limitations could threaten the accuracy of this work, it is clear that this provides a more targeted strategy for diagnosis and treatment, surveillance and vector control and therefore, a clear way to malaria elimination in Honduras. The results of this methodology, beyond contributing to the scientific community, have served to reorient the activities and interventions included in the National Strategic plan for Malaria Elimination 2018–2023 of Honduras. (9, 15) This approach has been adopted by the Pan American Health Organization and has been adapted and applied in Central American countries for strategic and operational planning for malaria elimination. (42–44)The methodology provides the use of local available data to improve response and is especially useful in those countries where malaria incidence is high enough that each case can't be followed individually yet the disease is concentrated in a few districts / municipalities.

Several methods have been used since 1950s to identify and prioritize malaria control intervention in endemic countries, from annual parasite incidence at state level to high resolution risk maps. Evidence-based decisions are the core recommendation of WHO guidelines; however, limited country evidence is published on this subject and moreover, scientific reports from the American countries are basically historical.(45) To the best of the authors' knowledge, the results here are the first efforts to characterize local malaria transmission hotspots in Mesoamerica using an operational investigation approach based on available epidemiological and entomological data, human movement information, ecological and demographic parameters, and health system factors at the level of a locality. National malaria elimination programs must include a similar evidence-based approach using all available data for operational planning as a priority to achieve the global goal of malaria elimination.

# Conclusions

Malaria elimination pathway urges the adoption and implementation of different strategies on national policy; microstratification appears as the main recommendation for guide the strategic planning on malaria-endemic countries. Here we show the on-field micro-stratification process of 12 "micro-areas" carried out in one endemic department of Honduras. This information has been useful and included as part of the National Strategic Plan for Malaria Elimination providing a more targeted strategy for diagnosis and vector control interventions and therefore, a clear way to malaria elimination in Honduras.

# List Of Abbreviations

GTS
Global Technical Strategy
WHO
World Health Organization
PAHO
Pan American Health Organization
CHAI
Clinton Health Access Initiative

# Declarations

***Ethics approval and consent to participate.***

Not applicable

***Consent for publication***

Not applicable.

*Availability of data and materials*

***Competing interest***

The authors declare that they have no competing interests.

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***Authors' contributions***

JON, PS, REM and EB conceived and contributed with study design, JON, PS, REM and JRV participate on funding acquisition and field-work supervision, PS, EB and JRV participate on data curation and analysis, PS and DE wrote the first draft of manuscript. EB and JRV contributed to the final version. All authors read and approved the final manuscript.

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# Tables

**Table 1.** Evaluation of the risk factors and the network health by stratification in Honduras

| Micro-area | | Risk factors | Health network factors |
|---|---|---|---|
| 1 | Kauquira Sector | *) Permanent jellyfish processors | *) Inadequate supply chain. Insufficient logistics (motorcycles and boats) |
| | | *) Population living in temporary shelters | *) Lack of supervision |
| | | *) Presence of military personnel concentrated in Yahurabila and risk of malaria export to other areas of the country. | *) Insufficient logistics (motorcycles and boats) |
| | | *) Population without personal protection measures in hours of vector bite (T-shirt, underpants) | *) Lack of electricity. |
| 2 | Nicaragua border | *) Refugees in shelters | *) Limited diagnostic network |
| | | *) Mining activities | *) Lack of supplies |
| | | *) Citizen insecurity, does not offer guarantees for interventions in communities | *) Trained but limited human resources |
| | | *) Social conflicts over land tenure in Nicaragua | |
| | | *) Movement of localities accessible via land and water between them (Honduras - Nicaragua) | |
| 3 | Tikiraya, plain of Lakatabila, Auka and Lisagnipura | *) Neglected area, own conditions - unprotected houses and breeding sites | *) Very limited diagnostic network (number of col-vols versus number of communities) |
| | | *) Mobilization of people between communities | *) Inadequate supply chain |
| | | *) Communities predominantly of the Miskito language | *) Lack of monitoring and supervision |
| | | *) Intermittent or no radio communication | *) Trained but limited human resources |
| 4 | Raya | *) Permanent hatcheries due to swampy areas | *) Three health units, only one with a microscopist. |
| | | *) 16 communities - 11 small (<1000 inhabitants) | |
| | | *) Illicit drug trafficking activities | *) Trained but limited human resources |
| | | *) Mobilization towards Nicaragua, Kauquira, head of Puerto Lempira | |
| 5 | Barra Patuca | *) An isolated community difficult to access with high cost of mobilization | *) Overpopulation in jurisdiction assigned to the health center (3500 people) |
| | | *) Rural conditions - several permanent breeding sites | *) Lack of regular monitoring and evaluation |
| | | *) Continuous mobilization to Brus Laguna | *) High turnover of health promoters and limited technical capacities |
| 6 | Ibans-Cocobila and other nearby localities | *) Permanent jellyfish processors - people living in unprotected houses | *) Localities belonging to different municipalities |
| | | *) Illicit drug trafficking activities | |
| 7 | Patuca River Basin (Ahuas and Wampusirpi) | *) Mosquito breeding sites in the streets due to water accumulation in sub-urban and rural areas | *) Human resources with limited technical capacity. Private Hospital, 3 Health Unit with 4 technicians, 39 col-vol (9 locations), 9500 population |
| | | *) Transit zone to and from headwater communities such as Wampusirpi, Puerto Lempira and Brus Laguna. | |
| 8 | Puerto Lempira center (Brus Laguna) | *) Breeding sites during rainy seasons | *) 2 microscopists - Center and one in CMI, 2 technicians per 4000 inhabitants, |

| | | | |
|---|---|---|---|
| | | *) Wooden houses on rollers | *) Scarce LLIN´s promotion |
| 9 | Lower Aguán Valley (Colón and Olanchito) | *) Presence of scattered cases | *) Very limited diagnostic network (number of col-vols versus number of communities) |
| 10 | Sula Valley (Cortés and El Progreso) | *) Most cases correspond to *P. Vivax* | *) Limited inputs for response and research |
| 11 | El Paraiso and Francisco Morazán | *) Mobilization of people between and within communities | *) HR with limited technical capacity |
| | | *) Transmission related to economic activities behavior | *) Lack of trained human resources |

**Table 2.** Response plan at the health network level and health policies according to stratification in Honduras

| Micro-area | | Health Network response | Political -strategic responses |
|---|---|---|---|
| 1 | Kauquira Sector | *) Improve microscopy conditions in health center and keep human resources | *) Biweekly visits to the population dedicated to the harvest of jellyfish.<br><br>*) Install Col-Vol post with RDT.<br><br>*) Monthly proactive detection during the season |
| | | *) Maintain high coverage (> 80%) with mosquito nets throughout the area | *) Mosquito nets for population dedicated to jellyfish activities |
| | | *) Monthly follow-up visits by the Puerto Lempira municipality team | |
| | | *) Local on-site training in outbreak detection, analysis, and response | |
| 2 | Nicaragua border | *) Motorcycle vehicle for transportation | *) Refugee coverage - col-vol with RDT, mosquito nets, monthly visits by health personnel. |
| | | *) Eliminate the charge for consultation of Lps 10 as administrative payment | |
| | | *) Field training of local ES staff | |
| | | *) Maintain current coverage and have a stock of medicines and mosquito nets as a local response to outbreaks. | |
| 3 | Tikiraya, plain of Lakatabila, Auka and Lisagnipura | *) Train col-vol in RDT and Microscopists | *) Alliance with education, Church - follow-up to LLIN´s and take full treatment |
| | | *) Increase in Microscopist personnel, train them in PDR and microscopy. | *) Partnerships with NGOs - monitoring and promoting use of LLIN´s and management of supply chain |
| | | *) Large-scale intervention - BAC - IVM | |
| | | *) Forms, documents in Miskito language (pilot) | |
| 4 | Raya | *) Have emergency support from LLIN´s (BAC) | *) Logistics for mobilization (2 motorcycles / 1 boat with gasoline quota) |
| | | *) Supervision of the use of LLIN´s with local participation | *) Alliances with NGOs for the installation of LLIN´s, promotion, and supervision of its use |
| | | *) 100% col-vol with RDT for PCB | *) Cross-border information exchange (Waspan,Nicaragua) |
| | | *) Follow-up 15 days at col-vol (2 TSA) | |
| 5 | Barra Patuca | *) Hematic survey scheduled in time of high transmission at the beginning of the stage | *) Promotion of the use of LLIN´s by col-vol, technicians, social actors, and NGOs (MIMAT) |
| | | *) Active investigation of cases and control of outbreaks | |
| | | *) Network of volunteer collaborators with an active role in response to outbreaks | |
| 6 | Iban-Cocobila and other nearby locatilites | *) Use Ibans as primary diagnostic laboratory | *) Promotion of the use of LLIN´s by technician, col-vol, NGO (MIMAT) and community alliances. |
| | | *) 100% of cases investigated focusing on *P. falciparum* | |
| | | *) Alignment of intersectoral interventions in the area | |
| | | *) Coverage of people related to jellyfish activities | |
| 7 | Patuca river basin (Ahuas and Wampusirpi) | *) Active proactive searches scheduled at the beginning of the stage | *) Col-vol with RDT in strategic areas and near the mobilization site |
| | | *) Monitoring for *P. vivax* reinfections up to 6 months | *) Local HR training in local analysis, case |

| | | | |
|---|---|---|---|
| | | | investigation and response |
| | | *) Network of ColVol with an active role in response to outbreaks | |
| 8 | Puerto Lempira center (Brus Laguna) | *) Information exchange with municipalities for cases introduced from others. | *) Use of mass media for malaria communication (local radio stations) |
| | | *) Quality control when filling out the suspicious malaria case notification form (M1) and malaria case investigation form (M7) | *) Functioning of the sectoral table to address malaria |
| 9 | Lower Aguán Valley (Colón and Olanchito) | *) Alignment of actions and analysis of information | *) Follow - up of training to HR / col-vol on transmission and study of outbreaks |
| | | *) Passive surveillance aimed at improving access and early diagnosis | *) Supervision of active search for suspected cases, supervised treatment, and follow-up |
| 10 | Sula Valley (Cortés and El Progreso) | *) Detection for prompt diagnosis in nearest detection center, without considering municipalities boundaries | *) Monitoring of cases with modified IVM implementation |
| 11 | El Paraiso and Francisco Morazán | *) Weekly information exchange at the local level (nominal basis) | *) Monitor the increase in col-vol and its active role in case investigation and response |
| | | *) Local on-site training in outbreak detection, analysis, and response | *) Monitor the increase in sentinel sites for febrile surveillance |
| | | | *) Tracking the use of travel and occupation history as key information in fever patients. |

# Figures

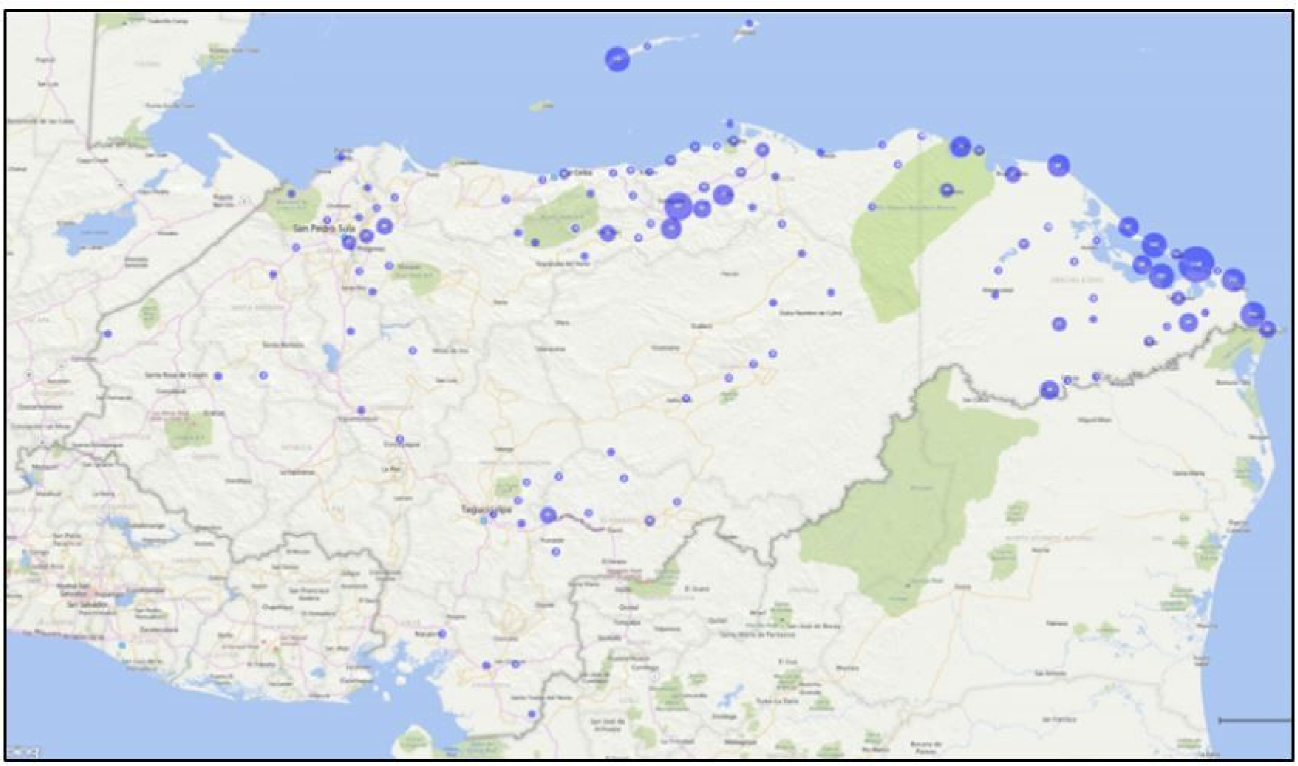

Figure 1

Map with cases geo-referenced at locality level, Honduras, 2016. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

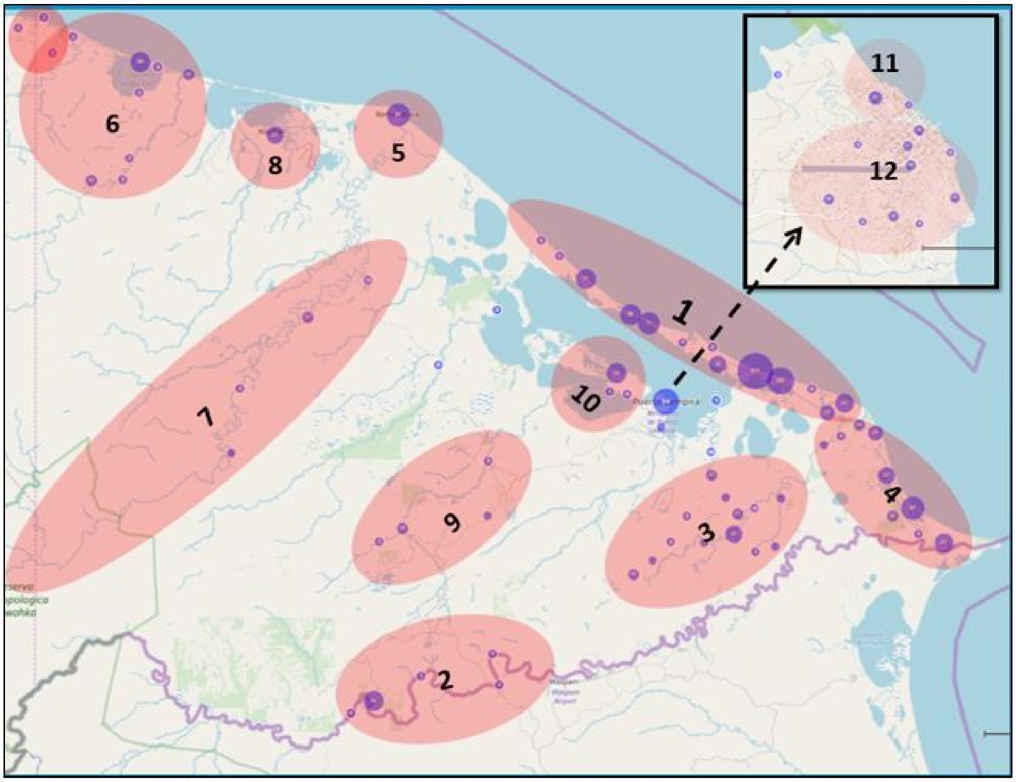


**Figure 2**

Map of malaria micro-areas: 1) Kauquira Sector, 2) Suhi, 3) Tikirraya, 4) Raya, 5) Barra Patuca, 6) Ibans-Cocobila and other nearby localities, 7) Patuca River Basin (Ahuas and Wampusirpi), 8) Brus Laguna, 9) Mocoron, 10) Tansin , 11) Puerto Lempira town centre I, 12)Puerto Lempira town centre II Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

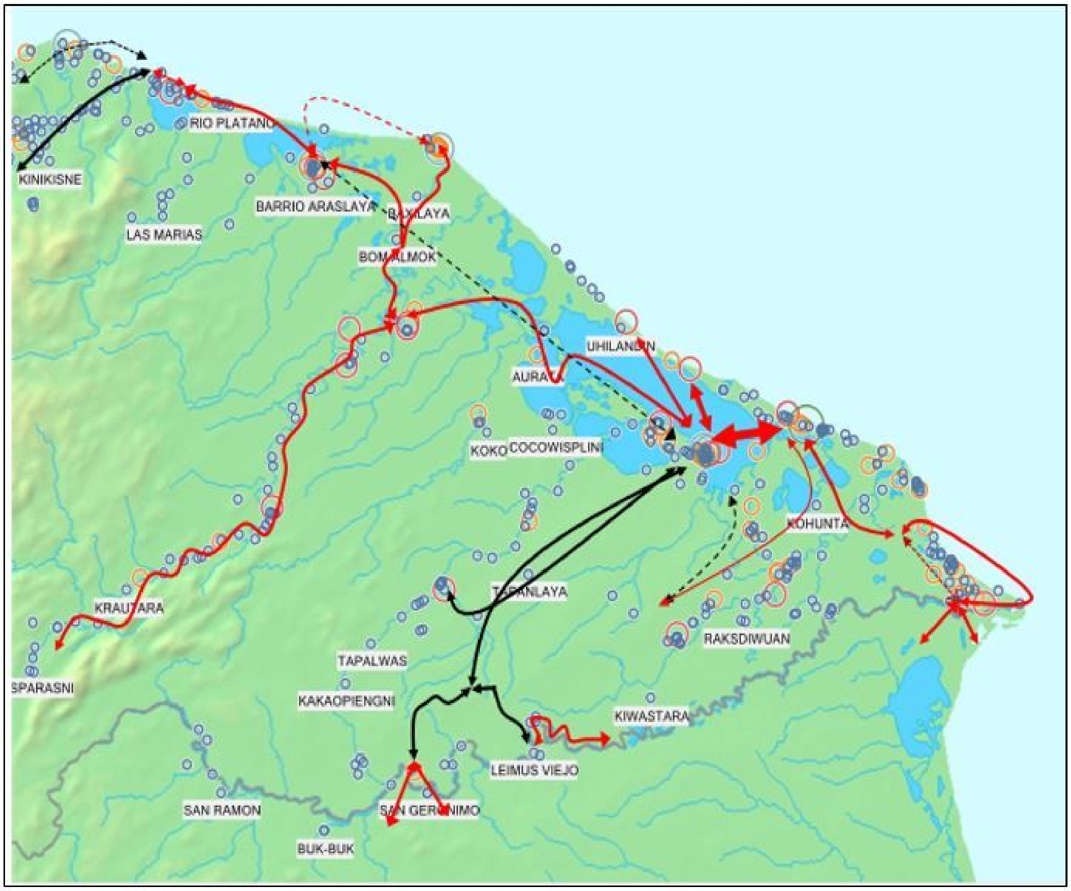


**Figure 3**

Map of mobilisation routes: land (black), water(red) and air (black interrupted) routes between localities of Gracias a Dios state, Honduras. Thickness of the line varies by the intensity of movement of people. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

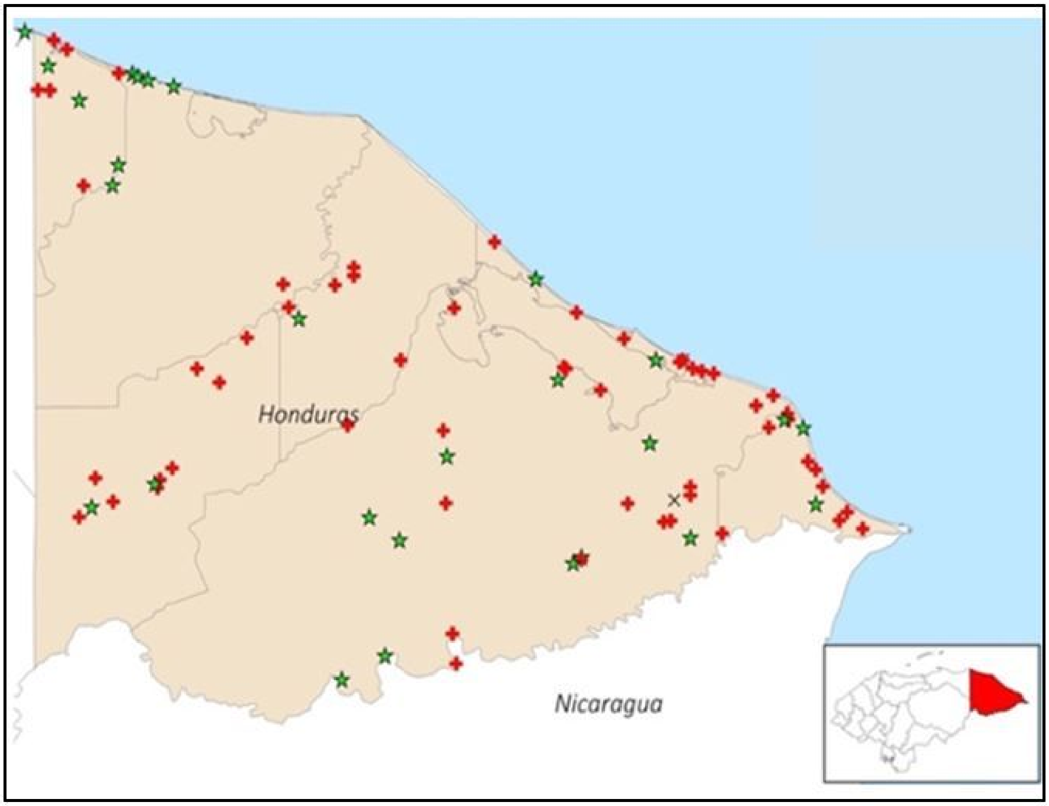


**Figure 4**

Coverage of malaria diagnosis in Gracias a Dios: Map indicating with green: health centres with microscopy/RDTs, red: Community Health Worker with RDTs Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.