Current state of residual malaria transmission in the Amazon region: knowledge gaps and potential control strategies

Gissella M. Vasquez
Department of Entomology
U.S. Naval Medical Research Unit No.6 (NAMRU-6)

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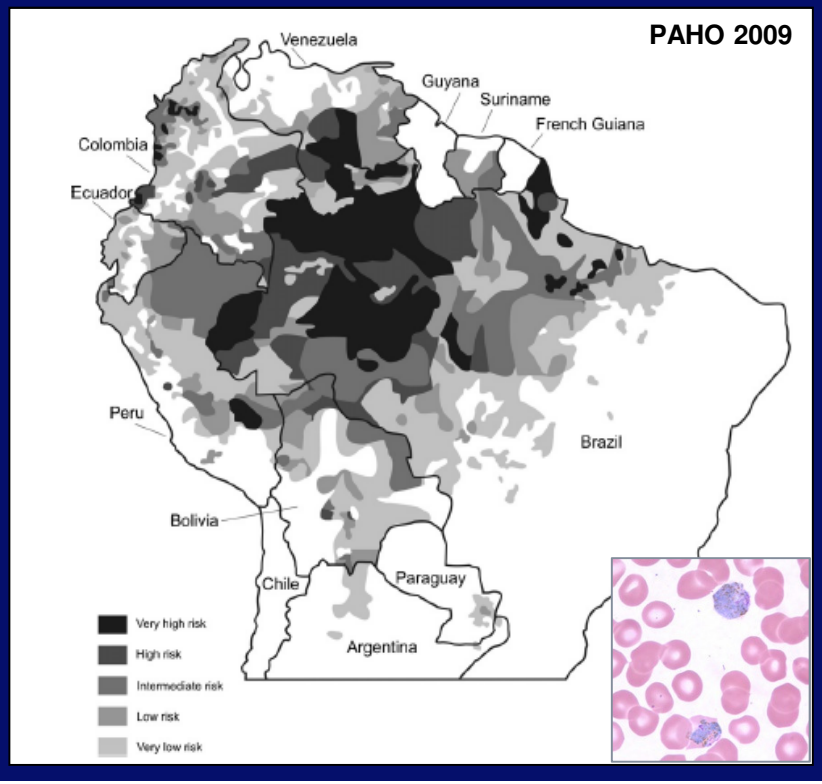
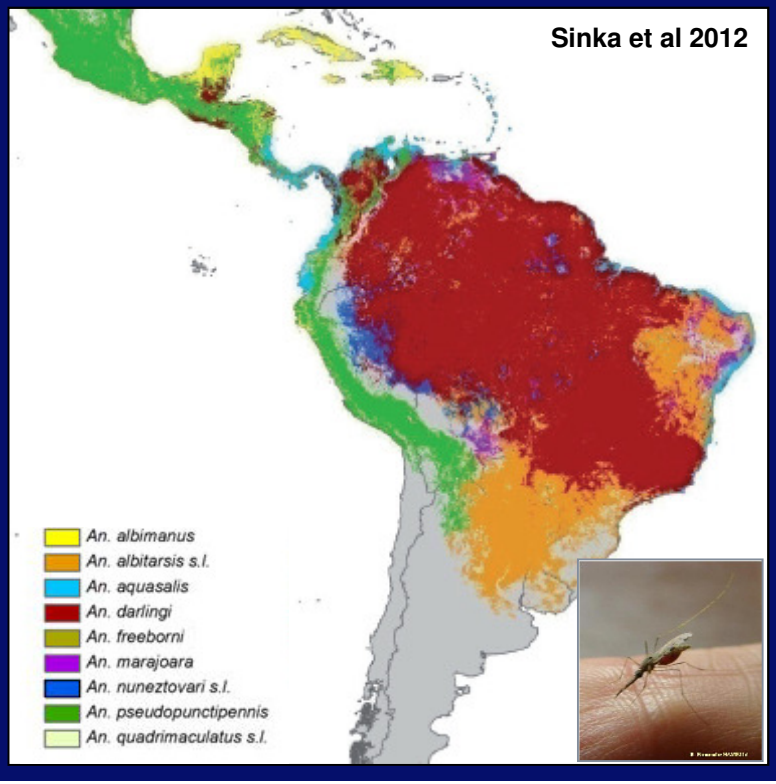
Malaria in the Amazon

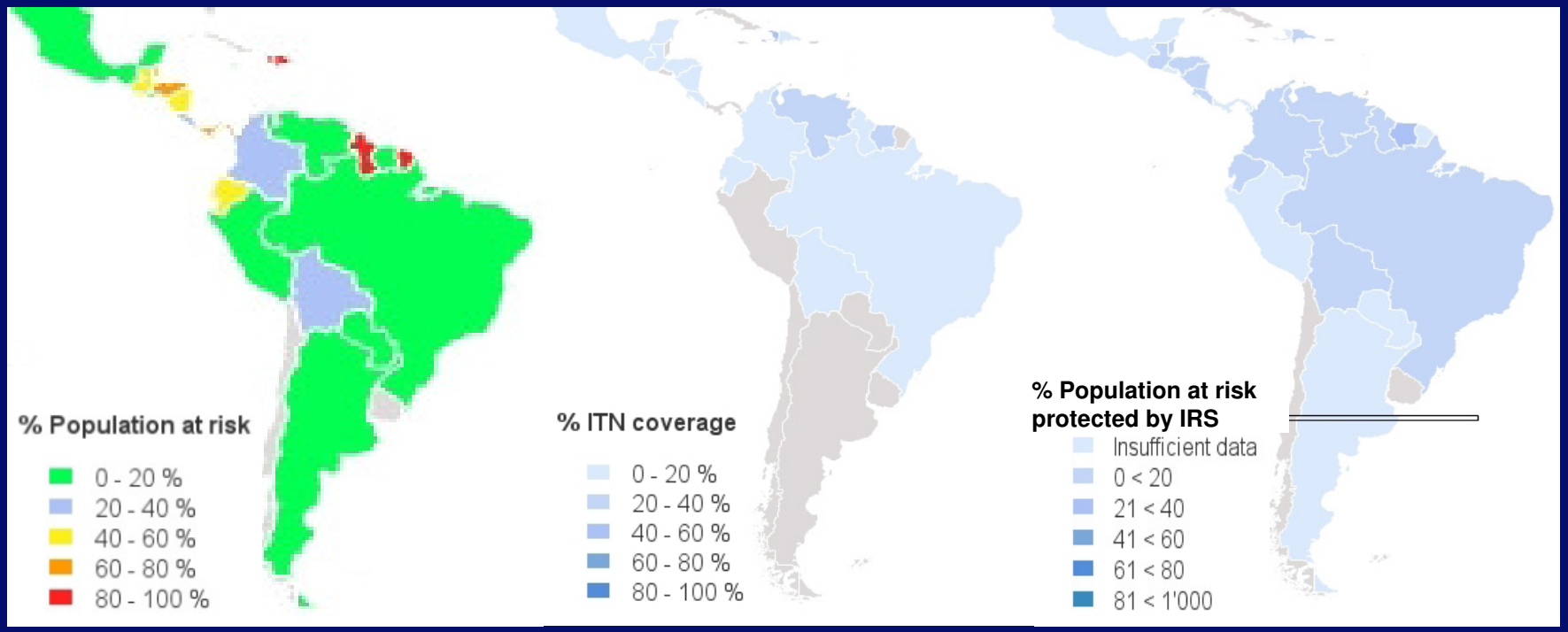
- In 2012: 469,000 malaria cases in the Americas, 91% in Amazonian countries, >70% *Plasmodium vivax* (WHO 2013). Transmission risk: low to moderate, hotspots.
- Diversity of anopheline vectors, *An. darlingi* most important.





ITNs and IRS coverage in the Amazon

- Variable use, less than 80% coverage in all countries.
- Few efficacy studies: ITNs provided 50% malaria reduction in Colombia and Venezuela.
- Differences in vector and human behavior: ITNs and IRS may not be effective in all transmission settings.



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Residual transmission in the Amazon?

- ITNs and IRS may not provide transmission control:
- Malaria transmission hotspots: mining/logging camps and new agricultural settlements in remote forest areas composed mainly of malaria-naïve immigrants that live in open dwellings and move frequently.

- Amazonian anopheline vectors: exophagic/endophagic, unimodal, exophilic. Environmental changes alter their behavior and ecology.

- Medical care and vector control is limited in these human settlements: residual transmission foci.

- Low transmission areas where context-specific malaria control strategies are lacking.

Residual transmission in the Amazon

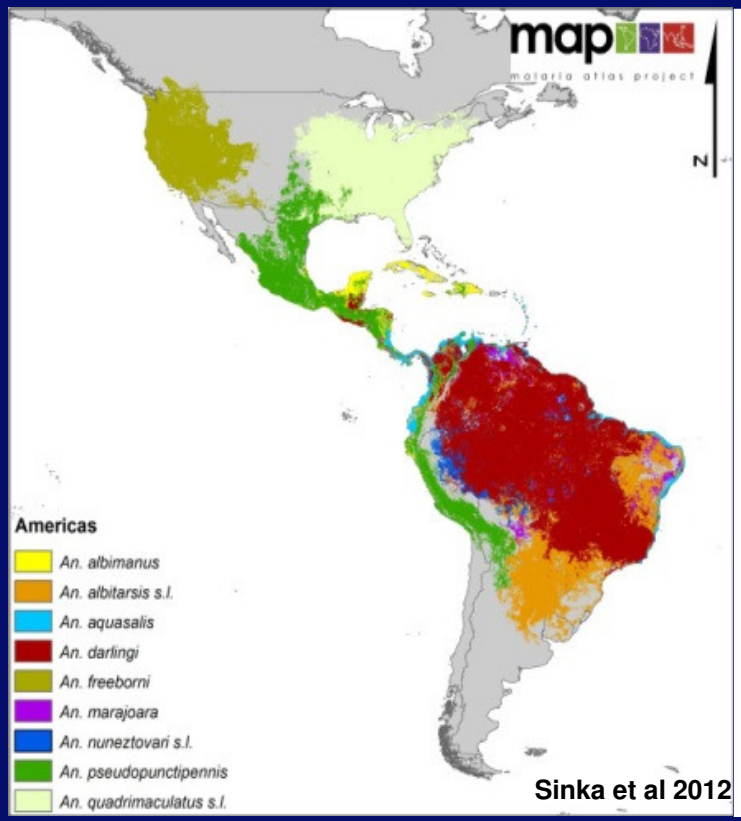
- Residual transmission likely but it is not yet perceived as a problem:
  - NMCPs following standard malaria control practices that do not directly address this issue.
  - NMCPs conducting very limited active/passive surveillance in highly-mobile populations in remote forest areas difficult to access.

- Evidence for the role of residual transmission in maintaining malaria in the Amazon needs to be gathered and quantified so that it is clear that it should be a target for malaria eradication.

What information is available to address residual transmission?

Malaria vector distribution and bionomics

- Distribution of DVS, *An. darlingi* most dominant.
- Behavioral plasticity: natural/man-made larval sites, anthro/zoophilic, exo/endophagic, dusk/night/dawn biting, exo/endophilic.



Sinka et al 2012

Table 6 Adult feeding and resting behaviour

Species	Source	Feeding habit		Biting habit		Biting time				Pre-feeding resting habit		Post-feeding resting habit	
		Anthro-pophilic	Zoo-philic	Exo-phagic	Endo-phagic	Day	Dusk	Night	Dawn	Exo-philic	Endo-philic	Exo-philic	Endo-philic
An. albimanus	Summary	2	2	9	2		7	9	0			1	3
An. albimanus	TAG	•	•	•	•		•	•		•		•	
An. albitarsis	Summary	2	2	4	3		7	3				2	
An. albitarsis	TAG	•	•	•	•		•	•		•		•	○
An. aquasalis	Summary	1	1	2	2	1	2	1		1		1	
An. aquasalis	TAG	•	•	•	•		•	•		•		•	
An. darlingi	Summary	12		9	6		15	23	3	1		2	
An. darlingi	TAG	•	○	•	•		•	•	•	•		•	
An. freeborni	Summary	1	1										
An. freeborni	TAG	•	•	•	•		•	•	•	•		•	
An. marajoara	Summary	2	2	3			4	1		1		2	
An. marajoara	TAG	•	•	•	•		•	•		•		•	
An. nuneztovari	Summary	2	4	5	1		3	1		1		2	
An. nuneztovari	TAG	•	•	•	•		•	•	•	•		•	
An. pseudopunctipennis	Summary	3	2	3				1			1	1	2
An. pseudopunctipennis	TAG	•	•	•	•			•		•		•	•
An. quadrimaculatus	Summary		3	2			1		1	2		2	
An. quadrimaculatus	TAG	•	•	•		○	•	•	•	•		•	

TAG: Rubio-Palis & Manguin (unpub. obs., 2009, 2010), • = typical, ○ = examples exist. Numbers indicate the number of studies that found adults under each listed circumstance. *Anopheles albitarsis* refers to the *An. albitarsis* complex, which includes *An. albitarsis*, *An. albitarsis* sp. B, sp. E and *An. deaneorum*. *Anopheles marajoara* is listed separately.

Sinka et al 2010

Integrated vector management efficacy

- *Anopheles darlingi* predominant species in new agricultural settlements in Western Brazil.
- Positive correlation between *An. darlingi* HBRs and MIR.
- Control measures (ITN/IRS) reduced *An. darlingi* HBRs and EIRs.

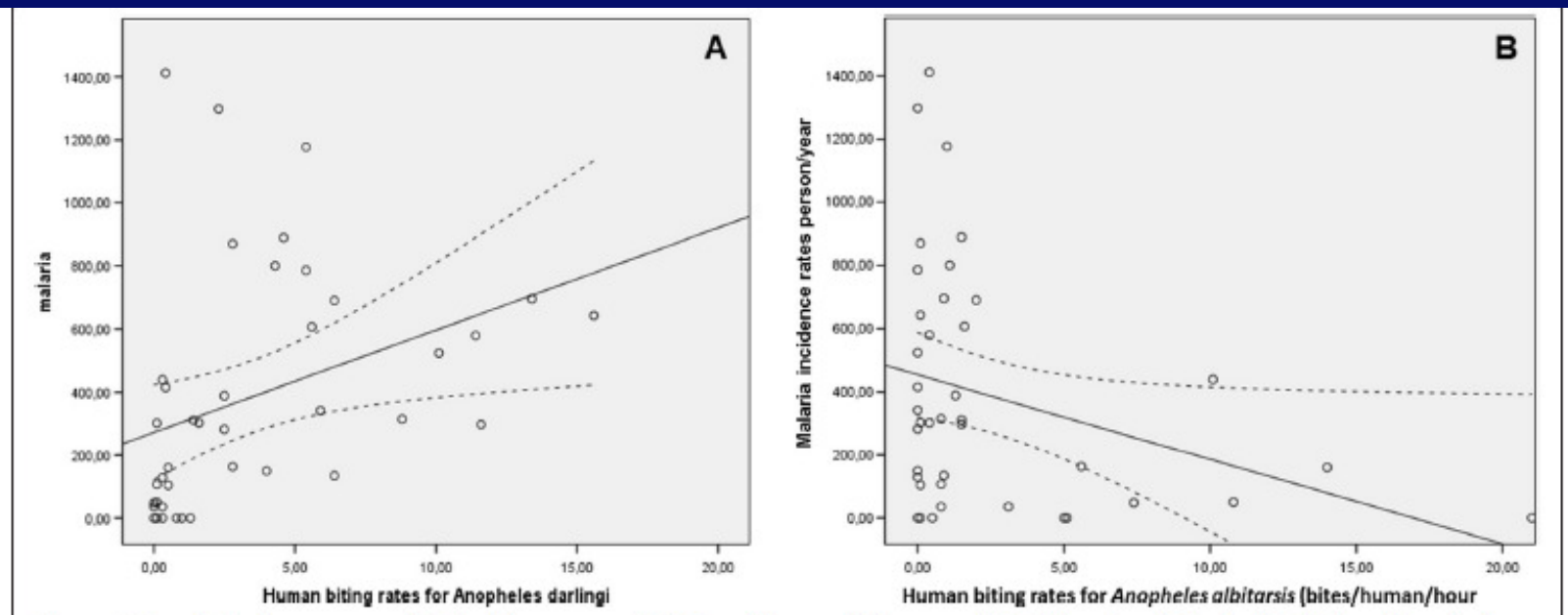


Figure 3 Correlation between malaria incidence rates (MIRs) and human biting rates (HBRs) for *Anopheles darlingi* (A) and *Anopheles albitarsis* (B), with 95% confidence intervals (dashed lines), respectively.

Martins-Campos et al. 2012

Anopheles collection methods for quantifying entomological parameters

- Different collection strategies for different epidemiological situations (landscape, vector, human culture/behavior).
- HLC/Shannon trap most accurate, effective anopheline collection method.

Number of anophelines caught using seven collection methods during the first comparison during seven consecutive nights at sunset for 4 h (40 min + 20 min interval) in a total of 18.7 h of collection in 1996, Peixoto Farm, municipality of Peixoto de Azevedo, state of Mato Grosso, Brazil

Anopheline species	Human landing catch n (%)	Shannon nylon human n (%)	CDC CO_2 + octenol n (%)	CDC UV n (%)	CDC light + CO_2 n (%)	CDC light n (%)	CDC light + octenol n (%)	Total (n)
An. strodei	220 (54.1)	125 (30.7)	58 (14.3)	2 (0.5)	2 (0.5)	0 (0)	0 (0)	407
An. marajoara	116 (57.1)	54 (26.6)	23 (11.3)	4 (2)	5 (2.5)	0 (0)	1 (0.5)	203
An. darlingi	111 (44)	136 (54)	1 (0.4)	4 (1.6)	0 (0)	0 (0)	0 (0)	252
An. triannulatus	100 (35.6)	179 (63.7)	0 (0)	0 (0)	2 (0.7)	0 (0)	0 (0)	281
An. nuneztovari	92 (52.6)	71 (40.6)	3 (1.7)	7 (4)	0 (0)	2 (1.1)	0 (0)	175
An. rangeli	57 (45.2)	68 (54)	0 (0)	0 (0)	1 (0.8)	0 (0)	0 (0)	126
An. oswaldoi	9 (23.7)	29 (76.3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	38
An. argyritarsis	7 (100)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	7
An. benarrochi	4 (80)	1 (20)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	5
An. rondoni	2 (22.2)	7 (77.8)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	9
An. evansae	0 (0)	4 (100)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	4
Total	718 (47.6)	674 (44.7)	85 (5.6)	17 (1.1)	10 (0.7)	2 (0.1)	1 (0.1)	1,507

CO_2: carbon dioxide; UV: ultraviolet light.

Bento Pereira Lima et al. 2014

Populations at increased risk of residual transmission

- Highly mobile populations (clinical/asymptomatic) in areas difficult to access in terms of malaria treatment and vector control:
  - Agricultural settlements
  - Gold mining and logging camps
  - Military outposts

Ongoing efforts/resources against residual transmission

1. Combined entomological/disease surveillance in hotspots: vector species composition, behavior, molecular characterization, correlation of densities with incidence rates.

2. Characterization of *An. darlingi* behavioral/physiological patterns, ecology, population structure, insecticide resistance.

3. Establishment of *An. darlingi* laboratory colonies.

4. Evaluation of new surveillance/control assessment tools.

5. Identification and treatment of asymptomatic cases.

6. ITNs efficacy studies: vector control and human practices.

Development of new tools for residual transmission control

1. Continuous, cost-effective vector surveillance: odorant-based traps, treated fence barriers, vector exposure biomarkers.

2. Novel control strategies: spatial repellents, toxic sugar baits, durable wall liners, transgenic mosquitoes, new drugs.

3. Models to quantify residual transmission.

4. Alternative insecticides (chemical and biological) to reduce development of insecticide resistance.

5. Rapid, reliable diagnostics and effective treatment for asymptomatic cases.

6. Acceptability and cost-effectiveness of new tools.

Partnerships to target residual transmission

- Strategic partners:
  - NMCPs
  - WHO RBM
  - USAID/AMI
  - PAHO/RAVREDA
  - BMGF
  - Research and academic institutions working in the region: 2 ICEMRs, CDC-CAP, NAMRU-6.

Goal: Develop evidence-based, strategic plans to control residual transmission in the Amazon taking into account eco-epidemiological context (vector, pathogen, human variation).

Role of residual transmission work stream

- Establish a regional initiative, (e.g. South American Residual Malaria Transmission Working Group- SARMaT WG) headed by regional experts (strategic partners) to increase exchange and dissemination of relevant information from current malaria surveillance and control activities.
- SARMaT WG will use existing initiatives such as WHO RBM/PAHO, AMI/RAVREDA, BMGF to access the larger network of research/academic institutions conducting epidemiological, entomological and social studies relevant to residual transmission.
- SARMaT WG will reach potential industry partners from multiple sectors and encourage them to participate so that their efforts can be focused through close communication with regional NCMPs and scientific institutions.

Role of Residual transmission work stream

- Following successful establishment of research priorities and goals, a regional plan approved by each participating partner will be developed. SARMaT will use the existing initiatives to disseminate information through traditional and online media, and ultimately develop an online database where partners can contribute epidemiological, social information regarding populations at risk; information on anopheline vector behavior, abundance, geographic distribution, insecticide resistance; efficacy of treatment (malaria drugs) and vector control practices, both standard and novel.

- SARMaT will support continuous technology transfer and capacity building in NCMPs.

Acknowledgements

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