Swiss TPH
Swiss Tropical and Public Health Institute
Schweizerisches Tropen- und Public Health-Institut
Institut Tropical et de Santé Publique Suisse
Assoziiertes Institut der Universität Basel

Department of Epidemiology & Public Health
Health Systems Research and
Dynamical Modelling

Modelling vector control interventions against malaria in Haiti

Thomas Smith

On behalf of Swiss TPH malaria modelling team

RBM-VCWG

Geneva

31 January 2019

Motivation

- Most field trials of the impact of vector control interventions against malaria have been carried out in Sub-Saharan Africa.
- Malaria vectors elsewhere differ from African vectors in key behavioural parameters
- Mathematical models can be used to infer the likely impact of different interventions from entomological field data

Approach

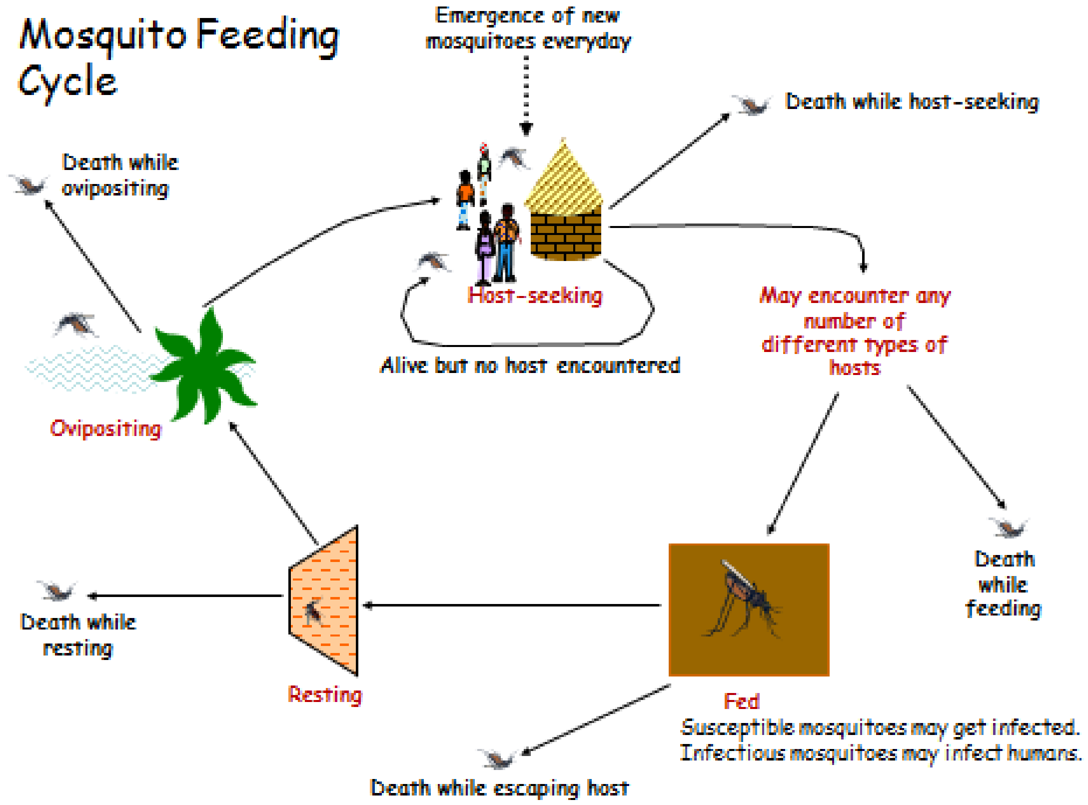
- Discrete time model of the oviposition cycle.
- Incrementally build-up a library of field data (not formal systematic review)
- Use the model to predict the impact by coverage, on vectorial capacity

We started with:

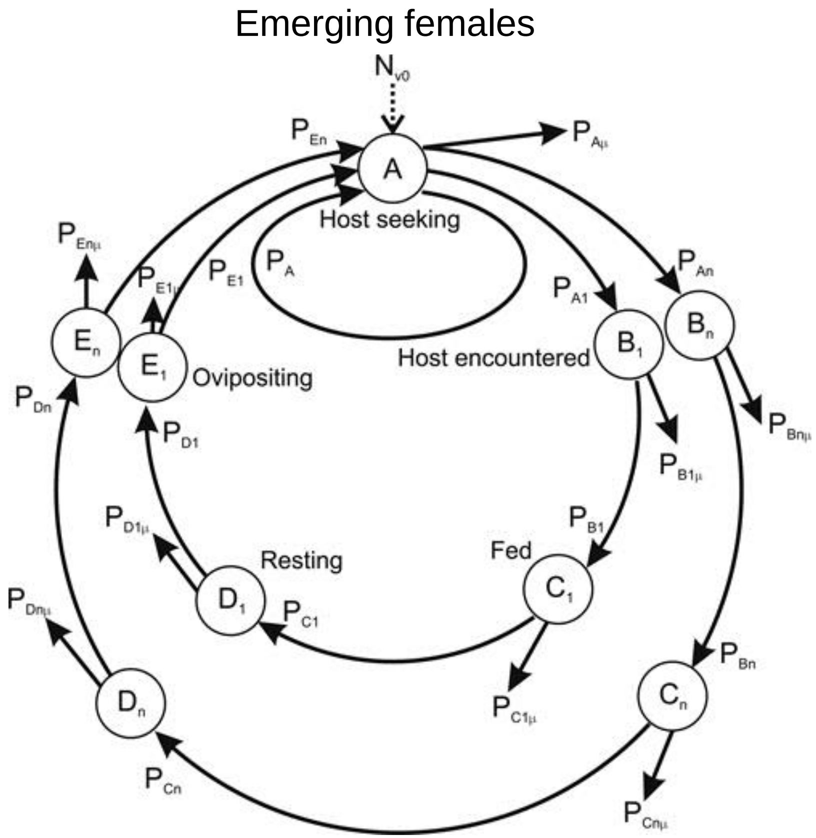
An. aconitus	*An. balabacensis*	*An. minimus*	*An. dirus*
An. albimanus (Haiti)	*An. barbirostris*	*An. sinensis*	*An. flavirostris*
	An. coluzzii	*An. subpictus*	*An. funestus*
An. annularis	*An. culicifacies*	*An. sundaicus*	*An. gambiae s.s.*
An. arabiensis			*An. maculatus*

Entomological Model of Chitnis *et al*, 2008, 2010

Swiss TPH



Discrete time population model of vector

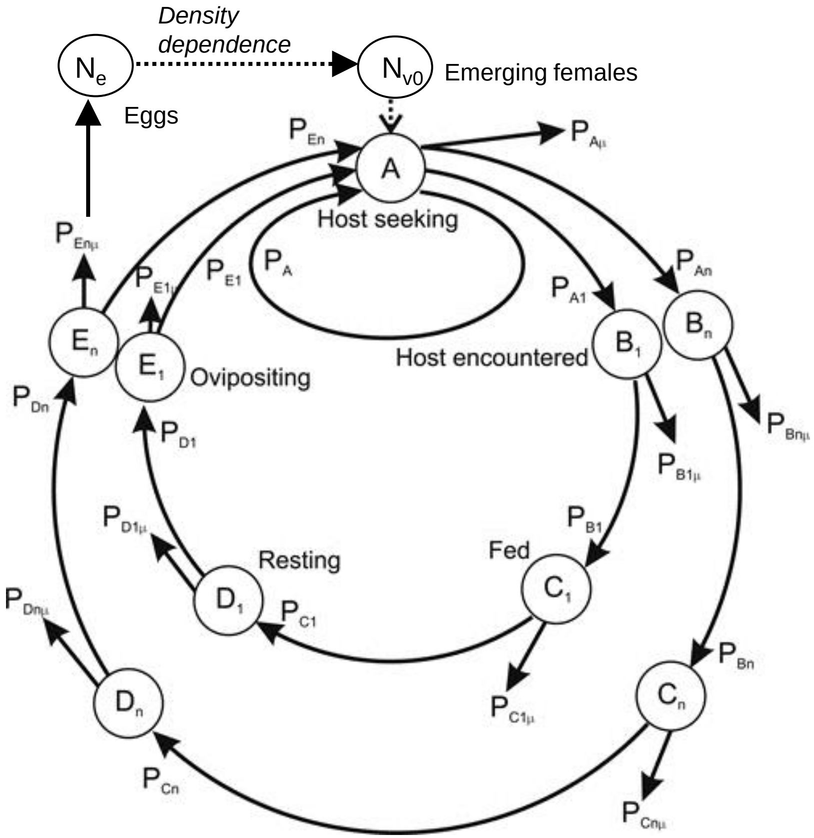


Different kinds of hosts (with or without intervention, human or animal) correspond to different circles

At each stage the mosquito can progress or die.

Based on Saul et al, (1989); Discrete time extension of Ross-Macdonald model

Discrete time population model of vector



The model can be extended to allow for density dependence in larval stages.

This is essential for modeling interventions that may drive the vector to extinction.

Required data

Swiss TPH

- Build up a database of entomological parameters for each vector species:

Vector-specific Entomological Parameters

Parous rate

Sac rate

Proportion of a day that a mosquito actively seeks a host

Time required for a mosquito that has encountered a host to return to host-seeking

Time required for sporozoites to develop into mosquitoes

Oocyst development time

Biting Rhythm

Host-specific Entomological Parameters

Probability of biting host i

Probability of finding a resting place after biting host i

Probability of surviving resting phase after biting host i

Probability of laying eggs and returning to host seeking after biting host i

Proportion of susceptible that become infected after biting host i

Availability rate to mosquitoes of host i

Intervention-specific Entomological Parameters

Probability of biting host i

Probability of finding a resting place after biting host i

Probability of surviving resting phase after biting host i

Probability of laying eggs and returning to host seeking after biting host i

Availability rate to mosquitoes of host i

Standard entomological data

Swiss TPH

For decades, medical entomology has used more or less standard approaches for measuring malaria transmission:

- Based on the Ross-Macdonald formula for R_0 :

$$R_0 = \frac{m a^2 b_1 b_2 e^{-\mu T}}{r \mu}$$

m : Number of mosquitoes per host.
a : Biting rate of mosquitoes on their host.
μ : Mortality of adult mosquitoes
T : Incubation time of the the parasite in the mosquito vector
r : Recovery rate of humans
b1 : Infectiousness of hosts to mosquitoes.
b2 : Susceptibility of humans

m, a from CDC light traps or human landing collections (host seeking)

a from the proportion recently fed, among resting mosquitoes

μ from the parous rate (among host seeking mosquitoes)

r, b_1 and b_2 are properties of the infection in humans and treated as invariant

Bionomics of *Anopheles albimanus*

- *An. albimanus* is the main malaria vector in Central America and The Caribbean
- Field data for *An. albimanus* from 3 locations: Dame Marie, North and South of Haiti and Laborde and for *An. gambiae* from Tanzania
- Important bionomic differences between *An. albimanus* and *An. gambiae*

Standard parameters of the entomological model without intervention

Parameter	Symbol	Value
Maximum length of time that a mosquito searches for a host in one 24 hour period if it is unsuccessful	τ_d	0.33 days
Probability that a mosquito bites after encountering a host	P_B	0.95
Probability that a mosquito finds a resting place after biting	P_C	0.95
Probability that a mosquito survives the resting phase after biting	P_D	0.46
Probability that a mosquito lays eggs and returns to host-seeking after biting	P_E	0.88

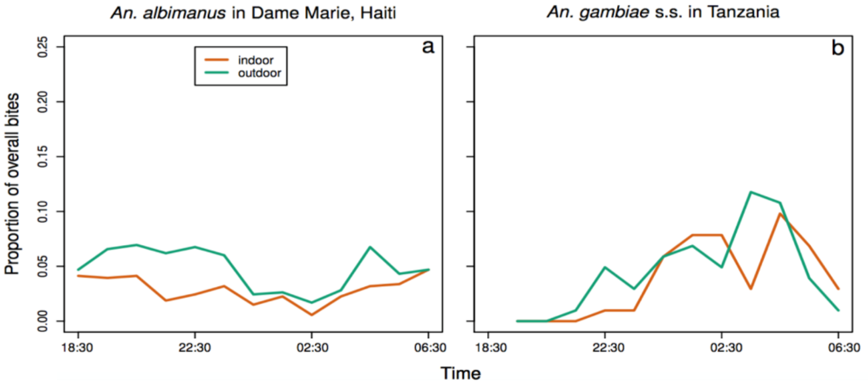
Bionomic parameter values of *An. albimanus* in Hispaniola extracted from the literature

Parameter	Symbol	Value	Reference
Human blood index	χ	5.4%	Mekuria et al
Parous rate	M	0.484	Molez et al
Resting period duration	τ	3.5 days	Molez et al
Sac rate	A_0	0.405	Molez et al

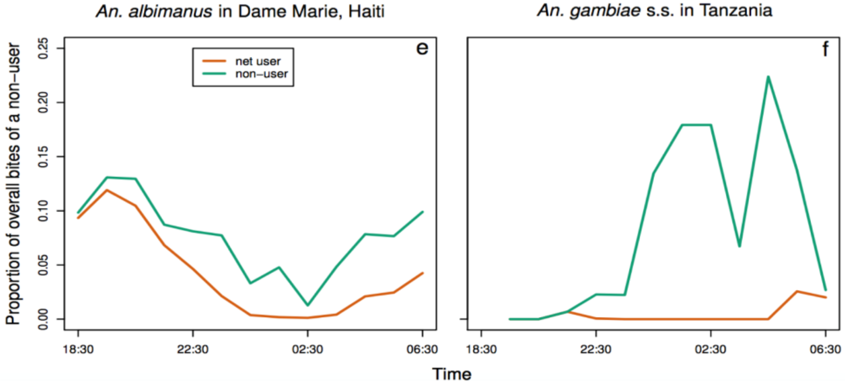
Briët *et* al., under review, 2019

Parameterisation of LLIN model

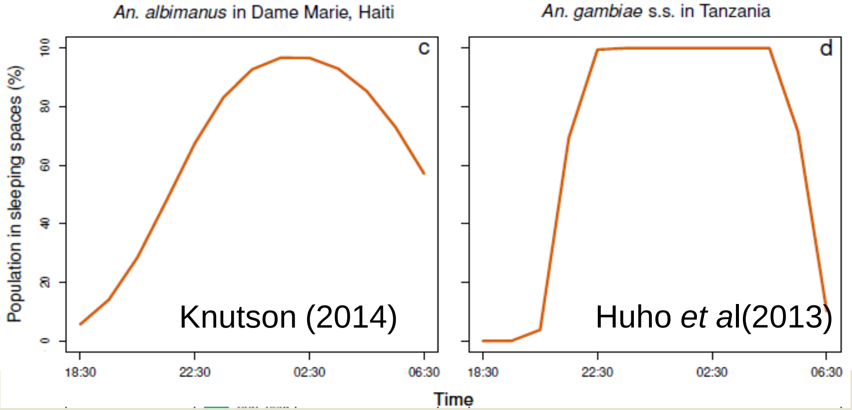
- Biting rhythms (mosquito collectors):



- Exposure of the population



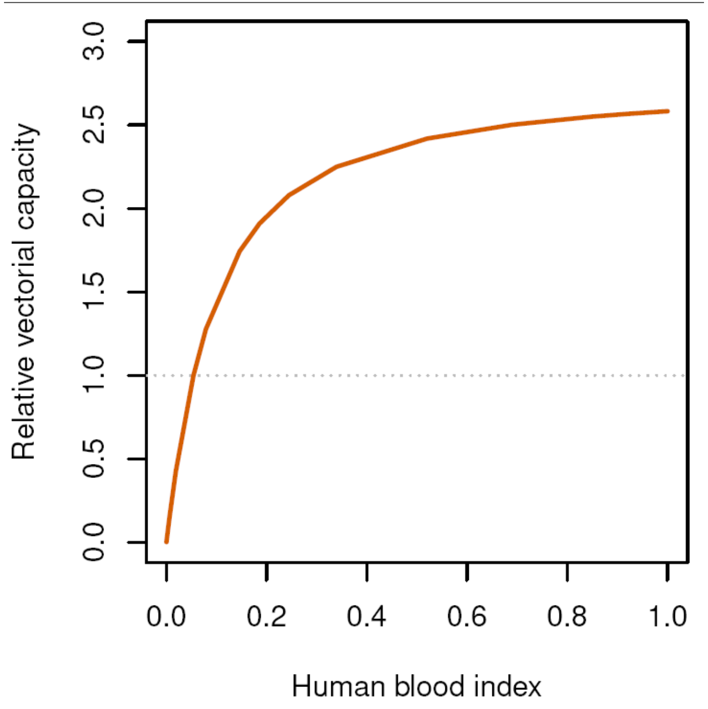
- Time people go to bed:



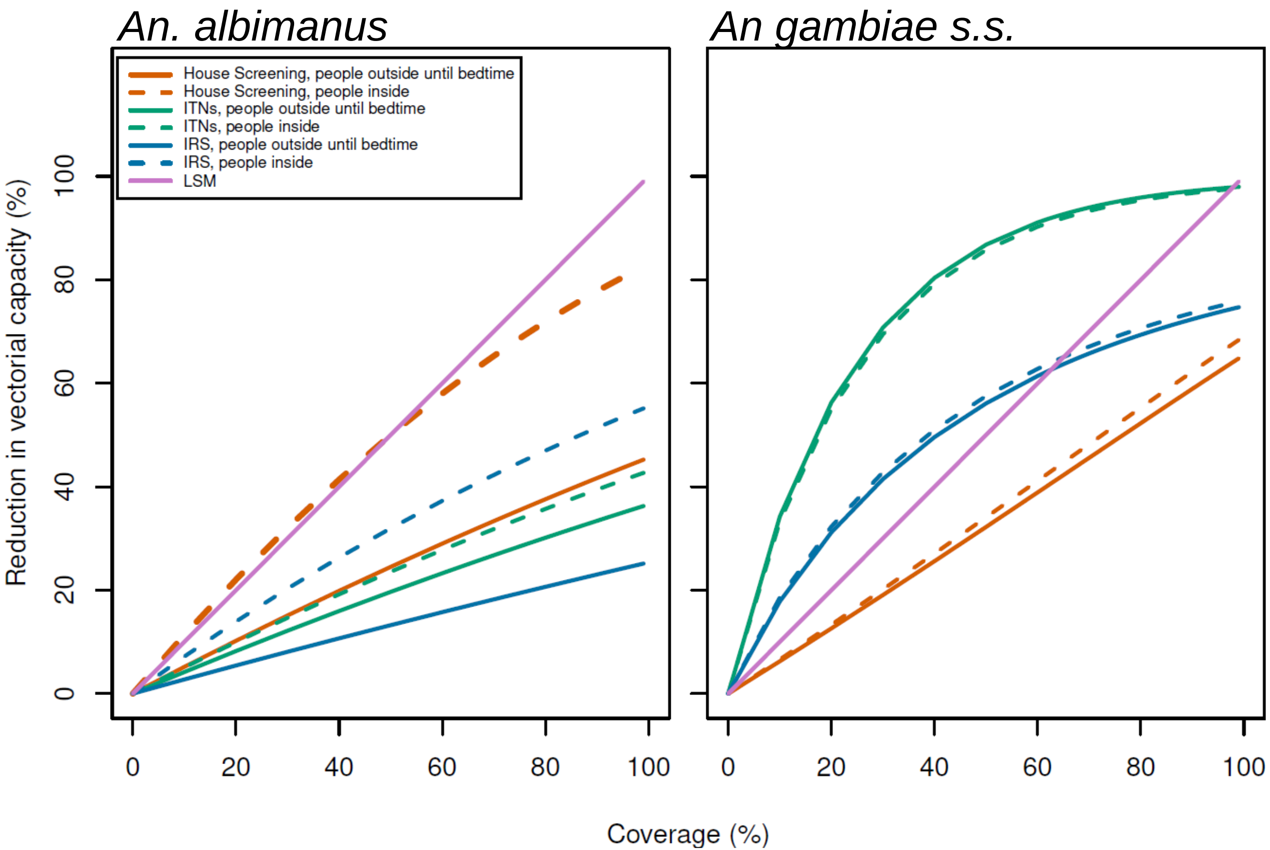
Briët *et al.*, under review, 2019

Predicted effects of deterrency and zooprophylaxis

- *An. albimanus* is an opportunistic feeder.
- This means that
  - (i) It can be deterred easily from biting humans (potential of spatial repellents).
  - (ii) Zooprophylaxis may be effective
  - (iii) These two effects should be synergistic.



Comparison of impacts of different interventions



- At similar coverage, house screening has a higher impact than ITNs, especially if people are indoors
- IRS impact similar to ITNs if people are outdoors
- Stronger IRS impact if people are indoors

IRS = indoor residual spray, ITNs = insecticide treated nets, LSM=larval source management, δ = deltamethrin, λ = lambdacyhalothrin, NA = not applicable /

Briët *et al.*, under review, 2019

Comparison of impacts of different interventions

Swiss TPH

Per cent effect at 10% coverage of vector control and human side interventions

Intervention	Active ingredient	Evening location of people (until bed time)	*An. albimanus* northern and central Haiti	*An. albimanus* Dame Marie	*An albimanus* Laborde	*An. gambiae* s.s.
IRS	Bendiocarb	Inside	7.21	7.17	7.17	18.56
		Outside	0.40	2.74	5.13	17.81
	DDT	Inside	6.55	6.55	6.55	17.29
		Outside	0.55	2.96	4.95	17.10
	δ	Inside	2.44	2.49	2.49	22.50
		Outside	0.04	0.66	1.55	21.38
	λ	Inside	NA	NA	NA	10.05
		Outside	NA	NA	NA	9.62
ITNs	λ	Inside	0.62	4.17	7.94	34.22
		Outside	1.82	5.06	7.51	33.28
House screening	NA	Inside	11.35	11.35	11.35	6.60
		Outside	0.97	5.17	8.61	6.25
LSM	NA	NA	10.00	10.00	10.00	10.00
RTS,S vaccination	NA	NA	3.70	3.70	3.70	3.70
Test and treat	NA	NA	5.47	5.47	5.47	5.47
Case management	NA	NA	2.13	2.13	2.13	2.13

IRS = indoor residual spray, ITNs = insecticide treated nets, LSM=larval source management, δ = deltamethrin, λ = lambdacyhalothrin, NA = not applicable / available. The impacts of vector control is on vectorial capacity, and the impact of human side interventions is on the reproduction number.

Conclusions

- House-screening and repellent IRS are potentially highly effective against *An. albimanus* if people are indoors during the evening.
- This is consistent with historical impacts of IRS with DDT, which can be largely attributed to excito-repellency.
- It also supports the idea that housing improvements have played a critical role in malaria control in the Americas.
- For elimination planning, impact estimates need to be combined with feasibility and cost-analysis.

Acknowledgements

Olivier Briët

Nakul Chitnis

Daniel Impoimvil (Centers for Disease Control)

Monica Golumbeanu

Melissa Penny

Guojing Yang

Thom Eisele (Tulane University)

Swiss TPH Infectious Disease Modelling Unit

Supported by BMGF grant number OPP1032350