# Use of mathematical modeling to inform insecticide-treated bednet distribution campaigns in Haiti

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IDM symposium May 2023

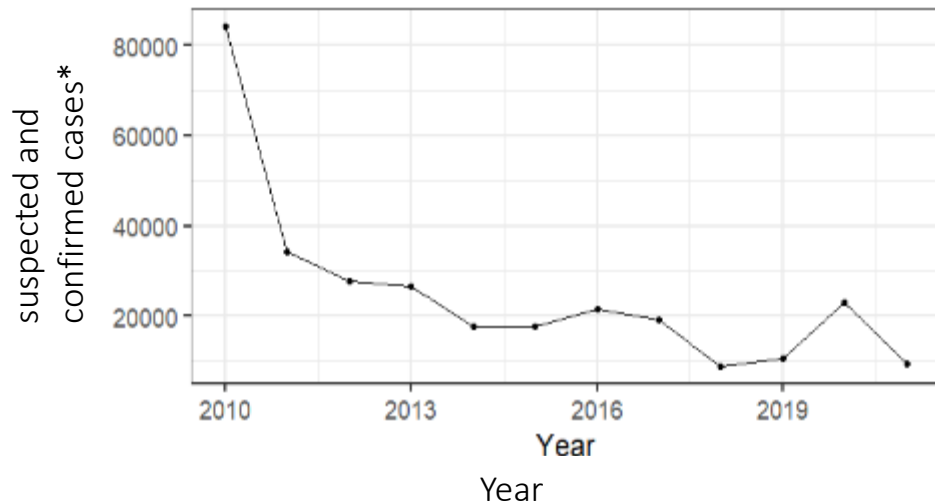# Plan

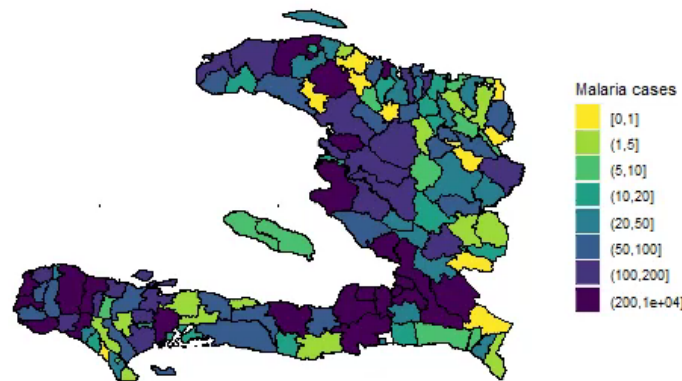Introduction and background

Materials and Methods

Results

Discussion

# Introduction and background



suspected and confirmed cases*

Year

Year: 2014



Malaria cases
[0,1]
(1,5]
(5,10]
(10,20]
(20,50]
(50,100]
(100,200]
(200,1e+04]

- In 2020, Swiss TPH/CHAI supported the PNCM for the same issue, using a mathematical model.

- **We have updated our modeling analysis to include 2020 and 2021 data.**
  Risk of malaria has changed in the country, with an upsurge of cases observed in the Sud-East department, which was not visible in the previous data.

**Objectives:**

- **Simulate future intervention** deployed in a subset of areas only, and **evaluate the impact** at the national scale

- **Identifying the administrative units** in which **LLIN distributions** would have **most impact**

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*Data from the WHO Malaria Report December 2022 p. 256-257

# Plan

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# Materials and Methods

$R_0$

Transmission intensity in each commune is represented by a local R0

Intervention:
**Distribution of mosquito nets**

Movement of people between communes (n = 125)

Trends in Malaria cases
Aggregated at the commune level
Data provided by PNCM

Data source: Digicel/Flowminder, shared via CHAI & Sudampton University
Predicted using a gravity model that Nick Ruktanonchai fitted using the CDR data. It refers to a 6 month subset from 2016.

Human mobility
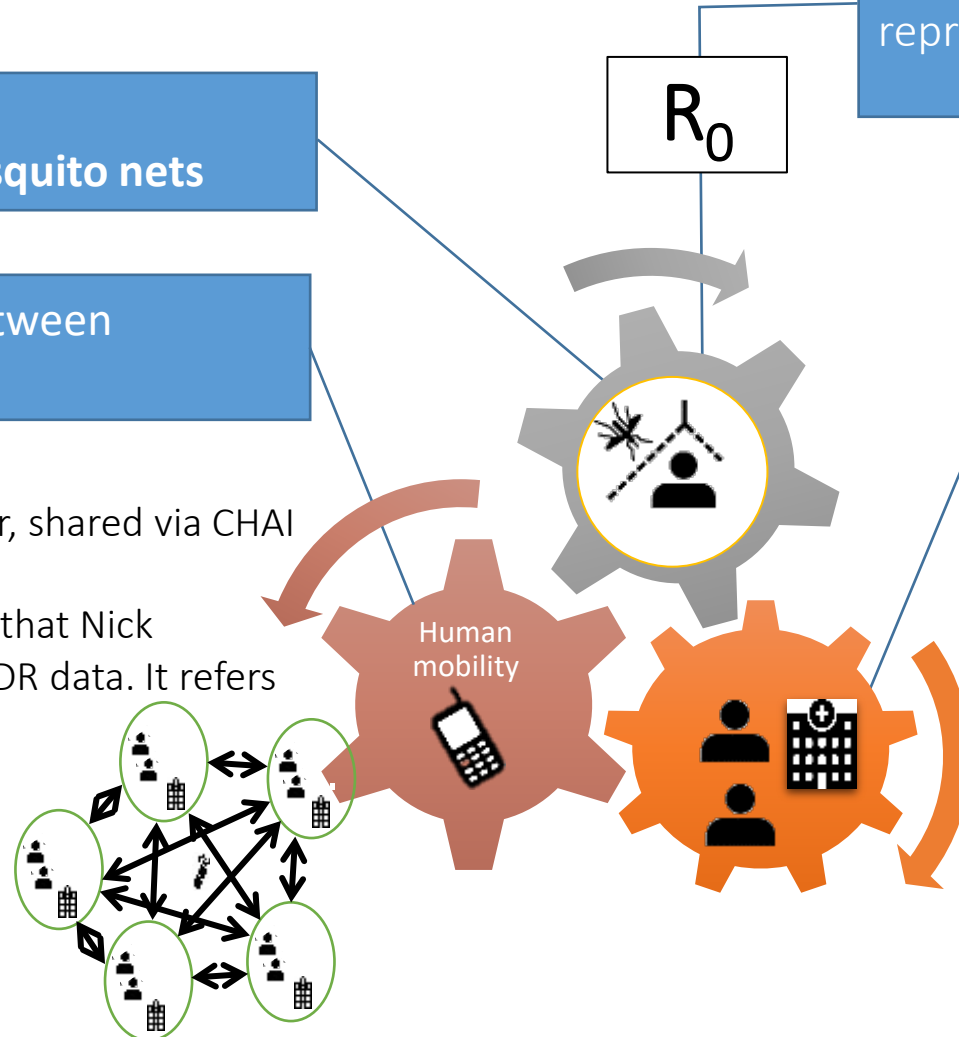
Metapopulation model:
132 parameters (6 fixed):

*Based on Ruktanonchai et al. 2016, PloS Comp. Biol*
*Based on Briët et al. 2019, Malar. J.*

=> **list of communities** where **net distribution** would have **the greatest impact nationwide**.

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# Checking the model

## National forecast

The model is calibrated using data through 2019 only.
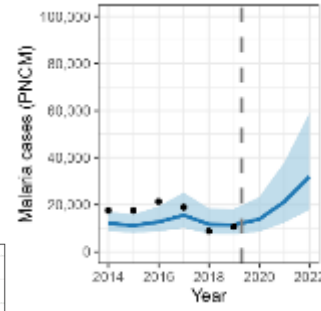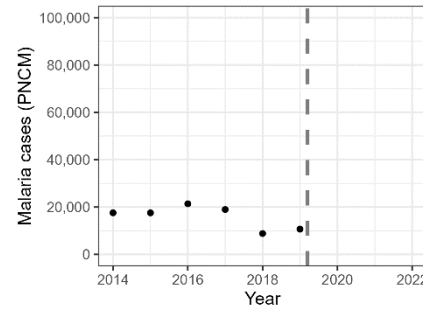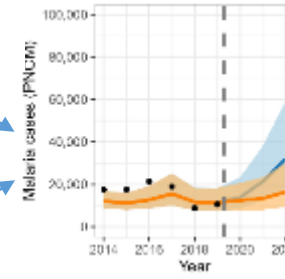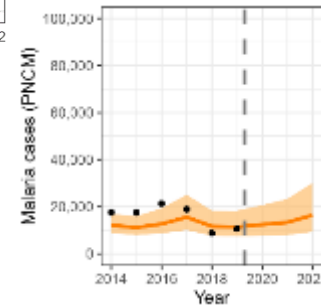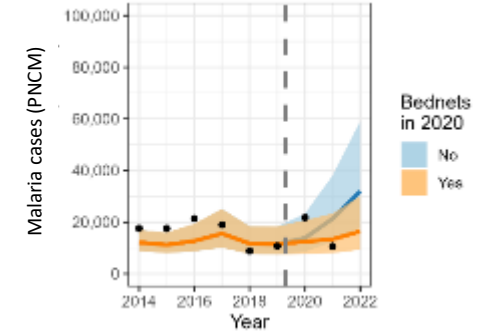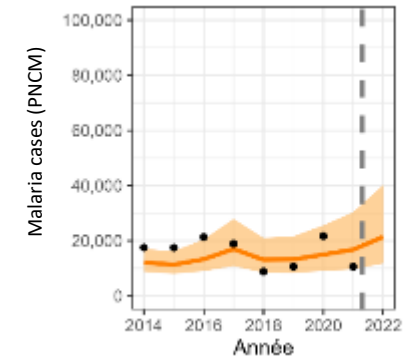
2 scenarios are compared:
1. Ignore the distribution of nets in 2020
2. Consider the distribution of mosquito nets in 2020

The **final model** uses **2014-2021 data** and includes 2020 net distribution.

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# Use of the model for prioritization of communes



Counterfactual:
No nets in 2023

Intervention:
mosquito nets in 1 commune in 2023

Human mobility

Human mobility

Cases avoided

Number of cases in 2026

Number of cases in 2026
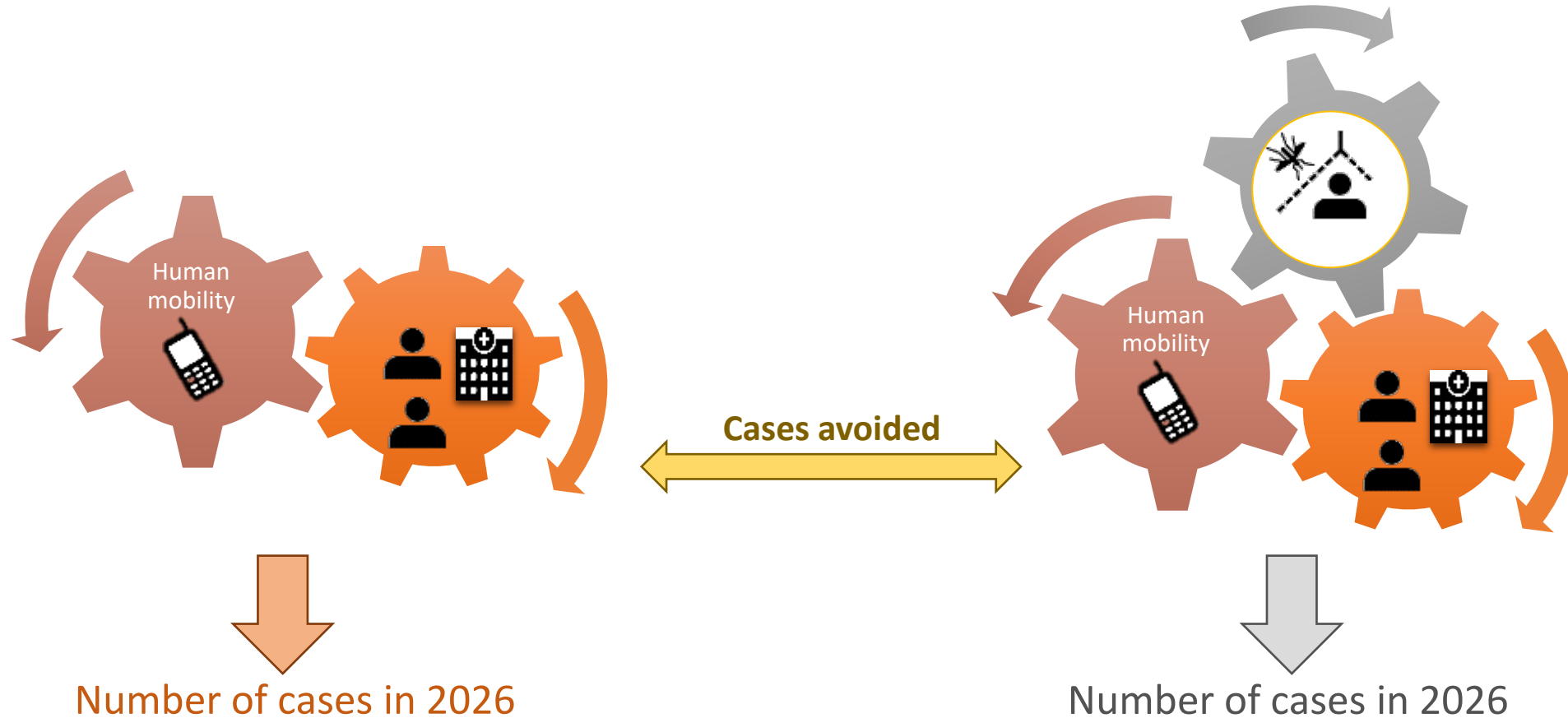
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# Prioritization of communes

*If we distribute nets in **just one commune**, what would be the impact on the national number of cases in 2026?*



Number of cases prevented
- [0,1)
- [1,10)
- [10,20)
- [20,50)
- [50,100)
- [100,1e+03)
- [1e+03,1e+05]
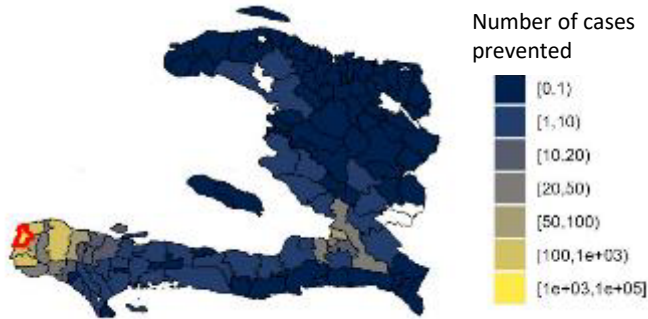
Distribution of mosquito nets only in Dame-Marie:
=> 7% reduction in national cases

*Which commune would lead to the lowest number of cases nationwide in 2026?*



A **commune** with **a high ranking** would mean that **net distribution** in that commune **would not have much impact** on **the level of cases nationwide.**

*Locations of the 20 selected communes*



Selected communes:
- Yes
- No

Grand-Anse remains the most affected department

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# Prioritization of communes

Dataset:
- Based on cases reported by PCNM
- Accessibility to cities
- Elevation, humidity, etc.

**Raw data points**
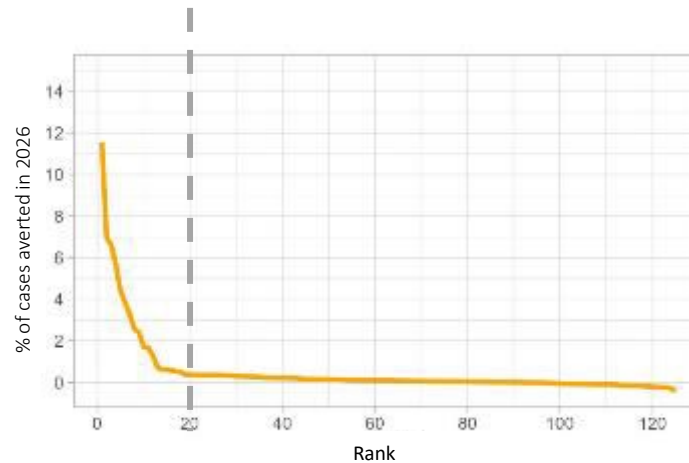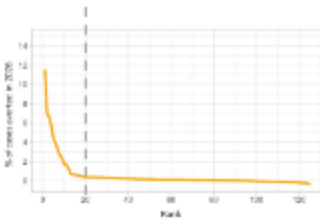
If we distribute nets in **just one commune**, what would be the impact on the national number of cases in 2025?

Number of cases prevented

Distribution of mosquito nets only in Dame-Marie:

=> 7% reduction in national cases

Which commune would lead to the lowest number of cases nationwide in 2025?

A commune with **a high ranking** would mean that **net distribution** in that commune **would not have much impact** on the level of cases nationwide.

Locations of the 20 selected municipalities

Selected communes
Yes
No

Grand-Anse remains the most affected department

**Geospatial estimates**

Selected communes
Yes
No

Selected communes:
No
Only by geospatial estimates (5)
Only by the PNCM model (5)
By both models (15)

By combining both versions of the model, **we can provide a list of communes that can be targeted for net distribution.**

map

# Communities selected for bednet distribution in 2023

Recommendations: 25 Communes
*those locations accounted for 82% of observed cases*

- Older ones and suggests to keep them
- New commune to be prioritized
  - Capital
- To be de-prioritized
  - Center
  - North-Ouest

| Commune | Department | Model 1 | Model 2 | Population | Bednets |
|---|---|---|---|---|---|
| Jeremie | Grand'Anse | 1 | 2 | 134084 | 70571 |
| Anse d'Hainault | Grand'Anse | 2 | 6 | 36401 | 19158 |
| Dame Marie | Grand'Anse | 3 | 3 | 39638 | 20862 |
| Irois | Grand'Anse | 4 | 4 | 23374 | 12302 |
| Roseaux | Grand'Anse | 5 | 12 | 35852 | 18869 |
| Les Anglais | Sud | 6 | 9 | 29891 | 15732 |
| Abricot | Grand'Anse | 7 | 5 | 37675 | 19829 |
| Bonbon | Grand'Anse | 8 | 10 | 8843 | 4654 |
| Port a Piment | Sud | 9 | 11 | 18922 | 9959 |
| Tiburon | Sud | 10 | 1 | 23279 | 12252 |
| Bainet | Sud'Est | 11 | 65 | 109341 | 57548 |
| Corail | Grand'Anse | 12 | 14 | 36708 | 19320 |
| Pestel | Grand'Anse | 13 | 24 | 39428 | 20752 |
| Beaumont | Grand'Anse | 14 | 48 | 19573 | 10302 |
| La Chapelle | Artibonite | 15 | 43 | 31461 | 16558 |
| Verrettes | Artibonite | 16 | 13 | 144863 | 76244 |
| Chambellan | Grand'Anse | 17 | 7 | 25568 | 13457 |
| Chardonnieres | Sud | 18 | 19 | 25240 | 13284 |
| Moron | Grand'Anse | 19 | 8 | 31157 | 16398 |
| ... | ... | .... | ... | ... | ... |
| Les Cayes | Sud | 30 | 18 | 166512 | 87638 |
| Coteaux | Sud | 63 | 16 | 21302 | 11212 |
| Baraderes + Grand Boucan | Nippes | 88 | 20 | 52270 | 27511 |
| Maniche | Sud | 125 | 15 | 8742 | 4601 |
| Total | | | | | 579013 |
| Delmas + Cité Soleil +Tabarre | Ouest | 25 | 17 | 1160735 | 644853 |
| Carrefour | Ouest | 20 | 28 | 525331 | 291851 |

| Commune | Département | Modèle 1 | Modèle 2 |
|---|---|---|---|
| Aquin | Sud | 122 | 25 |
| Port Salut | Sud | 33 | 38 |
| Jacmel + La Vallee | Sud'Est | 65 | 95 |
| Saint Louis du Sud | Sud | 78 | 33 |

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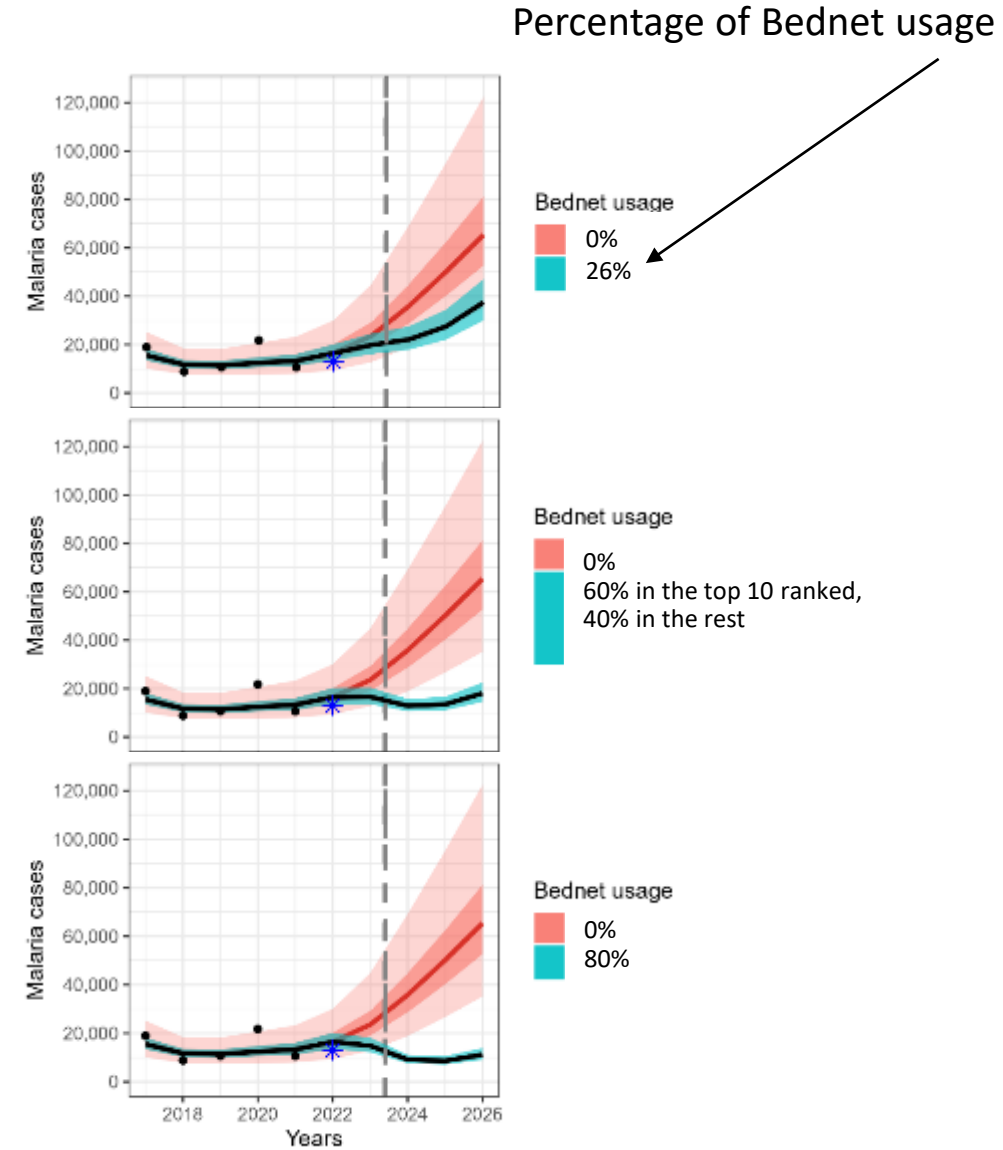# Impact of increasing Bednets usage

Distribution campaign 2023

Percentage of Bednet usage

Bednets campaign in April 2023
- No
- Yes
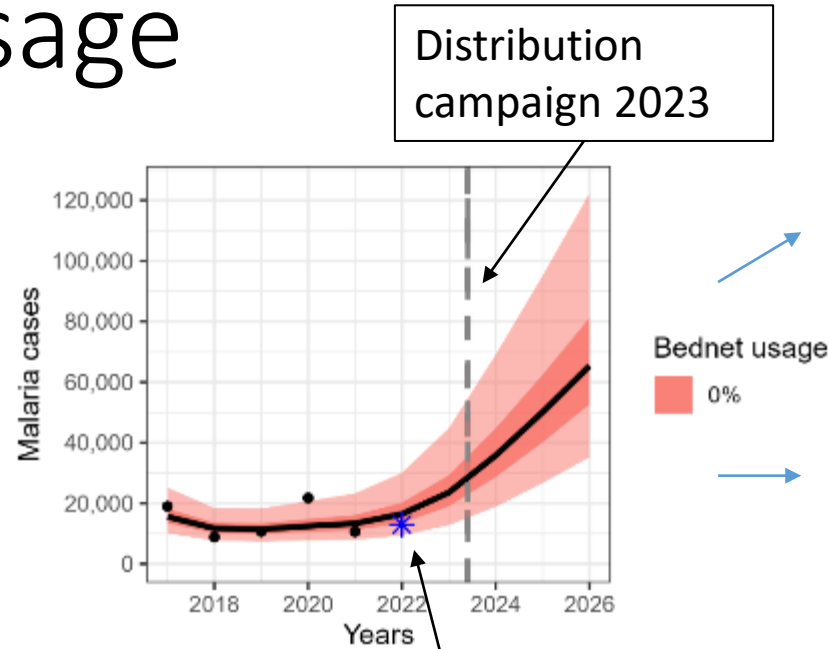
With the 25 communes suggested by the models

Preliminary estimation of cases in 2022: ~ 12975 (+ 22% of 2021 cases)

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# Discussion

- The prioritization provided by the model reflects the trend in **malaria case intensity** in each commune, the **connectivity of the commune** with the rest of the country, and the **impact of net distribution**.

- Our **model can provide clues** as to where **it will be optimal** to distribute bednet
  - Greatest impact on the number of cases at the national level.

- Given the current constraints**, bednets usage alone** would be **insufficient to reach malaria zero**
  - Limited number of Bednets
  - Limited Bednets usage in the population, although **increasing the bednet usage would be necessary** to **inverse current trend**
  - Alternative strategies: combine LLIN, case management, IRS and MDA?

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# Additional slides

# Materials and Methods

- Metapopulation model
  - Parameters: 132
    - Fixed: 6 (table)
    - Estimated: 126
      - R0 per commune
      - Over-dispersion
- Simulation:
  - No. of chains: 10
  - Iterations: 100000
  - Thinning: 10

$$\frac{dX_i}{dt} = (1 - X_i)(1 - \alpha_i) \sum_{j=1}^{n} p_{i,j} \omega_j \lambda_j \kappa_j - rX_i \quad \forall i = 1 \ldots n$$

| | Definition |
|---|---|
| $\epsilon_i$ | Effective treatment rate in commune $i$ |
| $\tau_i$ | Probability to seek care when febrile, in commune $i$ |
| s | Probability to develop symptoms |
| $\alpha_i$ | Proportion of infected individuals that clear their malaria infection before becoming infectious |
| $\widetilde{\alpha}_i$ | Proportion of infections that are reported |
| r | Malaria clearance rate |
| $R_{0_i}$ | Basic reproduction number, in commune $i$ |
| $\phi$ | Over-dispersion parameter |

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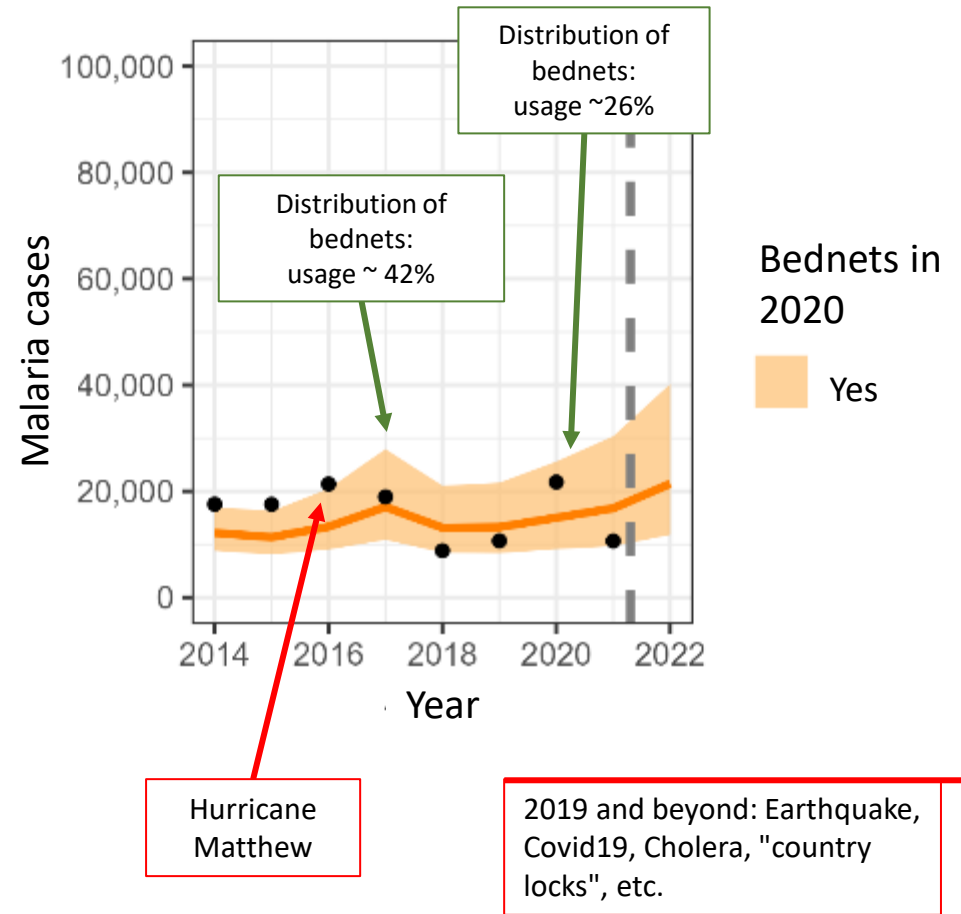CLINTON
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# Checking the model

The final model uses 2014-2021 data and includes 2020 net distribution.
- no. of chains: 10
- Iterations: 100000

Distribution of bednets:

- Percentage of bednet usage:
  - 2017: informed by the 2018 OHMASS survey.
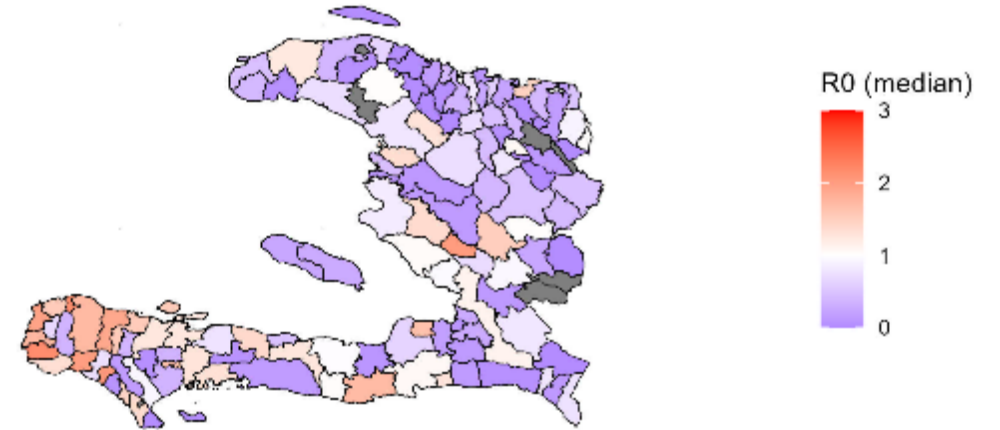  - 2020 : preliminary results



Distribution of bednets: usage ~26%

Distribution of bednets: usage ~ 42%

Bednets in 2020

Yes

Hurricane Matthew

2019 and beyond: Earthquake, Covid19, Cholera, "country locks", etc.

$$\frac{dX_i}{dt} = (1 - X_i)(1 - \alpha_i) \sum_{j=1}^{n} p_{i,j} \omega_j \lambda_j \kappa_j - r X_i \quad \forall i = 1 \dots n$$

# Risk map: distribution of R0

In each communes:

- $R_0$ >1: source of malaria transmission
- $R_0$ <1: sink for malaria transmission
- $R_0$ =1 : the credible interval contains 1

PNCM data 2014-21



Geospatial data 2014-21