Forest malaria in Myanmar: tracking landscapes at risk within a hidden diversity of environments.

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Malaria in the Greater Mekong subregion

→ *P. falciparum* & *P. vivax*

→ Progress over past 15 years
- Decreasing incidence
- Increasing % *P. vivax*
- under threat from P. falciparum artemisinin & multidrug resistance

→ Increasing spatial heterogeneity
- Hard to reach regions
- Focus on « forest-goers »

P. falciparum | *P. vivax*

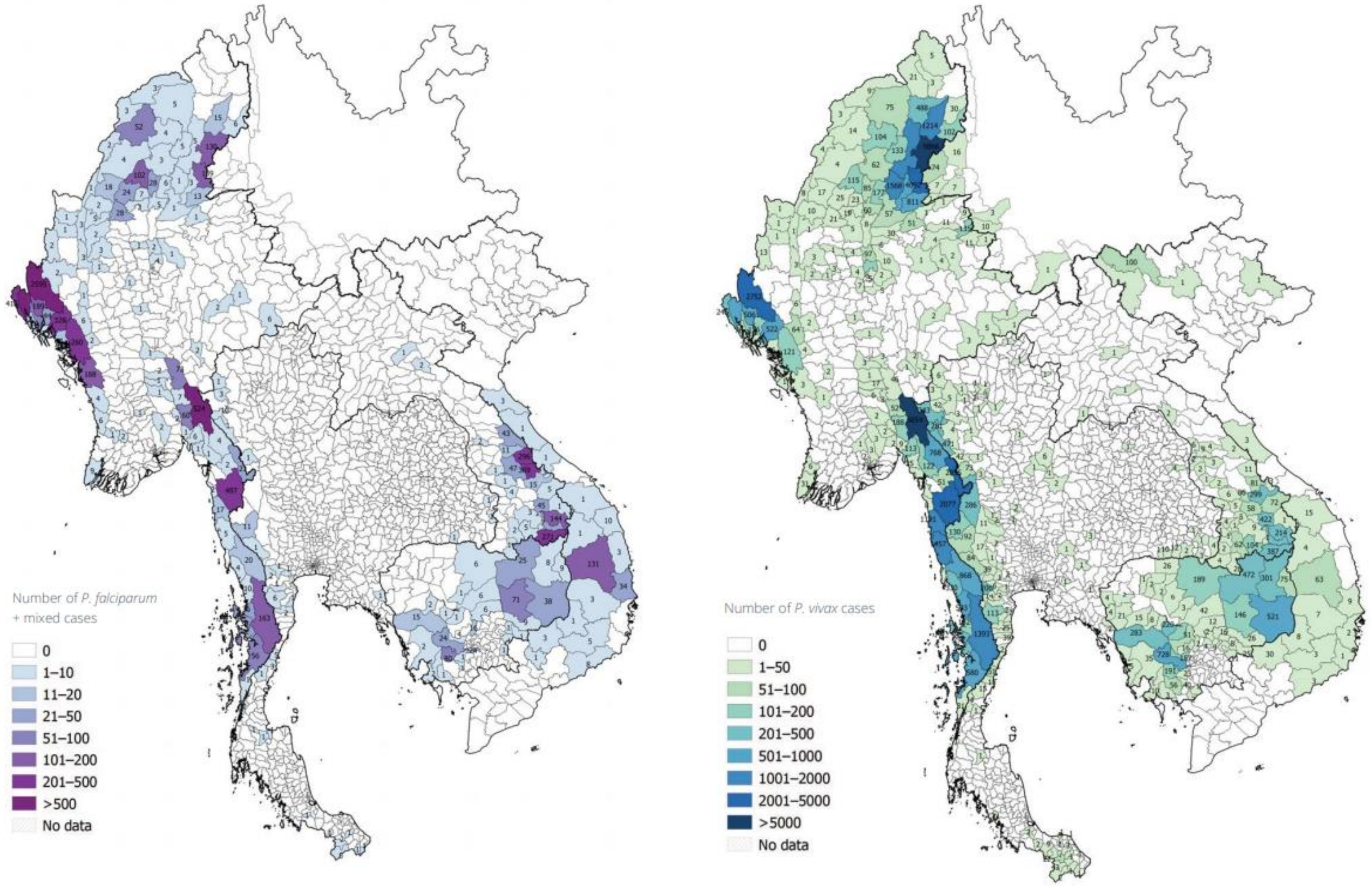
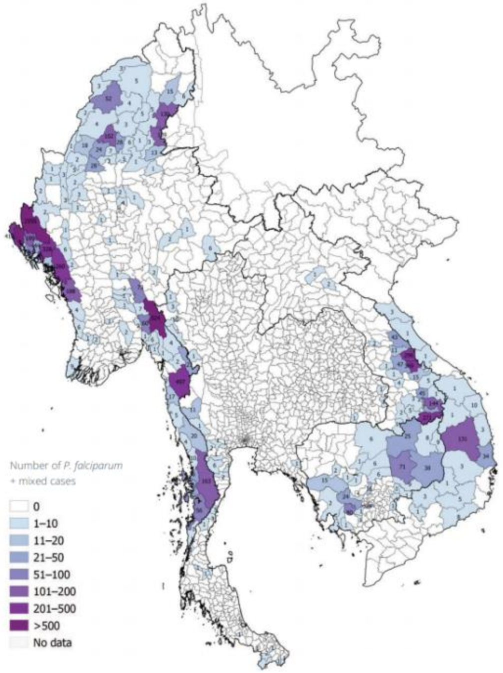
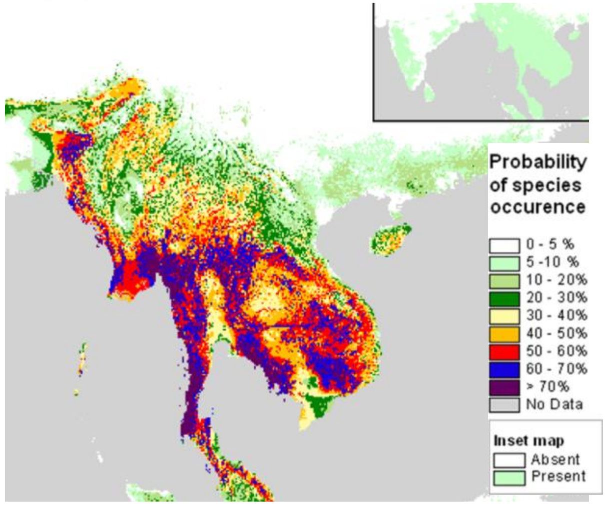


Figure 2. Distribution of *P. falciparum* & *P. vivax* malaria cases in the GMS in 2021. Source : The Mekong Malaria Elimination Program, Bulletin March 2022.

- **Forest malaria in the GMS**
- **Malaria associated with forested regions at regional scale**
  - Ecological correlation
  - Ecological niche of major malaria vector *An. dirus* linked to forests (Obsomer)
  - Specific patterns in relation to deforestation described in Lao (Rerolle)
- **Malaria is associated with forest activities in individual case-control studies**





- **Forest malaria in the GMS**
- Different environments unlikely to support homogenous malaria vector population
- Human activity patterns may allow transmission or not: seasonality, frequency+duration of exposure, population density and mixing in forest sites…

+ presence of a Human reservoir of parasites

Are all forested environments sharing the same risk of malaria ?

Elimination phase:

→ Specific locations or types of locations (linked to specific activities) which could be targeted more accurately/specifically

→ Proxies of receptivity to define areas at higher risk of resurgence

- **Malaria Elimination Task Force (METF) in Karen State, Myanmar**

Initiated in 2014 to drastically decrease malaria incidence and limit the spread of multidrug resistant *P. falciparum* beyond the GMS.

Setting: hard-to-reach mountainous and forested Eastern Karen State, Myanmar

Intervention strategy:

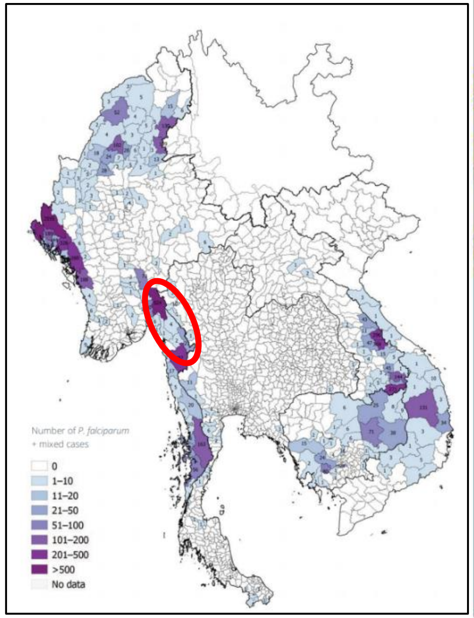
➔ Malaria posts (MP) in all villages (>1000 posts, 95% of villages)

➔ Identification of high prevalence hotspots and mass drug administration (70 hotspot communities).

➔ Routine surveillance through MP weekly reports

➔ Monitoring & evaluation to ensure continuous function of MP

Objectives: characterize environments associated with specific local malaria dynamics



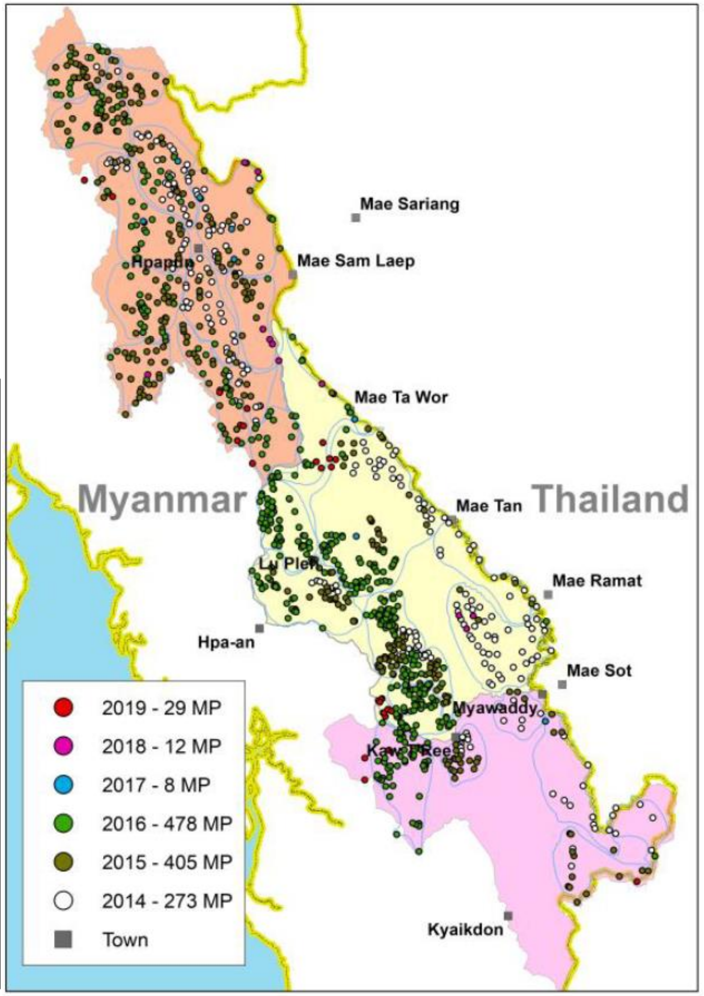
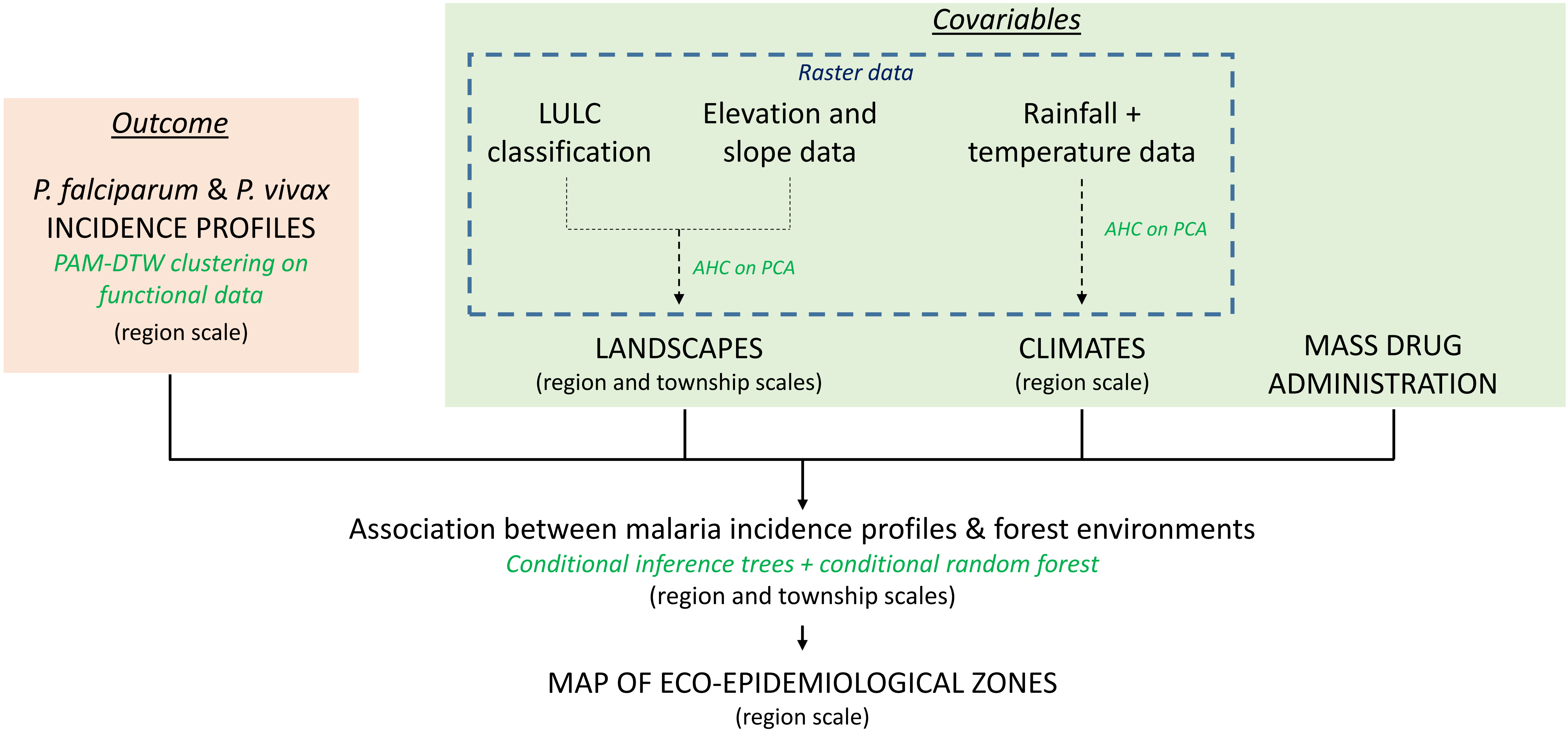
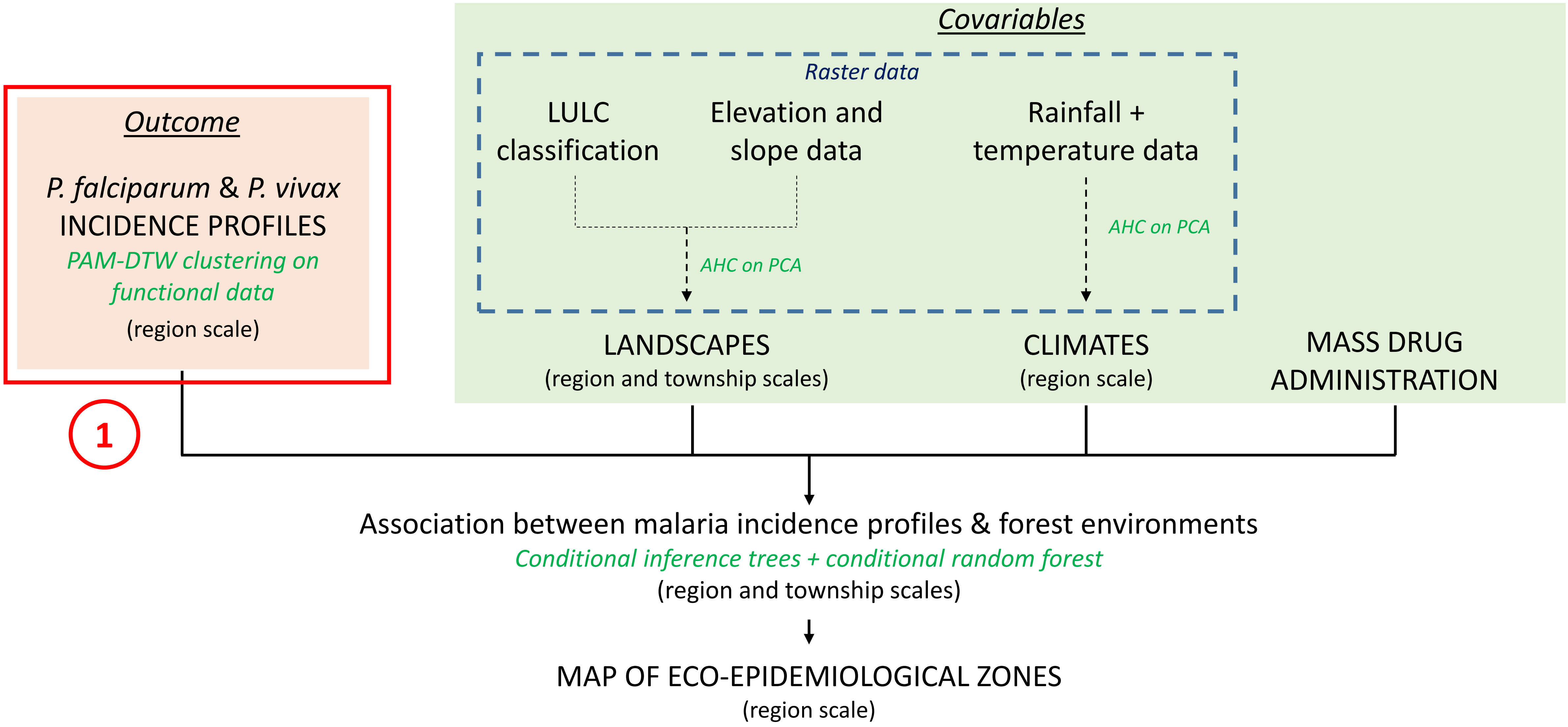


Figure 3. Carte de la région cible du programme METF et de l'état d'ouverture des malaria postes en décembre 2019 (n=1205). Source : Malaria Elimination Task Force Activity Report Update May 2014 – December 2019


Covariables
Raster data
LULC classification
Elevation and slope data
Rainfall + temperature data
AHC on PCA
AHC on PCA
Outcome
P. falciparum & P. vivax INCIDENCE PROFILES
PAM-DTW clustering on functional data
(region scale)
LANDSCAPES
(region and township scales)
CLIMATES
(region scale)
MASS DRUG ADMINISTRATION
Association between malaria incidence profiles & forest environments
Conditional inference trees + conditional random forest
(region and township scales)
MAP OF ECO-EPIDEMIOLOGICAL ZONES
(region scale)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Association between malaria incidence profiles & forest environments
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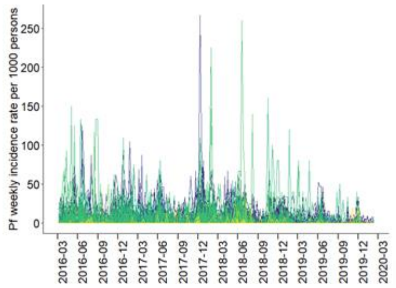
(region scale)

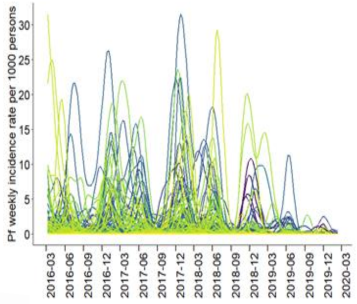
A. Outcome: defining groups villages sharing the same incidence dynamics over a 4-year period

- Data: clinical malaria incidence (*P. falciparum* & *P. vivax*) recorded by MP from 2016 to 2020 (n=662 villages)
- Method: clustering villages using PAM algorithm on DTW metric after functional transformation of incidence series.
- 2 sets of profiles: PF and PV separately

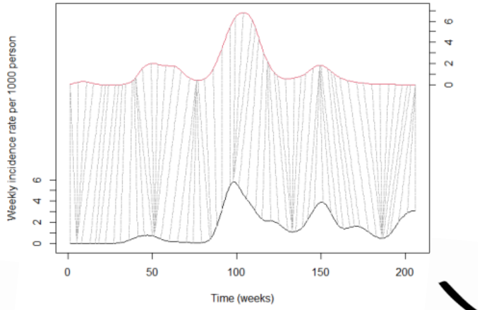
Raw data : weekly PF and PV incidence rate



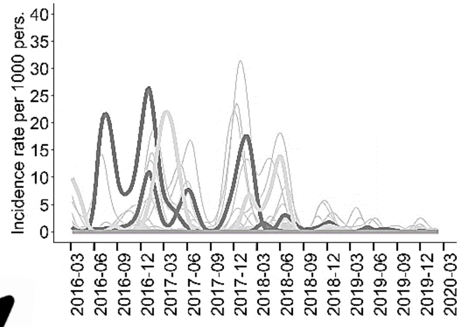
Functional data



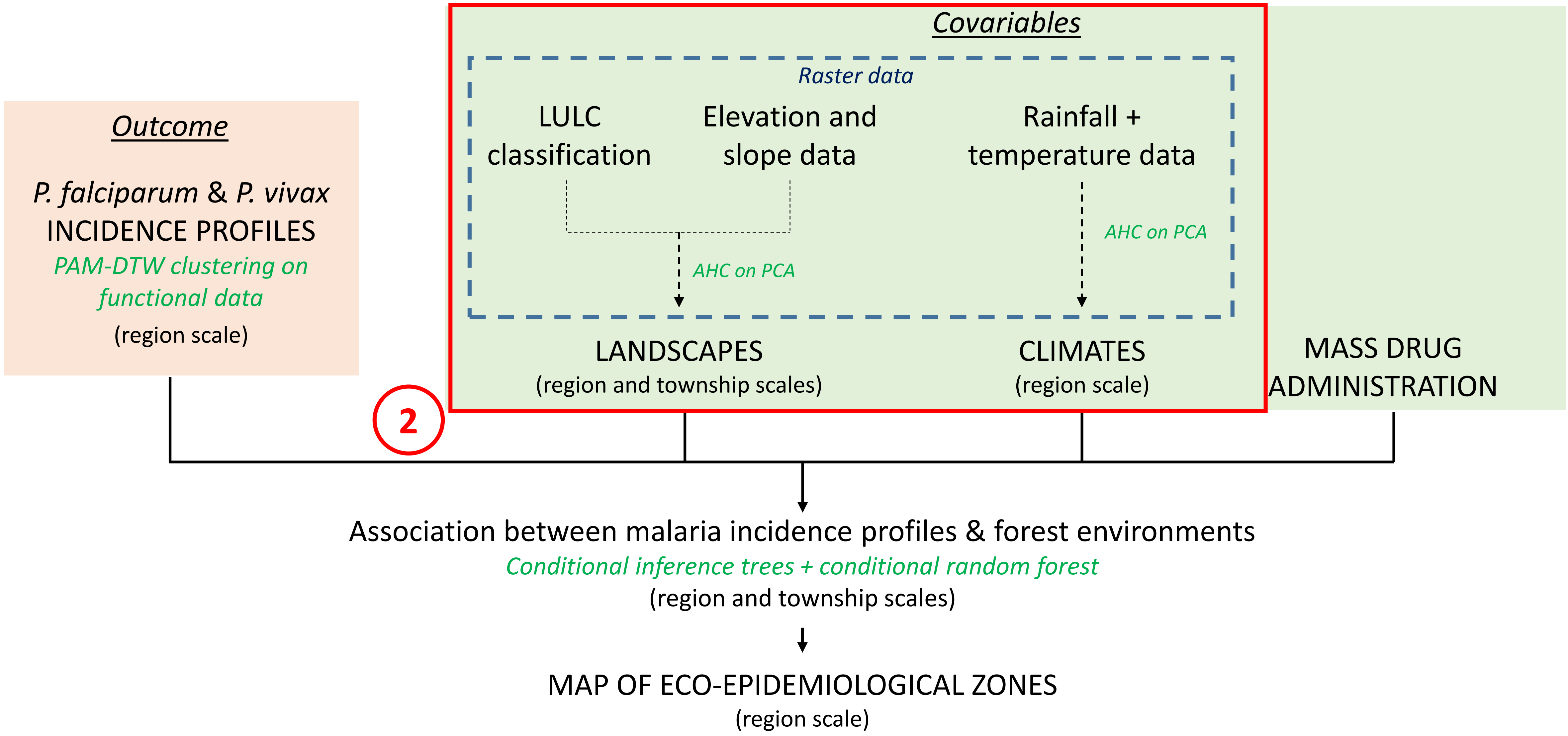
Dynamic time-warping distance matrix



Incidence profiles



1. *smooth time series using functional transformation*
2. *Distance calculation between each village-level smoothed series (DTW)*
3. *PAM clustering*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B. Environment data

Extraction using a 2-km hexagonal grid

Landscape:

- **altitude + slope** : GMTED 2010 digital elevation model
- **Landuse/landcover** : UMR ESPACE DEV team

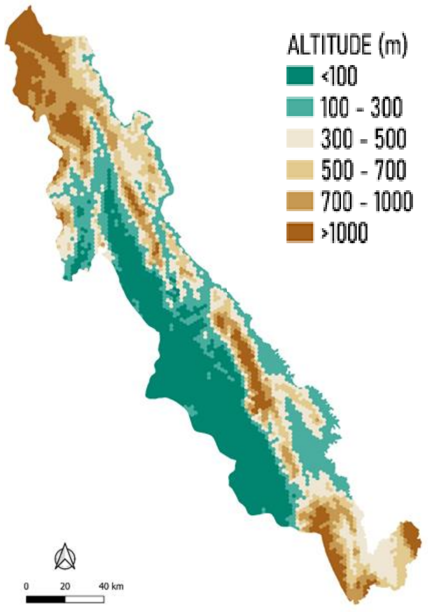
→ Sentinel 2 de 2019 à 2020, 10m resolution

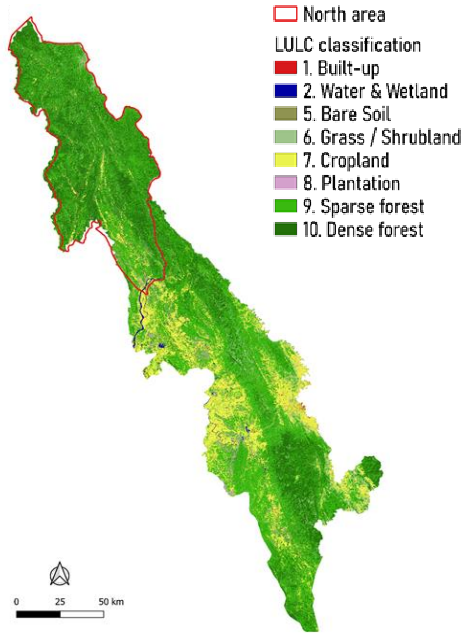
→ OBIA : object-based image analysis

→ ground-truthing with 300 random points (field team and Google Earth interpretation)

Climate:

- **Day and night temperature**: MODIS/006/MOD11A2 (1km resolution): monthly average over study period
- **Daily rainfall** : UCSB-CHG/CHIRPS/DAILY (5.5km resolution): average monthly cumulative over study period





Mean, median, sd, min, max

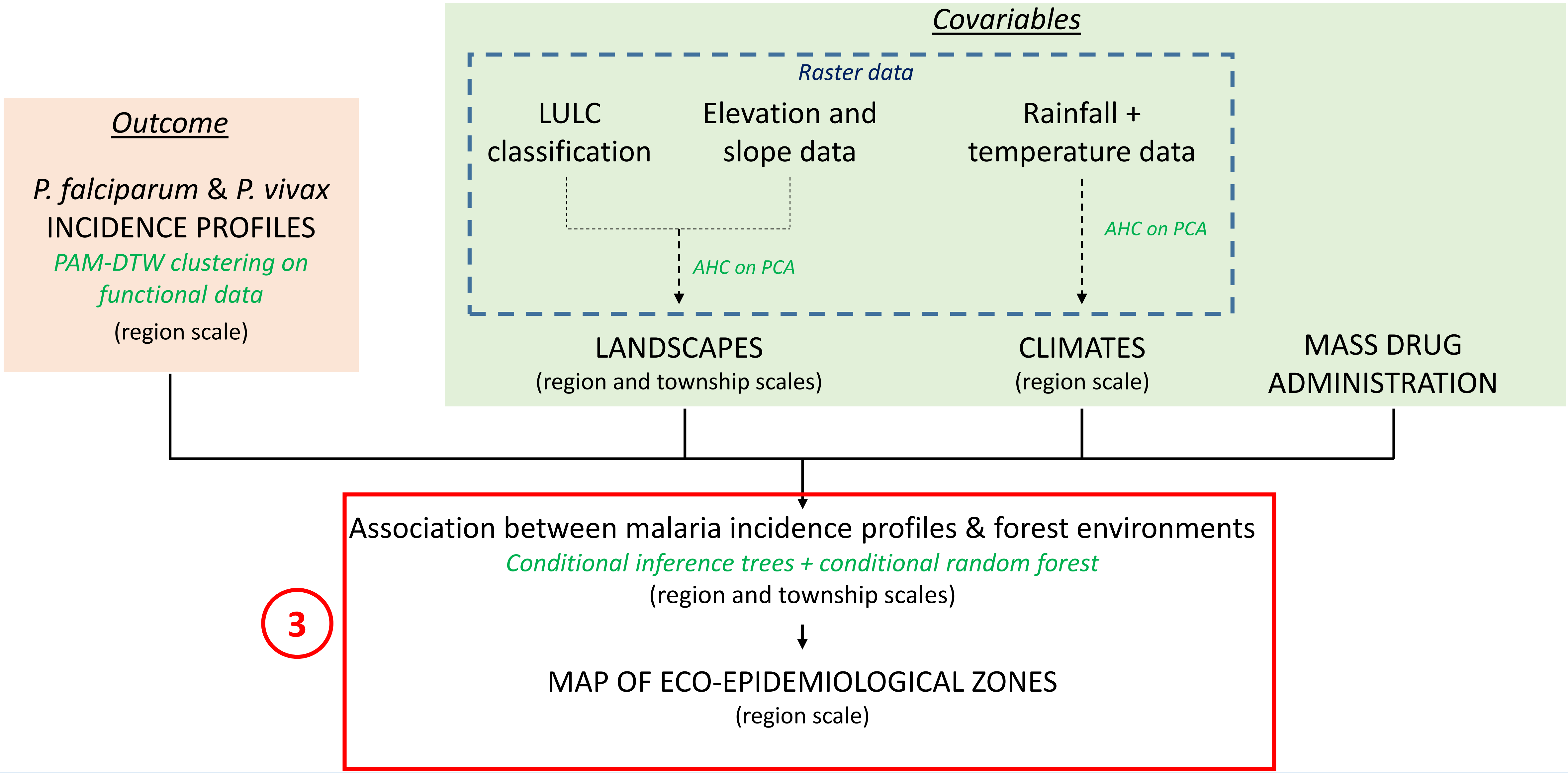
Fragmentation % area…

HCPC

Landscapes

→ METF region

→ Northern area only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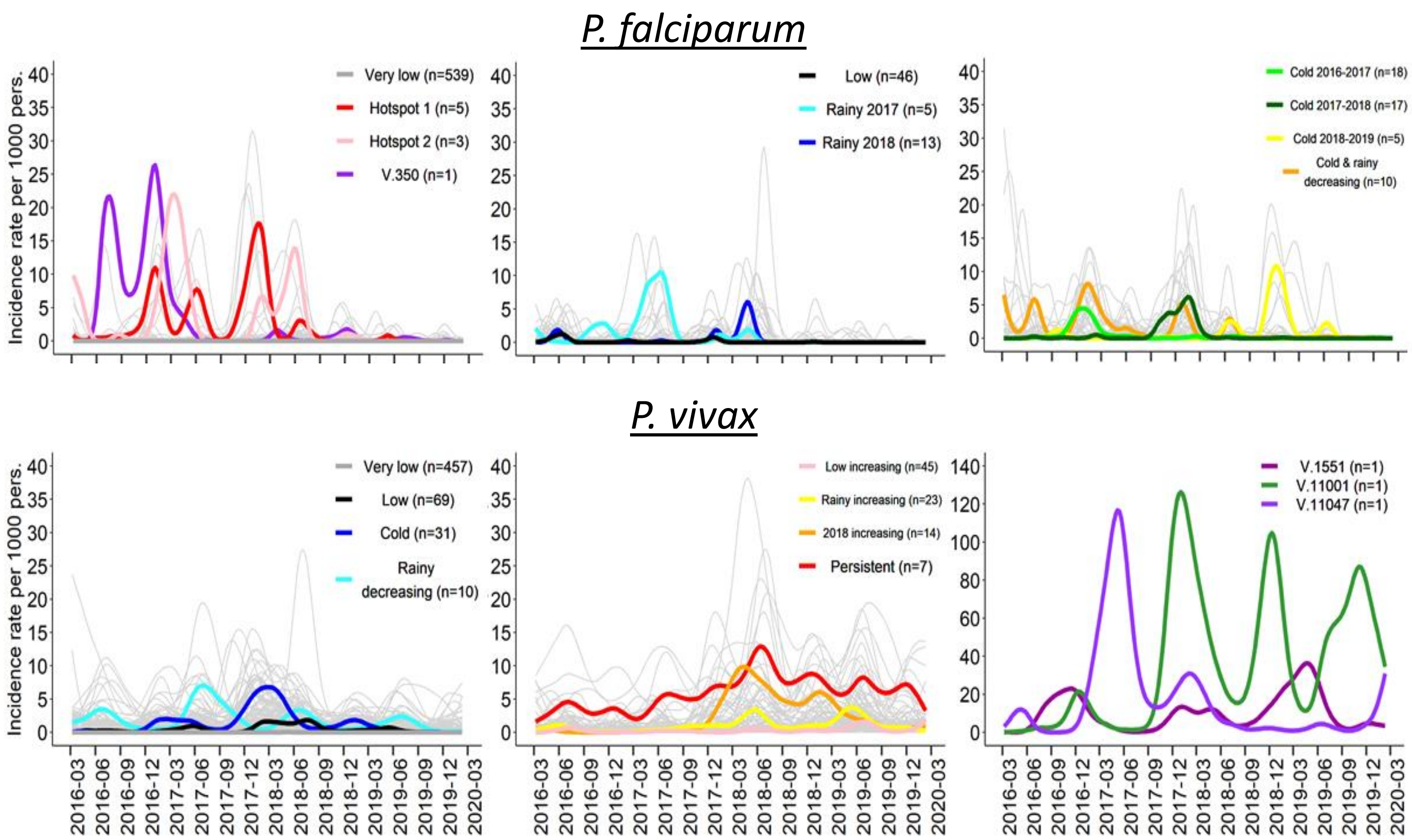
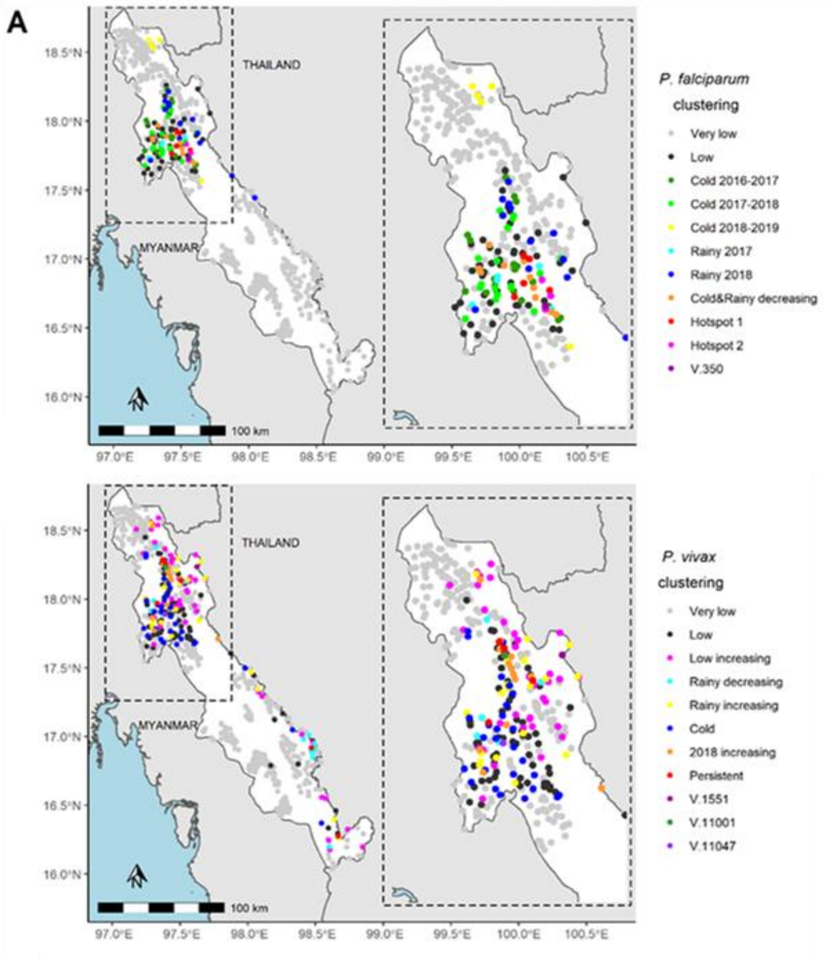
A. Incidence profiles

➔ 11 profiles for *P. falciparum* and *P. vivax* incidence.

➔ Group villages sharing similar dynamics = amplitude, seasonality and trend.





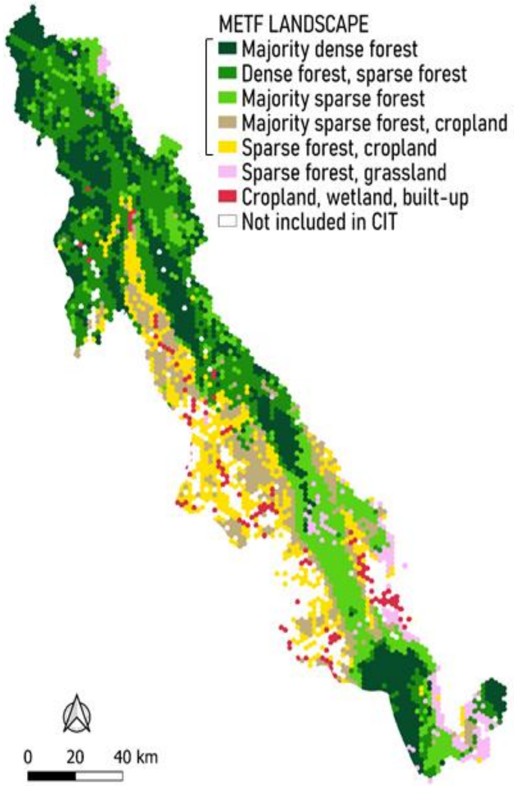
B. Landscape and climate

- >70% of the region is covered with forest (sparse or dense)
- LULC included 10 classes
- LULC (% + fragmentation) + topography combined identified 17 Landscapes
  - → 6 different major forest landscapes
  - → 2 specific landscapes in the northern region

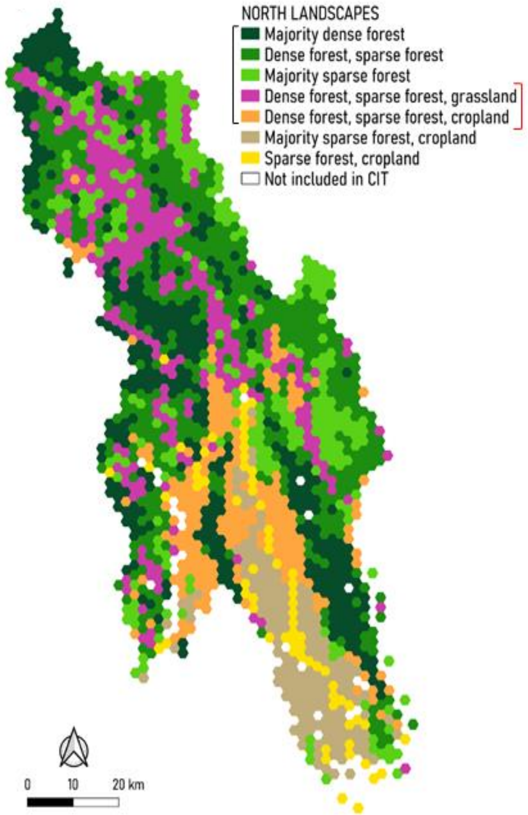
→ A wide diversity of landscapes identified within a forested region

- Gradients
  - → pristine > anthropic
  - → altitude/slope
- Types of agricultures (paddies vs slope)

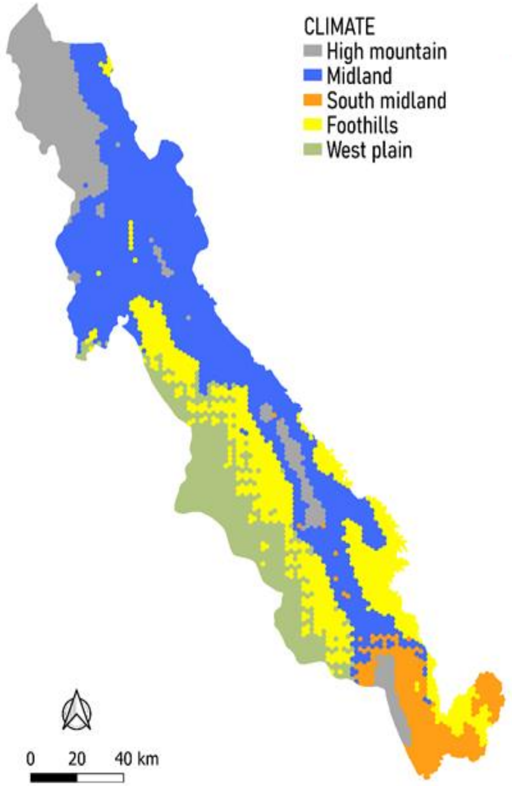
METF region landscapes



Northern landscapes



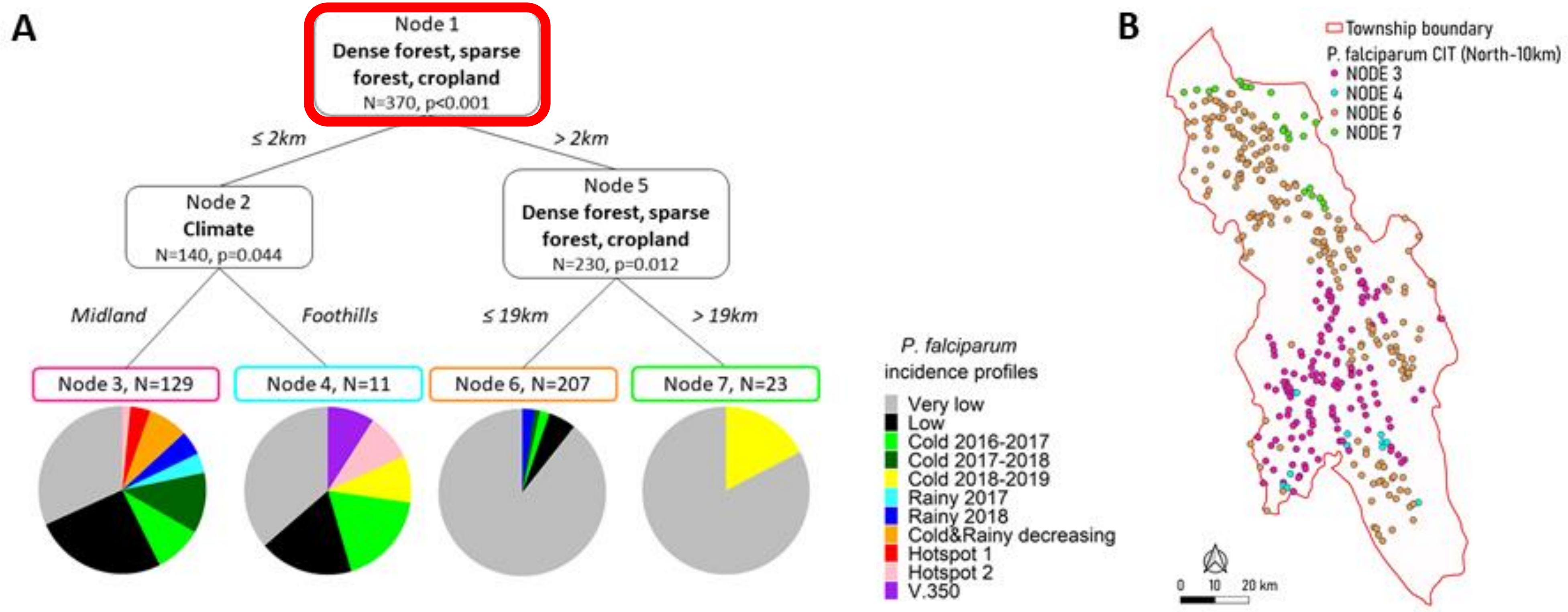
Climates



C. Association between incidence profile and environment

Northern area

P. falciparum

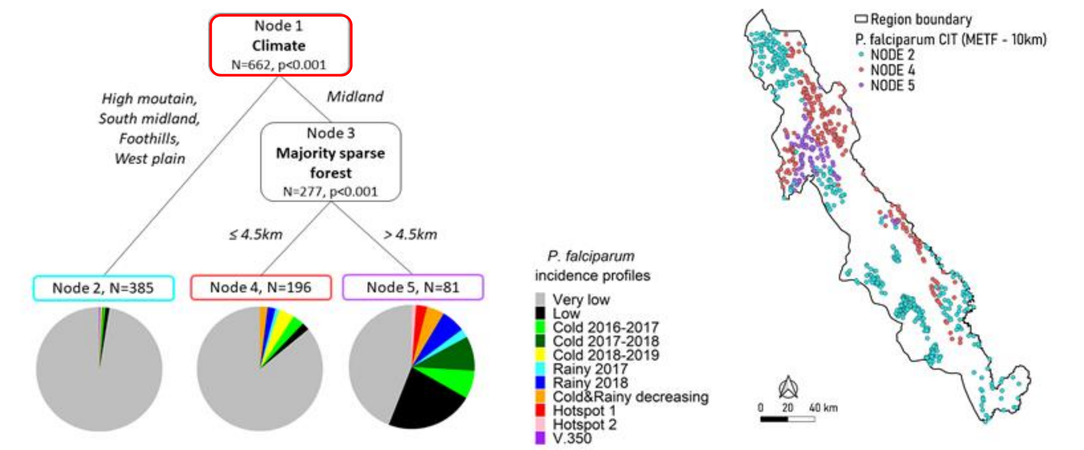


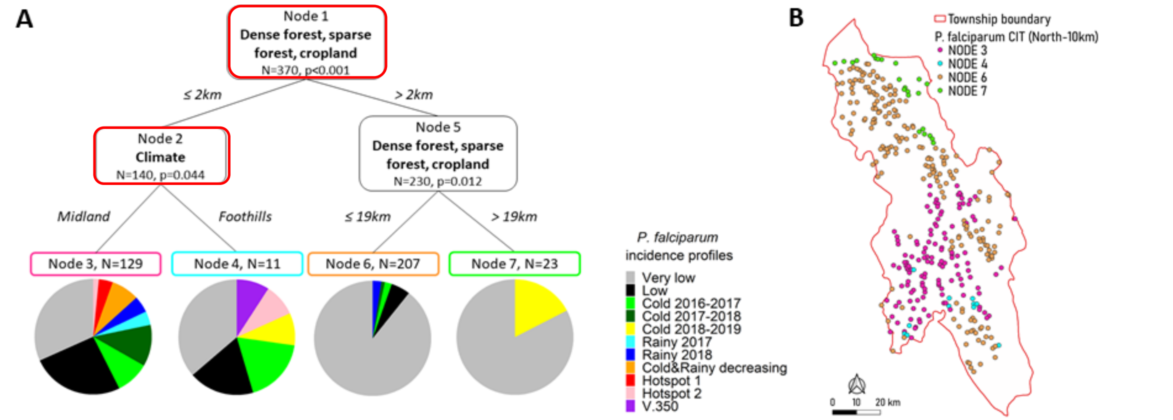
C. Association between incidence profile and environment

➔ Mainly 1 climate and 2 landscapes associated with malaria-affected incidence profiles

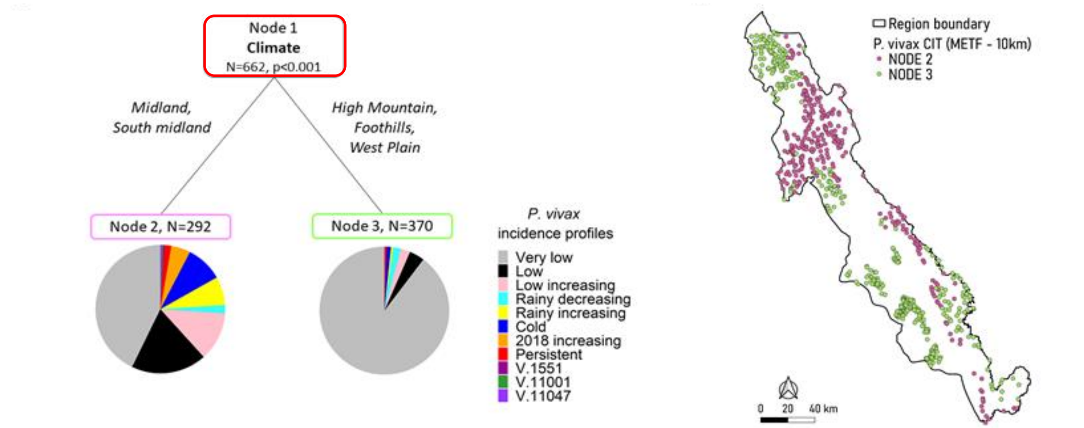
	METF region	Northern area

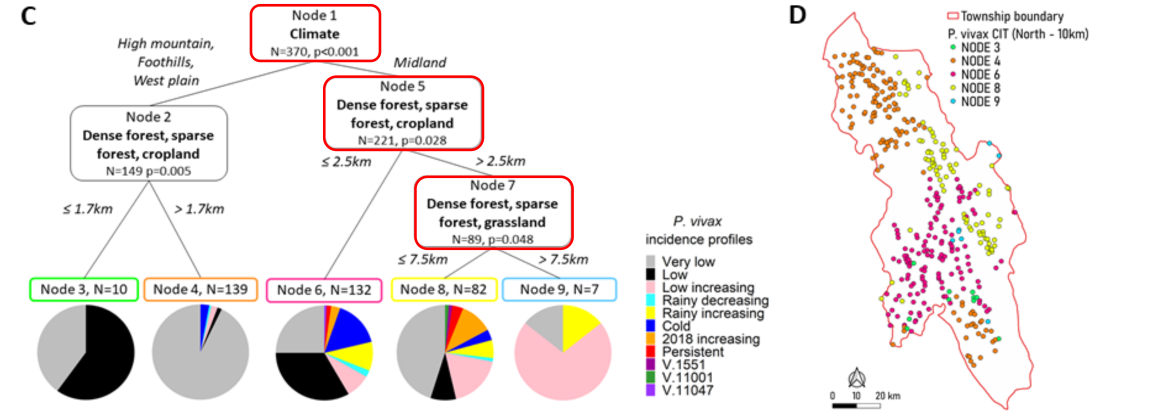
P. falciparum





P. vivax





D. Eco-epidemiological zones

A. METF region vs. North area for *P. falciparum*

A)	METF region		Total
	Midland (N3)	Not in Midland (N2)	
North area: ≤2km DSC; Midland (N3)	129 (19.5)	0 (0)	129 (19.5)
North area: ≤2km DSC; Foothills (N4)	0 (0)	11 (1.7)	11 (1.7)
North area: >2km DSC (N5)	92 (13.9)	138 (20.8)	230 (34.7)
Not in North area	56 (8.5)	236 35.6	292 (44.1)
Total	277 (42)	385 (58)	662 (100)

➔ 4 risk profiles

B. METF region vs. North area for *P. vivax*

B)	METF region, 15 km			Total
	Midland, South Midland (N2)	Not in Midland, South Midland ; <900m SG (N4)	Not in Midland, South Midland ; >900m SG (N5)	
North area, 10 km: Not in Midland; <1.7km DSC (N3)	0 (0)	0 (0)	10 (1.5)	10 (1.5)
North area, 10 km: Not in Midland; >1.7km DSC (N4)	0 (0)	5 (0.7)	134 (20.2)	139 (21)
North area, 10 km: Midland; <2.5km DSC (N6)	132 (19.9)	0 (0)	0 (0)	132 (19.9)
North area, 10 km: Midland; >2.5km DSC; <7.5km DSG (N8)	82 (12.4)	0 (0)	0 (0)	82 (12.4)
North area, 10 km: Midland; >2.5km DSC; >7.5km DSG (N9)	7 (1.1)	0 (0)	0 (0)	7 (1.1)
Not in North area	71 (10.7)	19 (2.9)	202 (30.5)	292 (44.1)
Total	292 (44.1)	24 (3.6)	346 (52.3)	662 (100)

➔ 6 risk profiles

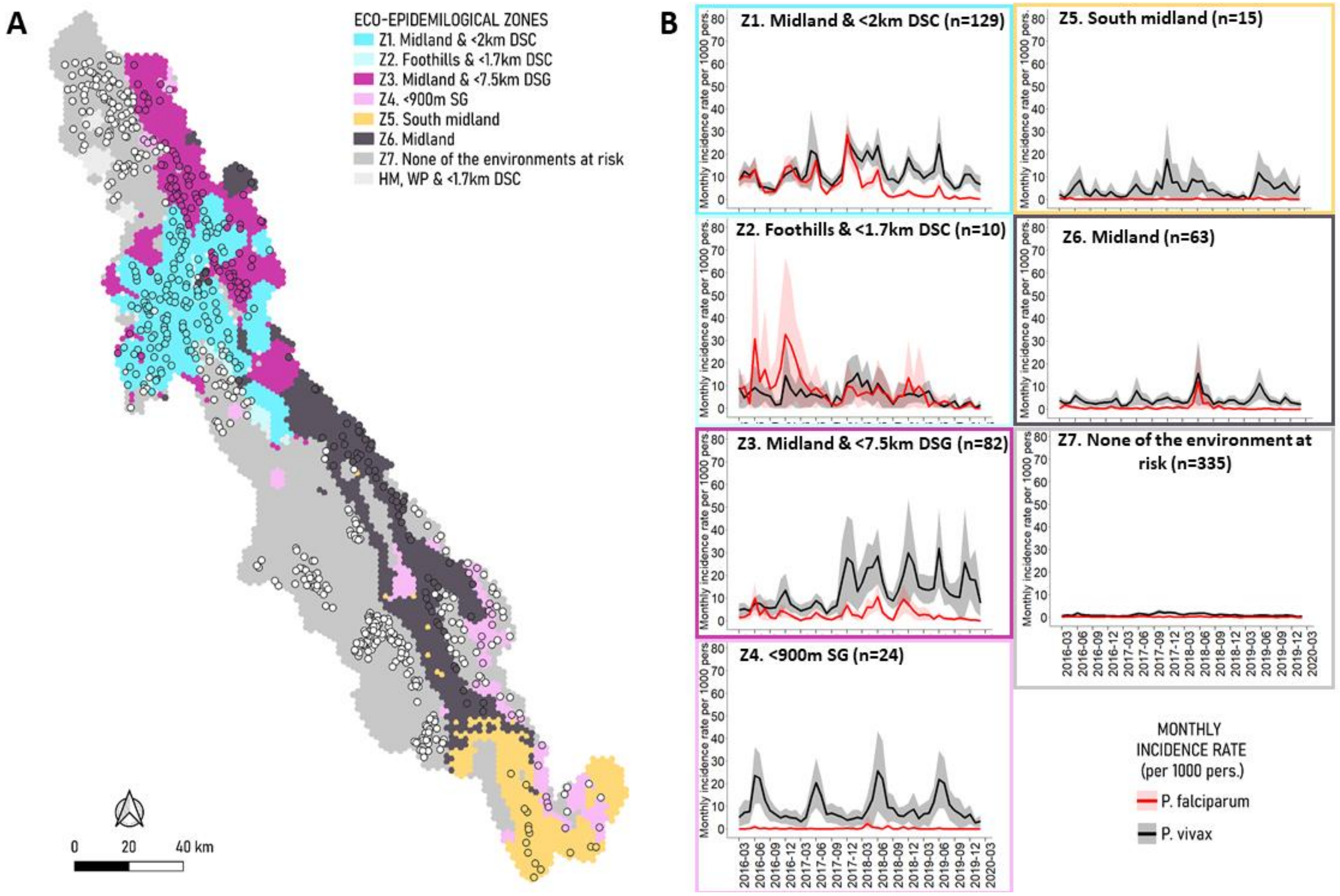
C. *P. falciparum* vs. *P. vivax*

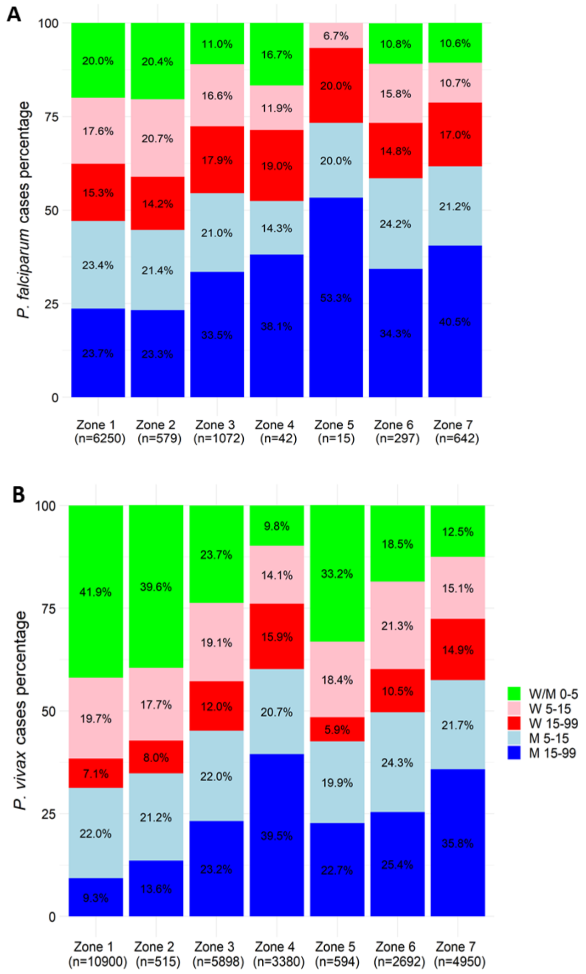
C) Pv \ Pf	Not in Midland; >2km DSC	In Midland; >2km DSC	Foothills; <2km DSC	In Midland; <2km DSC
Not in Midland, South Midland; >900m SG; >1.7km DSC	**335 (50.6)** Z7	0 (0)	1 (0.15)	0 (0)
Not in Midland, South Midland; <900 SG; >1.7km DSC	**24 (3.6)** Z4	0 (0)	0 (0)	0 (0)
Not in Midland, South Midland; <1.7km DSC; >900m SG	0 (0)	0 (0)	**10 (1.5)** Z2	0 (0)
In Midland, South Midland; >2.5km DSC; >7.5km DSG	**15 (2.3)** Z5	**63 (9.5)** Z6	0 (0)	0 (0)
In Midland; <2.5km DSC	0 (0)	3 (0.45)	0 (0)	**129 (19.4)** Z1
In Midland; >2.5km DSC; <7.5km DSG	0 (0)	**82 (12.4)** Z3	0 (0)	0 (0)

➔ 7 eco-epidemiological zones

D. Eco-epidemiological zones

➔ 7 eco-epidemiological zones with different environment, incidence trends and at-risk populations





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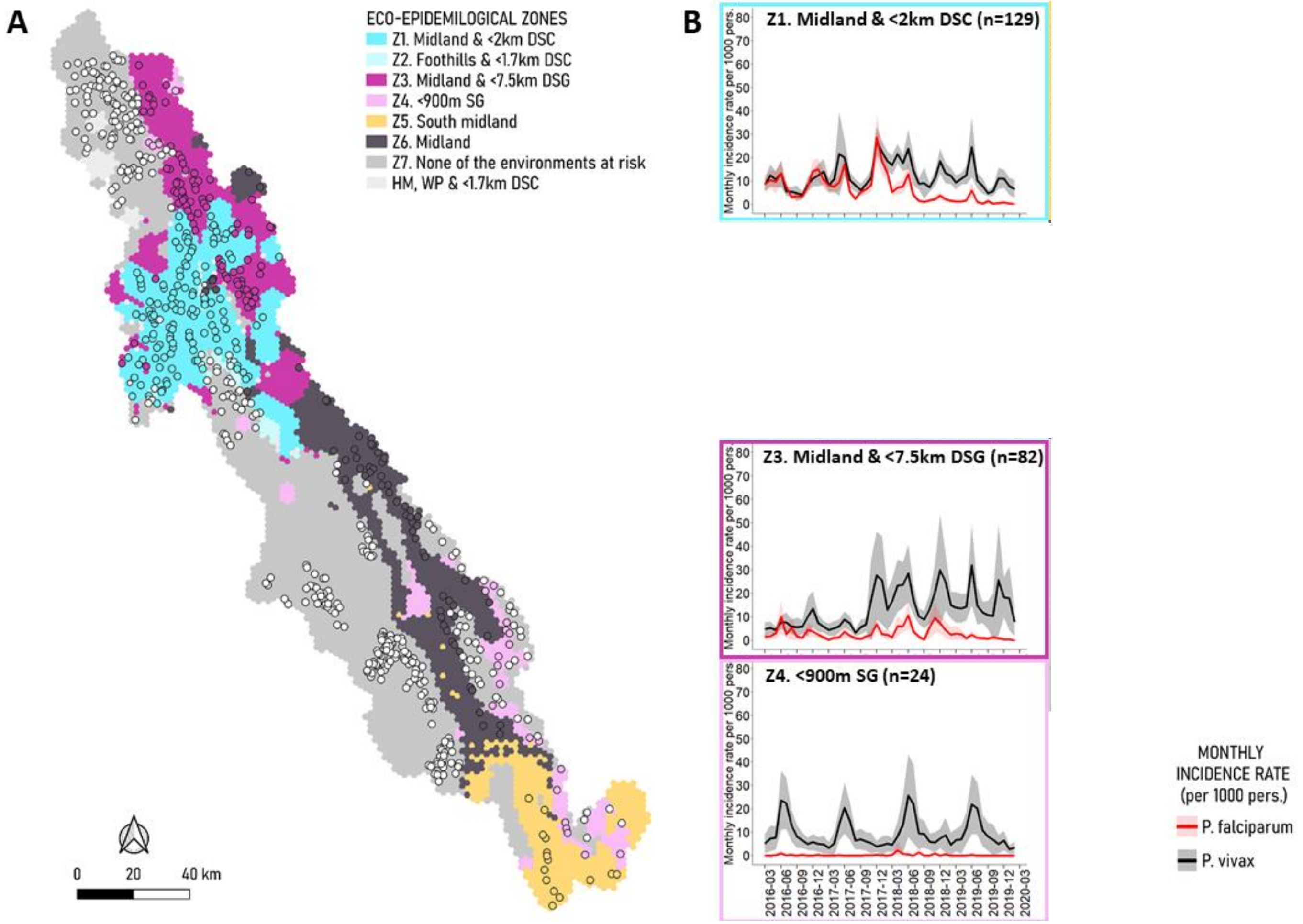

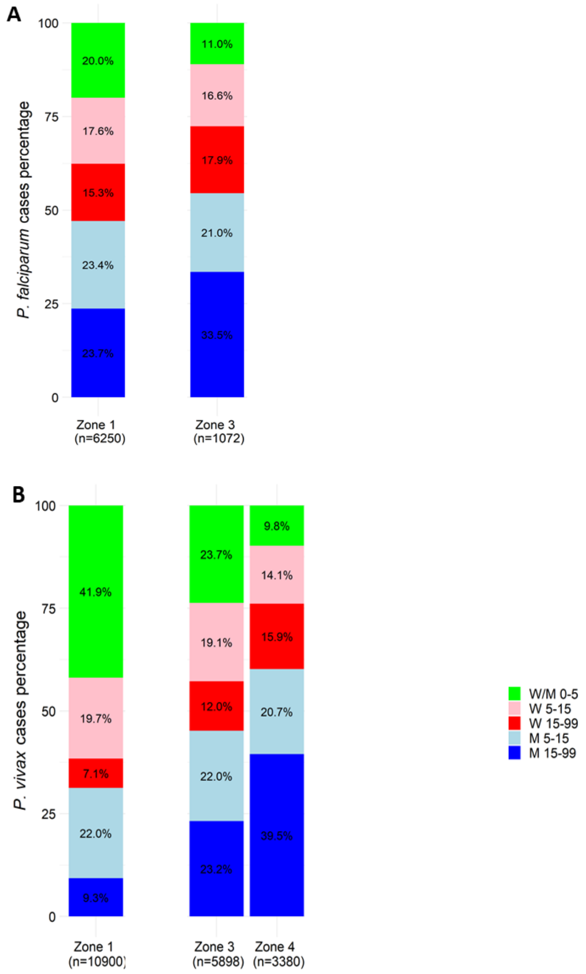

Dense forest, sparse forest, Grass/shrubland

Traditional Karen "taung yar" slope agriculture

Mean elevation: 640m
Min elevation: 547m

% 0-5° = 10%
% 5-10° = 18%
% >10° = 71%

Dense forest, sparse forest, Cropland

Cropland located in broad valley bottoms indicative of wet rice paddies

Mean elevation: 223m
Max elevation: 342m

% 0-5° = 30%
% 5-10° = 27%
% >10° = 43%

3. DISCUSSION

- Large diversity of
  - malaria village-dynamics
  - forest landscapes

    ➔ topography, ratio agriculture/forest, type of agriculture (no details on floristic composition)

- Malaria dynamics & environment association : broad > detailed profiles
  - 1 climate + 2 landscapes associated to malaria affected profiles

- 7 ecoepidemiological zones with different incidence patterns and at-risk population

3. DISCUSSION

- ➔ Forest is not a homogenous environment: it is shaped locally by humans and this results in different malaria risks
- ➔ Age distributions across zones suggest a gradient of within versus outside village transmission, linked to specific environments
- ➔ Post-MDA incidence analysis sugggests interventions impact differ between Z1 and Z3 (higher post-MDA incidence associated with DSC proximity)
- ➔ Suggests that the type of agriculture may be a proxy of receptivity
- ➔ Interest to target intervention and plan surveillance - especially in the light of current disruptions

ACKNOWLEDGEMENTS

METF communities in Karen State and partner organizations

SMRU: Francois Nosten, Gilles Delmas, Aung Myint Thu, Khin Maung Lwin, Jade D Rae & METF team

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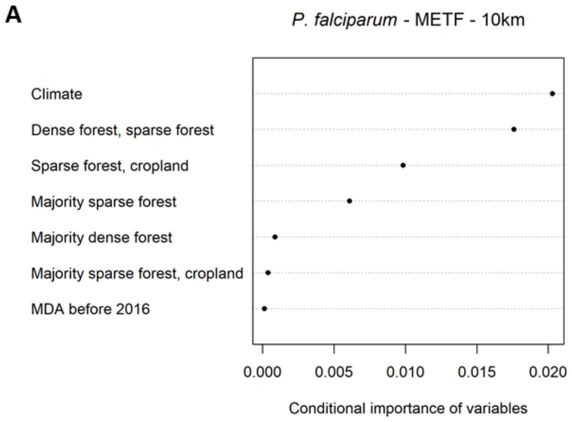
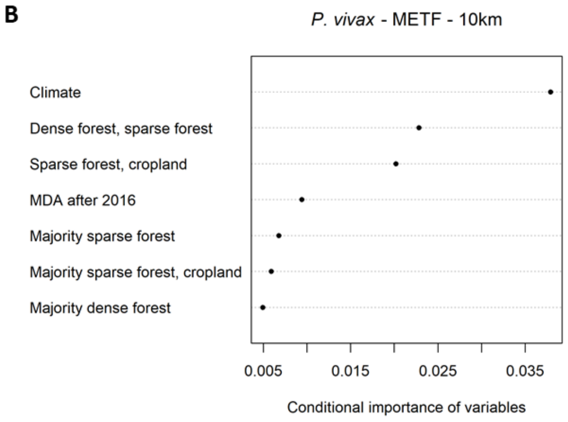
SESSTIM: Jean Gaudart, Laurent Lehot, Sokhna Dieng

METF funded by: **Bill and Melinda Gates Foundation, The Global Fund, The Wellcome Trust**

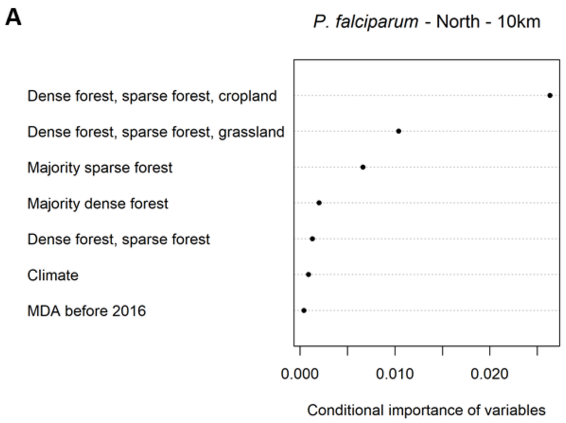
EASIMES project funded by: **The Global Fund (RAI2E operational research)**

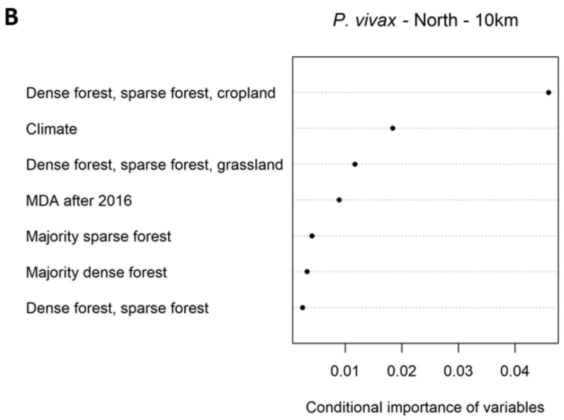
CRF - Région – 10 km

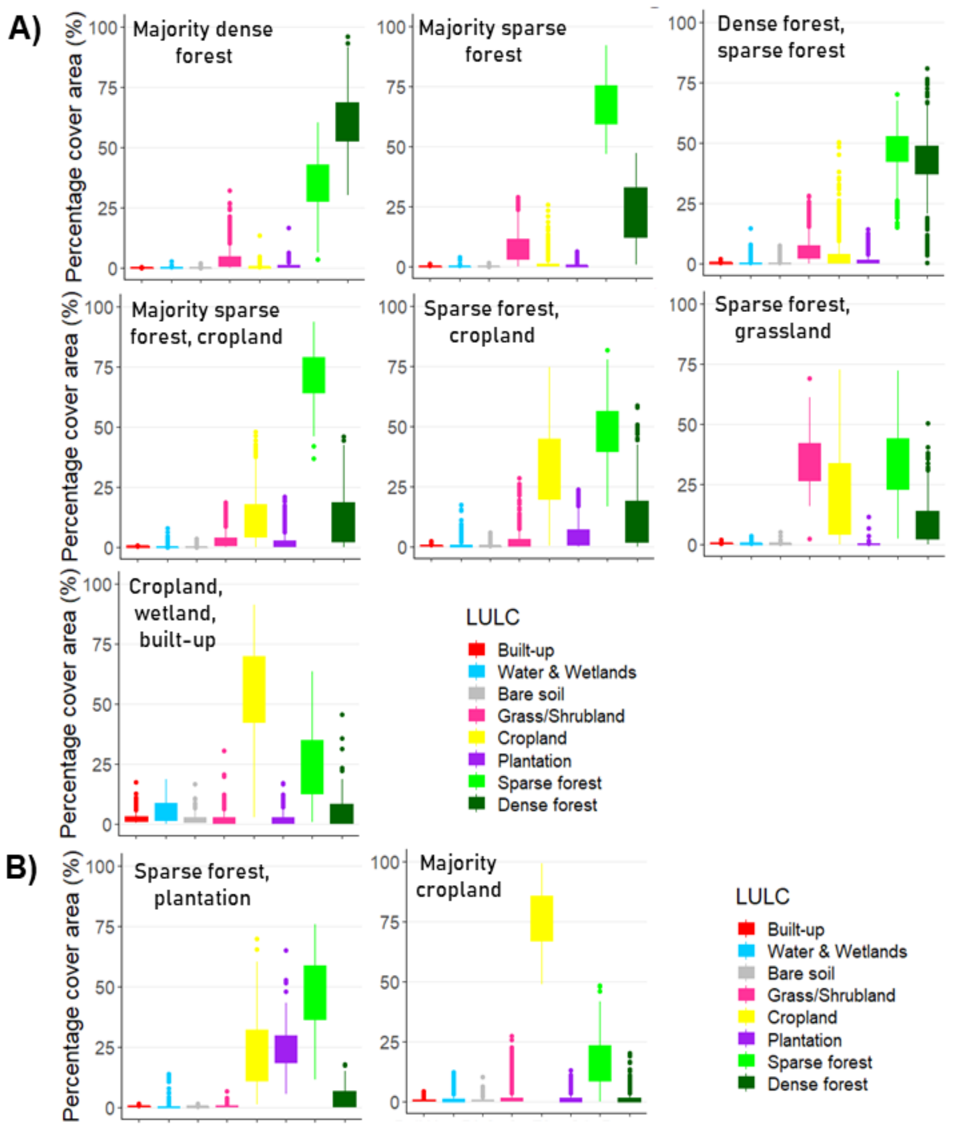


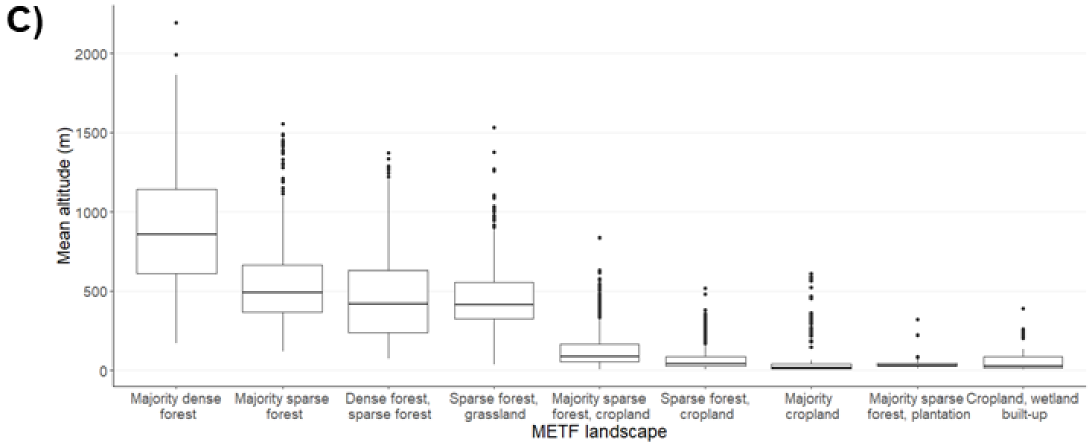


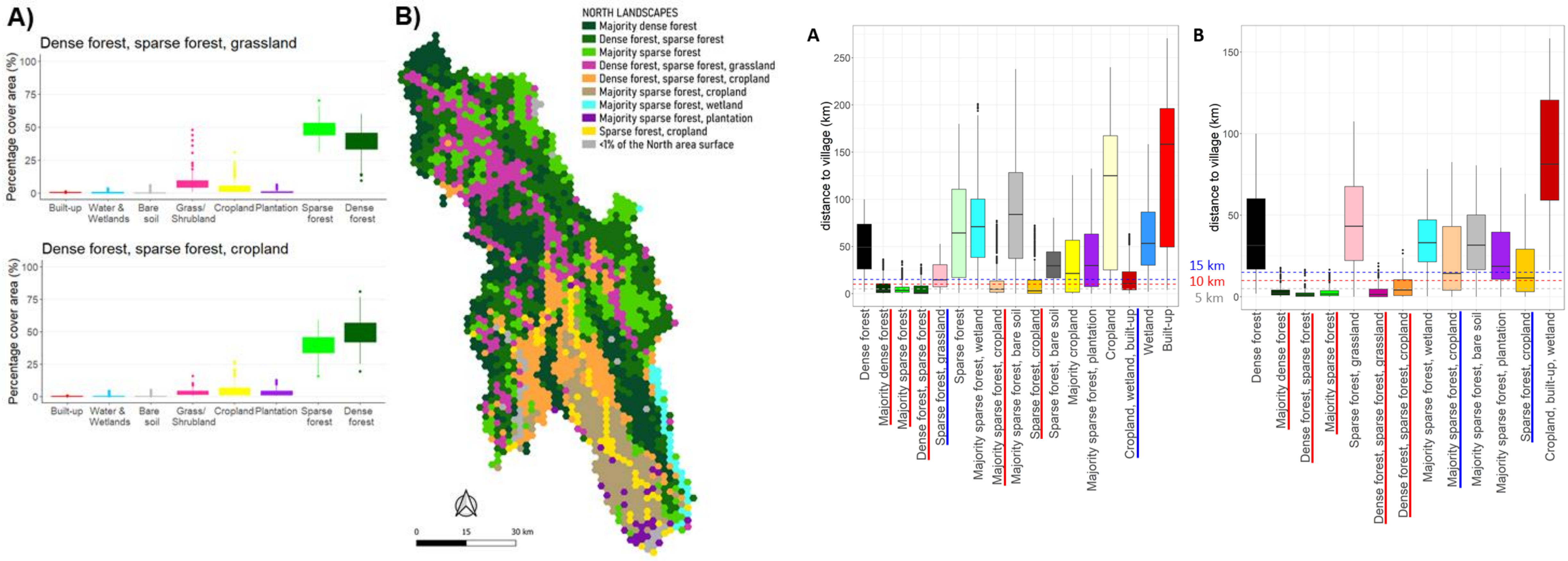
CRF - Zone Nord – 10 km

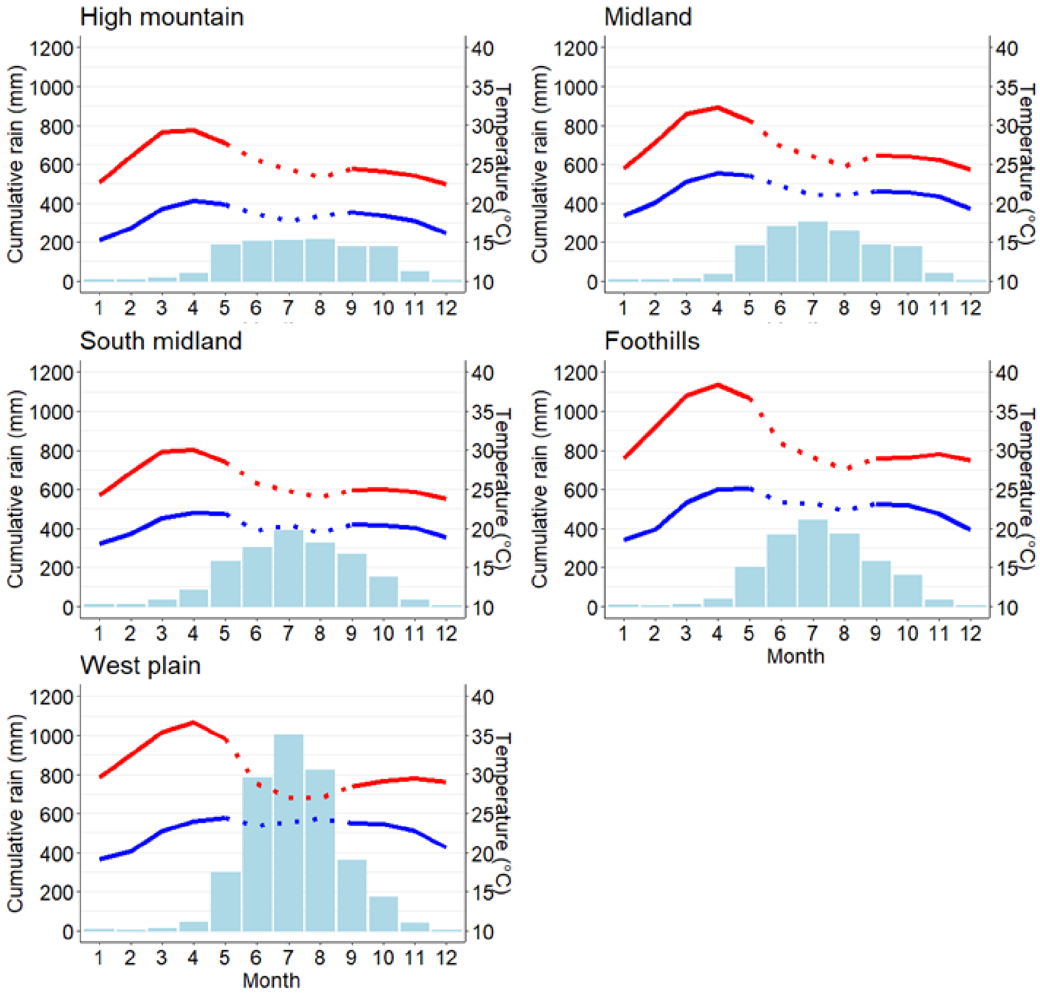





A)
B)
Percentage cover area (%)
Majority dense forest
Majority sparse forest
Dense forest, sparse forest
Majority sparse forest, cropland
Sparse forest, cropland
Sparse forest, grassland
Cropland, wetland, built-up
Sparse forest, plantation
Majority cropland
LULC
Built-up
Water & Wetlands
Bare soil
Grass/Shrubland
Cropland
Plantation
Sparse forest
Dense forest


C)
Mean altitude (m)
METF landscape
Majority dense forest
Majority sparse forest
Dense forest, sparse forest
Sparse forest, grassland
Majority sparse forest, cropland
Sparse forest, cropland
Majority cropland
Majority sparse forest, plantation
Cropland, wetland built-up


A)
Dense forest, sparse forest, grassland
Percentage cover area (%)
Built-up
Water & Wetlands
Bare soil
Grass/ Shrubland
Cropland
Plantation
Sparse forest
Dense forest
Dense forest, sparse forest, cropland
B)
NORTH LANDSCAPES
Majority dense forest
Dense forest, sparse forest
Majority sparse forest
Dense forest, sparse forest, grassland
Dense forest, sparse forest, cropland
Majority sparse forest, cropland
Majority sparse forest, wetland
Majority sparse forest, plantation
Sparse forest, cropland
<1% of the North area surface
0 15 30 km
A
distance to village (km)
Dense forest
Majority dense forest
Majority sparse forest
Dense forest, sparse forest
Sparse forest, grassland
Sparse forest
Majority sparse forest, wetland
Majority sparse forest, cropland
Majority sparse forest, bare soil
Sparse forest, cropland
Sparse forest, bare soil
Majority cropland
Majority sparse forest, plantation
Cropland
Cropland, wetland, built-up
Wetland
Built-up
B
15 km
10 km
5 km
Dense forest
Majority dense forest
Dense forest, sparse forest
Majority sparse forest
Sparse forest, grassland
Dense forest, sparse forest, grassland
Dense forest, sparse forest, cropland
Majority sparse forest, wetland
Majority sparse forest, cropland
Majority sparse forest, bare soil
Majority sparse forest, plantation
Sparse forest, cropland
Cropland, built-up, wetland


High mountain
Midland
South midland
Foothills
West plain
Cumulative rain (mm)
Temperature (°C)
Month
1200
1000
800
600
400
200
0
40
35
30
25
20
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