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Factors associated with mosquito-borne disease protective behaviour: a pre-registered cross-sectional study in metropolitan France

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Abstract

Background

Mosquito-borne diseases (MBDs) are increasing and expanding their range throughout metropolitan France. Promoting individual protective behaviour is imperative, but research on its determinants is limited to southern regions. This study aims to quantify the knowledge, attitudes, and practice around MBDs and examine factors influencing protective behaviour in the metropolitan French population.

Methods

2,087 subjects responded an online questionnaire in November 2023. We fitted two mixed effects models to estimate the frequency and count of protective behaviours across different sociodemographic groups and to identify which factors influence protective behaviour.

Results

Frequency of protective behaviour is significantly associated with perceived MBD threat ($\beta = 0.11$; 95% CI: 0.06, 0.15), having financial difficulties ($\beta = 0.23$; 95% CI: 0.02, 0.43), and getting bitten by mosquitoes often ($\beta = 3.39$; 95% CI: 3.10, 3.69) and sometimes ($\beta = 1.54$; 95%

CI: 1.31, 1.76) compared to almost never. Count of protective behaviours is associated with getting bitten by mosquitoes often (β = 0.39; 95% CI: 0.30, 0.49) and sometimes (β = 0.14; 95% CI: 0.05, 0.23), perceived MBD threat (β = 0.02; 95% CI: 0.00, 0.03), MBD knowledge (β = 0.06; 95% CI: 0.04, 0.08), and having a chronic disease (β = 0.08; 95% CI: 0.02, 0.14). Models were adjusted for place of residence, education, and age. No associations were found for sex, having experienced an MBD, or confidence in public authorities to manage health crises.

Conclusions

This study provides insights into MBD protective behaviour and its associated factors considering all metropolitan French regions. Our results highlight factors which may inform prevention communication and policies focused on increasing protective behaviour.

Keywords: Mosquito-borne disease, Aedes albopictus, protective behaviour, prevention

Facteurs associés aux comportements de protection contre les maladies transmises par les moustiques : étude transversale pré-enregistrée en France métropolitaine

Résumé

Contexte

Les maladies transmises par les moustiques (MTM) sont en augmentation et étendent leur aire de répartition dans toute la France métropolitaine. Il est impératif de promouvoir les comportements individuels de protection, mais les recherches sur leurs déterminants sont limitées aux régions méridionales. Cette étude se propose de quantifier les connaissances, les attitudes et les pratiques concernant les MTM et d'examiner les facteurs influençant les comportements de protection dans la population française métropolitaine.

Les méthodes

2 087 sujets ont répondu à un questionnaire auto-administré en ligne en novembre 2023. Nous avons ajusté deux modèles à effets mixtes pour estimer la fréquence et le nombre de comportements protecteurs dans différents groupes sociodémographiques et pour identifier les facteurs qui influencent des comportements protecteurs.

Résultats

La fréquence des comportements de protection est significativement associée à la perception d'une menace de MTM (β = 0.11; 95% CI: 0.06, 0.15), aux difficultés financières (β = 0.23; 95% CI: 0.02, 0.43) et au fait d'être piqué par des moustiques souvent (β = 3.39; 95% CI: 3.10, 3.69) et parfois (β = 1.54; 95% CI: 1.31, 1.76) par rapport au fait de ne presque jamais être piqué. Le nombre de comportements protecteurs est associé au fait d'être piqué par des moustiques souvent (β = 0.39; 95% CI: 0.30, 0.49) et parfois (β = 0.14; 95% CI: 0.05, 0.23), à la perception d'une menace de MTM (β = 0.02; 95% CI: 0.00, 0.03), la connaissance de la MTM (β = 0.06; 95% CI: 0.04, 0.08) et le fait d'être atteint d'une maladie chronique (β = 0.08; 95% CI: 0.02, 0.14). Les modèles ont été ajustés en fonction du lieu de résidence, du niveau d'éducation et de l'âge. Aucune association n'a été trouvée pour le sexe, le fait d'avoir connu une MTM ou la confiance dans les autorités publiques pour gérer les crises sanitaires.

Conclusions

Cette étude donne un aperçu des comportements de protection contre la MTM et des facteurs qui y sont associés dans toutes les régions métropolitaines de France. Nos résultats mettent en évidence des facteurs susceptibles d'éclairer la communication et les politiques de prévention visant à renforcer les comportements de protection.

Mots-clés: Maladie transmise par les moustiques, Aedes albopictus, comportement de protection, prévention

1. Introduction

1.1. Landscape of mosquito-borne diseases

Mosquito-borne diseases (MBDs) are a worldwide health challenge. Approximately half of the global population is at risk of infection, with disadvantaged groups experiencing the highest burden (1). MBDs, such as dengue, chikungunya, and Zika virus disease, are transmitted by species prevalent in tropical and subtropical regions. Nonetheless, MBDs are expanding their geographic range to previously unaffected territories and re-emerging in zones where it had subsided, suggesting that outbreaks could occur where the population is immunologically naïve, health infrastructure is ill-equipped to treat MBDs, and context-specific research is scarce (2).

Climate change, urbanization, and globalization contribute to the expansion of MBDs (1). MBD transmission occurs along a spectrum from low-level year-round endemic infections to

substantial interannual or seasonal outbreaks (3). Climate change is expected to heighten MBD transmission through increased vector population size, survival, competence, reproduction, and biting (2). Given the influence of climate on egg and larvae viability, climate change may overwrite the geographic limits of medically relevant mosquito species to allow their spread across historically temperate zones (4,5). For example, a study found that mosquito eggs and adult mosquitos were more abundant after extreme rainfall and land surface temperature, which are projected to become more frequent (6). Beyond environmental effects, migration and land use shifts due to climate change increase MBD risk due to urbanization (4).

Urban areas are particularly vulnerable because they increase human-created mosquito breeding sites and the likelihood of vector-human interactions due to high population density (2). Evidence suggests that population density drives mosquito preferences for biting humans, and rapid urbanization could further increase human biting (7). Moreover, urban areas have more larval habitats and greater mosquito development and survivorship rates than semi-urban or rural areas (8). A meta-analysis found that urbanization, along with deforestation and agricultural development, favour the abundance of *Aedes aegypti*, *Aedes albopictus*, and other medically relevant mosquito species (9).

Globalization has facilitated the establishment of *Aedes* mosquitoes in environments where they were not previously present (10). For example, *Aedes albopictus* is thought to have reached Europe through commercial routes from Southeast Asia and is now established in 20 European countries, benefitting from the loss of biodiversity, biotic homogenisation, urbanization, and climate change (11). Affected countries include Spain, France, Italy, Greece, Croatia, and Germany (12). Currently, 49% of European urban areas are environmentally suitable for *Aedes albopictus,* and predictions suggest this number will rise to 83% by 2050 (13). Presently, dengue, chikungunya, and Zika virus disease infections in Europe are mostly imported due to the volume of people travelling to or from endemic areas (14). However, research on MBDs has increased since 2000 in Southern Europe, where locally transmitted MBD cases have been more frequently identified (10,14–16).

1.2. Mosquito-borne diseases and prevention in metropolitan France

Since January 2023, *Aedes albopictus* has been established in 73.95% (71/96) of French departments (17). Locally-transmitted outbreaks of MBDs have been documented in mainland France in the past ten years (18–23). For comparison, 53.78% (155/273) of reported locally transmitted MBD cases in mainland Europe since 2010 have been in France (24). High year-

round tourism, high-profile international events (2024 Summer Olympics, Le Tour de France, 2027 Cycling World Championship), and increasing migration could further increase MBD risk by introducing arboviruses via imported MBD cases (25,26). Other *Aedes* mosquito species already present in France could potentially behave as MBD vectors which demonstrated to be competent in transmitting the West Nile virus in controlled lab environments (27).

To increase promote protective practices, authorities have released animated videos (28,29), educational posters (30), mosquito control tutorials (31), preventive behaviour checklists (32), mosquito reporting portals (33), and communication kits for communities and children (34,35). Despite educational efforts and the growing MBD risk, metropolitan residents may not be as knowledgeable and likely to adopt MBD protective measures as the French overseas population with a higher perceived risk (36,37). Evidence suggests that people in Southern France see mosquitoes as nuisances rather than disease vectors, have imprecise estimates of mosquito activity in their area, and do not adopt behaviour to prevent biting (37–41).

1.3. Challenges of mosquito-borne disease prevention

The most common forms of MBD prevention focus on reducing vector-human interactions through vector control (42). Vector control comprises removing breeding habitats (e.g., removing standing water), targeting immature vectors (e.g., chemical larvicides), killing vectors (e.g., indoor residual spraying, eave tubes), and controlling mosquito populations through bacterial infection (e.g., Wolbachia), genetic modification, or sterilization (43). Reducing vector contact includes using repellents, insecticide-treated bed nets, or long clothing (43). Recently, there has been progress in developing vaccines to prevent MBDs (44,45).

MBD prevention efforts require varying degrees of population tolerance, acceptance, support, or consent. For example, given availability, using insecticide-treated bed nets is a function of individual decision-making and adherence (46). Indoor residual spraying campaigns are government- or NGO-sponsored but need people's consent to intervene in their households (47). Wolbachia-based or genetic interventions do not go through individual explicit consent, but public acceptance is crucial given its known and theorised ethical and environmental effects (48). While interventions like vaccines have developed acceptance models, research on acceptance of Wolbachia- or genetic-based technology is incipient (48,49).

Successful mosquito control requires high community participation, underpinned by the population's information and perception of the strategy in question (10). Irrespective of the intervention's effectiveness, assessing the potential acceptance of local communities where

implementation may occur is imperative (50). Despite the increase in MBD cases, studies on the metropolitan population's perception of MBDs and prevention are scarce and limited to southern regions (38). Thus, this study aims to quantify the knowledge, attitudes, and practice around MBDs and examine factors influencing protective behaviour in the metropolitan French population.

2. Methods

2.1. Study design

The study is cross-sectional. Knowledge, attitude, and practices (KAP) surveys are a well-established method to identify key parameters that drive good or bad practices, knowledge, and attitudes regarding MBDs and their prevention (51,52). We conducted a KAP survey through a self-administered online questionnaire on a general population sample in metropolitan France. The planned statistical analyses were pre-registered prior to any variable manipulation and statistical analysis (53).

2.2. Participants

Participants were recruited through an online panel using quotas to ensure a representative sample according to age, sex, region of residence, and socioeconomic status based on census data. Any resident of metropolitan France between 18 and 79 years old was eligible.

2.3. Ethical considerations

The study received approval from the institutional review committee of the Institut Pasteur. Participants read the study information and consented to participate before starting the questionnaire. Data collection and management were performed in adherence to international research ethics (Helsinki Declaration) and data protection (GDPR).

2.4. Data collection

The questionnaire is available in the Annex 1. The questionnaire consisted of i) socio-demographic and socio-economic information, ii) presence of MBD risk factors, iii) knowledge of MBDs, iv) lifestyle and good health practices, v) lived experience of MBDs, vi) known and protective practices, and vii) theoretical acceptance of preventive interventions against MBDs. Participants were contacted through email by a third-party contractor. The survey was completed in November 2023.

2.5. Data preparation

Following a standardized reporting framework (54), detailed documentation of pre-registration deviations can be found in the Annex 2. No outliers were identified. Participants were required to answer all items included in the analysis. Thus, missing data was limited to secondary variables. To simplify analysis and obtain information with useful real-world implications, items exploring different components of the same psychological construct were merged into indicators.

2.5.1. Variable definitions

A table with the description of the variables can be found in Annex 3. Main variables were assessed as follows.

Frequency of protective behaviour was assessed by asking participants 'Last summer, how often did you make efforts to avoid mosquitoes?' (never, only a few times, several times).

Count of protective behaviours was measured as the number of unique practices marked when participants were asked to 'Please list any preventative activities you have been involved in to avoid mosquitoes' out a list of common MBD protective practices (e.g., removing stagnant water, using insecticide). Participants were able to write unlisted practices as free text.

Perceived MBD threat was assessed as the average of two items measured on a scale from 1(low threat) to 10 (high threat). The first item asked 'How likely do you think it is that you will have a mosquito-borne disease in the near future?' on a scale from 1 ('no chance') to 10 ('it will certainly happen'). The second item asked 'Are you worried about diseases transmitted by mosquitoes?' on a scale from 1 ('not at all') to 10 ('very much').

Place of residence was assessed by combining region of residence and size of the city of residence to create 52 possible categories (e.g., large city in the Paris region, village in Normandy, medium city in Brittany). Region of residence included all 13 metropolitan administrative regions in France. Size of the city of residence included large city (>100,000 inhabitants), medium city (20,000-100,000 inhabitants), small city (2,000-20,000 inhabitants), or village (<2,000 inhabitants).

MBD knowledge was assessed as a score -4 (low knowledge) to 5 (high knowledge) based on the following. Participants were asked 'In your opinion, what diseases can be transmitted by mosquitoes in general?' and prompted to mark options from a list of diseases including dengue, zika, COVID, diabetes, etc. A correct choice increases MBD knowledge score by one and an incorrect choice decreases it by one. Exclusive option 'Mosquitoes transmit diseases, but I don't

know them' was coded as 0. Exclusive option 'Mosquitoes do not transmit any diseases' was coded as -1. Participants were also asked 'True or false: All mosquitoes regardless of gender bite' (true, I don't know, false). 'False' increases MBD knowledge score by one. 'True' decreases MBD knowledge score by one. 'I don't know' does not change the score.

Confidence in public authorities to manage health crises was assessed as the average of two items measured on a scale from 1(low confidence) to 10 (high confidence). The first item asked 'How much confidence do you place in national authorities (ministry of health, etc.) to manage a health crisis?' and the second item asked 'How much confidence do you place in municipal and regional authorities (town hall, etc.) to manage a health crisis?' on a scale from 1 ('not at all) to 10 ('completely').

Financial difficulty was assessed by asking participants 'Over the last 12 months, has your household experienced any financial difficulties (for example, not being able to pay rent, a mortgage, credit purchases or current bills on time)?' (no, never; yes, sometimes; yes, often). Response categories *yes, sometimes* and *yes, often* were merged. Thus, the variable is binary (yes, no).

2.6. Model specification

Our model selection strategy started with a theory-informed mixed model including random intercepts and a minimally sufficient set of confounding variables of each predictor-outcome relationship, as identified through Directed acyclic graphs (DAGs) (Annex 4). DAGs are used to identify causal relationships and facilitate statistical analysis specification (55). Due to sampling design, data were naturally clustered by geographic regions, which have different climates and policies [insert citation]. Therefore, to account for the within-group correlation amongst people in similar communities, random intercepts were used with variable *place of residence*. For the sake of parsimony and interpretability, we followed a series of steps to simplify our models. If the intraclass correlation coefficient (ICC) of the random effect was ≤ .05, we conducted a likelihood ratio tests (LRT) comparing a mixed-effects model with a nested fixed-effects-only model to examine the utility of applying a multilevel modelling approach. Given that variance cannot be negative and this test is on the boundary of the parameter space, a more correct p-value was obtained by halving the nominal LRT p-value when testing fixed-effects-only models versus mixed-effects models (56). If the LRT suggested that the random intercept did not provide a significantly better fit compared to the nested model, we favoured the latter. In every model comparison step, the LRT was used in a similar fashion, where a non-significant p-value

favoured the nested model, and a significant value favoured the model with more parameters. Then, we removed variables that had weak associations with the outcome at $|\beta| < .05$ in one block. LRT was used to understand if the nested model with fewer parameters performs significantly worse than the full model. Finally, we provided goodness-of-fit measures and effect estimates of the best fitting models.

2.6.1. Cumulative link mixed models for three-level frequency outcome

The associations between predictors and frequency of protective behaviour were assessed using cumulative link mixed models (CLMMs), also known as ordered logit mixed models or proportional odds mixed model for the logit link function. CLMMs offer several advantages over other approaches to analyse ordinal outcome data, namely multinomial logistic regression and ordinary linear regression (57). Multinomial logistic regression loses information as it ignores the ordering of the outcome data. Linear regression assumes homoscedasticity, normality of residuals, and equal distance between ordinal levels, and these assumptions are often violated. Moreover, linear regression often yields predictions beyond the possible response scale (58,59).

CLMMs handle the outcome data as ordered categories that arise from the application of thresholds to a latent continuous variable (59–61). Given that frequency of MBD protective behaviour is defined by the number of events per unit time, it is reasonable to assume that the verbally labelled discrete responses (never, a few times, several times) result from the categorization of a latent, unobservable, continuous variable. Therefore, cumulative modelling is theoretically justified for the data. CLMM relies on the independence of observations and proportional odds assumptions (62). The independence of observations assumption was observed by study design and inclusion of the geographic clustering variable. The proportional odds assumption holds that the associations between each pair of outcome groups are the same. Assessment of this assumption is reported in the Results section.

The adaptive Gauss-Hermite quadrature method set at 10 was implemented to compute the likelihood function, as it provides more accurate model parameters compared to the Laplace approximation (56). Given that confidence intervals (CI) calculated via the Wald method can be imprecise when the asymptotic properties of the maximum likelihood estimator are not reached, profile likelihood CI were calculated as a robust alternative (63). The condition number of Hessian measures was checked to assess identifiability. Numbers over 10^6 may imply certain parameters remain unidentifiable (56). Further model optimization was carried out by testing alternative structured thresholds and link functions. Standard unstructured thresholds were

maintained because log-likelihood did not improve when thresholds were restricted to be equidistant or symmetrical. Out of probit, complementary log–log, loglog, and cauchit links, only cauchit slightly improved model log-likelihood ($\Delta < 2$). Logit link was kept because the negligible goodness-of-fit improvement did not outweigh the reduction in ease of interpretation.

2.6.2. Zero-inflated negative binomial mixed models for count outcome

The associations between predictors and count of protective behaviours were tested using negative binomial mixed models (NBMMs). Since count data are non-negative whole numbers that tend to have a right-skewed distribution, Poisson regression is often used. However, real-world count data is typically overdispersed and violates the equidistribution assumption of Poisson regression (64,65). NBMMs appropriately address overdispersion. Given that our outcome had substantial zero inflation, we also used a zero-inflated model to improve goodness-of-fit (66). Zero-inflated models assume that zero counts result from two distributions: participants exposed to the outcome who did not report the outcome, and participants not at risk of the outcome who always produce zero counts (67). Alternatives to zero-inflated models are zero-truncated or hurdle models, which imply that all zero counts come from the latter distribution, which is also referred to as structural zeros (67). We assumed that all people had the opportunity to experience the outcome but could provide zero counts due to a multiplicity of factors including chance. Thus, a zero-inflated negative binomial mixed model (ZINBMMs) was more appropriate and reported an improved AIC ($\Delta = 3$) over zero-truncated models.

Dispersion was assessed by comparing the variance of observed raw residuals against the variance of simulated residuals. Collinearity was assessed via variance inflation factors (VIFs). The CIs for VIFs and tolerance were based on Marcoulides et al (68). Typical thresholds are 10, 5, and 3 VIFs for high, medium, and low collinearity, respectively (69,70). Further model optimization was carried out by testing alternative zero-inflation formula. Log-likelihood did not improve when the zero-inflation formula was allowed to vary by perceived MBD threat, financial difficulty, or age instead of by biting frequency. Thus, no changes on the zero-inflation formula were made.

Statistical significance was set at $p \leq .05$. R version 4.3.3 was used for all analyses. Packages used for modelling were ordinal and glmmTMB (71,72). Packages used for model performance selection and evaluation were lmtest, performance, and DHARMa (73–75). The full reproducible code, including functions and package versions, is available in Annex 5.

3. Results

3.1. Descriptive analysis

A total of 2,087 participants completed the survey. Table 1 presents their main characteristics. 52% were women. Age groups 18 to 39 years, 40 to 59 years, and 60 to 75 years contributed 35%, 35% and 29%, respectively. The Paris region, Northeast, Northwest, Southeast, and Southwest regions represent 19%, 22%, 23%, 25%, and 11% of the sample, respectively. These statistics are aligned with census data. Furthermore, most participants studied for up to 2 to 4 years beyond secondary school (85%), did not have financial difficulties in the last 12 months (73%), speak exclusively French at home (80%), do not have dependent children (67%), and do not have chronic diseases (69%). The majority gets bitten by mosquitoes sometimes or often (73%) and never had an MBD (94%).

Table 2 presents the KAP of MBD prevention in the sample. Overall, most participants reported engaging in MBD protective behaviour a few times (39%) or several times (41%) during the summer, as opposed to never (20%). The median number of unique protective behaviours undertaken by participants was 2 (IQR: 1 – 4), which increases to 3 (IQR: 2 – 4) when omitting participants who do not engage in protective behaviours. The majority (64%) knew that not all mosquitoes regardless of sex bite; and nearly half (49%) correctly identified all four diseases (chikungunya, dengue, Zika, malaria) that were mosquito-borne from a list of nine possible choices. In terms of attitudes, on average, participants believed they had a 60% probability (IQR: 40% – 70%) of contracting an MBD in a near future. On a scale from 1 to 10, where 1 represented “not at all” and 10 represented “immensely”, participants had an average score of 6 when responding to whether they were afraid of MBDs (IQR: 4 – 8).

Table 3 reports the protective behaviours by region. The most common protective behaviours were storing containers out of the rain to avoid stagnant water (37%), using skin repellents (36%), using mosquito candles and coils (35%), and avoiding stagnant water at the base of flowerpots and vases (35%). These practices remained the most common at 46%, 44%, 45%, and 44%, respectively, amongst Southern regions, namely Provence-Alpes-Côte d'Azur (PACA), Occitanie, Auvergne-Rhône-Alpes (ARA), Nouvelle-Aquitaine, and Corse. On the other extreme, using mosquito traps (19%) and maintaining gutters to ensure drainage (16%) were the least common practices in the total sample.

Table 1

Description of the study population per region

Characteristic	Overall, N = 2,087[1]	Region												
		Île-de-France, N = 392[1]	Centre-Val de Loire, N = 78[1]	Provence-Alpes-Côte d'Azur, N = 159[1]	Occitanie, N = 196[1]	Nouvelle-Aquitaine, N = 194[1]	Auvergne-Rhône-Alpes, N = 258[1]	Hauts-de-France, N = 207[1]	Normandie, N = 117[1]	Grand Est, N = 162[1]	Bourgogne-Franche-Comté, N = 89[1]	Bretagne, N = 118[1]	Pays de la Loire, N = 112[1]	Corse, N = 5[1]
Sex														
Man	1,012 (48%)	226 (58%)	31 (40%)	75 (47%)	91 (46%)	89 (46%)	130 (50%)	97 (47%)	53 (45%)	79 (49%)	37 (42%)	48 (41%)	52 (46%)	4 (80%)
Woman	1,075 (52%)	166 (42%)	47 (60%)	84 (53%)	105 (54%)	105 (54%)	128 (50%)	110 (53%)	64 (55%)	83 (51%)	52 (58%)	70 (59%)	60 (54%)	1 (20%)
Age group														
18 to 39	736 (35%)	206 (53%)	22 (28%)	57 (36%)	61 (31%)	61 (31%)	98 (38%)	64 (31%)	36 (31%)	40 (25%)	24 (27%)	36 (31%)	28 (25%)	3 (60%)
40 to 59	738 (35%)	125 (32%)	26 (33%)	55 (35%)	69 (35%)	69 (36%)	94 (36%)	74 (36%)	41 (35%)	58 (36%)	37 (42%)	47 (40%)	42 (38%)	1 (20%)
60 to 79	613 (29%)	61 (16%)	30 (38%)	47 (30%)	66 (34%)	64 (33%)	66 (26%)	69 (33%)	40 (34%)	64 (40%)	28 (31%)	35 (30%)	42 (38%)	1 (20%)
Type of settlement														
Village (<2 000 inhabitants)	482 (23%)	8 (2.0%)	25 (32%)	11 (6.9%)	56 (29%)	68 (35%)	62 (24%)	56 (27%)	42 (36%)	52 (32%)	50 (56%)	19 (16%)	31 (28%)	2 (40%)
Small town (between 2.000 and 20.000 inhabitants)	631 (30%)	71 (18%)	27 (35%)	41 (26%)	61 (31%)	58 (30%)	88 (34%)	75 (36%)	34 (29%)	53 (33%)	21 (24%)	57 (48%)	45 (40%)	0 (0%)
Medium-sized city (between 20 000 and 100 000 inhabitants)	557 (27%)	166 (42%)	16 (21%)	63 (40%)	40 (20%)	52 (27%)	57 (22%)	54 (26%)	22 (19%)	29 (18%)	8 (9.0%)	31 (26%)	17 (15%)	2 (40%)
Large city (>100 000 inhabitants)	417 (20%)	147 (38%)	10 (13%)	44 (28%)	39 (20%)	16 (8.2%)	51 (20%)	22 (11%)	19 (16%)	28 (17%)	10 (11%)	11 (9.3%)	19 (17%)	1 (20%)
Educational attainment														
Below Bac (no diplome, BEPC, CAP, etc.)	450 (22%)	56 (14%)	24 (31%)	29 (18%)	40 (20%)	50 (26%)	46 (18%)	45 (22%)	37 (32%)	45 (28%)	26 (29%)	16 (14%)	34 (30%)	2 (40%)
Bac (général, pro or technologique)	502 (24%)	72 (18%)	16 (21%)	38 (24%)	46 (23%)	48 (25%)	73 (28%)	65 (31%)	29 (25%)	29 (18%)	27 (30%)	38 (32%)	20 (18%)	1 (20%)
Bac+2 (BTS or other)	472 (23%)	73 (19%)	11 (14%)	45 (28%)	49 (25%)	46 (24%)	56 (22%)	39 (19%)	24 (21%)	41 (25%)	20 (22%)	29 (25%)	37 (33%)	2 (40%)
Bac+3/4 (Licence, Maîtrise)	345 (17%)	83 (21%)	17 (22%)	23 (14%)	33 (17%)	31 (16%)	47 (18%)	36 (17%)	13 (11%)	25 (15%)	8 (9.0%)	20 (17%)	9 (8.0%)	0 (0%)
Bac+5 or higher (Master, doctoral, post-doc)	318 (15%)	108 (28%)	10 (13%)	24 (15%)	28 (14%)	19 (9.8%)	36 (14%)	22 (11%)	14 (12%)	22 (14%)	8 (9.0%)	15 (13%)	12 (11%)	0 (0%)
Had financial difficulties in the past 12 months	572 (27%)	134 (34%)	18 (23%)	49 (31%)	54 (28%)	60 (31%)	62 (24%)	53 (26%)	33 (28%)	36 (22%)	21 (24%)	28 (24%)	20 (18%)	4 (80%)
Has a chronic disease	653 (31%)	107 (27%)	30 (38%)	43 (27%)	58 (30%)	66 (34%)	71 (28%)	75 (36%)	37 (32%)	53 (33%)	26 (29%)	46 (39%)	39 (35%)	2 (40%)
Frequency of mosquito bites														
Never or almost never	575 (28%)	73 (19%)	32 (41%)	31 (19%)	28 (14%)	35 (18%)	55 (21%)	83 (40%)	46 (39%)	73 (45%)	29 (33%)	50 (42%)	38 (34%)	2 (40%)
Sometimes	896 (43%)	194 (49%)	34 (44%)	62 (39%)	77 (39%)	68 (35%)	114 (44%)	88 (43%)	44 (38%)	70 (43%)	29 (33%)	58 (49%)	56 (50%)	2 (40%)
Often	616 (30%)	125 (32%)	12 (15%)	66 (42%)	91 (46%)	91 (47%)	89 (34%)	36 (17%)	27 (23%)	19 (12%)	31 (35%)	10 (8.5%)	18 (16%)	1 (20%)
Frequency of protective behaviour														
Never	414 (20%)	62 (16%)	26 (33%)	20 (13%)	17 (8.7%)	31 (16%)	55 (21%)	46 (22%)	35 (30%)	45 (28%)	20 (22%)	34 (29%)	22 (20%)	1 (20%)
A few times	808 (39%)	146 (37%)	37 (47%)	44 (28%)	58 (30%)	54 (28%)	84 (33%)	97 (47%)	49 (42%)	82 (51%)	36 (40%)	63 (53%)	57 (51%)	1 (20%)
Several times a week	865 (41%)	184 (47%)	15 (19%)	95 (60%)	121 (62%)	109 (56%)	119 (46%)	64 (31%)	33 (28%)	35 (22%)	33 (37%)	21 (18%)	33 (29%)	3 (60%)

[1] n (%)

Table 2

Knowledge, attitudes, and practices of mosquito-borne diseases and prevention per region

		Region												
Indicator	**Overall**, N = 2,087[1]	**Île-de-France**, N = 392[1]	**Centre-Val de Loire**, N = 78[1]	**Provence-Alpes-Côte d'Azur**, N = 159[1]	**Occitanie**, N = 196[1]	**Nouvelle-Aquitaine**, N = 194[1]	**Auvergne-Rhône-Alpes**, N = 258[1]	**Hauts-de-France**, N = 207[1]	**Normandie**, N = 117[1]	**Grand Est**, N = 162[1]	**Bourgogne-Franche-Comté**, N = 89[1]	**Bretagne**, N = 118[1]	**Pays de la Loire**, N = 112[1]	**Corse**, N = 5[1]
Count of protective behaviour (0 to 10)	2 (1, 4)	2 (1, 3)	2 (0, 3)	3 (2, 4)	4 (2, 5)	3 (1, 4)	3 (1, 4)	2 (1, 4)	2 (0, 3)	2 (0, 3)	2 (1, 4)	2 (0, 3)	2 (1, 3)	3 (1, 3)
Perceived likelihood of contracting a mosquito-borne disease (1 to 10)	6 (4, 7)	6 (4, 7)	6 (4, 6)	6 (4, 7)	6 (5, 8)	6 (5, 7)	6 (4, 7)	6 (4, 7)	6 (4, 7)	6 (4, 7)	6 (4, 7)	6 (4, 7)	6 (5, 7)	5 (4, 5)
Concern of contracting a mosquito-borne disease (1 to 10)	6 (4, 8)	6 (4, 8)	6 (4, 8)	6 (3, 8)	6 (4, 8)	6 (4, 8)	6 (4, 8)	6 (4, 8)	6 (3, 8)	6 (4, 8)	6 (4, 8)	6 (4, 8)	6 (4, 8)	7 (5, 8)
Confidence in national authorities in the management of health crises (1 to 10)	7 (6, 8)	7 (5, 8)	7 (5, 8)	7 (5, 8)	7 (6, 8)	7 (5, 8)	7 (5, 9)	7 (6, 9)	7 (6, 9)	7 (5, 8)	8 (6, 9)	7 (6, 8)	8 (6, 9)	7 (7, 9)
Confidence in regional authorities in the management of health crises (1 to 10)	7 (6, 8)	7 (6, 8)	7 (5, 8)	7 (6, 8)	7 (6, 8)	7 (6, 8)	7 (6, 9)	7 (6, 9)	7 (6, 8)	7 (6, 9)	8 (6, 9)	7 (6, 8)	8 (6, 9)	9 (7, 9)
Mosquito-borne disease knowledge score (-4 to +5)	2.56 (1.41)	2.38 (1.61)	2.59 (1.40)	2.78 (1.38)	2.59 (1.34)	2.81 (1.22)	2.69 (1.42)	2.35 (1.44)	2.50 (1.32)	2.71 (1.30)	2.89 (1.18)	2.25 (1.36)	2.53 (1.33)	1.80 (2.17)

[1] Median (IQR); Mean (SD)

Table 3

Mosquito-borne disease protective behaviours per region

		Region												
Protective behaviour	**Overall**, N = 2,087[1]	**Île-de-France**, N = 392[1]	**Centre-Val de Loire**, N = 78[1]	**Provence-Alpes-Côte d'Azur**, N = 159[1]	**Occitanie**, N = 196[1]	**Nouvelle-Aquitaine**, N = 194[1]	**Auvergne-Rhône-Alpes**, N = 258[1]	**Hauts-de-France**, N = 207[1]	**Normandie**, N = 117[1]	**Grand Est**, N = 162[1]	**Bourgogne-Franche-Comté**, N = 89[1]	**Bretagne**, N = 118[1]	**Pays de la Loire**, N = 112[1]	**Corse**, N = 5[1]
Maintaining gutters to ensure drainage	327 (16%)	42 (11%)	8 (10%)	23 (14%)	49 (25%)	37 (19%)	40 (16%)	39 (19%)	21 (18%)	22 (14%)	13 (15%)	18 (15%)	15 (13%)	0 (0%)
Using mosquito traps	390 (19%)	90 (23%)	9 (12%)	39 (25%)	41 (21%)	39 (20%)	41 (16%)	37 (18%)	17 (15%)	26 (16%)	14 (16%)	16 (14%)	20 (18%)	1 (20%)
Wearing long, loose, light-coloured clothing	452 (22%)	105 (27%)	13 (17%)	31 (19%)	50 (26%)	47 (24%)	57 (22%)	42 (20%)	18 (15%)	26 (16%)	20 (22%)	23 (19%)	18 (16%)	2 (40%)
Using insecticide or fumigating	504 (24%)	100 (26%)	10 (13%)	50 (31%)	62 (32%)	53 (27%)	61 (24%)	58 (28%)	17 (15%)	28 (17%)	22 (25%)	20 (17%)	22 (20%)	1 (20%)
Using mosquito nets in windows	529 (25%)	88 (22%)	14 (18%)	54 (34%)	89 (45%)	40 (21%)	80 (31%)	58 (28%)	15 (13%)	28 (17%)	29 (33%)	15 (13%)	18 (16%)	1 (20%)
Avoiding stagnant water at the base of flowerpots and vases	729 (35%)	106 (27%)	21 (27%)	73 (46%)	101 (52%)	77 (40%)	102 (40%)	57 (28%)	34 (29%)	57 (35%)	31 (35%)	28 (24%)	40 (36%)	2 (40%)
Using mosquito candles and coils	734 (35%)	127 (32%)	20 (26%)	79 (50%)	96 (49%)	91 (47%)	99 (38%)	56 (27%)	29 (25%)	45 (28%)	28 (31%)	26 (22%)	35 (31%)	3 (60%)
Using skin repellents	756 (36%)	142 (36%)	20 (26%)	67 (42%)	98 (50%)	84 (43%)	105 (41%)	57 (28%)	40 (34%)	44 (27%)	33 (37%)	33 (28%)	32 (29%)	1 (20%)
Storing containers out of the rain to avoid stagnant water	777 (37%)	106 (27%)	19 (24%)	71 (45%)	104 (53%)	93 (48%)	104 (40%)	63 (30%)	44 (38%)	60 (37%)	36 (40%)	34 (29%)	42 (38%)	1 (20%)

[1] n (%)

3.2. Frequency of protective behaviour

As described in the methods, we followed a stepwise model selection process that began with the most complex model (CLMM with random intercepts for place of residence and predictors biting frequency, MBD threat, age, sex, educational attainment, MBD knowledge score, chronic disease status, financial difficulty, and history of MBD [Model C1]) and simplified accordingly (See Table 4). Due to the low ICC (< .05), model C1 was compared to a nested CLM with only fixed effects (Model C2), but a significant LRT (p-value < .001) led us to retain model C1. After removing all variables weakly associated (|β| < .05) with the outcome or otherwise not statistically significant, we compared this reduced model (Model C3) with Model C1 and found that the LRT (p-value > .05) did not suggest that Model C1 significantly fit the data better than Model C3. Therefore, Model C3 (CLMM with random intercepts and variables MBD threat, biting frequency, age, educational attainment, financial difficulty) was our final model. Table 5 presents the final CLMM.

Table 4

Model selection via likelihood ratio test for frequency of protective behaviour.

Model	LogLik	AIC	Compared, nested vs complex	LRT	p*
C1	-1792.48	3618.95	-	-	-
C2	-1798.67	3629.34	C2 vs C1	12.39	0.000
C3	-1793.45	3610.90	C3 vs C1	1.943	0.857

*p-values when testing random effects were halved because given that variance cannot be negative and this test is on the boundary of the parameter space, a more correct p-value is obtained by halving the nominal LRT p-value.
LogLik: Log-Likelihood; AIC: Akaike Information Criterion; LRT: Likelihood ratio test

Table 5

Adjusted association of frequency of protective behaviour with perceived MBD threat, biting frequency, and financial difficulty

	Fixed Effects				
	β	SE	95% CI	z	p
Threshold: Never | A few times	0.98	0.25	0.49 – 1.47	3.96	<0.001
Threshold: A few times | Several times	3.36	0.26	2.85 – 3.87	12.89	<0.001
Perceived MBD threat (1-10)	0.11	0.02	0.06 – 0.15	4.72	<0.001
Biting frequency (Reference level: never or almost never)					

Sometimes	1.54	0.11	1.31 – 1.76	13.37	<0.001
Often	3.39	0.15	3.10 – 3.69	22.54	<0.001
Education (Reference level: below Bac)					
Bac (général, pro, or technologique)	0.19	0.13	-0.07 – 0.45	1.41	0.158
Bac+2 (BTS or other)	0.06	0.14	-0.21 – 0.33	0.44	0.657
Bac+3/4 (Licence or maîtrise)	0.22	0.15	-0.07 – 0.52	1.47	0.142
Bac+5 or higher (Master, doctoral, or post-doc)	0.22	0.16	-0.09 – 0.53	1.36	0.173
Age in years	0.01	0.00	0.00 – 0.01	2.75	0.006
Having financial difficulties	0.23	0.11	0.02 – 0.43	2.12	0.034

Random Effects			
		Variance	**SD**
Place of residence (Intercept)		0.092	0.30
σ^2	**τ_{place}**		**ICC**
3.29	0.09		0.03

Model fit		
Marginal R^2	**Conditional R^2**	**Cond. number of Hessian**
0.34	0.36	10^5

Maximum likelihood estimates of the parameters are provided using the adaptive Gauss-Hermite quadrature method. CI were calculated from the profiled likelihood. Thresholds are set to flexible. σ^2: residual variance; τ_{place}: random effect variance.
Model equation: Frequency of protective behaviour ~ Perceived MBD threat + Biting frequency + Educational attainment + Age + Financial difficulty + (1 | Place of residence)

The final model fit statistics do not suggest unidentifiability (Cond. number of Hessian < 10^6). Conditional pseudo R^2 was .36. Variable perceived MBD threat presents a VIF (VIF = 13.18) beyond the threshold but was kept because it is a hypothesised predictor of the outcome variable.

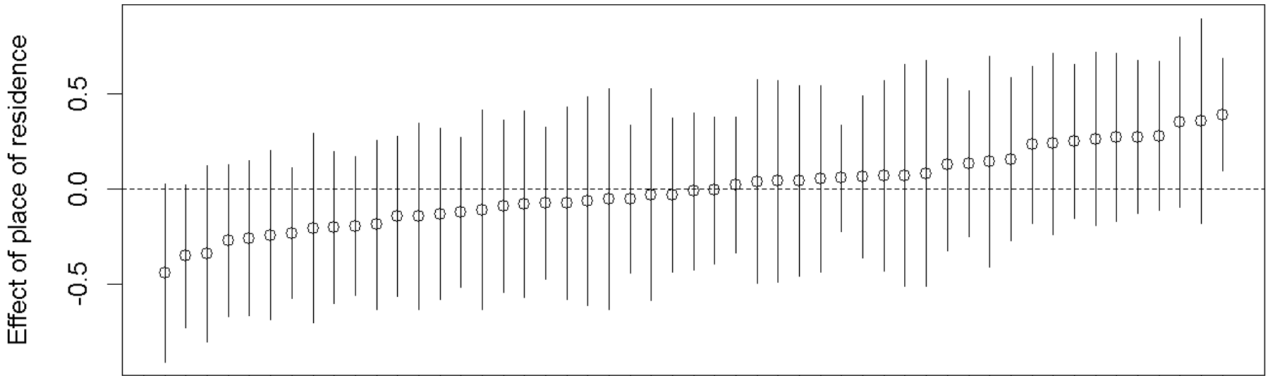
Notably, non-proportional odds structures among the predictor variables were identified for perceived MBD threat and biting frequency. Literature suggests that almost all cumulative models on real data show some evidence of non-proportional odds but that does not always imply that alternative models are the more useful (76). Violations of the proportional odds assumption usually do not prevent the models from providing reasonable estimates, especially for larger samples (77–79).

When controlling for place of residence, education attainment, and age, higher perceived MBD threat was associated with higher odds of engaging in protective behaviour more frequently. Compared to people who never or almost never get bitten by mosquitoes, people who get bitten often (cumulative odds ratio [COR] = 29.67; 95% CI: 22.10, 39.85) or sometimes (COR = 4.64; 95% CI: 3.71, 5.81) had higher odds of engaging in more frequent protective behaviours (Table 5). Similarly, people who experienced financial difficulties in the past 12 months also had higher odds (COR = 1.25; 95% CI: 1.02, 1.54) of engaging in more frequent protective behaviour compared to those who did not experience financial difficulties, while maintaining all other variables constant.

Place of residence accounted minimal explained variance (ICC = 0.03). Figure 1 presents the effect of place of residence on the frequency of protective behaviour via conditional modes with 95% CI based on the conditional variance It is important to note that these CIs are useful as measures of uncertainty but provide no inferential thresholds. Among places of residence, living in a large city in Île-de-France has the highest conditional mode (CM = 0.42; 95% CI: 0.13, 0.72) and it is the only place of residence with CIs removed from the null.

Figure 1

Effect of place of residence on the frequency of protective behaviour via conditional modes with 95% CI based on the conditional variance.



Note: Given the low ICC, the effect of place of residence should not be analysed per level. Thus, X axis labels are removed.

3.1. Count of protective behaviours

As described in the methods, we began our model fitting procedure with a NBMM with random intercepts for place of residence and covariates MBD threat, age, sex, educational attainment,

MBD knowledge score, chronic disease status, and history of MBD (Model N1). However, the ratio of observed zeros over zeros expected from simulations in Model N1 was 1.30 (p-value < .05), suggesting zero-inflation. Thus, we proceeded with a ZINBMM with random intercepts for place of residence, random slopes for biting frequency, and covariates MBD threat, age, sex, educational attainment, MBD knowledge score, chronic disease status, and history of MBD (Model N2). Given that the probability of zero counts was not the same for all observations, zero counts were allowed to vary by biting frequency. Due to the low ICC (< .05), we compared Model N2 to a nested ZINBM with only fixed effects (Model N3), and the significant LRT (p-value < .05) led us to keep Model N2. After removing all variables or predictors with weak associations (|β| < .05) with the outcome or otherwise not statistically significant, we compared this reduced model (Model N4) with Model N2 and the non-significant LRT (p-value > .05) led us to choose Model N4, a reduced ZINBMM with random intercepts and covariates MBD threat, biting frequency, age, educational attainment, MBD knowledge, and chronic disease status. Table 6 presents the model selection via likelihood ratio tests. Table 7 presents the final ZINBMM.

Table 6

Model selection via likelihood ratio test for count of protective behaviours.

Model	LogLik	AIC	Compared, nested vs complex	LRT	p*
N1	-4117.7	8265.5	-	-	-
N2	-3823.8	7687.7	-	-	-
N3	-3832.3	7702.6	N3 vs N2	16.90	0.000
N4	-3824.1	7680.2	N4 vs N2	0.57	0.966

*p-values when testing random effects were halved because given that variance cannot be negative and this test is on the boundary of the parameter space, a more correct p-value is obtained by halving the nominal LRT p-value.
LogLik: Log-Likelihood; AIC: Akaike Information Criterion; LRT: Likelihood ratio test

Table 7

Adjusted association of count of protective behaviours with perceived MBD threat, biting frequency, and MBD knowledge.

	Fixed Effects				
	β	SE	95% CI	z	p
Perceived MBD threat (1-10)	0.02	0.01	0.002 – 0.03	2.19	0.028
Biting frequency (Reference level: never or almost never)					
Sometimes	0.14	0.05	0.05 – 0.23	2.92	0.004
Often	0.39	0.05	0.30 – 0.49	8.04	0.000

Education (Reference level: below Bac)					
Bac (général, pro, or technologique)	0.04	0.04	-0.05 – 0.12	0.827	0.409
Bac+2 (BTS or other)	0.05	0.04	-0.04 – 0.14	1.111	0.267
Bac+3/4 (Licence or maîtrise)	0.12	0.05	0.03 – 0.22	2.577	0.010
Bac+5 or higher (Master, doctoral, or post-doc)	0.08	0.05	-0.02 – 0.18	1.590	0.112
Age in years	0.01	0.00	0.003 – 0.01	5.080	0.000
MBD knowledge score (-4 to +5)	0.06	0.01	0.04 – 0.08	5.115	0.000
Having a chronic disease	0.08	0.03	0.02 – 0.14	2.434	0.015

	Zero-inflated model				
	β	**SE**	**95% CI**	**z**	**p**
Biting frequency (Reference level: never or almost never)					
Sometimes	-2.27	0.22	-2.70 – -1.84	-10.37	0.000
Often	-4.93	1.68	-8.22 – -1.64	-2.94	0.003

Random Effects		
	Variance	**SD**
Place of residence (Intercept)	0.009	0.09
σ^2	**τ_{place}**	**ICC**
0.36	0.01	0.02

Model fit	
Marginal R^2	**Conditional R^2**
0.104	0.126

CI for fixed effects were calculated from the profiled likelihood. σ^2: residual variance; τ_{place}: random effect variance.
Model equation: Count of protective behaviour ~ Perceived MBD threat + Biting frequency + Educational attainment + Age + MBD knowledge + Chronic disease status + (1 | Place of residence), ziformula=~1 + Biting frequency

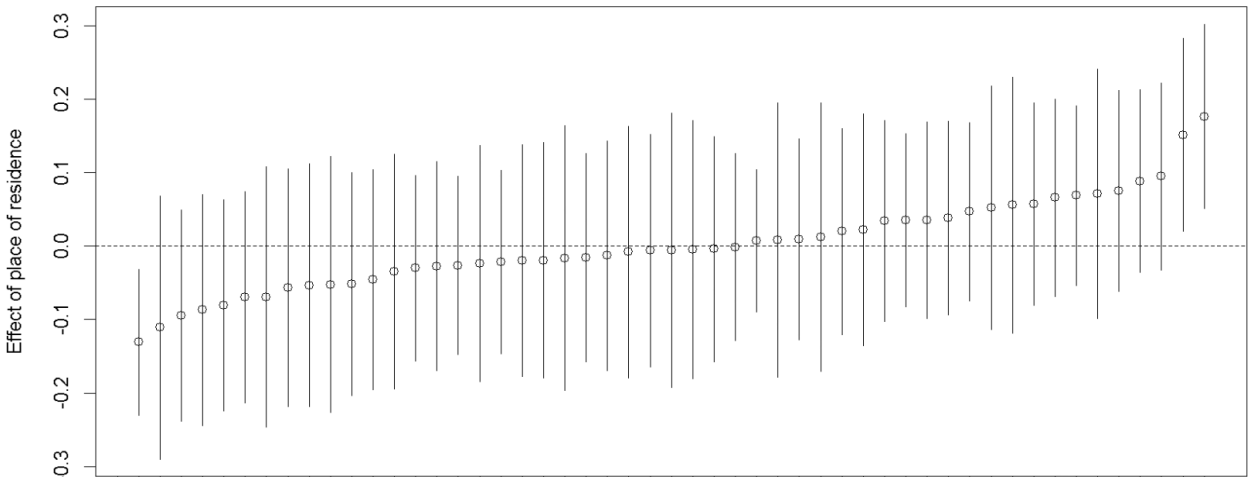
Regarding model fit, VIFs indicate very low correlation at the most conservative threshold (< 2), thereby providing no evidence of multicollinearity. Nonparametric dispersion test via fitted versus simulated residuals was not significant (0.93, p-value < .05), providing no evidence of over or underdispersion. Zero-inflation test via comparison of observed number of zeros with expected number of zeros was not significant (ratio = 0.99, p-value < .05). Conditional pseudo R-squared was 0.13.

From the zero-inflated model, we estimated that the odds of observing an excess zero in the count of protective behaviours are smaller among people who are bitten by mosquitoes often (OR = 0.01; 95% CI: 0.00, 0.19) and sometimes (OR = 0.10; 95% CI: 0.07, 0.16) compared to people who are never or almost never bitten. Following the latent class interpretation in zero-inflated models, we calculated adjusted rate ratios (RR) to reflect the estimates of the continuous frequency of the count of protective behaviour for people in the ‘‘not always zero group’’ (65).

Compared to people who never or almost never get bitten by mosquitoes, the expected count of protective behaviours for people who get bitten often and sometimes would increase by a factor of 1.48 (95% CI: 1.35, 1.63) and 1.15 (95% CI: 1.05, 1.26), respectively, while keeping all other variables constant. Likewise, each 1-point increase in MBD knowledge score was also associated with a higher count of protective behaviours (RR = 1.06; 95% CI: 1.04, 1.08). Similarly, a one-point increase in perceived MBD threat was associated with an increase in the expected count of protective behaviours by a factor of 1.02 (95% CI: 1.00, 1.03). Lastly, the expected count of protective behaviours for a person with a chronic disease is 1.08 (95% CI: 1.02, 1.16) times that of a person without chronic diseases while maintaining other variables constant. In the final model, place of residence accounted for 2% of the explained variance. The highest conditional modes corresponded to small towns (CM = 0.18; 95% CI: 0.05, 0.30) and villages (CM = 0.15; 95% CI: 0.01, 0.28) in Occitanie, while the lowest conditional mode corresponded to medium-sized cities in Île-de-France (CM = -0.13; 95% CI: -0.03, -0.23). Figure 2 presents the effect of place of residence on the count of protective behaviours via conditional modes with 95% CI based on the conditional variance.

Figure 2

Effect of place of residence on the count of protective behaviours via conditional modes with 95% CI based on the conditional variance.



Note: Given the low ICC, the effect of place of residence should not be analysed per level. Thus, X axis labels are removed.

4. Discussion

This study provides data on the KAP on MBDs, and evidence of factors associated with protective behaviour in a general population sample that considered every region in metropolitan France. Through an online survey, we found that most people got bitten by mosquitoes in their daily life (73%) and protected themselves a few (39%) or several times (41%) during the summer of 2023. The most common behaviours focused on controlling mosquito populations (storing containers out of the rain to avoid stagnant water, 37.2%; avoiding stagnant water at the base of flowerpots and vases, 34.9%) and repelling mosquitoes (using skin repellents, 36.2%; using mosquito candles or coils, 35.2%). Excluding those who do not protect themselves, the median of number of protective behaviours was 3 (IQR: 2 –4). Respondents believed they had a 60% (IQR: 40% – 70%) probability of contracting an MBD and averaged six (IQR: 4 – 8) on a 10-point scale when asked how afraid they were of MBDs. Furthermore, we found that biting frequency and perceived MBD threat are associated with a higher count of unique protective behaviours and frequency of engagement in protective behaviour. MBD knowledge was positively associated with the count of unique protective behaviours but not frequency, while experiencing financial difficulties increased protective behaviour frequency but not the count of behaviours.

To our knowledge, no evidence in Northern French populations is available for comparison, but our findings echo those of past studies in Southern France. In 2012, Raude et al. found in

Languedoc-Roussillon[1], PACA, and Corse that 56% of participants were sometimes or often bitten and 40% took preventive measures (38). When compared to the data of Occitanie, PACA, and Corse in this study, these percentages grew to 83% and 90%, respectively. These increments may be in response to higher mosquito populations, biting frequency, number of MBD cases, MBD media coverage, and MBD prevention campaigns compared to 2012, but cross-sectional data is insufficient to explore the reasons for this change. Raude et al. also found that the most frequent protective behaviours were using indoor insecticide (20.2%), removing stagnant water (17.7%), and using skin repellent (17.4%) in their sample (38). In 2023, we found that the most frequent protective behaviours were using mosquito candles and coils (49.4%), storing containers out of the rain to avoid stagnant water (48.9%), and avoiding stagnant water at the base of flowerpots and vases (48.9%). Using skin repellent and insecticide grew to 46.1% and 31.4%, respectively. These preferred measures are similar to those found in other non-endemic countries like Spain, Greece, the United States, and the United Kingdom (52). Data from PACA, Corse, ARA, and Occitanie found that people favoured using lotions, sprays or creams (65.4%), using diffusers, coils, or traps (65.3%), and wearing long, loose, light-coloured clothes (42.9%) in 2016 (40). However, questionnaire differences prevent a vis-a-vis comparison.

In previous studies, mosquito biting and constructs akin to threat (i.e., feelings of worry, fear of contracting an MBD, perceived exposure, and perceived vulnerability) were found to drive protective behaviour in the general population in Southern France (38–40), and this aligns with the results of our analysis. Evidence suggests that mosquito biting, a factor notably difficult to modify, is the leading environmental cue prompting protective behaviour. Although people are likely to take more precautions against MBDs as the biting rate goes up, the risk of MBD outbreaks may already be too high by then. Thus, exploring modifiable risk factors of protective behaviours should be prioritized to inform public health interventions. For example, an in-depth understanding of the process of people's MBD risk assessment, paired with exploration of avenues to influence such assessments, could be fruitful. As researchers warn about future MBD outbreaks in Europe, studies aiming to produce actionable information for timely policy and communication are needed (2,80). This is especially true considering that people struggle to accurately estimate their health risks and adjust behaviours during epidemics, and European

[1] In 2016, former regions Languedoc-Roussillon and Midi-Pyrénées were united to form Occitanie. Occitanie is the closest region to compare with Languedoc-Roussillon.

governments have demonstrated poor communication of risks during health emergencies (81–84).

Contrary to our expectations, place of residence accounted for a minimal portion of the variance explained when approached as a grouping structure. This contrasts with past findings and our conjecture that residents of urban areas with high mosquito populations protect themselves more due to social modelling, a higher exposure to MBD campaigns and media coverage, or other unobserved variables (38,39). This may be attributed to risk denial, a phenomenon observed in other health studies where high-risk groups tend to actively minimise or ignore their unfavourable conditions (85). In that case, people in dense urban areas in Southern France may not consider MBD as more serious or common than people residing in other regions or rural areas. Controlling for biting frequency and perceived threat may further remove explanatory power from place of residence. Geospatial analyses with more granular data at the department level may offer a clearer picture on the role of urban density and geographic location.

We found that MBD knowledge was associated with the count of protective behaviours. However, there is little consensus on which information regarding mosquitoes or MBD may directly motivate the uptake of protective behaviour, nor is there a standardized instrument to measure said knowledge. Notwithstanding, references to the knowledge-behaviour gap, including the role of intention strength and self-efficacy, are markedly absent in the research on MBDs in Europe (86–88). Moreover, past research in metropolitan France gives some evidence on age, sex, and education, but provides none on chronic disease status or financial difficulties and their relationship with MBD protective behaviour (38–40). While our study found age and educational attainment to be important covariates, we found no significant associations with sex.

This study has certain limitations. The sample was obtained through an online paid panel, which naturally excludes people who do not access the internet, have low technological literacy, or are not in the banking system. The sample distribution matches census data on age, sex, region of residence, and socioeconomic status, but it is not guaranteed to be representative or sufficient at stratified levels. For example, despite being a region of high interest, our sample size for Corse is five as it corresponds to its contribution to the metropolitan French population. The study is also vulnerable to measurement error due to estimating psychological constructs (e.g., MBD threat, confidence in public authorities) and social desirability bias because it studies healthy behaviour. We found no validated instruments for these constructs that fit within the time limit for survey administration. Multiple items were merged into indexes to increase validity, even if the complete multidimensional structure of these constructs was not captured. Moreover,

verbally labelled discrete responses are suboptimal measures due to the inherent ambiguity of semantic dimensions. Finally, our outcome variables attempt to estimate protective behaviour through its frequency and count but cannot capture their interconnectedness. We have no data on how frequently each protective behaviour is practiced. Presumably, a higher frequency and count of protective behaviour further reduces MBD risk. However, we cannot gauge the necessity, overuse, or diminishing return of specific protective behaviour patterns, which may render them ineffective or uneconomical.

This study also has several strengths. We had access to a large and well-characterised sample of metropolitan French residents. The potential impact of missing data was addressed by design through the data collection strategy. Although not a standardised questionnaire, the measurement tool was derived from the best available information retrieved from past studies in metropolitan France, which allow for close comparison. This study is likely to provide acceptable, although provisional, effect estimates of determinants associated with MBD protective behaviour in metropolitan French residents amidst growing MBD risk.

5. Conclusion

We present insights into MBD protective behaviour and its associated factors considering all metropolitan French regions. Our results highlight factors which may inform prevention campaigns focused on increasing individual protective behaviour, namely perceived threat and to a lesser extent MBD knowledge. These findings may assist public health practitioners to improving communication and dialogue with the public around the increasingly important emergence of arboviruses in previously unaffected regions in metropolitan France. The study also underscores the role of biting frequency and sociodemographic characteristics, such as age and educational attainment, in shaping the adoption and practice of protective behaviours. Although most participants engaged in protective behaviour, its efficacy in the face of potential epidemics is unknown Further research should focus on people's MBD risk assessment as means to effectively promote protective behaviours. Moreover, comparing the cost-benefit of promoting individual versus collective protective behaviours through community participatory approaches may prove useful. Investigation of population acceptance to mosquito control strategies is warranted. Capitalizing on the international literature on mosquito reduction and MBD prevention, coupled with national data, is key to minimising the future burden of MBD in metropolitan France.

6. References

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7. List of appendices

- Appendix 1: Questionnaire
- Appendix 2: Pre-registration deviations
- Appendix 3: Description of variables
- Appendix 4: Directed acyclic graphs
- Appendix 5: Reproducible code

Annex 1. Questionnaire

Q#	Question	Code	Réponse
SECTION A. Questions introductoires			
	Merci d'avoir accepté de participer à cette étude. Le questionnaire commence par 10 questions simples vous concernant. À la fin de cette section, nous allons vous poser 2 questions sur vos connaissances. Veuillez y répondre sans consulter d'autres sources d'information.		
A1	Vous êtes :	1	Une femme
		2	Un homme
A2	Quelle est votre tranche d'âge ?	1	18 à 29 ans
		2	30 à 39 ans
		3	40 à 49 ans
		4	50 à 59 ans
		5	60 à 69 ans
		6	70 à 79 ans
A2bis	Plus précisément, quel est votre âge ?	____	ans
A3	Quel est votre niveau d'études le plus élevé ?	1	Aucun diplôme
		2	Brevet de collèges ou BEPC
		3	CAP/BEP (ou autre diplôme technique)
		4	Bac (général, pro et technologique)
		5	Bac+2 (BTS ou autre)
		6	Bac+3/4 (Licence, Maîtrise)
		7	Bac+5 (Master, écoles d'ingénieurs, écoles d'arts, DEA, DESS, etc.)
		8	Bac+7 et au-delà (Doctorat, post-doc, thèse)
A4	Quelle option décrit au mieux votre situation de travail (une seule réponse) ?	1	Agriculteur
		2	Artisan/commerçant/chef d'entreprise
		3	Cadre ou profession libérale (cadre supérieur, cadre de direction, catégorie A de la fonction publique)
		4	Profession intermédiaire (technicien, contremaitre, agent de maitrise, catégorie B de la fonction publique)
		5	Employé, agent de la fonction publique (catégorie C)
		6	Ouvrier
		7	Retraité

Q#	Question	Code	Réponse
		8	Sans activité professionnelle actuelle
		9	Étudiant
		10	Autre
A5	Êtes-vous : (une seule réponse) [Branchement logique : si A4 == 1, 2, ou 3 ou 4 ou 5 ou 6]	1	Salarié
		2	Indépendant
A6	Veuillez préciser : (une seule réponse) [Branchement logique : si A4 == 8]	1	Au chômage
		2	Homme/Femme au foyer
		3	N'a jamais exercé d'activité
A7	Votre région de résidence est :		• Auvergne-Rhône-Alpes • Bourgogne-Franche-Comté • Bretagne • Centre-Val de Loire • Corse • Grand Est • Hauts-de-France • Île-de-France • Normandie • Nouvelle-Aquitaine • Occitanie • Pays de la Loire • Provence-Alpes-Côte d'Azur
A8	Dans quel type de commune habitez-vous ?	1	Grande ville (plus de 100 000 habitants)
		2	Ville (entre 20 000 et 100 000 habitants)
		3	Ville de taille moyenne (entre 2 000 et moins de 20 000 habitants)
		4	Village / Zone rurale (moins de 2 000 habitants)
A9	Vous habitez :	1	En colocation
		2	Seul
		3	En couple
		4	En famille
A10	Combien de personnes (y compris vous) habitent chez vous ?	____	personnes
B1	Selon vous, quelles sont les maladies qui peuvent être transmises par les moustiques en général ? (choix multiples)	1	VIH
		2	La dengue
		3	La diabète
		4	Le chikungunya
		5	Le COVID
		6	Le paludisme

Q#	Question	Code	Réponse
		7	Le Zika
		8	Les moustiques transmettent des maladies, mais je ne les connais pas. exclusif
		9	Les moustiques ne transmettent aucune maladie. exclusif
B2	Vrai ou Faux : Tous les moustiques, quel que soit leur sexe, piquent.	1	Vrai
		2	Faux
		3	Je ne sais pas

Merci pour vos réponses. Ce questionnaire concerne des maladies virales transmises par le moustique tigre. Même si ces maladies sont rares en France métropolitaine, le nombre de cas augmente chaque année. Les symptômes les plus courants sont de la fièvre et des douleurs articulaires et musculaires. La gravité et la durée de ces maladies varient d'une personne à l'autre, mais elles guérissent généralement en une semaine environ. Les complications graves sont rares, mais plus fréquentes chez les femmes enceintes et les personnes âgées.

SECTION C. DCE

Imaginez que vous assistez à une réunion d'information organisée par votre mairie, animée par les services de santé locaux et régionaux. ***Ils vous informent que dix personnes vivant près de chez vous (dans votre commune ou votre quartier) sont récemment tombées malades à cause d'une maladie transmise par le moustique tigre.*** *Le but de la réunion est de sensibiliser les habitants et de proposer des mesures préventives pour éviter de nouveaux cas pendant l'été.* ***Ces mesures ont prouvé leur efficacité scientifiquement et sont totalement gratuites pour les habitants.***

À la fin de la réunion, vous êtes invité à ***voter pour vos préférences parmi différentes mesures possibles****. Les mesures diffèrent selon quatre caractéristiques. Si vous ne pouvez pas vous décider, choisissez une option au hasard et indiquez un degré de certitude de « pas du tout sûr ». Vous allez faire 10 votes au total.*

C1	Voulez-vous voir un exemple avant de commencer ces 10 votes ?	1	Oui, montrez-moi un exemple
		2	Non, allez directement aux 10 votes

[Branchement logique : si C1 == 1]

Voici un exemple de vote :

Bulletin N°	Mesure A	Mesure B

Q#	Question	Code	Réponse

Participation et protection	**La commune** mettra en œuvre la mesure et **tous les habitants seront protégés** de la même façon.	La mesure doit être mise en œuvre **par les particuliers** - **votre protection dépendra uniquement de votre adhésion**.
Fréquence de l'intervention	La mesure sera menée **une fois tous les 5 ans**.	La mesure doit être menée **une fois par mois** pendant la saison ; elle durera **une heure**.
Effets indésirables sur la santé humaine	Les études scientifiques n'ont trouvé **aucun effet indésirable** sur la santé humaine.	Les études scientifiques indiquent que des **réactions passagères sont probables** - elles disparaissent en quelques jours sans intervention médicale.
Effets environnementaux	La recherche suggère que cette mesure ne représente **aucune menace pour l'environnement**.	La recherche suggère que cette méthode comporte **un effet négatif systématique sur les animaux et la végétation**.
Je préfère la mesure :	☐ A	☐ B

Nous vous demandons de faire un choix entre deux mesures. La mesure A peut être menée par la commune, une fois tous les 5 ans, et elle ne représente aucune menace pour la santé humaine ni pour l'environnement. La mesure B nécessite que les particuliers la mettent en œuvre une fois par mois, elle peut causer des réactions passagères chez l'homme, et elle comporte un effet négatif systématique sur l'environnement.

Vous indiquerez quelle mesure vous préférez, puis le degré auquel vous êtes sûr de cette décision.

Mon niveau de certitude de cette décision :	1 ---------- 10 Pas du tout sûr — Complètement sûr

Indiquez votre niveau de certitude entre « pas du tout sûr » (1) et « complètement sûr » (10). Si vous ne pouvez pas vous décider, choisissez une option au hasard et indiquez un degré de certitude de 1.

	Présentation aléatoire des bulletins 1 à 10, mais veuillez indiquer le progrès au participant après chaque vote.		

Q#	Question	Code	Réponse

Bulletin 1	**Mesure A**	**Mesure B**
Participation et protection	La mesure doit être mise en œuvre **par les particuliers**. **Votre protection ne dépend pas uniquement de votre adhésion, mais aussi de l'adhésion de vos voisins.**	La mesure doit être mise en œuvre **par les particuliers** - **votre protection dépendra uniquement de votre adhésion**.
Fréquence de l'intervention	La mesure doit être menée **une fois par mois** pendant l'été ; elle durera **une heure**.	La mise en œuvre doit être régulière pendant l'été, elle prendra **une heure par semaine**.
Effets indésirables sur la santé humaine	Les études scientifiques indiquent que les **effets indésirables sont très rares mais peuvent être graves**, comme les allergies, les maladies auto-immunes ou le cancer.	Les études scientifiques n'ont trouvé **aucun effet indésirable** sur la santé humaine.
Effets environnementaux	La recherche suggère que cette mesure ne représente **aucune menace pour l'environnement**.	La recherche suggère que cette méthode comporte **un effet négatif systématique sur les animaux et la végétation**.
Je préfère la mesure :	☐ A	☐ B

Mon niveau de certitude de cette décision :	1 ---------- 10 Pas du tout sûr — Complètement sûr

Bulletin 2	**Mesure A**	**Mesure B**

Q#	Question		Code	Réponse
	Participation et protection	La mesure doit être mise en œuvre **par les particuliers** - **votre protection dépendra uniquement de votre adhésion**.	La mesure doit être mise en œuvre **par les particuliers**. **Votre protection ne dépend pas uniquement de votre adhésion, mais aussi de l'adhésion de vos voisins**.	
	Fréquence de l'intervention	La mise en œuvre doit être régulière pendant l'été, elle prendra **10 minutes par jour**.	La mesure doit être menée **une fois par mois** pendant l'été ; elle durera **une heure**.	
	Effets indésirables sur la santé humaine	Les études scientifiques indiquent que **les effets indésirables sont très rares mais peuvent être graves**, comme les allergies, les maladies auto-immunes ou le cancer.	Les études scientifiques n'ont trouvé **aucun effet indésirable** sur la santé humaine.	
	Effets environnementaux	La recherche suggère que cette mesure ne représente **aucune menace pour l'environnement**.	L'effet de la mesure sur l'environnement est **en cours d'évaluation**.	
	Je préfère la mesure :	☐ A	☐ B	

Mon niveau de certitude de cette décision :	1 ---------- 10 Pas du tout sûr Complètement sûr

	Bulletin 3	**Mesure A**	**Mesure B**	

Q#	Question		Code	Réponse
	Participation et protection	La mesure doit être mise en œuvre **par les particuliers - votre protection dépendra uniquement de votre adhésion**.	La mesure doit être mise en œuvre **par les particuliers - votre protection dépendra de votre adhésion. Votre adhésion pourra aussi protéger vos voisins**.	
	Fréquence de l'intervention	La mise en œuvre doit être régulière pendant l'été, elle prendra **une heure par semaine**.	La mesure sera menée **une fois tous les 5 ans**.	
	Effets indésirables sur la santé humaine	Les études scientifiques indiquent que **des réactions passagères sont probables** - elles disparaissent en quelques jours sans intervention médicale.	Les études scientifiques indiquent que **les effets indésirables sont très rares mais peuvent être graves**, comme les allergies, les maladies auto-immunes ou le cancer.	
	Effets environnementaux	La recherche suggère que cette mesure ne représente **aucune menace pour l'environnement**.	La recherche suggère que cette méthode comporte **un effet négatif systématique sur les animaux et la végétation**.	
	Je préfère la mesure :	☐ A	☐ B	

Mon niveau de certitude de cette décision :	1 ---------- 10 Pas du tout sûr Complètement sûr

	Bulletin 4	**Mesure A**	**Mesure B**	

Q#	Question		Code	Réponse
	Participation et protection	**La commune mettra en œuvre la mesure** et tous les habitants seront protégés de la même façon.	La mesure doit être mise en œuvre **par les particuliers** - **votre protection dépendra uniquement de votre adhésion**.	
	Fréquence de l'intervention	La mise en œuvre doit être régulière pendant l'été, elle prendra **une heure par semaine**.	La mise en œuvre doit être régulière pendant l'été, elle prendra **10 minutes par jour**.	
	Effets indésirables sur la santé humaine	Les études scientifiques indiquent que **des réactions passagères sont probables** - elles disparaissent en quelques jours sans intervention médicale.	Les études scientifiques n'ont trouvé **aucun effet indésirable** sur la santé humaine.	
	Effets environnementaux	La recherche suggère que cette méthode comporte **un effet négatif systématique sur les animaux et la végétation**.	L'effet de la mesure sur l'environnement est **en cours d'évaluation**.	
	Je préfère la mesure :	☐ A	☐ B	

Mon niveau de certitude de cette décision :	1 ---------- 10 Pas du tout sûr Complètement sûr

	Bulletin 5	**Mesure A**	**Mesure B**	

Q#	Question		Code	Réponse
	Participation et protection	**La commune mettra en œuvre la mesure** et tous les habitants seront protégés de la même façon.	La mesure doit être mise en œuvre **par les particuliers - votre protection dépendra de votre adhésion. Votre adhésion pourra aussi protéger vos voisins**.	
	Fréquence de l'intervention	La mise en œuvre doit être régulière pendant l'été, elle prendra **10 minutes par jour**.	La mesure sera menée **une fois tous les 5 ans**.	
	Effets indésirables sur la santé humaine	Les études scientifiques indiquent que **les effets indésirables sont très rares mais peuvent être graves**, comme les allergies, les maladies auto-immunes ou le cancer.	Les études scientifiques indiquent que **des réactions passagères sont probables** - elles disparaissent en quelques jours sans intervention médicale.	
	Effets environnementaux	La recherche suggère que cette méthode comporte **un effet négatif systématique sur les animaux et la végétation**.	La recherche suggère que cette mesure ne représente **aucune menace pour l'environnement**.	
	Je préfère la mesure :	☐ A	☐ B	
	Mon niveau de certitude de cette décision :		1 ---------- 10 Pas du tout sûr — Complètement sûr	
	Bulletin 6	**Mesure A**	**Mesure B**	

Q#	Question		Code	Réponse
	Participation et protection	La mesure doit être mise en œuvre **par les particuliers. Votre protection ne dépend pas uniquement de votre adhésion, mais aussi de l'adhésion de vos voisins**.	**La commune mettra en œuvre la mesure** et tous les habitants seront protégés de la même façon.	
	Fréquence de l'intervention	La mise en œuvre doit être régulière pendant l'été, elle prendra **une heure par semaine**.	La mesure doit être menée **une fois par mois** pendant l'été ; elle durera **une heure**.	
	Effets indésirables sur la santé humaine	Les études scientifiques indiquent que **les effets indésirables sont très rares mais peuvent être graves**, comme les allergies, les maladies auto-immunes ou le cancer.	Les études scientifiques n'ont trouvé **aucun effet indésirable** sur la santé humaine.	
	Effets environnementaux	L'effet de la mesure sur l'environnement est **en cours d'évaluation**.	La recherche suggère que cette mesure ne représente **aucune menace pour l'environnement**.	
	Je préfère la mesure :	☐ A	☐ B	

Mon niveau de certitude de cette décision :	1 ---------- 10 Pas du tout sûr — Complètement sûr

	Bulletin 7	**Mesure A**	**Mesure B**	

Q#	Question		Code	Réponse
	Participation et protection	La mesure doit être mise en œuvre **par les particuliers - votre protection dépendra uniquement de votre adhésion**.	La mesure doit être mise en œuvre **par les particuliers - votre protection dépendra de votre adhésion. Votre adhésion pourra aussi protéger vos voisins**.	
	Fréquence de l'intervention	La mesure sera menée **une fois tous les 5 ans**.	La mise en œuvre doit être régulière pendant l'été, elle prendra **une heure par semaine**.	
	Effets indésirables sur la santé humaine	Les études scientifiques indiquent que **des réactions passagères sont probable**s - elles disparaissent en quelques jours sans intervention médicale.	Les études scientifiques n'ont trouvé **aucun effet indésirable** sur la santé humaine.	
	Effets environnementaux	La recherche suggère que cette méthode comporte **un effet négatif systématique sur les animaux et la végétation**.	La recherche suggère que cette mesure ne représente **aucune menace pour l'environnement**.	
	Je préfère la mesure :	☐ A	☐ B	

Mon niveau de certitude de cette décision :	1 ---------- 10 Pas du tout sûr Complètement sûr

	Bulletin 8	**Mesure A**	**Mesure B**	

Q#	Question		Code	Réponse
	Participation et protection	La mesure doit être mise en œuvre **par les particuliers - votre protection dépendra de votre adhésion. Votre adhésion pourra aussi protéger vos voisins**.	La mesure doit être mise en œuvre **par les particuliers. Votre protection ne dépend pas uniquement de votre adhésion, mais aussi de l'adhésion de vos voisins**.	
	Fréquence de l'intervention	La mise en œuvre doit être régulière pendant l'été, elle prendra **10 minutes par jour**.	La mesure sera menée **une fois tous les 5 ans**.	
	Effets indésirables sur la santé humaine	Les études scientifiques indiquent que **des réactions passagères sont probables** - elles disparaissent en quelques jours sans intervention médicale.	Les études scientifiques n'ont trouvé **aucun effet indésirable** sur la santé humaine.	
	Effets environnementaux	L'effet de la mesure sur l'environnement est **en cours d'évaluation**.	La recherche suggère que cette mesure ne représente **aucune menace pour l'environnement**.	
	Je préfère la mesure :	☐ A	☐ B	

Mon niveau de certitude de cette décision :	1 ---------- 10 Pas du tout sûr — Complètement sûr

	Bulletin 9	**Mesure A**	**Mesure B**	

Q#	Question		Code	Réponse
	Participation et protection	La mesure doit être mise en œuvre **par les particuliers. Votre protection ne dépend pas uniquement de votre adhésion, mais aussi de l'adhésion de vos voisins**.	**La commune mettra en œuvre la mesure** et tous les habitants seront protégés de la même façon.	
	Fréquence de l'intervention	La mise en œuvre doit être régulière pendant l'été, elle prendra **10 minutes par jour**.	La mesure doit être menée **une fois par mois** pendant l'été ; elle durera **une heure**.	
	Effets indésirables sur la santé humaine	Les études scientifiques indiquent que **des réactions passagères sont probables** - elles disparaissent en quelques jours sans intervention médicale.	Les études scientifiques indiquent que **les effets indésirables sont très rares mais peuvent être graves**, comme les allergies, les maladies auto-immunes ou le cancer.	
	Effets environnementaux	La recherche suggère que cette méthode comporte **un effet négatif systématique sur les animaux et la végétation**.	L'effet de la mesure sur l'environnement est **en cours d'évaluation**.	
	Je préfère la mesure :	☐ A	☐ B	

Mon niveau de certitude de cette décision :	1 ---------- 10 Pas du tout sûr Complètement sûr

	Bulletin 10	**Mesure A**	**Mesure B**	

Q#	Question		Code	Réponse
	Participation et protection	La mesure doit être mise en œuvre **par les particuliers - votre protection dépendra uniquement de votre adhésion**.	**La commune mettra en œuvre la mesure** et tous les habitants seront protégés de la même façon.	
	Fréquence de l'intervention	La mesure doit être menée **une fois par mois** pendant l'été ; elle durera **une heure**.	La mesure sera menée **une fois tous les 5 ans**.	
	Effets indésirables sur la santé humaine	Les études scientifiques indiquent que **les effets indésirables sont très rares mais peuvent être graves**, comme les allergies, les maladies auto-immunes ou le cancer.	Les études scientifiques indiquent que **des réactions passagères sont probables** - elles disparaissent en quelques jours sans intervention médicale.	
	Effets environnementaux	La recherche suggère que cette méthode comporte **un effet négatif systématique sur les animaux et la végétation**.	L'effet de la mesure sur l'environnement est **en cours d'évaluation**.	
	Je préfère la mesure :	☐ A	☐ B	

Mon niveau de certitude de cette décision :	1 ---------- 10 Pas du tout sûr Complètement sûr

C2	Est-ce que cet exercice vous a paru compliqué ?	Échelle entre 1 et 10	*Sur une échelle de 1 à 10 :* *10 - si cet exercice vous a paru extrêmement compliqué,* *1 - pas du tout compliqué*

SECTION D. Attitudes et pratiques

Merci d'avoir complété la série de tâches de choix. Nous passons maintenant à l'avant-dernière section.

Q#	Question	Code	Réponse
D1	L'été dernier, avec quelle fréquence avez-vous fait des efforts pour éviter les moustiques ?	1	Plusieurs fois par semaine
		2	Quelques fois seulement
		3	Jamais
D2	Veuillez indiquer toutes les activités préventives dans lesquelles vous vous êtes impliqué pour éviter les moustiques : (choix multiples) [branchement logique : si D1 != 3]	1	Le vidage régulier ou la suppression des coupelles sous les pots de fleurs, vases (ou le remplissage avec de sable afin de conserver l'humidité sans qu'il y ait d'eau stagnante)
		2	Le rangement des récipients divers (les seaux, le matériel de jardinage, les jouets, etc.) à l'abri de la pluie pour éviter l'eau stagnante
		3	L'entretien des gouttières pour faciliter le bon écoulement des eaux
		4	L'application d'insecticides (ou la fumigation) à l'intérieur ou à l'extérieur de la maison
		5	Usage des pièges à moustiques
		6	Usage de bougies et/ou de spirales anti-moustiques
		7	Utilisation de moustiquaires (sur les fenêtres)
		8	Usage des répulsifs cutanés
		9	Le port des vêtements longs, amples et clairs
		10	Autre _____
D3	[branchement logique : si D2 = 4, 5, 6, 8, ou 10] Privilégiez-vous les produits anti-moustiques qui sont labellisés « naturels » ou « écoresponsables » ?	1	Oui
		2	Non
D4	Avez-vous la climatisation chez vous ?	1	Oui
		2	Non
D5	Avez-vous déjà eu une maladie transmise par les moustiques ?	1	Oui
		2	Non
		3	Je ne suis pas sûr
D6	Quelle confiance accordez-vous aux autorités nationales (ministère de la santé, etc.) pour gérer une crise sanitaire ?	Échelle entre 1 et 10	*La note 1 signifie que vous ne leur faites pas du tout confiance ; 10 signifie que vous leur faites complètement confiance*

Q#	Question	Code	Réponse
D7	Quelle confiance accordez-vous aux autorités municipales et régionales (la mairie, etc.) pour gérer une crise sanitaire ?	Échelle entre 1 et 10	*La note 1 signifie que vous ne leur faites pas du tout confiance ; 10 signifie que vous leur faites complètement confiance*
D8	A votre avis, quelle est la probabilité que vous ayez une maladie transmise par les moustiques dans un futur proche ?	Échelle entre 1 et 10	*La note 1 signifie « aucune probabilité » et 10 signifie que cela est certain d'arriver.*
D9	Craignez-vous les maladies transmises par les moustiques ?	Échelle entre 1 et 10	*La note 1 signifie « pas du tout » et 10 signifie « énormément »*
D10	Dans d'autres pays, des moustiques génétiquement modifiés ont été introduits pour lutter contre les maladies transmises par les moustiques. Ces modifications génétiques permettent de réduire la capacité des moustiques à transmettre des maladies et/ou à se reproduire. Seriez-vous d'accord avec l'introduction de moustiques qui ont été génétiquement modifiés dans votre commune ?	Échelle entre 1 et 10	*La note 1 signifie « pas du tout d'accord », 5 « peut-être / je ne suis pas sûr » ; et 10 « tout à fait d'accord »*
SECTION E.			
	Merci d'avoir complété la section précédente. Nous passons maintenant à la dernière section, qui comprend 10 questions simples vous concernant.		
E1	Quelle option décrit au mieux votre domicile principal ?	1	Appartement
		2	Centre d'hébergement
		3	Maison mitoyenne
		4	Maison individuelle
		5	Autre _____
E2	Parlez-vous une autre langue que le français à votre domicile ?	1	Oui
		2	Non
E3	Au cours de ces **12 derniers mois**, votre ménage a-t-il connu des difficultés financières (par exemple : l'impossibilité de payer à temps un loyer, un prêt immobilier, des achats à crédit, ou des factures courantes) ?	1	Oui, souvent
		2	Oui, parfois
		3	Non, jamais
E4	[branchement logique : si A1=1 + filtre âge] Êtes-vous enceinte ou prévoyez-vous de l'être ?	1	Oui
		2	Non
		3	Je ne souhaite pas répondre
E5	Avez-vous des enfants à charge ?	1	Oui
		2	Non

Q#	Question	Code	Réponse
E6	Avez-vous une maladie chronique, c'est-à-dire une maladie durable qui nécessite un suivi à long terme (asthme, diabète, hypertension/pression élevée, cancer, etc.) ?	1	Oui
		2	Non
E7	L'été dernier, avec quelle fréquence avez-vous été piqué par les moustiques dans votre quotidien (hors voyages) ?	1	Souvent
		2	Moins souvent
		3	Jamais ou presque jamais
E8	Veuillez estimer combien de fois par semaine vous avez été piqué par les moustiques l'été dernier (hors voyages). [Branchement logique : si E7 != 3]	1	Environ 1 à 5 fois par semaine
		2	Environ 5 à 10 fois par semaine
		3	Plus que 10 fois par semaine
E9	Quel type de régime alimentaire suivez-vous le plus souvent ?	1	Je suis omnivore et je mange sans restriction
		2	J'essaie de diminuer ma consommation de viande, mais je ne suis pas strictement un régime
		3	Je suis végétarien (pas de viande ni poisson, mais des produits laitiers et des œufs)
		4	Je suis végan (pas de produits d'origine animale)
		5	Autre : _____
E10	Quelles sources d'information privilégiez-vous lorsque vous cherchez à mieux comprendre votre santé ? (Choix multiple)	1	Réseaux sociaux (Facebook, X [ex Twitter], Instagram, WhatsApp)
		2	Les médias ? (journaux, magazines, télévision, radio)
		3	Vos amis, voisins ou autres sources communautaires
		4	Famille
		5	Professionnels de santé
		6	Votre propre recherche par internet
		7	Autre : _____

Annex 2. Preregistration deviations

Deviations					
#		Details	Original Wording	Deviation Description	Reader Impact
1	Type	Sample	We recruited 2,083 participants.	We recruited 2,087 participants. The exact sample size was unknown.	We expect this deviation to have no impact on the interpretation of the study.
	Reason	New knowledge			
	Timing	After data access			
2	Type	Variables	Variable *financial difficulty* was intended to be coded for analysis as two disjoint indicator variables: “yes, often” and “yes, sometimes”. The reference level for both indicator variables was “no, never”.	Variable *financial difficulty* was coded as binary (yes, no) by merging response categories “yes, often” and “yes, sometimes”. The reference level remained unchanged. The original coding presented a stark sample size imbalance which may obscure the association with the outcomes of interest. Categories “no, never”, “yes, sometimes”, and “yes, often” had 1,515, 410, and 162 answers, respectively. The binary coding presented more balanced categories “yes” and “no, never” with 572 and 1515, respectively. Thus, it provides higher power at the loss of granularity.	This deviation impacts the model selection and the interpretation of results for the predictor *financial difficulty.*
	Reason	New knowledge			
	Timing	After data access			
3	Type	Variables	Variable educational attainment was intended to be coded for analysis as seven disjoint indicator variables. The reference level for all indicator variables was “no diploma”.	Variable educational attainment was coded as four disjoint indicator variables as follows. Response categories “no diploma”, “Brevet de collèges or BEPC”, and “CAP, BEP or other technical diploma” were merged into “Below Bac (no diploma, BEPC, CAP, etc.)”, which was made the reference category. Response categories “Bac+5 (Master, DEA, DESS, etc.)” and “Bac+7 or higher (Doctoral, post-doc)” were merged into “Bac+5 or higher (Master, doctoral, post-doc)”. The original coding presented a stark sample size imbalance which may obscure the association with the outcomes of interest. Categories “no diploma”, “Brevet de collèges or BEPC”, and “Bac+7 or higher (Doctoral, post-doc)” had 41, 72, and 31, respectively.	This deviation impacts the model selection and the interpretation of results for the predictor *educational attainment*.
	Reason	New knowledge			
	Timing	After data access			

				The new categories presented more balanced categories “Below Bac (no diploma, BEPC, CAP, etc.)” and “Bac+5 or higher (Master, doctoral, post-doc)” with 450 and 318, respectively. Thus, it provides higher power at the loss of granularity. It also provides a more relevant reference category given the French educational context.	
4	Type	Analysis	Variable *pregnancy status* was intended to be included as a covariate for analysis.	Variable *pregnancy status* was excluded for analysis due to lack of power. Pregnant women were less than 3% of the total sample size.	This deviation removes *pregnancy status* from the study.
	Reason	New knowledge			
	Timing	After data access			
5	Type	Analysis	We did not specify any variation to the zero-inflated component formula of the ZINBMM.	The zero-inflated component of the ZINBMM was allowed to vary by variable *biting frequency*. The ZINBMM performance increased substantially with the addition. Additionally, it is theoretically justified as the probability of a zero-count in the count of protective behaviours may not be the same across all observations.	This deviation impacts the interpretation of results.
	Reason	New knowledge			
	Timing	After data access			

Unregistered steps

#	Details		Original Wording	Deviation Description	Reader Impact
1	Type	Analysis	We specified modelling random slopes and comparing its performance.	We reported a model selection without random slopes specified at any stage. Allowing for random slopes for *biting frequency* is not theoretically well-justified and impedes result comparison with other studies.	This deviation impacts the results.
	Timing	After results known			

Annex 2 – Description of variables

Variable	Role	Type	Coding	Validity assessment*
Frequency of protective behaviour	Main outcome	Ordinal	Three-level ordinal 0: Never 1: Only a few times 2: Several times a week	It may have residual bias due to only having three unequally spaced levels labeled using vague terminology (e.g., several, few).
Count of protective behaviours	Main outcome	Discrete	Count, ranging from 0 to 10	We may have unreliable counts for participants who engage in preventive practices that are not enlisted as response options or are not perceived as mosquito related.
Perceived threat	Main predictor	Continuous	Numeric, ranging from 1 (low threat) to 10 (high threat). It can take numbers with decimal places (e.g., 2.5).	It may disregard other core components of perceived threat beyond the two measured components: likelihood of having a MBD, and MBD concern. Likert scales are vulnerable to extreme responding and other sources of bias.
Financial difficulty	Main predictor	Ordinal	Two disjoint indicator variables: yes, often & yes, sometimes. Reference level: never. Annex 2 clarifies preregistration deviations on this variable.	It may be prone to recall bias due to a recall period of 12 months. It may have residual bias due to only having three unequally spaced levels labeled using vague terminology (e.g., often, sometimes).
Biting nuisance	Main predictor	Ordinal	Two disjoint indicator variables: often & less often. Reference level: never or almost never.	It may be prone to recall bias due to a recall period of 3 months (last summer to survey completion date). It may have residual bias due to only having four unequally spaced levels

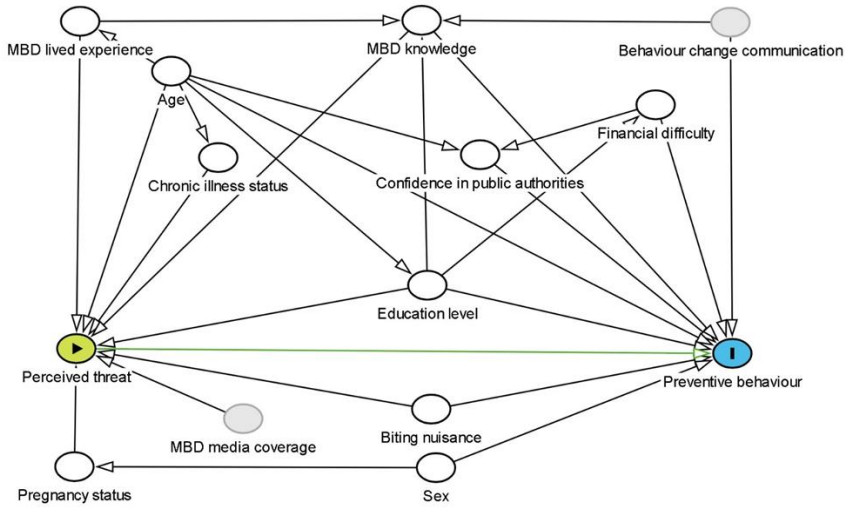
				labeled using vague terminology (e.g., often, almost never).
Place of residence	Main predictor	Nominal	Grouping variable. 52 possible categories.	Well-measured. Some individuals may not accurately estimate the size of their city, leading to (presumably non-differential) misclassification.
Sex	Potential confounder and effect modifier	Dichotomous	Reference level: men	Well-measured.
Age	Potential confounder	Discrete	Numeric, ranging from 18 to 80.	Well-measured.
Educational attainment	Potential confounder	Nominal	Seven disjoint indicator variables: College certificate, CAP/BEP, Baccalaureate, Bac+2, Bac+3/4, Bac+5, Bac+7 and beyond. Reference level: no diploma. Annex 2 clarifies preregistration deviations on this variable.	Well-measured.
MBD knowledge	Potential confounder and effect modifier	Discrete	Numeric, ranging from -4 (low knowledge) to 5 (high knowledge).	It may disregard other core components of MBD knowledge beyond the two measured aspects.

Confidence in public authorities	Potential confounder	Discrete	Numeric, ranging from 1 (low confidence) to 10 (high confidence). It can take numbers with decimal places (e.g., 2.5).	Likert scales are vulnerable to extreme responding and other sources of bias.
Chronic illness status	Potential confounder	Dichotomous	Reference level: no chronic illness	Well-measured.
MBD lived experience	Potential confounder	Dichotomous	Reference level: no MBD lived experience	Well-measured. If the participant fails to identify MBD lived experience as such (e.g., does not know given disease is mosquito-transmitted), it would not be theoretically associated with the main predictors.

* This is a brief qualitative assessment of the quality of the measurement based on potential limitations.

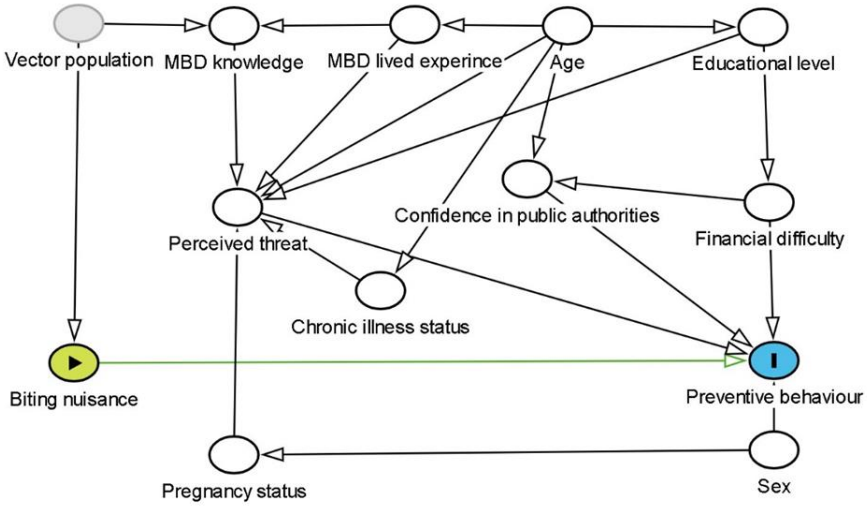
Annex 3. Directed acyclic graphs (DAGs)

1. Perceived threat



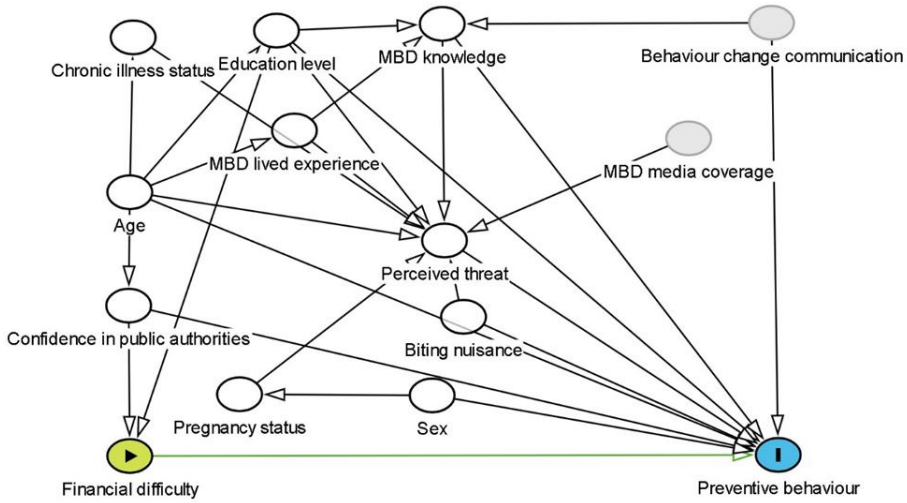
Minimal sufficient adjustment set: Age, Biting nuisance, Chronic illness status, Confidence in public authorities, Education level, Financial difficulty, MBD knowledge, MBD lived experience, Pregnancy status, Sex

2. Biting nuisance



Minimal sufficient adjustment sets: Age, Chronic illness status, Confidence in public authorities, Educational level, Financial difficulty, MBD knowledge, MBD lived experince, Perceived threat, Pregnancy status, Sex

3. Financial difficulty



Minimal sufficient adjustment set: Age, Biting nuisance, Chronic illness status, Confidence in public authorities, Education level, MBD knowledge, MBD lived experience, Perceived threat, Pregnancy status, Sex

Legend:

- exposure
- outcome
- ancestor of exposure
- ancestor of outcome
- ancestor of exposure *and* outcome
- adjusted variable
- unobserved (latent)
- other variable
- causal path
- biasing path