

A 3-year entomological cluster randomised controlled trial to assess the efficacy of mass-trapping for *Aedes albopictus* control in France: The vectrap project

Paulina A. Pontifes^a, Nicolas Le Doeuff^b, Yvon Perrin^b, Cyrille Czeher^b, Jean-Baptiste Ferré^b, Yves Rozier^c, Remi Foussadier^c, Gregory L'Ambert^b, David Roiz^{a,*}

^a MIVEGEC, Université Montpellier, IRD, CNRS, Montpellier, France

^b Entente Interdépartementale Pour la Démoustication du Littoral Méditerranéen (EID Méditerranée), Montpellier, France

^c Entente Interdépartementale Rhône-Alpes Pour la Démoustication (EIRAD), Chindrieux, France

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ABSTRACT

The Asian tiger mosquito, *Aedes albopictus*, is a significant public health threat due to its ability to spread diseases such as dengue and chikungunya. Traditional insecticide-based control methods are increasingly ineffective due to mosquito resistance and environmental concerns. This has driven interest in alternative strategies like mass trapping, although its effectiveness in reducing *Ae. albopictus* populations at the community level remains unclear. This study aimed to evaluate a mass trapping intervention over three years in six peri-urban communities in France, using a Cluster Randomized Controlled Trial (CRCT) design. The intervention combined passive oviposition and host-seeking traps with source reduction and larviciding in the first two years. In the third year, control shifted to a community-based approach, with residents maintaining traps and managing breeding sites.

Mass trapping reduced mosquito abundance by 36–64 % in some communities, though efficacy varied due to local conditions, trap density, and implementation differences. The highest reductions occurred with high trap density and house coverage. The third year revealed challenges in sustaining community participation, impacting overall effectiveness.

This study provides valuable insights into the practical application of mass trapping, emphasizing the need for tailored approaches adapted to local contexts.

1. Introduction

The Asian tiger mosquito, *Aedes albopictus*, has spread across five continents in recent decades, demonstrating remarkable ecological and physiological plasticity. (Hawley, 1998) Due to its rapid range expansion and adaptability, *Ae. albopictus* is a vector of increasing public health concern in both tropical and temperate areas. (Kraemer et al., 2015) This species has become widespread in Mediterranean Europe, leading to autochthonous outbreaks of dengue and chikungunya in the region, with a trend of increasing sporadic transmission with almost 300 reported dengue cases over the past 14 years. (ECDC European Centre for Disease Prevention and Control 2024) France has been the most affected country, reporting 65 autochthonous dengue cases in 2022, 45 in 2023 and 83 in 2024 (Cochet et al., 2024). This burden is greatly increasing, as for the 27th of August 2025, 228 cases of chikungunya and

15 cases of dengue, totalling 37 episodes and outbreaks were reported (SpF, 2025).

The control of *Ae. albopictus* populations presents significant challenges. One of the primary deficiencies is a weak evidence base for the effectiveness of *Aedes* control strategies, which combined with ineffective implementation, insufficient capacities and the challenges of eliciting community participation has led to disappointment in the fight against these vectors. (Roiz et al., 2018) In emergency situations involving imported and autochthonous dengue and chikungunya cases in Europe, outdoor space spraying or outdoor residual spraying on vegetation has been employed, raising concerns due to potential impacts on non-target insects, environmental and health impacts and increased insecticide resistance of mosquitoes (Esu et al., 2010; Faraji and Unlu, 2016; Boubidi et al., 2016; Bengoa et al., 2017; Pichler et al., 2022). As a result, there is a growing interest in the novel, preventive, and

* Corresponding author.

E-mail address: david.roiz@ird.fr (D. Roiz).

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non-insecticidal approaches for *Ae. albopictus* control, particularly those that balance cost, efficacy and minimize impacts on non-target species.

Control interventions for *Ae. albopictus* in Europe have primarily targeted the larval stages using various types of larvicides (Guzzetta et al., 2017) or by eliminating breeding sites (Abramides et al., 2011; Baldacchino et al., 2015; Suter et al., 2016) which requires coordinated community participation. (Maoz et al., 2017) However, the removal and treatment of breeding sites are usually limited to human-accessible oviposition sites, which can hamper their effectiveness at high availability of inaccessible breeding sites. To address these limitations, integrated management strategies that combine complementary methods to target both larval and adult stages need to be evaluated. Mass trapping interventions are emerging as a strategic and flexible tool to include in integrated vector control campaigns. These traps can target different mosquito life stages and have been shown to be effective in combination with classical larval control interventions. (Jaffal et al., 2023) Host-seeking traps, designed to attract female mosquitoes seeking a blood meal through the use of CO₂ or proprietary lures, have been tested as control tools to reduce mosquito-human interactions. Field trials have shown these traps can significantly decrease the number of biting females of several *Aedes* species, achieving moderate to high degrees of success. (Degener et al., 2014; Englbrecht et al., 2015; Akhouni et al., 2018; Pontifes et al., 2024) However, their high costs currently limit large-scale implementation. (Barrera, 2022) Another option is to target gravid females with gravid traps, which have been purported to maximize control efforts through sustained reductions in population growth and limit disease transmission in areas with endemic transmission, as demonstrated in a trial with *Ae. aegypti* in Puerto Rico (Barrera et al., 2019; Sharp et al., 2019). A review by Johnson and colleagues (Johnson et al., 2017) of this control strategy highlighted high trap coverage as a crucial factor for the success of this strategy, which can be achieved through the deployment of vector control field operators and/or citizen engagement, with the additional advantage of more affordable costs.

To enhance evidence-based decision-making in *Ae. albopictus* control, it is essential to develop entomological field trials with robust designs that provide evidence that interventions against this species are effective. In this context, we propose the development of entomological Cluster Randomised Control Trials (CRCTs) to evaluate the effectiveness of mass-trapping interventions for *Ae. albopictus* control. This paper presents the findings of one such trial, conducted over a three-year period across two regions in southern France. The study aimed to evaluate the effectiveness of a mass-trapping strategy, with the joint implementation of passive gravid *Aedes* traps (GAT) and host-seeking female traps (BG-Mosquitaire), to reduce adult *Ae. albopictus* density under field conditions by targeting host-seeking females and gravid females, in conjunction with larval source reduction campaigns.

The trial featured a unique deployment strategy wherein specialized field operators initially set GATs and host-seeking female traps at resident houses for two years. During the second year, a campaign for public and private source reduction was added to test for potential synergies between the two strategies in terms of mosquito reduction. In the third year, residents took over the responsibility for GAT trap deployment and maintenance. By comparing *Ae. albopictus* abundance across control and treated sites using a randomised design, this research contributes relevant data for evaluating the efficacy of mass trapping as a potential component of integrated vector management programs. Moreover, the insights gained from this study can inform the design of future mass trapping trials and further serve as a platform to engage community support to coordinate efforts to control *Ae. albopictus* in residential settings

2. Materials & methods

2.1. Study area

The study was conducted in two regions of France: Montpellier and

the Rhône-Alpes region. *Ae. albopictus* has been reported in these regions since 2006 and 2009, respectively, with its presence continuously monitored by a network of ovitrap-based surveillance operated by the Interdepartmental Agreement for mosquito control in the Mediterranean coast and the Rhône-Alpes Interdepartmental Agreement for mosquito control (hereafter, EID and EIRAD, respectively) (Roche et al., 2015). In each region, control and treatment blocks were implemented in three municipalities (Fig. 1), for a total of 6 municipalities in both regions. Municipalities within a region were within a radius of 50 km of each other, and a minimum distance of 3 km. In the Montpellier region, the municipalities were Clapiers, Castelnau-le-Lez and Saint-Clément-de-Rivière, close to the coastal city of Montpellier. This area has a Mediterranean climate, with warm and dry summers and precipitation occurring mostly between fall and winter. In the Rhône-Alpes region, the experiment was implemented in the municipalities of Aix-les-Bains, Eybens and Montbonnot-Saint-Martin. This region is in a more mountainous area, with altitude ranging from an average of 251 to 320 m in these municipalities, and a temperate continental climate and significant seasonal differences in temperature as well as heavier rainfall than in the Mediterranean region.

2.2. Study design

The multisite study was conducted over three years between 2021 and 2023, with the same design across regions. Each of the 6 communities had at least one treatment and one control block, for a total of 4 replicates of each level, and a total of 8 blocks per region (Fig. 1). Blocks were selected based on expert knowledge from field operators working in the area, as well as a remote sensing analysis to ensure blocks had similar urban landscape (code 112 of Corine Landcover). The surface area of blocks in Montpellier ranged from 6.40 – 12.75 ha, and 6.78 – 14.63 ha in Rhône-Alpes. Most of the buildings (90–100 %) in each block consisted mostly of private residences, with an average of 95 houses per block in the Montpellier region and 100 houses per block in the Rhône-Alpes region. We randomised the choice of treated or control blocks in each region by random draw (World Health Organization, 2024). Blocks within a community were at a minimum distance of 340 m (average distance = 777.6 m) between treated and control blocks to avoid contamination with mosquitoes from control to treated sites (Table S1). This distance was considered adequate given the short flight range of European populations of *Ae. albopictus* (~250 m on average) (Bellini et al., 2010; Marini et al., 2010). Note, however, that in the case of one community, Eybens, this minimum distance could not be achieved due to logistic reasons.

2.3. Pre-treatment monitoring

During the first trapping session (2021), we monitored pre-treatment abundance of *Ae. albopictus* for 48-hour periods on a weekly basis (Tuesday to Thursday) for 5 weeks in both regions, with 5 BG-Sentinel (Biogents: Germany) traps per block (for a total of 80 traps, 40 per region, one trap per 1–2 Ha), baited with CO₂ and BG-Lure or equivalent aromatic lures from the same manufacturer, and replenished following manufacturer's instructions. The number of BG-traps per cluster ($n = 5$) was determined to provide a representative estimate of the mean adult density within each cluster while balancing operational logistics and budget constraints of the large-scale trial. Traps were set at an average distance of 123 m from each other in blocks in Montpellier, and 192 m in the Rhône-Alpes region, placed in areas protected for wind, rainfall and direct sunlight and close to vegetation. This pre-treatment sampling design (8 blocks per region, 2 sampling nights each with 5 traps for 5 weeks) resulted in a total of 50 trap-nights per block. Because the lure is designed to attract host-seeking females, male mosquitoes were considered accidental catches and excluded from all further analysis. BG-Sentinel traps during pre-treatment monitoring were serviced weekly to ensure they were functioning and to replenish CO₂ cylinders.

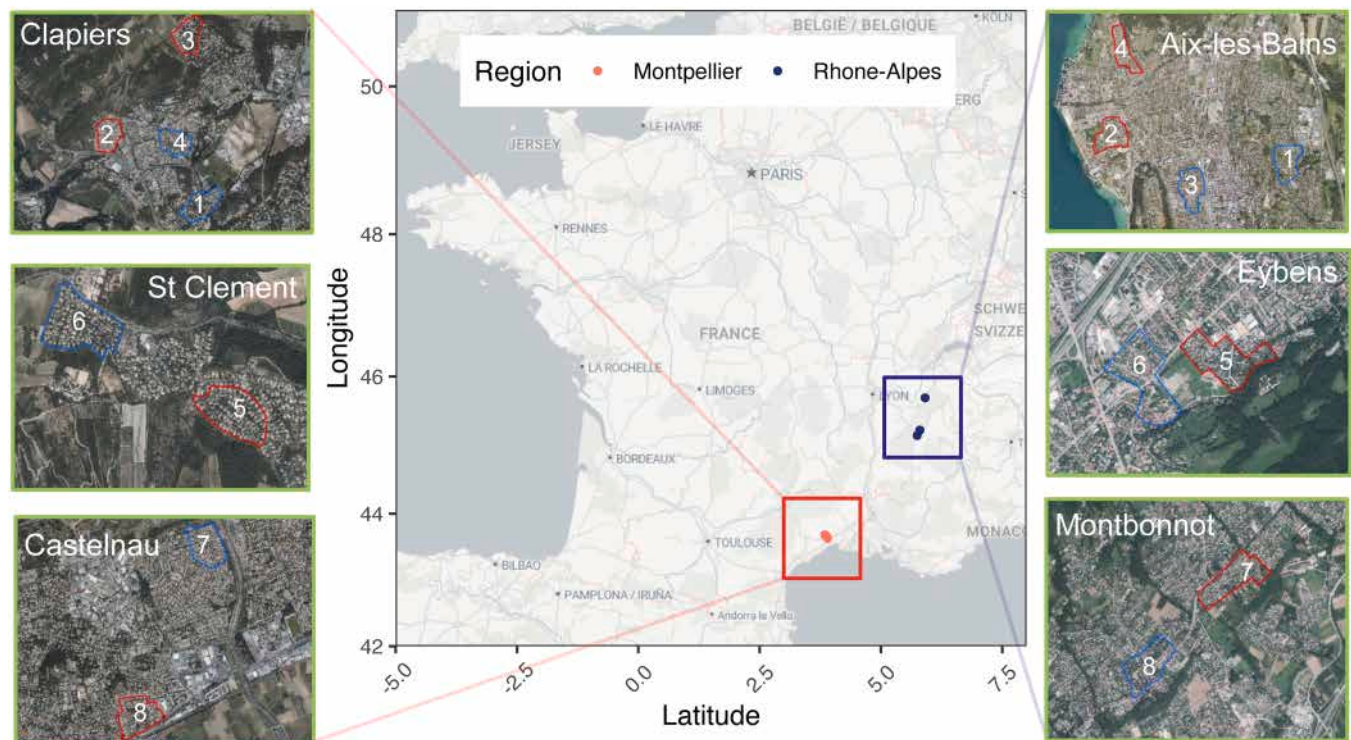


Fig. 1. Study region map. Map of the study regions in the south of France and the communities where the trial was implemented. Each community had at least one control block and one block where the mass trapping strategy was implemented.

After collection, mosquitoes were brought back to the laboratory for morphological identification, using taxonomic keys (Becker et al., 2003) and the MosKey Tool interactive identification key (Gunay et al., 2018). Although pre-treatment monitoring of mosquito populations was also conducted during 2022 and 2023, the mass trapping strategy was deployed earlier during these years, in anticipation of the start of the mosquito season, resulting in low pre-treatment captures.

2.4. Mass-trapping strategy

The experiment had different duration between regions. In the Montpellier region, mass trapping was implemented from July to early October 2021, and subsequently from May to early November in 2022 and 2023, whereas in the Rhône-Alpes region, traps were deployed from July to late September during 2021 and then from May to mid-October in the two subsequent years.

The mass trapping strategy involved deploying BG-Mosquitaire traps (Biogents, USA) and BG-GAT traps (Biogents, Germany). BG-GAT traps consist of large 10 L black container with a translucent upper chamber that simulates an oviposition site for gravid females by containing water. These traps capture and kill mosquitoes by means of sticky papers inside the transparent dome, making them a passive trapping tool that does not require electricity once set. BG-Mosquitaire traps simulate human hosts, by using a patented lure and an air plume to mimic convection currents created by a human body, and they require an electrical current to operate (Bisia et al., 2023).

For trap deployment in treatment blocks during the first year, 16 field agents (2 per block) were mobilised in each region to contact residents to explain the experiment and obtain consent for trap installations in their gardens. A flyer with information on the biology of *Ae. albopictus* and source-reduction strategies for its control were distributed to all residents both in control and treated areas (File S1). This mobilisation aimed for at least 80 % of the houses equipped with BG-GAT traps in treated blocks, with at least one trap per property with a surface <499 m², and a minimum of 2 BG-GATs for properties with a surface larger

than 500 m² or with separate (back and front) garden areas. The target density for BG-Mosquitaire traps was at least 1 trap/ha. Traps were installed following the manufacturer's recommendations, and placed in areas protected for wind, rainfall and direct sunlight and close to vegetation. Bi-monthly checks of the BG-GAT and BG-Mosquitaire traps to verify adequate functioning were performed by field agents during the first and second years, with the permission of residents who agreed to participate.

In the second year (2022), larviciding and source reduction strategies were implemented in public spaces and in private properties participating in the trial. These activities were conducted both in treated and control blocks. Prior to trap deployment, potential breeding sites were identified in public spaces by EID field agents and treated on a case-by-case basis with surface films (Aquatrain drops ®) at a dose of 4 capsules per m² or Bti pellets at a dose of 10 g per collector to prevent mosquito breeding. Treatment was only administered once, at the same time that the mass trapping strategy was deployed. Only breeding sites of >10 L, rainwater collectors, buried tanks, gutter descents, productive drains, and other large non-removable breeding sites were censused, mapped and treated with the aforementioned solutions. Field operators conducted a door-to-door campaign to contact residents to identify potential breeding containers within the property during the week of BG-GAT trap installation in treated blocks, and the same week in the control blocks. A document with detailed information on source reduction actions was given to all residents. For residents that could not be contacted, the document was left in their mailbox. For residents that engaged with the source reduction strategy, mosquito nets were installed in non-removable breeding sites and a single dose of larviciding solution was also applied to these sites. For the third year (2023) the strategy was modified to evaluate community participation. At the end of the second trapping season, BG-GAT traps were left with participating residents for their deployment. During the trapping session in 2023, field agents conducted visits to houses of residents with BG-GAT traps to assess if traps had been reset. BG-Mosquitaire traps were reinstalled by EID agents. A set of 6 sticky cards (per installed trap) were distributed

per household in treated blocks, accompanied by a flyer with recommendations for the trap set-up, monitoring and maintenance, including changing the sticky card once a month and regularly check that the traps were in good condition (card in place and presence of water at the recommended level in the bottom of the trap).

2.5. Monitoring of *Ae. albopictus* female abundance during mass trapping intervention

In all treated and control blocks, 5 BG-Sentinel traps (BioGents: Germany) per block were baited with CO₂ (adjusted to 0,5 kg/j) and the same aromatic lures as used during pre-treatment monitoring. These traps were set in the same locations used for pre-treatment monitoring. BG-Sentinel traps were sampled every two weeks over 48-hour sampling periods. Collected mosquitoes were brought back to the laboratory for morphological identification with taxonomic keys. Trap checks were also conducted every two weeks to ensure adequate trap functioning and to replenish CO₂, if needed. Any trap issues on these checks were systematically recorded, with malfunctioning traps replaced as needed. The sampling effort was the same for treatment and control blocks within a region but varied by year due to different duration of the implementation (Table S4).

2.6. Statistical analyses

All statistical analyses were generated with R v.4.3.2 (R Core team, 2023). We calculated the total sum of each mosquito species in each community on each year of the trial and used it to estimate the relative abundance of *Ae. albopictus* in relation to other mosquito species. We tested for differences in pre-treatment abundances between control and treated blocks in each region with a generalised linear mixed model (GLMM). These models were fit with a negative binomial error distribution, and mosquito abundance as a response variable. To control for local variation in mosquito abundance and the effects of temperature, vegetation and rainfall which are known to affect *Ae. albopictus* populations, we included community identity, average weekly temperature, 2-week prior accumulated precipitation and the proportion of vegetation cover of each block as fixed effects, in addition to the treatment level of the block. The 2-week precipitation timeframe was selected as representative of the life cycle of *Ae. albopictus* from eggs to adult mosquitoes under optimal conditions (Roiz et al., 2010; Garrido et al., 2024). The calendar date of trap setup, trap ID and block number were included as random factors to account for repeated measures. If significant differences were detected, a model with the same error structure and random variables, but with block number as fixed effect was used to test which blocks were driving the differences. Differences in pre-treatment abundances were only assessed for the first year, as shorter pre-treatment sampling and earlier trap deployment in 2022 and 2023 resulted in low pre-treatment numbers of *Ae. albopictus*, which has naturally low abundances in the early months of the year.

Climatic data (precipitation and temperature) for the sampling period were obtained from the Montpellier airport (ID: 34,154,001) and Prade weather stations (ID: 34,217,001) for the Montpellier region, and from the Grenoble (ID: 38,185,012 and ID: 38,538,002) and Chambéry-Aix Aéroport stations (ID: 7332,900) for the Rhône-Alpes region (refer to Table S2 for details on the distance of each weather station to its corresponding community). Vegetation cover was estimated from Landsat images, and further processed with Qgis (v.3.38.3), 'sp' (v. 2.1–3) and 'tmap' (v. 3.3–4) packages in R to obtain the proportion of vegetation cover per block (see Table S3 for details).

To monitor the behaviour of *Ae. albopictus* across years within each region and community, we calculated the weekly mean and standard deviation for each year and community by treatment level. To estimate the effect of the trapping intervention on *Ae. albopictus* abundance, we used generalised mixed models with negative binomial error distribution to test the null hypothesis that there were no differences in post-

treatment mosquito abundance between control sites and sites where BG-GAT and BG-Mosquitaire traps were deployed, with control as the reference level. Due to the yearly differences in the design described above, we conducted separate GLMMs for each year, using the 'glmmTMB' package (v. 1.1.2). In all models, mosquito counts were the response variable. Fixed effects included the treatment level, average weekly temperature and 2-week accumulated precipitation prior to the sampling date. Random effects included trap ID, block and calendar date of trap setup. The statistical significance of the covariates was tested using likelihood ratio test to compare full models without these terms. The efficacy of the intervention (*E*) was estimated as the percent reduction in mosquito abundance in treated sites with respect to the control sites, using the incidence rate ratios (IRR) obtained from the models to calculate $E = (1 - IRR) \times 100$ (Vazquez-Prokopec et al., 2022). We calculated *E* separately for each year and each community, to obtain an estimate of the efficacy with reference to the control site of each community.

Trap coverage has been reported to play a crucial role in the success of mass trapping interventions (Mackay et al., 2013; Barrera et al., 2020), with a recent trial targeting the sister mosquito taxa, *Aedes aegypti*, uncovering a non-linear relationship of trap coverage with abundance (Juarez et al., 2021). Thus, we investigated if trap coverage modulated the success of the intervention in each region. Trap coverage was measured as trap density, considering the number of GAT traps and the number of BG-Mosquitaire traps per hectare (GAT/ha and BG-Mos/ha, respectively), estimated separately for each trap type considering the area of the corresponding block (trap density was 0 for control blocks). Firstly, we fit a GLMM to assess how the density of each trap type was associated with mosquito abundance. These models included year and trap density as a fixed effect, as well as the influence of environmental variation (average weekly temperature and 2-week accumulated precipitation). Because these models were fit for the two years of data for each region for which trap density information was available, they also included an offset term for the number of trapping days (Table S4). Random effects had the same structure as previous GLMM models. For all GLMM models, diagnostics were conducted with DHARMA (v. 0.4.6) to ensure the models did not violate any assumptions (Zuur et al., 2010). To assess for potential non-linear effects of trap density, we employed General Additive Mixed Models (GAMM) with negative binomial error distribution, fit via restricted maximum likelihood (REML) to female *Ae. albopictus* abundance. These models included a smooth spline penalizing effects for trap density, included an offset term for the number of trapping days, and controlled for the effect of the year, temperature and precipitation, which were modelled as linear variables. These models were only fit for BG-GAT traps, given the smaller range of variation in the density of BG-Mosquitaire traps (Table 1). To test whether the effect of trap density depended on the community, we included an interaction between trap density and community, where we used a factor-smooth interaction and specified a varying intercept for each community level. An information criteria approach was used to determine if including this interaction provided a better model fit than a simpler model (no interaction). We assessed if effective degrees of freedom (EDFs) >1 to determine if BG-GAT density was better represented as a smooth or a linear variable. Random effects had the same structure as those for the GLMM models. GAMM models were generated using the 'mgcv' (v.1.8–31) package.

3. Results

In the Montpellier region, we collected a total of 67,215 specimens of 13 species of 4 genera, with *Ae. albopictus* comprising 83–93 % of the total catch in each community (Fig. S1; Table S5). In the Rhône-Alpes region, we collected a total of 53,266 specimens of 14 species of 4 genera, of which *Ae. albopictus* represented 87 to 91 % of the total catch (Fig. S1; Table S5).

Pre-treatment abundances did not differ between control and treated

Table 1
Mass trapping strategy implementation by number of traps, surface of intervened areas, percentage of house coverage and trap density. Note the number of traps refers to BG-GAT and BG-Mosquitaire traps.

Region	Community	Block	Surface (ha)	GAT/ ha	2021		GAT/ ha	2022	
					Mos/ ha	cov		Mos/ ha	cov
MONT	Clapiers	1	7.89	0	0	0	0	0	0
	Clapiers	2	6.44	13	1.9	66.3	17.2	1.4	71.3
	Clapiers	3	7.31	8.8	1.4	67.8	15.7	1.1	78.2
	Clapiers	4	6.37	0	0	0	0	0	0
	St Clement	5	9.99	8.3	0.8	65.9	11.2	0.8	75.6
	St Clement	6	12.75	0	0	0	0	0	0
	Castelnau	7	6.40	0	0	0	0	0	0
	Castelnau	8	7.03	12.2	1.3	70.1	14.4	0.9	72.2
RA	Aix	1	14.03	0	0	0	0	0	0
	Aix	2	14.63	5.9	1.1	81	5.3	1.1	73
	Aix	3	14.55	0	0	0	0	0	0
	Aix	4	11.28	8.8	1.3	83	6.4	1.4	60
	Eybens	5	6.78	11.6	2.1	98	11.8	2.1	99
	Eybens	6	8.16	0	0	0	0	0	0
	Montbonnot	7	12.83	5.0	1.0	59	6.5	1.0	81
	Montbonnot	8	11.97	0	0	0	0	0	0

blocks in any of the regions during the assessed year (2021) (Table S6). However, we detected significant differences in pre-treatment abundances of *Ae. albopictus* between communities in the Montpellier region; specifically, the community of St. Clement presented lower pre-treatment abundances compared to the other communities in the

region (Fig. S2). Peak abundance of *Ae. albopictus* in the Montpellier region occurred between July and August, with a second uptick occurring between September and October, followed by a sharp decline by early November (Fig. 2). In the Rhône-Alpes region, *Ae. albopictus* abundances began a

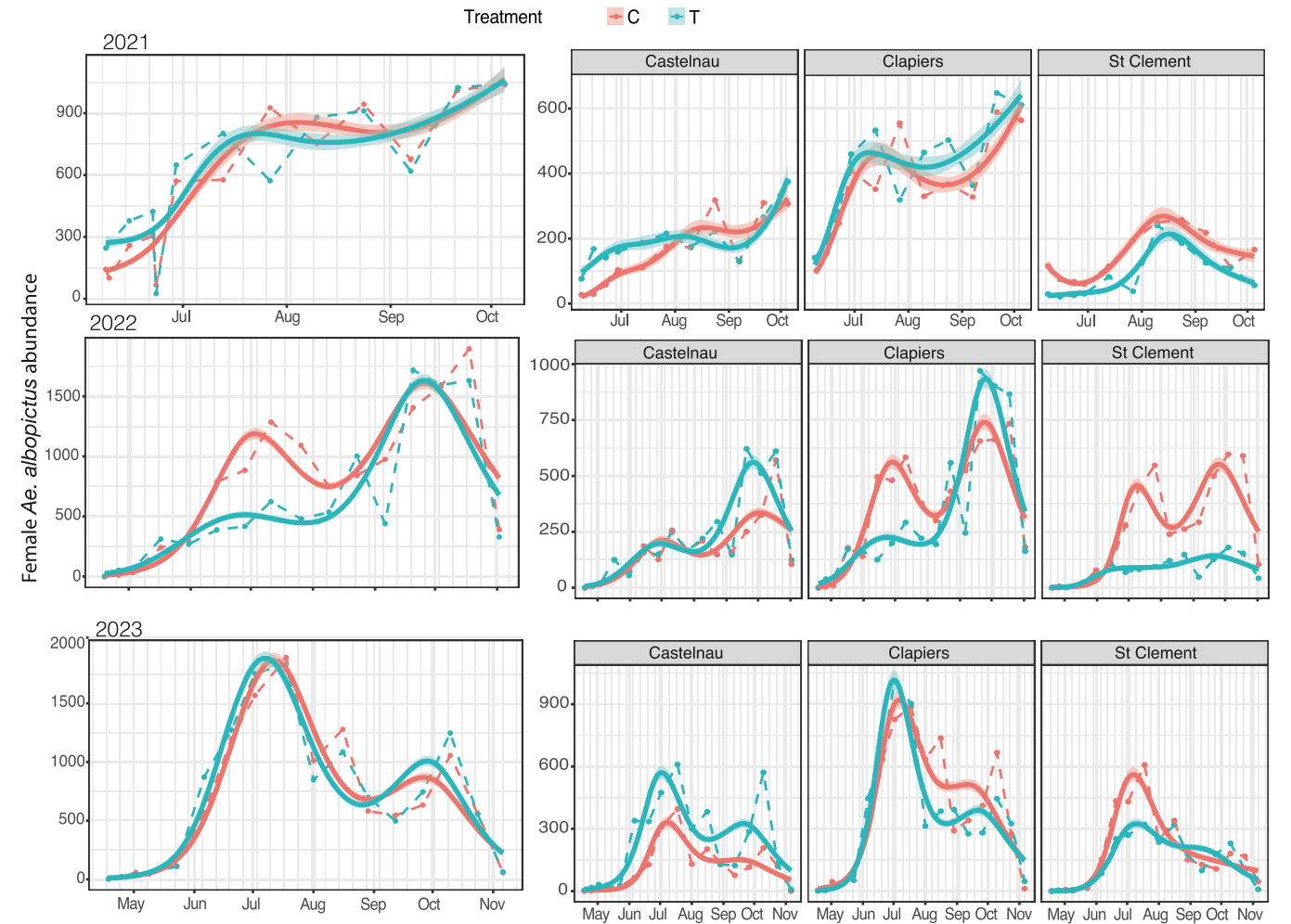


Fig. 2. Temporal variation in mosquito abundance in Montpellier. Comparison of the variation in weekly abundance of the number of female *Ae. albopictus* mosquitoes captured over a 48-hour period in BG-Sentinel traps, in control and treatment sites by region and locality in Montpellier.

sustained increase after early to mid-July, reaching peak abundances between August and September, with a drop in abundance observed towards early to mid-October (Fig. 3). These trends were present in both control and treated areas (Fig. 2, 3).

Mass trapping significantly reduced mosquito abundance, albeit not in all sites or years, and with variation in the efficacy of the intervention. In the region of Montpellier, the highest significant reduction was observed in 2022 in St Clement, with an estimated 64.4 % (C.I. 31.3 – 81.5 %) decrease in *Ae. albopictus* abundance in comparison with control sites within the same community. A moderate reduction of 35.5 % (C.I. 2 – 59 %) was detected in 2022 in Clapiers. For other years, the models detected low to moderate (but non-significant) decreases in these two communities (Fig. 4; Table S7). Mosquito abundance during the last session in Castelnau was significantly higher in treated than control sites in 2023 (Fig. 4, Table S7). Average temperature and accumulated precipitation had significant but small, negative effects of mosquito abundance in this region in 2021, whereas in 2023, only temperature had a significant positive effect on abundance. No effects of environmental variables on abundance were detected in 2022 (Table S7).

In the Rhône-Alpes region, mosquito abundance was reduced in half in comparison to control sites during the 2021 session in the communities of Montbonnot (56.8 %, CI: 28.2 – 74.0 %) and Aix-les-Bains (51.8 %, CI: 4 – 75 %), with no effect detected in Eybens. In the 2022 session, model coefficients indicated moderate but non-significant reductions in Montbonnot and Aix-les-Bains, and no effect of mass trapping in mosquito abundance in Eybens (Table S7). During the final session in 2023 in Eybens, the mass trapping strategy was associated with a non-

significant reduction in mosquito abundance in Eybens (25 %) and in Aix-les-Bains (35.9 %), and a significant but moderate reduction in Montbonnot (36.4 % CI: 10.6 – 54.7) (Fig. 4; Table S7). In terms of the effect of environmental variables on mosquito abundance, accumulated precipitation generally had a negative, although small effect on abundance, with inconsistent significance. For example, only in 2021 it was associated with lower mosquito abundance in all communities (Table S7). Higher average weekly temperatures were associated with increased abundance, but statistical significance was only detected in specific years and communities.

Although we initially aimed at a minimum of 80 % trap coverage in each block, trap coverage by block ranged from 60 to 99 % between 2021 and 2022 (Table 1), as not all residents could be timely contacted or were not willing to participate. During the first year of implementation, we had a participation ranging of 66 to 70 % of houses per block in the Montpellier region, and a participation of 60 to 98 % in the Rhône-Alpes region. A total of 318 traps for an average of 1.3 traps per house were deployed in Montpellier, and 332 in Rhône-Alpes. House coverage increased in the Montpellier region during the second year, with increased effort for timely contact of residents. Coverage on this year ranged between 71 – 78 % of houses per block, with 444 traps deployed for an average of 1.6 traps per house. In the Rhône-Alpes region, while overall coverage remained similar to the first year (60 – 99 % of houses per block), acceptability was reduced compared to the previous year in specific blocks (Table 1), limiting a systematic verification of trap setup. Higher BG-GAT trap density was associated with a significant decrease in mosquito abundance in the communities of the Montpellier region,

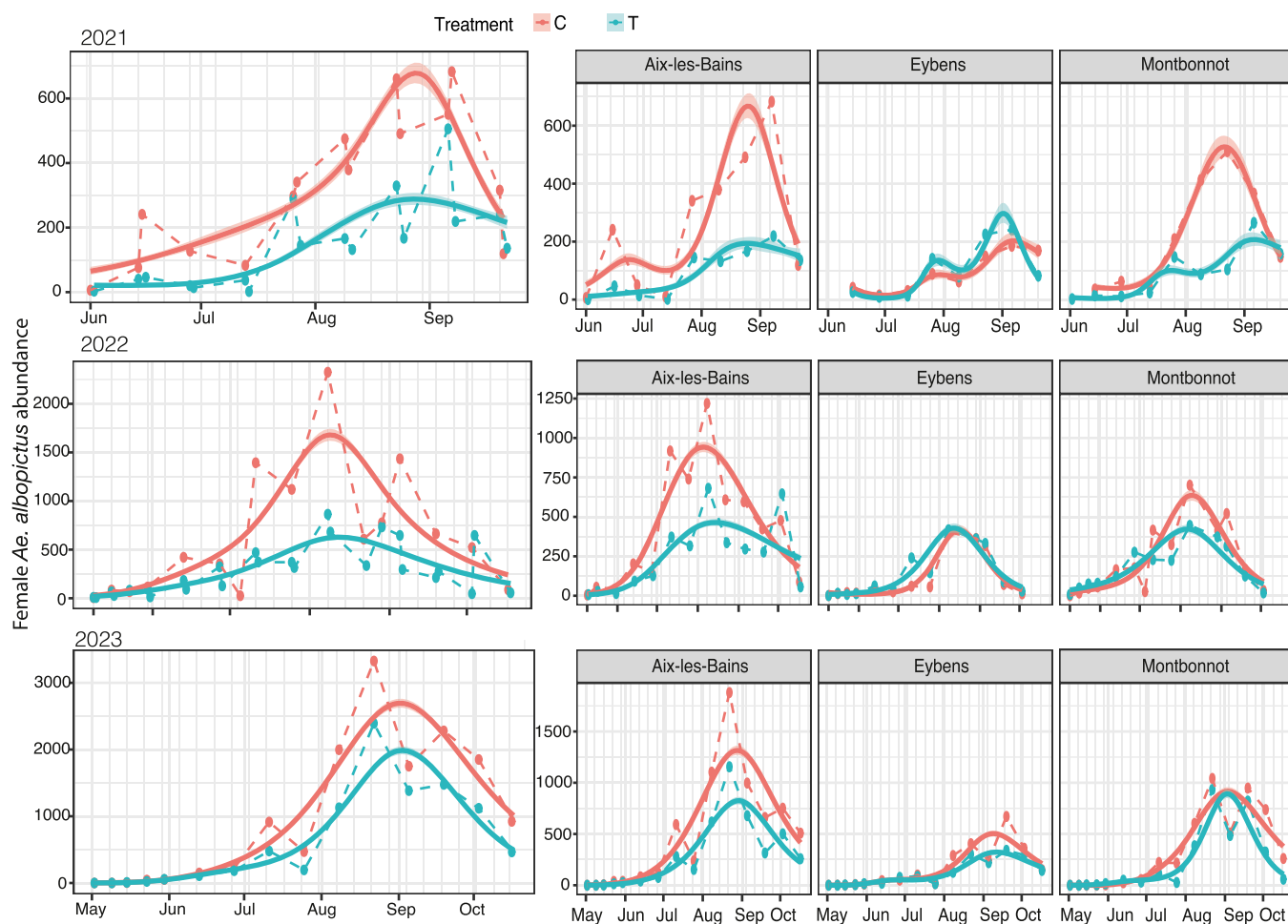


Fig. 3. Temporal variation in mosquito abundance in Rhône-Alpes. Comparison of the variation in weekly abundance of the number of female *Ae. albopictus* mosquitoes captured over a 48-hour period in BG-Sentinel traps, in control and treatment sites by region and locality in Rhône-Alpes.

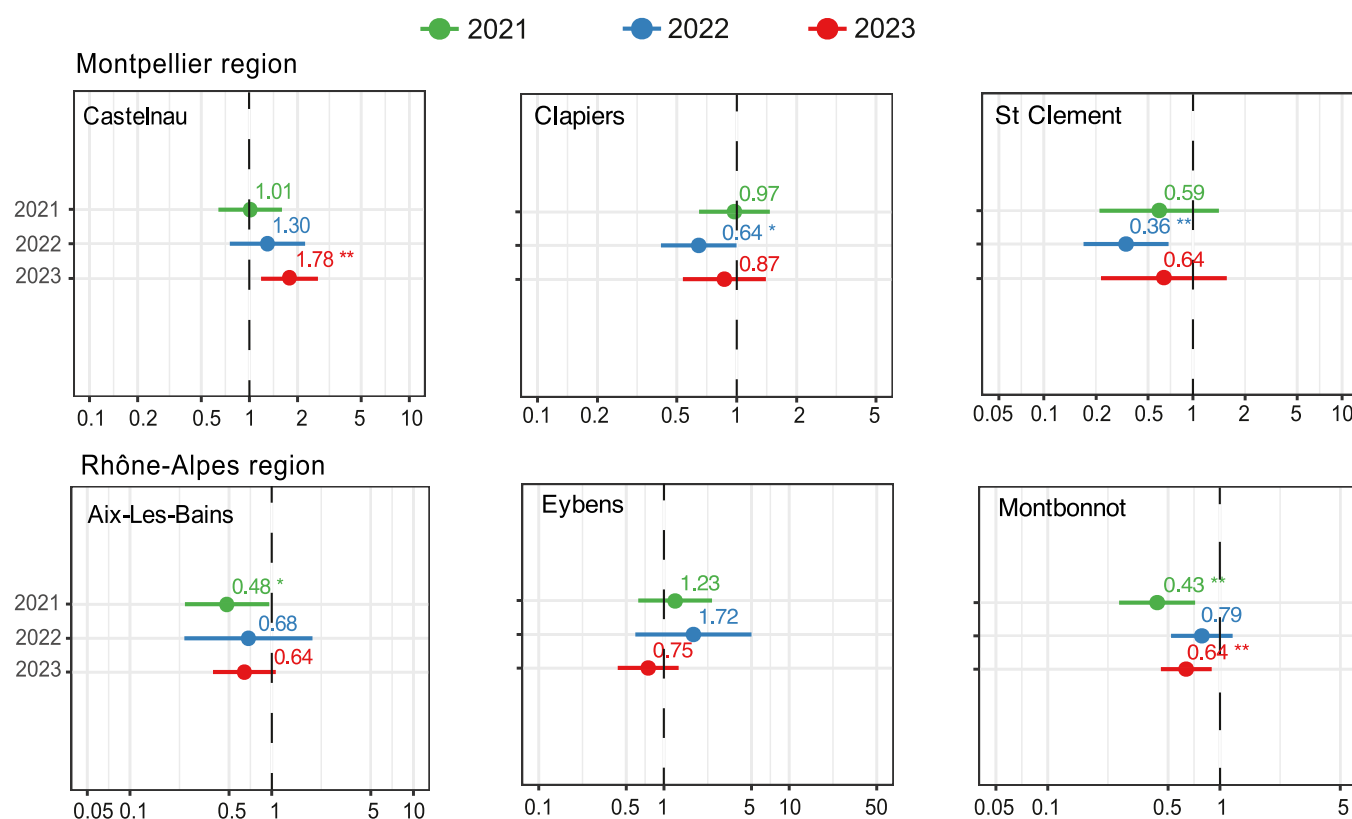


Fig. 4. Incidence rate ratio estimate of effect on mosquito abundance. Visual representation of the Incidence Rate Ratios values for each treated site, as estimated from the model coefficients (obtained from model tables). An IRR value lower than 1 (dashed vertical line) indicates a reduction in mosquito abundance. Asterisks (**) indicate whether the estimate is statistically significant. IRR values were used to estimate the efficacy of the intervention, as detailed in the methods section with the formula: $E = (1 - \text{IRR}) \times 100$.

whereas BG-Mosquitaire density did not have a significant effect (Table S8), which was further confirmed by model comparison with an LRT (LRT: $X^2 = 3.71$, $df = 3$, $p = 0.295$), where including the term representing BG-Mosquitaire traps did not significantly increase model fit. In the Rhône-Alpes region, increased trap density was associated with a significant decrease in mosquito abundance for both trap types (Table S8). The GAMM models indicated a positive association between higher trap coverage resulting in lower abundances of *Ae. albopictus*, but with site-specific effects and potential non-linear behavior (Table S9; Fig. 5). In the Montpellier region, higher trap density resulted in a decreased mosquito abundance in St Clement and Clapiers. However, in Clapiers the model indicated that only trap density above 10 GAT/ha would result in decreased mosquito abundance, whereas the opposite effect would be expected at lower density (Fig. 5). Note that coverage in treated blocks ranged between 8 and 13 traps/ha in 2021 in the Montpellier region, whereas it increased to 11.1 – 17.2 traps/ha in 2022 (Table 1). In Castelnau, higher trap density was associated with higher mosquito abundance, according to the model, although the p -value > 0.05 indicates there is not enough certainty in the shape or direction of the effect of density in this community (Table 2). In the Rhône-Alpes region, the model also detected a steady decrease in mosquito abundance at higher GAT trap density in Aix-les-Bains and Montbonnot, with the opposite effect in Eybens (Fig. 5). Coverage in treated blocks ranged between 5 – 11.6 traps/ha in 2021 in the Rhône-Alpes region, and remaining similar (range 5.3 – 11.8 traps/ha) during the second year.

4. Discussion

Effective control of the Asian tiger mosquito, *Ae. albopictus*, has become increasingly relevant in public health due to its rapid global spread and its role as a vector of several diseases, including dengue and

chikungunya. Given the environmental and sanitary impacts of insecticide-based methods and the increase of insecticide resistance, developing alternative control strategies for this species is crucial, especially in urban and semi-urban environments where it thrives. A key to succeed in these efforts is assessing the evidence of control effectiveness, which ensures that interventions work under real-world conditions. In this study, we present an evaluation of an entomological CRTC to evaluate mass trapping as a method to control *Ae. albopictus* populations in two regions of southern France. Our findings indicate that mass trapping can significantly reduce mosquito populations, though with local variations in efficacy across different areas and deployment strategies. Such variability highlights the complexity of vector control and underscores the need for locally tailored approaches.

Reductions in *Ae. albopictus* populations in treated sites were detected in both study regions, with the lowest significant estimate indicating that mass trapping reduced mosquito abundance by a third, with higher estimates indicating a reduction of 50% and up to 64 % in comparison to control sites. These results are on the lower end of reported reductions in other mass trapping studies. For instance, Lega et al. (Lega et al., 2020) found that strategic removal of 20–30 % of gravid females could result in a 60–80 % reduction in overall mosquito populations, demonstrating the potential of mass trapping when effectively implemented. Similarly, Barrera et al. (Barrera et al., 2020) reported sustained, area-wide control of *Aedes aegypti* using ovitraps, achieving long-term reductions of around 70–80 %. In both studies, trap coverage equal to or above 80 % was associated with effective reductions in mosquito populations. Indeed, because the success of ovitrap-based methods depends largely on their ability to compete with other oviposition sites in the environment (natural or man-made), adequate terrain coverage has been proposed as critical for the success of the intervention (Johnson et al., 2018). During the first year of our experiment, the percentage of

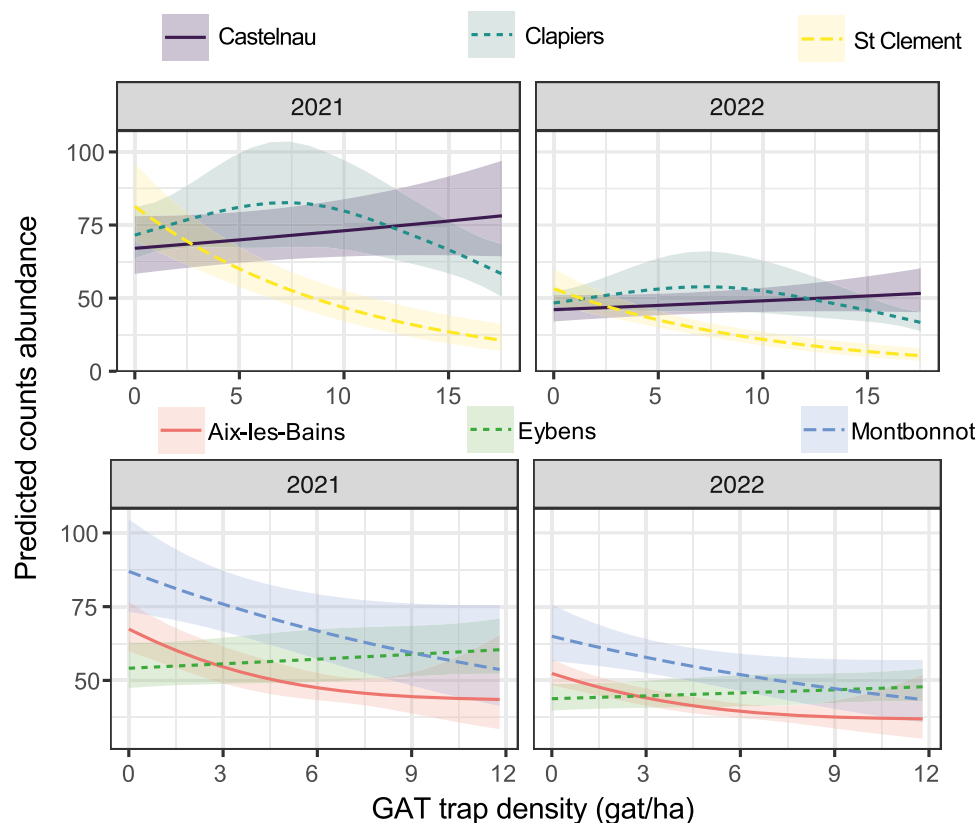


Fig. 5. GAMM model predictions. Visualization of the predictions of GAMM for counts of *Ae. albopictus* in communities in A) Montpellier and B) Rhône-Alpes at increasing trap density.

Table 2

Table of model coefficients of the GAMM models to test the effect of BG-GAT trap density on the abundance of *Ae. albopictus* in treated and control areas. P-values of <0.05 are considered significant and highlighted in bold.

Montpellier			
Parametric coefficients	Estimate	Std. Error	p-value
Intercept	1.80	0.26	<0.001
CommuneClapiers	−0.01	0.09	0.886
CommuneStClem	−0.40	0.11	<0.001
Year2022	−0.68	0.09	<0.001
av weekly °C	−0.03	0.01	0.012
Pp 2w	0.00	<0.001	0.020
Smooth terms	edf	Chi.sq	p-value
s(gat_ha):Castelnaud	1.002	1.05	0.307
s(gat_ha):Clapiers	2.132	11.32	0.007
s(gat_ha):StClem	1.003	42.56	<0.001
Rhône-Alpes			
Parametric coefficients	Estimate	Std. Error	p-value
Intercept	0.88	0.09	<0.001
CommuneEybens	0.03	0.12	0.811
CommuneMontb	0.47	0.11	<0.001
Year2022	−0.44	0.09	<0.001
Smooth terms	edf	Chi.sq	p-value
s(gat_ha):Aix	1.49	1.74	<0.001
s(gat_ha):Eybens	1.00	1.00	0.253
s(gat_ha):Montb	1.00	1.00	0.016

intervened houses ranged between 66 and 70 % in the Montpellier region, with GAMM models indicating that this level of coverage required trap density above 10 GAT/ha in treated areas of Clapiers to observe reductions in mosquito populations. Trap density below that resulted in increased abundance. A similar non-linear effect was reported by Juarez et al. (Juarez et al., 2021) in a study that found that lower coverage could paradoxically lead to an increase in *Ae. aegypti* abundance due to

decreased competitive pressure in other colonized larval habitats, highlighting the importance of assessing trap density thresholds for effective mosquito density reductions. In St Clement, predicted mosquito abundance at a density of 10–12 GAT/ha was half of that predicted at 0 GAT/ha. However, in most treatment blocks in the region, implemented trap density was lower than 10 GAT/ha during 2021, which could account for the lack of a significant effect on mosquito abundance in Montpellier during the first session. Coverage above 80 % was achieved during 2021 in Rhône-Alpes (except in one community), with trap density between 5 – 9 GAT/ha resulting in approximately 50 % reductions in mosquito abundance in two of the three treatment communities, according to GLMM results. Although this could suggest that higher coverage can compensate for lower trap density to some extent, other factors could account for these regional differences. For example, BG-Mosquitaire trap density was associated with lower mosquito abundance in the Rhône-Alpes region, which could have led to more substantial reductions in mosquito populations despite lower BG-GAT trap density, potentially due to the complementary mechanism of action of both traps. In contrast, these traps did not significantly enhance the reduction of mosquito populations in the Montpellier region, despite presenting a similar density on average, highlighting the potential influence of other factors that could limit the effectiveness of BG-Mosquitaire traps in this region. Further analyses are required to assess the potential synergies of host-seeking traps in combination with gravid traps, as the current literature is scarce (Jaffal et al., 2023).

The second year of our experiment aimed to simultaneously achieve high trap coverage and reduce alternative oviposition sources by integrating a complementary larval control method. Thus, this dual strategy was expected to yield the highest reductions in mosquito populations. While this approach did result in significant reductions, the anticipated high efficacy was only observed in one site in the Montpellier region. The lack of expected results in the Rhône-Alpes could be attributed to

operational difficulties that limited trap verification in comparison to the previous year (Personal Communication of field agents). In line with this finding, a recent field trial in Trinidad using yeast-baited oviposition traps found that, while traps were highly attractive to gravid *Aedes* females, low coverage due to limited access to private residential compounds significantly affected the estimation of the effect of the intervention (James et al., 2022). Another non-exclusive possibility is that not all alternative oviposition sources were effectively targeted by the larviciding strategies. Source reduction and larviciding have been purported to enhance the overall effectiveness of mass trapping by reducing the number of breeding sites and larvae (Jaffal et al., 2023). However, if any of the complementary strategies is not implemented widely enough, the overall impact on the mosquito population may be minimal. Despite time consuming, conducting extensive surveys (and control) of potential water containers to assess the risk of mosquito breeding would be a relevant addition to mass trapping trials, to ensure sufficient coverage of complementary source reduction and larviciding strategies. In our case, although public spaces and some private residences were targeted, non-participating residences could represent persistent mosquito breeding sites, affecting the efficacy of the strategy. Thus, these findings indicate that while integrating larval control can enhance the efficacy of mass trapping, it also presents relevant logistical challenges that must be addressed to ensure uniform coverage and effectiveness. Furthermore, the GAT traps in our study were baited with water only. Future implementations could investigate the potential for increased efficacy by incorporating standardized organic infusions known to act as potent oviposition attractants, while balancing the added logistical complexity (Barrera, 2022; Johnson et al., 2017).

High trap coverage can be achieved through the activities of vector control field operators, but also through community engagement for source reduction, trap placement and maintenance, as these mosquitoes tend to develop in containers in residential or private areas (Fonseca et al., 2013). Thus, community participation can represent a pivotal element in the success of a mass trapping strategy, as well as ensuring the sustainability of the strategy. For example, the Citizen Action through Science (AcTS) model implemented in a small-scale trial to control *Ae. albopictus* in New Jersey, demonstrated that community-driven efforts could achieve substantial reductions in mosquito populations (Johnson et al., 2018). Although the involvement of local residents in the third year of the experiment generally resulted in lower abundances in treated sites, these reductions were only significant in one community of the Rhône-Alpes region (Montbonnot). Several potential factors could explain this discrepancy. First, varying levels of community participation and engagement led to inconsistent maintenance and performance of the traps (YR, NLD, personal communication). Although participating residents were aware of the project and had received a note with instructions for the trap set up and maintenance, additional support could have increased successful trap functioning. Drawing on successful models like Citizen AcTS can help guide and sustain community involvement, ensuring more consistent and effective outcomes across different regions. Therefore, translating entomological effectiveness into long-term operational success requires future research to better understand social, behavioral and organizational determinants of community participation.

Interestingly, two communities reported no effect of the mass trapping intervention, or even increased *Ae. albopictus* abundance. In one of these communities, Eybens, the proximity between control and treated sites (~100 m) likely resulted in spillover effects (Wilson et al., 2015) between blocks due to mosquito movement. In the case of Castelnau, field operators reported issues with traps functioning particularly during 2023, where random checks of trap set-up indicated a high percentage of undermanaged traps (~40–50 %), with the most common issue being that sticky cards had fallen into the water (YR, NLD, Personal Communication), rendering the trap useless as a control method. This issue highlights the potential risks of trap malfunction, as this would effectively increase the availability of breeding containers. In other trials, this

problem has been addressed by treating the collection chamber of the GAT traps with insecticides, or adding canola oil (Eiras et al., 2021; Heringer et al., 2016).

Despite promising results, ensuring uniform execution across diverse communities proved challenging. Limited data on the extent and consistency of community participation hindered our ability to fully assess its impact on the results. This lack of detailed information on community involvement makes it difficult to identify specific factors that influenced the success or failure of the intervention in different areas.

Our evaluation of mass trapping as a method to control *Ae. albopictus* populations in southern France demonstrates that while this strategy can significantly reduce abundance, its effectiveness varies based on community engagement, trap density, and coverage. The variation in efficacy across sites and years suggests that mass trapping strategies should be adapted to local contexts, to ensure that both coverage and trap density are optimized. From a cost-effectiveness perspective, although gravid traps can be made at low prices (Melo-Santos et al., 2010), the need for regular maintenance pose challenges for large-scale implementation. Thus, sustainable and cost-effective deployment of mass trapping strategies requires community-based approaches with a strong guidance component. Future research should focus on understanding the local environmental and social factors that influence trap efficacy, as well as assessing the potential synergies between different types of traps to enhance the scalability and sustainability of mass-trapping as a control method.

CRediT authorship contribution statement

Paulina A. Pontifes: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Nicolas Le Doeuff:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Investigation, Data curation. **Yvon Perrin:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Cyrille Czeher:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Investigation, Formal analysis, Data curation. **Jean-Baptiste Ferré:** Writing – review & editing, Supervision, Project administration, Investigation, Formal analysis, Data curation, Conceptualization. **Yves Rozier:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Remi Foussadier:** Writing – review & editing, Project administration, Investigation, Funding acquisition. **Gregory L'Ambert:** Writing – review & editing, Supervision, Project administration, Funding acquisition. **David Roiz:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.actatropica.2025.107810](https://doi.org/10.1016/j.actatropica.2025.107810).

Data availability

The data will be made publicly available in a public repository that issues datasets with DOIs upon publication of the article Link to repository <https://figshare.com/s/eaac866e1dbf7fe9b379>.

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