

Methods and Applications

Field Efficacy of Seven Nighttime Ultra-Low-Volume Spraying Strategies Against *Aedes albopictus* in Urban Green Spaces — Shenzhen City, Guangdong Province, China, October–November 2025

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ABSTRACT

Introduction: Daytime adult mosquito control in urban parks may disrupt public activities and constrain equipment movement. We evaluated whether nighttime ultra-low-volume (ULV) operations could reduce adult *Aedes albopictus* host-seeking activity in complex vegetation.

Methods: Descriptive field comparisons were conducted at three urban green-space sites in Shenzhen, China. Seven strategies were evaluated: ground ULV-only, unmanned aerial vehicle (UAV)-only, light- or wind-disturbance-assisted UAV, dual-insecticide UAV, and two coordinated ground-air regimens. Adult host-seeking activity was measured using protected human-bait collection, a modified human landing catch (HLC) procedure with full protective clothing and no skin exposure. Henderson–Tilton control-adjusted efficacy was the primary comparison, and direct reduction was used as a supporting measure.

Results: In the control-adjusted analysis, wind disturbance plus UAV spraying yielded the highest observed Day 1 efficacy, 91.7% (11/12). Ground-air coordinated dual-regimen ULV spraying yielded the highest observed overall efficacy, 75.9% (2,339/3,080). Dual-insecticide UAV spraying yielded efficacies of 77.8% (7/9) on Day 1 and 67.9% (112/165) overall. Ground-air coordinated same-regimen ULV spraying showed moderate control-adjusted efficacy, whereas ground ULV-only spraying produced negative estimates under the evaluated field conditions.

Conclusion: Under heterogeneous field conditions, wind disturbance plus UAV spraying had the highest observed Day 1 adjusted efficacy, whereas ground-air coordinated dual-regimen ULV spraying had the highest observed overall adjusted efficacy. Site, period, and baseline differences limit causal comparisons among strategies.

Aedes albopictus (*Ae. albopictus*) is an important vector of dengue and chikungunya in southern China (1–2). Daytime ultra-low-volume (ULV) spraying in public parks can interfere with visitors, require exclusion zones, and constrain coordinated equipment movement. Nighttime application coincides with lower public occupancy, but field evidence on nighttime adulticiding in complex vegetation remains limited.

Unmanned aerial vehicle (UAV) spraying can rapidly cover large outdoor areas and is increasingly used in vector surveillance and control (3–6). Ground ULV spraying can reach low vegetation levels, but vegetation may obstruct droplet movement and limit mosquito–aerosol contact (7–8). Because *Ae. albopictus* adults rest in shaded ground vegetation and shrub or tree layers outside peak host-seeking periods, disturbance-assisted aerial application and coordinated ground-air spraying may improve contact across vegetation strata.

Therefore, we compared seven nighttime strategies within one descriptive framework: ground ULV-only, UAV-only, light disturbance plus UAV, wind disturbance plus UAV, dual-insecticide UAV, and two ground-air coordinated regimens. The study prioritized control-adjusted efficacy while examining the operational feasibility and limitations created by heterogeneous sites and baselines.

METHODS

Study Setting and Period

The study was conducted from October 13 to November 17, 2025, in Zhongshan Park, Sanlian Country Park, and Tiezaishan Park in Shenzhen, Guangdong Province. Each experimental plot was a 30 m × 30 m square (900 m²), and the monitoring points were at least 15 m apart. Zhongshan Park had a

mixed tree–shrub–lawn landscape, Sanlian had denser secondary woodland and shrubs, and Tiezaishan had hilly woodland with a continuous canopy and shrub understory. The details are provided in [Supplementary Table S1](#) (available at <https://weekly.chinacdc.cn>).

Study Design and Operations

Seven nighttime strategies were evaluated. Field logs recorded spraying between approximately 23:00 and 03:45 under dry conditions with ambient winds of Beaufort force 1–2. The DJI T70P UAV was flown 5 m above the canopy at 5 m/s with 6 m flight-line spacing. For light disturbance, a KFFUNING G400 handheld white LED unit with a luminous flux of 10,000 lm was swept across the shrubs for 5 min immediately before UAV spraying; the flashing frequency was not documented in the supplied field records. Wind disturbance used a DLXDCGF812 blower at its maximum setting for 15 min immediately before UAV spraying; its rated outlet air speed was 162 km/h (45 m/s) and its rated air volume was 630 m³/h. Spraying was suspended when ambient wind speed reached 3.4 m/s. The characteristics, plot counts, and matched controls are summarized in [Table 1](#), and detailed formulations and application volumes are provided in [Supplementary Table S2](#) (available at <https://weekly.chinacdc.cn>).

Monitoring

Adult mosquito activity was monitored by protected human-bait collection, a modified human landing catch (HLC) procedure, between 17:00 and 19:00. At

each point, three trained collectors wore mosquito-proof hats, long-sleeved protective clothing, trousers, and gloves. No skin was intentionally exposed, and no double-net traps were used. Mosquitoes approaching or alighting on protective clothing were collected using an electric aspirator during a 30-min observation period. The landing index was expressed as female *Ae. albopictus* per person-hour. Because adult surveillance methods sample different behavioral processes, this index was interpreted as a relative host-seeking response to protected human bait, not absolute adult abundance or a conventional exposed-skin HLC biting rate (9–11). Procedural and ethical details are provided in [Supplementary Table S3](#) (available at <https://weekly.chinacdc.cn>).

Outcome Measures and Preprocessing

All recorded zero counts were retained and no value was imputed or excluded as an outlier. Within each plot, the first record was the pre-treatment baseline, and the second was Day 1. All post-baseline records, including Day 1 records, contributed to the overall estimates. Direct reduction was calculated as $(1 - T_{\text{post}}/T_{\text{pre}}) \times 100\%$. Henderson–Tilton adjusted efficacy was $[1 - (T_{\text{post}}/T_{\text{pre}}) \times (C_{\text{pre}}/C_{\text{post}})] \times 100\%$. For overall estimates, T_{post} and C_{post} were the arithmetic means of all post-baseline records within each matched treatment-control plot pair, and strategy estimates were the arithmetic means of the plot-level estimates. Calculation definitions and time-point rules are summarized in [Supplementary Table S4](#) (available at <https://weekly.chinacdc.cn>).

TABLE 1. Characteristics, plot counts, and matched controls for seven nighttime intervention strategies against *Aedes albopictus* in Shenzhen City, Guangdong Province, China, October–November 2025.

Group	Operational description	Primary monitoring	Matched control	n
Ground ULV-only spraying	Ground ULV application alone	Protected human-bait collection	Control 3	3
UAV-only spraying	Aerial ULV application alone	Protected human-bait collection	Control 1	2
Light disturbance + UAV spraying	Light disturbance followed by UAV application	Protected human-bait collection	Control 1	2
Wind disturbance + UAV spraying	Blower disturbance followed by UAV application	Protected human-bait collection	Control 1	2
Dual-insecticide UAV spraying	Single-platform aerial dual-insecticide ULV regimen	Protected human-bait collection	Control 1	2
Ground-air coordinated dual-regimen ULV spraying	Ground-air coordinated ULV using different formulations across platforms	Protected human-bait collection	Control 1	2
Ground-air coordinated same-regimen ULV spraying	Ground-air coordinated ULV using the same beta-cypermethrin plus propoxur formulation on both platforms	Protected human-bait collection	Control 2	3

Note: The two coordinated groups followed the same ground-air ULV sequence but differed in insecticide regimens. Protected human-bait collection was conducted without exposed skin or a double-net trap. n denotes independent experimental plots.

Abbreviation: UAV=unmanned aerial vehicle; ULV=ultra-low-volume.

Control Assignment

At Zhongshan, Control 1 point 2 was matched to the first experimental block, and Control 1 point 3 to the second block. Control 2 point 2 was matched to the same-regimen coordinated strategy at Sanlian, and Control 3 point 1 was matched to ground ULV-only at Tiezaishan. Matching followed the order recorded for each plot-specific control series (Supplementary Table S4, available at <https://weekly.chinacdc.cn>). Controls were not exchanged across parks; therefore, the adjustments did not remove between-site or between-period confounders.

Statistical Analysis

The five Zhongshan strategies comprised two independent plots each; the Sanlian same-regimen coordinated strategy and the Tiezaishan ground ULV-only strategy comprised three independent plots each. The two independent UAV-only plots shared source point identifier 1 in the worksheet but were analyzed separately by experimental block. Repeated follow-ups within a plot were not treated as independent replicates. Analyses were descriptive, and no formal between-group significance testing was performed.

RESULTS

Baseline landing indices differed materially. At Zhongshan, the intervention group means ranged from 4.3 to 18.0 mosquitoes/person-hour and Control 1 averaged 2.3; at Sanlian, the same-regimen coordinated group averaged 20.7, and Control 2 averaged 34.0; at Tiezaishan, ground ULV-only averaged 1.6, and

Control 3 averaged 4.0 (Supplementary Table S1, available at <https://weekly.chinacdc.cn>). After separating the two independent UAV-only plots that shared source point identifier 1, the UAV-only strategy's direct reduction was 63.2% (115/182) on Day 1 and 57.3% (417/728) overall. Ground ULV-only produced negative estimates of -111.1% (-10/9) on Day 1 and -52.8% (-19/36) overall, whereas the same-regimen coordinated group had the highest observed overall raw reduction, 86.4% (4,049/4,686) (Table 2; Figure 1A).

Control-adjusted efficacy was the primary comparison (Table 2; Figure 1B). UAV-only efficacy was 68.5% (499/728) on Day 1 and 58.9% (268/455) overall after block separation. Ground ULV-only produced negative estimates of -58.3% (-7/12) on Day 1 and -66.7% (-2/3) overall. Wind disturbance plus UAV had the highest observed Day 1 efficacy, 91.7% (11/12), whereas ground-air coordinated dual-regimen ULV had the highest observed overall efficacy, 75.9% (2,339/3,080). Dual-insecticide UAV yielded efficacies of 77.8% (7/9) on Day 1 and 67.9% (112/165) overall.

The same-regimen coordinated group showed a high raw reduction but moderate adjusted efficacy because its matched Control 2 series also declined from a high baseline. The dual-regimen group showed more similar raw and adjusted estimates. A negative ground ULV-only estimate arose in the later Tiezaishan series with a low baseline. Because the sites and periods were not randomized or crossed, these factors could not be statistically removed, and the comparisons were descriptive.

TABLE 2. Direct reduction and control-adjusted efficacy of seven nighttime intervention strategies against *Aedes albopictus* in Shenzhen City, Guangdong Province, China, October–November 2025.

Group	Direct reduction, day 1 (%)	Direct reduction, overall (%)	Control-adjusted efficacy, day 1 (%)	Control-adjusted efficacy, overall (%)	n
Ground ULV-only spraying	-111.1 (-10/9)	-52.8 (-19/36)	-58.3 (-7/12)	-66.7 (-2/3)	3
UAV-only spraying	63.2 (115/182)	57.3 (417/728)	68.5 (499/728)	58.9 (268/455)	2
Light disturbance + UAV spraying	66.7 (2/3)	55.6 (5/9)	66.7 (2/3)	51.7 (256/495)	2
Wind disturbance + UAV spraying	88.9 (8/9)	63.6 (229/360)	91.7 (11/12)	64.3 (637/990)	2
Dual-insecticide UAV spraying	77.8 (7/9)	66.7 (2/3)	77.8 (7/9)	67.9 (112/165)	2
Ground-air coordinated dual-regimen ULV spraying	79.2 (19/24)	74.6 (167/224)	80.2 (77/96)	75.9 (2,339/3,080)	2
Ground-air coordinated same-regimen ULV spraying	69.0 (1,616/2,343)	86.4 (4,049/4,686)	47.3 (11,071/23,430)	45.6 (1,069/2,343)	3

Note: Values are percentages followed by exact calculation fractions (numerator/denominator) derived from the unrounded arithmetic mean of plot-level estimates; these fractions are not binomial event counts. *n* denotes independent experimental plots.

Abbreviation: UAV=unmanned aerial vehicle; ULV=ultra-low-volume.

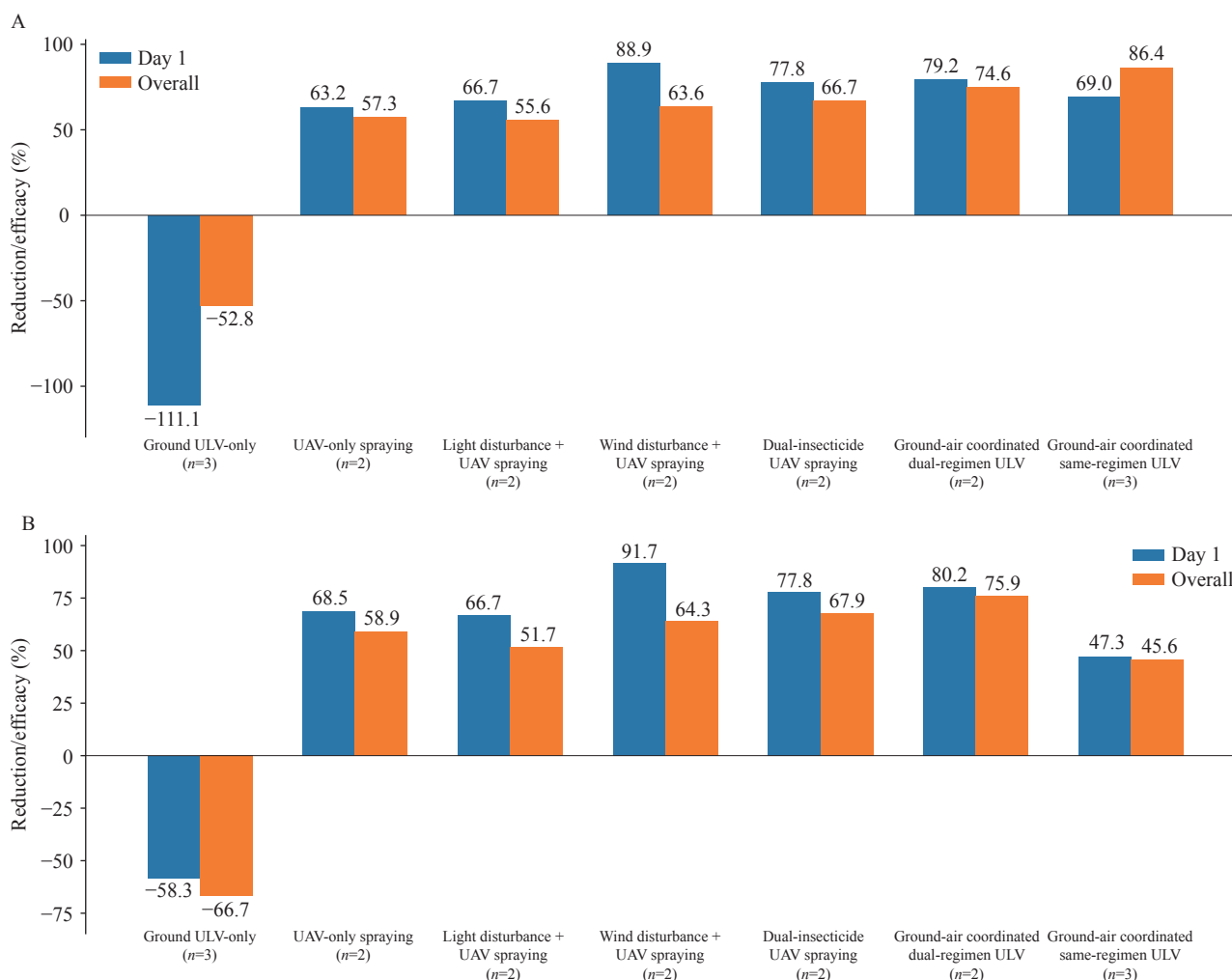


FIGURE 1. Direct reduction and control-adjusted efficacy of seven nighttime intervention strategies against *Aedes albopictus* in Shenzhen City, Guangdong Province, China, October–November 2025. (A) Direct reduction relative to the subsite baseline. (B) Henderson–Tilton control-adjusted efficacy.

Note: *n* denotes independent experimental plots: *n*=2 for UAV-only, light disturbance plus UAV, wind disturbance plus UAV, dual-insecticide UAV, and ground-air coordinated dual-regimen ULV; *n*=3 for ground ULV-only and ground-air coordinated same-regimen ULV. Overall estimates include repeated post-baseline observations within plots. Corresponding numerator/denominator calculation fractions are reported in Table 2.

Abbreviation: UAV=unmanned aerial vehicle; ULV=ultra-low-volume.

DISCUSSION

Seven nighttime adulticide strategies were compared descriptively. Wind disturbance plus UAV had the highest observed Day 1 adjusted efficacy, whereas the ground-air coordinated dual-regimen ULV had the highest observed overall adjusted efficacy. These patterns may inform different operational choices for emergency suppression and routine control but do not establish causal superiority across sites.

Metric mismatch was most evident for the same-regimen coordinated group: raw reduction was high, but Control 2 also declined from a high baseline,

lowering its Henderson–Tilton estimate. This illustrates why an unadjusted decline can overstate intervention performance when background mosquito activity changes concurrently.

The ground ULV-only group was evaluated later and at a different park, with a lower baseline than those of the other groups. Ratio-based estimates are unstable when baseline counts are low; vegetation obstruction, incomplete aerosol penetration, reinvasion, and short-term changes in host-seeking activity may also contribute to this (7–8,12). Therefore, its negative estimate cannot be interpreted as evidence that ground ULV is intrinsically ineffective.

Wind disturbance may dislodge mosquitoes resting

on the underside of leaves or within shaded shrubs into more exposed positions before UAV application, thereby increasing the probability of subsequent aerosol contact. High-output airflow may also transiently disturb the foliage and near-canopy airspace. By contrast, a visual stimulus may be attenuated by dense foliage and elicit less consistent movement. Because mosquito displacement and droplet deposition were not measured, these mechanisms remain hypotheses rather than causal explanations.

Published studies similarly show that UAV-based or conventional aerial ULV applications offer rapid area coverage, whereas effectiveness depends on droplet delivery, vegetation, weather, and access to cryptic habitats (3–8,12–13). Operational reviews and guidance also emphasize matching mosquito control methods to the habitat and implementation context (14–15). Relative to prior single-platform evaluations, this study adds a comparison of disturbance-assisted, dual-insecticide, and coordinated ground-air strategies within a common analytical framework, whereas its heterogeneous field design limits direct ranking.

Only three parks and two to three plots per strategy were available. Strategies were not randomized across parks or periods, and different vegetation types, baselines, and the later Tiezaishan schedule created residual confounding factors. Protected human-bait collection measured the host-seeking response to clothed human bait rather than absolute abundance or conventional exposed-skin HLC. Only short-term effects were assessed; residual efficacy and stratified effects of vegetation or baseline density were not evaluated.

Ground operations required three staff, UAV-only operations required one, and operations combining a ground component with UAV deployment required four (Supplementary Table S2, available at <https://weekly.chinacdc.cn>); formal monetary costs were not collected. Wind disturbance plus UAV may suit rapid responses in small-to-medium densely vegetated plots, whereas coordinated ground-air ULV may suit routine control in multilayered vegetation. UAV-only applications are operationally leaner in larger and more open areas. Ground ULV alone is not recommended in complex vegetation when rapid suppression is required.

Conflicts of interest: No conflicts of interest.

Ethical statement: No formal ethics committee review or exemption was obtained for field monitoring. The investigators treated the activity as non-invasive

vector surveillance conducted by trained project staff. Collectors wore mosquito-proof hats, long-sleeved protective clothing, trousers, and gloves. No skin was intentionally exposed, mosquitoes approaching or alighting on protective clothing were collected using an electric aspirator, and no participant-level personal data were collected.

Acknowledgments: We thank the field operation and monitoring teams for their support in implementing the nighttime interventions and collecting data.

Funding: Supported by the Prevention and Control of Emerging and Major Infectious Diseases, National Science and Technology Major Project (Grant No. 2026ZD01908804).

doi: 10.46234/ccdcw2026.168

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Submitted: June 07, 2026

Accepted: August 06, 2026

Issued: August 14, 2026

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SUPPLEMENTARY MATERIAL

SUPPLEMENTARY TABLE S1. Study Sites, Control Matching, and Baseline Landing Indices

Group	Site and field period	Matched control	Baseline plots, mosquitoes/person-hour	n	Mean baseline
Ground ULV-only	Tiezaishan; November 10–17, 2025	Control 3	Three plots (source IDs 4, 3, and 2): 0.7, 2.0, and 2.0	3	1.6
UAV-only	Zhongshan; October 13–21, 2025	Control 1	Two independent plots in blocks 1 and 2 (both source point ID 1): 4.7 and 8.7	2	6.7
Light disturbance + UAV	Zhongshan; October 13–21, 2025	Control 1	Two plots (source IDs 6 and 5): 9.3 and 6.0	2	7.7
Wind disturbance + UAV	Zhongshan; October 13–21, 2025	Control 1	Two plots (source IDs 5 and 6): 12.0 and 3.3	2	7.7
Dual-insecticide UAV	Zhongshan; October 13–21, 2025	Control 1	Two plots (source IDs 3 and 4): 2.7 and 6.0	2	4.3
Ground-air dual-regimen	Zhongshan; October 13–21, 2025	Control 1	Two plots (source IDs 4 and 2): 8.0 and 28.0	2	18.0
Ground-air same-regimen	Sanlian; October 18–25, 2025	Control 2	Three plots (source IDs 4, 3, and 1): 7.3, 7.3, and 47.3	3	20.7
Control 1	Zhongshan; October 13–21, 2025	—	Control plots (source IDs 2 and 3): 2.0 and 2.7	2	2.3
Control 2	Sanlian; October 18–25, 2025	—	Control plot (source ID 2): 34.0	1	34.0
Control 3	Tiezaishan; November 10–17, 2025	—	Control plot (source ID 1): 4.0	1	4.0

Note: Each experimental plot measured 30 m × 30 m (900 m²), and monitoring points were separated by at least 15 m. Baseline definition: First pre-treatment record within each independent experimental plot. The two UAV-only plots were independent experimental repeats in separate blocks despite sharing source point ID 1. Here, n denotes independent experimental plots. Site details: Zhongshan Park, Shenzhen (October 13–21, 2025): UAV-only, light disturbance + UAV, wind disturbance + UAV, dual-insecticide UAV, ground-air coordinated dual-regimen ULV, and Control 1. Treatment points included 1, 3, 4, 5, and 6; Control 1 used point 2 or 3 according to field record sequence. Two independent 30 m × 30 m experimental plots per intervention; Control 1 point 2 served block 1 and point 3 served block 2; spacing at least 15 m; mixed tree–shrub–lawn landscape. Site details: Sanlian Country Park, Shenzhen (October 18–25, 2025): Ground-air coordinated same-regimen ULV and Control 2. Treatment points 1, 3, and 4; Control 2 point 2. Three independent 30 m × 30 m treatment plots (source point IDs 4, 3, and 1) and Control 2 point 2; spacing at least 15 m; denser secondary woodland and shrubs. Site details: Tiezaishan Park, Shenzhen (November 10–17, 2025): Ground ULV-only spraying and Control 3. Treatment points 2, 3, and 4; Control 3 point 1. Three independent 30 m × 30 m treatment plots (source point IDs 4, 3, and 2) and Control 3 point 1; spacing at least 15 m; hilly woodland with a continuous canopy and shrub understory.

Abbreviations: ID=identifier; UAV=unmanned aerial vehicle; ULV=ultra-low-volume.

SUPPLEMENTARY TABLE S2. Operational Parameters, Personnel Requirements, and Potential Settings.

Strategy	Platform	Insecticide regimen and dilution	Application volume	Operational parameters	Field staff (relative staffing)	Potential operational setting
Ground ULV-only spraying	BK-2800 ground ULV	8% propoxur + transfluthrin formulation; dilution: 21-fold	Ground 0.5 L/mu (7.5 L/ha)	Single ground ULV application	3 (Moderate)	Small or accessible plots; avoid sole use in dense multilayer vegetation
UAV-only spraying	DJI T70P UAV	15% beta-cypermethrin + propoxur formulation; dilution: 30-fold	Aerial 2.0 L/mu (30 L/ha)	UAV at 5 m above canopy, 5 m/s, and 6 m flight-line spacing	1 (Low)	Larger or relatively open green spaces
Light disturbance + UAV spraying	KFFUNING G400 + DJI T70P	15% beta-cypermethrin + propoxur formulation; dilution: 30-fold	Aerial 2.0 L/mu (30 L/ha)	10,000-lm handheld white LED for 5 min immediately before UAV application; flashing frequency not documented; UAV settings as above	4 (High)	Small-to-medium-sized shrub-dense plots
Wind disturbance + UAV spraying	DLXDCGF812 + DJI T70P	15% beta-cypermethrin + propoxur formulation; dilution: 30-fold	Aerial 2.0 L/mu (30 L/ha)	Blower at maximum setting for 15 min immediately before UAV application; rated outlet air speed 162 km/h (45 m/s) and rated air volume 630 m ³ /h; UAV settings as above	4 (High)	Emergency suppression in small-to-medium-sized shrub-dense plots
Dual-insecticide UAV spraying	DJI T70P UAV	15% beta-cypermethrin + propoxur formulation + 8% propoxur + transfluthrin formulation; dilution: 30-fold + 21-fold	Aerial total 2.0 L/mu (30 L/ha; 1.5 + 0.5 L/mu)	Dual-insecticide aerial application; UAV settings as above	1 (Low)	Rapid aerial coverage where one platform is preferred
Ground-air coordinated dual-regimen ULV spraying	BK-2800 + DJI T70P	Ground: 8% propoxur + transfluthrin formulation; air: 15% beta-cypermethrin + propoxur formulation; dilution: 21-fold + 30-fold	Ground 0.5 + air 1.5 L/mu (7.5 + 22.5 L/ha)	Ground application followed by UAV application with different formulations; UAV settings as above	4 (High)	Routine control in multilayer vegetation
Ground-air coordinated same-regimen ULV spraying	BK-2800 + DJI T70P	15% beta-cypermethrin + propoxur formulation on both ground and aerial platforms; dilution: 30-fold	Two ULV applications; platform-specific volumes not documented	Ground application followed by UAV application with the same formulation; UAV settings as above	4 (High)	Routine control where one formulation is used across platforms

Note: The droplet size was approximately 60 μ m for all strategies. Ground-only operations used three staff members; UAV-only and dual-insecticide UAV operations used one; disturbance-assisted and ground-air combined strategies used four. For conversion, 1 mu = 1/15 ha. No formal monetary cost analysis was conducted; staff counts were reported as the available labor input measure. Operational settings are descriptive and were not derived from randomized comparisons.

Abbreviations: LED=light-emitting diode; UAV=unmanned aerial vehicle; ULV=ultra-low-volume.

SUPPLEMENTARY TABLE S3. Protected Human-Bait Collection and Ethics Documentation.

Item	Manuscript wording	Operational or ethical detail
Monitoring method	Protected human-bait collection, a modified HLC procedure	Collectors wore mosquito-proof hats, long-sleeved protective clothing, trousers, and gloves; no skin was intentionally exposed and no double-net trap was used.
Collectors, time, and duration	Three trained collectors per point for 30 min between 17:00 and 19:00	The landing index was standardized as female <i>Aedes albopictus</i> per person-hour.
Personnel protection	Mosquito-proof hats, long sleeves, trousers, and gloves throughout monitoring	Mosquitoes approaching or alighting on the protective clothing were collected with an electric aspirator.
Methodological interpretation	Relative host-seeking activity around a protected human bait	Not a direct measure of absolute adult abundance or a conventional exposed-skin HLC biting rate.
Ethics documentation	No formal ethics committee review or exemption determination was obtained for this field monitoring	The investigators treated the procedure as non-invasive vector surveillance by trained project staff; no skin was exposed and no participant-level personal data were collected.

Abbreviation: HLC=human landing catch.

SUPPLEMENTARY TABLE S4. Calculation Definitions, Time-Point Rules, and Control Assignment.

Section	Item or intervention group(s)	Definition, matched control, or rule
Calculation	Direct reduction	Direct= $(1 - T_{\text{post}}/T_{\text{pre}}) \times 100\%$, where T_{pre} is the pre-treatment value within an independent plot and T_{post} is the Day 1 value or the mean of all post-baseline values for the overall estimate.
Calculation	Control-adjusted efficacy	Adjusted= $[1 - (T_{\text{post}}/T_{\text{pre}}) \times (C_{\text{pre}}/C_{\text{post}})] \times 100\%$, calculated with the matched control plot using the Henderson–Tilton formula.
Time point	Day 1	The second record within each independent experimental plot.
Time point	Overall	For each plot, T_{post} and C_{post} were the arithmetic means of all post-baseline records, including Day 1. The Henderson–Tilton formula was then applied to that matched plot pair, and plot-level estimates were averaged within strategy.
Control assignment	UAV-only spraying; light disturbance + UAV spraying; wind disturbance + UAV spraying; dual-insecticide UAV spraying; ground-air coordinated dual-regimen ULV spraying	Matched control: Control 1. At Zhongshan, each strategy had two independent plots: block 1 used Control 1 point 2 and block 2 used Control 1 point 3
Control assignment	Ground-air coordinated same-regimen ULV spraying	Matched control: Control 2. Matched to Sanlian Control 2 point 2
Control assignment	Ground ULV-only spraying	Matched control: Control 3. Matched to Tiezaishan Control 3 point 1

Note: Controls were fixed using sites and experimental blocks. At Zhongshan, Control 1 point 2 was matched to block 1 and point 3 to block 2. Control 2 point 2 was used at Sanlian, and Control 3 point 1 was used at Tiezaishan. The first record within each plot was the pre-treatment baseline, and the second was on Day 1. All post-baseline records, including those on Day 1, were entered into the overall calculation. Zero counts were retained and no imputation or outlier exclusion was applied.

Abbreviations: C_{pre} =control value before treatment; C_{post} =control value after treatment; T_{pre} =treated-plot value before treatment; T_{post} =treated-plot value after treatment; UAV=unmanned aerial vehicle; ULV=ultra-low-volume.