Evaluation of Implementation Effects and Optimization Strategies for Helicopter Aerial Spraying Operations Against *Hyphantria cunea* in Zhangdian District, Zibo City

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Abstract This study aimed at the damage caused by *Hyphantria cunea* in Zhangdian District, Zibo City in 2023, and adopted helicopter low-volume aerial spraying technology for control operations. The implementation effects were evaluated and optimization strategies were proposed by real-time monitoring of operation data and analysis of the pesticide application effect and flight path coverage. The results showed that the actual sprayed area of the project was 1 348.67 hm^2, with the verified effective control area being 1 210.93 hm^2. The average pesticide application rate was 2 880 g/hm^2, with a lower deviation of 4%. The study found that some sorties had problems such as insufficient pesticide application and unstable flight speed. It is necessary to improve the control effect by optimizing route planning, enhancing operation standardization, and adjusting pesticide application rate.

Key words *Hyphantria cunea*; Aerial spraying operation; Aerial spraying; Implementation effect; Optimization strategy

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Hyphantria cunea, as one of the first batch of invasive alien species in China, is characterized by its polyphagous feeding habits, strong reproductive capacity, and rapid spread, posing a serious threat to forestry ecological security[1-7]. Traditional ground-based control methods suffer from low efficiency and limited coverage, whereas aerial pesticide application technology has gradually become an important approach for forestry pest control with its advantages of high efficiency and wide coverage[8-13]. In 2023, helicopters were employed to spray a 25% abamectin-chlorbenzuron suspension concentrate against the first-generation larvae of *H. cunea* in Zhangdian District, Zibo City. This study systematically analyzes the operational process and effectiveness of aerial spraying, aiming to provide a scientific basis for the standardized implementation of aerial control of forestry pests.

Materials and Methods

Control area and target pest

The control area was located in Zhangdian District, Zibo City, covering a total area of approximately 1 333 hm^2. The main host tree species included broadleaf trees such as poplar, willow, and elm. The target pest was the first-generation larvae of *H. cunea*, which have a high feeding capacity during this instar stage and can easily cause large-scale leaf damage.

Insecticide and equipment

Insecticide and mixing ratio: The primary insecticide was a 25% abamectin-chlorbenzuron suspension concentrate (active ingredient content: abamectin 0.5%, chlorbenzuron 24.5%), and urea was used as an adjuvant. The application rate was 3 000 g/hm^2 (750 ml of the original formulation + 150 g of urea + 2 100 ml of clean water).

Aircraft and parameters: A Robinson R44 helicopter (registration number B-7671) was employed, with a single-sortie payload capacity of 200 kg and a designed spray area of 66.67 hm^2 per sortie. The operating airspeed was controlled at 90 - 120 km/h, and the target droplet size was 100 μm.

Monitoring methods

On June 2, 2023, a total of 21 sorties (including one supplementary flight) were carried out. Real-time data on flight trajectory, flow rate, pressure, and other parameters were monitored via the ForestEyes FE-Cloud platform, while droplet deposition sampling was conducted simultaneously.

Results and Analysis

Operational completion status

Area verification: The actual sprayed area was 1 348.67 hm^2, of which 2 sorties (137.73 hm^2) were not included in the effective control area because the application rate was below 2 700 g/hm^2 (a negative deviation exceeding 10%). The final verified effective area was 1 210.93 hm^2, with a negative deviation of 9.18%.

Insecticide application: A total of 3 858 kg of diluted spray mixture was applied, with an average application rate of 2 880 g/hm^2 (a negative deviation of 4%). The average application rate per sortie was 184 kg (a negative deviation of 8% from the standard value). Airspeed fluctuations significantly affected application uniformity. When the airspeed exceeded 100 km/h, the deviation

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Table 1 Implementation sorties of aerial spraying against *H. cunea* in Zhangdian District, Zibo City in 2023

Sortie No.	Spray duration min	Spray mileage km	Average spray airspeed Kn	Average spray altitude m	Average instantaneous flow rate // m^3/h	Average instantaneous pressure // KPa	Average temperature ℃	Average humidity % RH	Spray area hm^2	Spray dosage kg	Application rate g/hm^2
1	5.97	9.78	53.12	78	1.781	159.162	34.2	43.53	44.00	177	4 020
2	6.67	11.76	57.16	89	1.663	152.640	30.5	42.29	52.93	185	3 495
3	5.80	12.12	67.67	113	1.679	161.618	30.1	42.12	54.53	163	2 985
4	7.03	14.79	68.15	112	1.583	166.938	30.3	42.00	66.60	186	2 790
5	6.93	15.45	72.19	122	1.668	166.792	30.1	41.63	69.53	193	2 775
6	6.90	15.21	71.42	138	1.633	164.155	30.0	41.30	68.47	188	2 745
7	6.97	14.63	68.04	129	1.630	165.058	30.4	41.00	65.87	190	2 880
8	7.33	16.01	70.73	118	1.597	162.174	30.9	40.73	72.07	196	2 715
9	7.32	15.68	69.43	105	1.558	163.815	31.7	40.39	70.53	190	2 685
10	6.07	12.71	67.87	111	1.555	164.777	31.6	39.94	57.20	157	2 745
11	6.02	12.43	66.92	114	1.563	164.662	30.8	39.52	55.93	157	2 805
12	6.98	14.78	68.55	126	1.588	166.252	29.6	39.20	66.47	185	2 775
13	7.47	15.98	69.34	173	1.576	164.527	28.9	39.07	71.93	196	2 730
14	6.98	14.93	69.28	176	1.545	163.560	29.2	38.93	67.20	179	2 670
15	7.67	15.33	64.80	186	1.542	162.255	30.1	39.67	69.00	197	2 850
16	7.57	16.11	68.97	116	1.558	164.563	31.1	38.55	72.47	197	2 715
17	6.93	14.59	68.18	121	1.568	162.509	31.7	38.27	65.67	181	2 760
18	7.50	15.65	67.62	109	1.587	163.264	32.9	37.70	70.47	198	2 805
19	6.82	14.62	69.49	110	1.631	166.186	31.6	37.12	65.80	186	2 820
20	7.75	15.08	63.04	96	1.522	165.725	31.0	36.90	67.87	196	2 895
21	5.80	12.04	67.28	100	1.674	168.281	30.7	36.76	54.20	162	2 985
Mean	6.88	14.27	67.11	121	1.605	163.758	30.8	39.79	64.20	184	2 880
Total	144.50	299.70									3 858

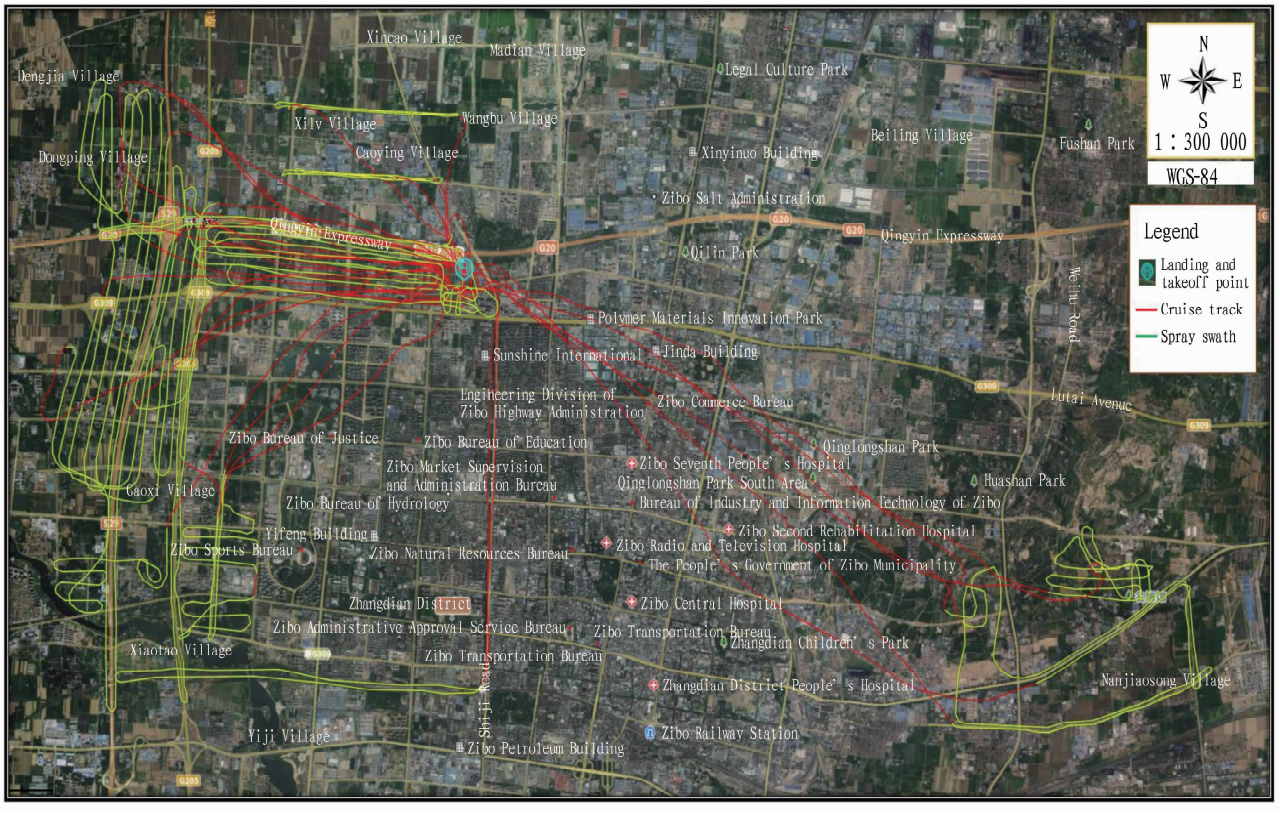

Fig. 1 Overall map of spray swath coverage areas for aerial control operations against *H. cunea* in Zhangdian District, Zibo City in 2023

in application rate increased to −10%.

Operational quality analysis

Droplet deposition: Monitoring using glass slides showed that the droplet density in the sampled areas ranged from 50 to 100 μm, meeting the standard for ultra-low volume spraying. The uniformity of droplet distribution on the outer branches and windward sides of the canopy was relatively good, but in some areas, excessive airspeed led to insufficient droplet deposition.

Flight trajectory and sorties: The 21 sorties covered areas concentrated in forest-dense zones such as the Bin-Lai Expressway and Qixin Avenue. However, the sprayed area per sortie fluctuated considerably, indicating insufficient stability in airspeed control.

Problems and Discussion

Reasons for insufficient application rate

The application rate in some sorties fell below the threshold, primarily due to excessive airspeed and flow rate control errors. Mismatches between airspeed and spray flow rate resulted in insufficient liquid coverage per unit area, thereby affecting the control effect. To balance efficiency and precision, dynamic flow rate adjustments or optimized flight path planning are needed.

Impact of airspeed stability

Differences in piloting operations led to airspeed fluctuations, which in turn caused uneven sprayed area per sortie. Optimizing flight path planning, for example, by reducing swath spacing and avoiding fragmented operational zones, can decrease the frequency of turns and improve airspeed stability.

Rationality of the application rate standard

The project adopted an application rate of 3 000 g/hm^2 as the lower limit for low-volume spraying. In areas with severe pest infestation, insufficient droplet deposition may compromise the control effect. Based on similar studies, it is recommended to increase the application rate to 3 300 – 3 750 g/hm^2 to ensure effective control.

Directions for technical improvement

GIS technology can be introduced to optimize flight path design and reduce missed spray areas. Pilot training should be strengthened to ensure stable airspeed. Intelligent monitoring platforms can be promoted to enable real-time feedback and adjustment of application parameters.

Conclusions and Recommendations

This project effectively controlled the spread of *H. cunea* through helicopter-based aerial spraying. The verified effective control area was 1 210.93 hm^2, with an average application rate of 2 880 g/hm^2. However, issues such as application rate deviation and unstable airspeed were observed. Droplet deposition monitoring indicated that operational quality was closely related to airspeed and flow rate control.

To improve the control effect in the future, the following measures are recommended. First, technology integration such as the use of unmanned aerial vehicles for assisted monitoring, parameter standardization, and multi-department collaborative management should be adopted to enhance control effectiveness. In similar projects, it is advised to give priority to implementing a dynamic application rate adjustment mechanism and to establishing a long-term ecological impact assessment system. Second, flight path design should be optimized. Before operations, the supervising and implementing units should jointly delineate continuous operational zones, reduce swath spacing to 30 – 40 m, and thereby increase coverage density. Third, operational standardization should be strengthened by conducting pilot training in airspeed control to ensure that the application rate deviation per sortie is kept within ±5%. Fourth, application parameters should be adjusted. For severely infested areas, the application rate should be increased to 3 300 g/hm^2, and supplementary flights should be added to cover missed areas. Fifth, the supervision system should be improved by using the FE-Cloud platform for real-time alerts of abnormal data and by implementing a flight suspension mechanism for crews that fail to take corrective action, thereby ensuring quality control throughout the entire operation.

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reduces edema, thereby facilitating the relief of lower back and leg pain.

Acupuncture treatment for Shaoyang spinal disease

From the perspective of the acupoints on the Shaoyang Gallbladder meridian, Juegu (Xuanzhong), the influential point of marrow among the Eight Influentialt Points, is the most representative manifestation of Shaoyang (Gallbladder) governing the bones. Some scholars have summarized the therapeutic experience of Juegu in the *Zhenjiu Dacheng* (*Great Compendium of Acupuncture and Moxibustion*), concluding that Juegu can be used to treat local disorders, Gallbladder meridian syndromes, and diseases related to "marrow." By virtue of its effect of tonifying essence and filling the marrow, it is utilized to treat conditions such as rickets and tremor diseases[12]. *Jingjin* (muscle region) of the Foot-Shaoyang Gallbladder meridian facilitates communication between the upper and lower, anterior and posterior, left and right sides, and even the entire body. It fully embodies the role of a transportation hub, perfectly illustrating the concept of "Shaoyang as the pivot." Clinically, when treating restricted spinal mobility, selecting acupoints on the Foot-Shaoyang meridian and Ashi points—such as Daimai, Juliao, Huantiao, as well as palpable tenderness points and cord-like indurations[13]—has demonstrated excellent efficacy in improving restricted lumbar movement in patients. During clinical practice, even when the pathology does not solely originate from the Shaoyang meridian itself, emphasizing the combined use of Shaoyang acupoints can ensure that the entry and exit of Qi mechanisms follow their proper pathways, thereby restoring the balance of Qi and blood within the meridians.

Conclusion

From the Shaoyang Sanjiao and Shaoyang Gallbladder as pivots to the relationship between the spine and Yang Qi as well as Qi and blood, it is evident that the Shaoyang pivot mechanism is closely related to the spine. However, there are still issues that need further exploration, such as whether the Shaoyang theory in *Huangdi Neijing* and the Shaoyang theory in *Shanghan Lun* have the same impact on the spine. Additionally, how to use modern scientific methods to confirm the influence of Shaoyang on the spine is also a topic that needs further exploration.

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