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Negative binomial regression analysis of factors influencing the number of distinct mosquito species in Zhejiang Province, China, 2023

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Mosquito species have different breeding environment requirements, understanding how environmental factors affect mosquito populations can help characterize mosquito vector ecology and facilitate control strategies. This study investigated the number of different mosquito species captured by mosquito trapping lights in relation to landscape, habitat, month, and the number of trapping lights. Field mosquitoes were collected using mosquito trapping lights at five different habitat locations in each monitoring site in Zhejiang Province, China from April to November 2023. The monitoring data were summarized using Excel 2016. Single-factor analysis was conducted using the chi-square (χ^2) test with SPSS 15.0 software, and multiple-factor analysis was performed using the negative binomial regression (NBR) model with Stata 16.0 software. The results indicated that landscape, habitat, and month all significantly impact the number of mosquitoes captured by mosquito trapping lights ($P < 0.001$). All regions in Zhejiang Province should develop targeted mosquito vector prevention and control strategies, taking into account local ecological conditions.

Abbreviations

CDC	The Center for Disease Control and Prevention
$\overline{x}$	Mean
s	Standard deviation
Min.	Minimum
Max.	Maximum
N in table headings	The number of mosquito vector ecology monitoring sites in Zhejiang Province from April to November 2023
β	The regression coefficient
SE	Standard error
IRR	Incidence rate ratio
95%CI	The 95% confidence interval

Vector management is an important means of prevention and control of vector-borne infectious diseases such as malaria and dengue fever, especially those for which there are no effective vaccines. Currently, vector organisms and vector-borne infectious disease control are still facing great challenges, and various factors affect the distribution and population dynamics of vector organisms. The epidemiological characteristics of mosquito-borne infectious diseases are related to the species, abundance, and spatial distribution of vectors, and clarifying the population composition, number, and density will help us carry out targeted and highly effective mosquito preventive and control measures[1–4].

Natural, social, and technological factors have all challenged and driven new higher demands on vector control work. A sustainable vector biological control strategy based on economic, ecological, and social factors has been proposed by Liu Qiyong of the Chinese Center for Disease Control and Prevention (China CDC) and

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other scholars. It states that sustainable vector biological population control should be implemented using the integrated vector biological management principle, should be based on information management, should be supported by new technologies, and should be oriented towards sustainable development.[5] It also states that the best technical combination scheme should be chosen to effectively control the population of vector organisms and maximize economic, ecological, and social benefits[5]. Liu Qiyong has also proposed that four systems should be set up in the prevention of vector biological control work: vector biological monitoring and early-warning system, vector biological control system, publicity and intervention network system, and sanitary supervision and law enforcement system[5].

Zhejiang Province strongly supports the strategy of sustainable vector biological control and insists on carrying out mosquito vector prevention and control work from ecological, economic, and social perspectives[6]. Many previous studies have investigated the effect of ecological factors on mosquito composition and densities in China and other countries[7–9], considering the diversity of Zhejiang Province's landscapes and habitats, we further investigated the comprehensive effect of ecological factors, month and light count on the number of mosquito species captured by mosquito trapping lights in each monitoring site and developed prediction models using negative binomial regression, which will provide a reference for the prevention and control of mosquito vectors and mosquito-borne diseases.

Materials and methods

Zhejiang Province overview

Situated on China's southeast coast, east of the East China Sea and south of the Yangtze River Delta, Zhejiang Province lies within the subtropical central humid monsoon climate zone. Its latitude and longitude range are 118°01′ to 123°10′ East and 27°02′ to 31°11′ North. The average annual temperature of Zhejiang Province ranges from 15 to 18 °C, with January and July being the lowest (2–8 °C) and the highest (27–30 °C) months of the year. May–July is the period of concentrated rainfall, with an average annual precipitation of 1100–2000 mm. Furthermore, the ocean and the Southeast Asian monsoon have an impact on Zhejiang Province, there are many sea typhoons throughout the summer months from August to September, leading to inland air temperature and humidity variations as well as increased rainfall[10].

Zhejiang Province has a diversity of geomorphic features, such as the basin-mountain region in the south, the comparatively rich water network plain in the north, and a network of small sea islands in the northeast. In our study, Zhejiang Province has been divided into six geographical zones[11]: the northern Zhejiang plain, the western Zhejiang hilly region, the eastern Zhejiang hills, the central Jinqu basin, the southern Zhejiang mountains, the southeast coastal area of Zhejiang. The geomorphological division of mosquito vector monitoring counties(cities and districts) is based on the 'Zhejiang Physical Geography Field Practice Tutorial'[12] and information sourced from the official website of the Zhejiang Digital Fangzhi Library (zj.gov.cn), detailed information shown in Table 1.

Monitoring tools and methods

In this study, we selected counties (cities and districts) as mosquito vector ecology monitoring sites in Zhejiang Province[13], distributed in six types of landscapes. Five types of habitats in each site, including urban residential areas, parks, hospitals, peasant households, and livestock sheds, were selected for field mosquito collection. We utilized mosquito trapping lights (LTS-M02, Kungfu Xiaoshuai brand), rated voltage 220 V 50HZ, power 24W, wind speed 1.4 m/s, to collect field mosquitoes.

From April to November 2023, we chose one of the afternoons each month to go to five types of habitats to hang mosquito trapping lights, no fewer than two trapping lights were deployed in each habitat. The lights were hung at a height of 1.5 m above the ground, in sheltered places to prevent wind disruption, and spaced at least 100 m apart to reduce interference from other light sources. One hour earlier than the local sunset, we turned on the mosquito collection devices' power and kept them active for a single night. Until the next day after sunset, we retrieved and removed the mosquito collecting bags, turned off the device, and noted the site, habitat, collection date, temperature, latitude and longitude information.

After returning to the local CDC, the mosquito collection bags were placed in a − 20 °C freezer for 10 min. Professional staff from the mosquito vector control department of the local CDC who have trained in mosquito vector identification carried out the identification of mosquito species under the optical microscope, the identification standard of mosquito species was adopted from the "Fauna sinica" monograph series[14]. The number of distinct types of female mosquitoes captured in each habitat was recorded. The dominance index[15] is calculated as follows.

$$Dominanceindex(D) = \frac{N_{max}}{N} \times 100\%$$

N_{max} is the amount of the dominant species, N is the amount of all mosquito species, and $D > 10\%$ is the dominant mosquito species.

Data analysis

From April to November 2023, we collected data on the number of female mosquitoes of each species captured by mosquito trapping lights in each habitat across Zhejiang Province, China. Excel 2016 was used to summarize the data. Statistical analysis includes two sections. Initially, to investigate whether the mosquito population composition would differ across different landscapes, habitats, or months, the chi-square (χ^2) test was employed to perform a single-factor statistical analysis, utilizing SPSS 15.0 software. A P-value of less than 0.05 was deemed to indicate a statistically significant difference. The Row × Column Split Method was employed to conduct

Western Zhejiang hilly region	Northern Zhejiang plain	Eastern Zhejiang Hills	Southern Zhejiang Mountains	Central Jinqu Basin	Southeast Coastal Area of Zhejiang
Changshan	Qiantang area	Shengzhou	Wencheng	Dongyang	Xiangshan
Fuyang	Shangcheng	Xinchang	Pingyang	Yongkang	Jiaojiang
Chunan	Tongxiang	Fenghua	Longquan	Jiangshan	Wenling
Tonglu	Yuecheng	Shangyu	Songyang	Kecheng	Cangnan
Kaihua	Xiaoshan	Jiangbei	Suichang	Wucheng	Longwan
Linan	Scenic area	Zhenhai	Huangyan	Longyou	Xincheng
Jiande	Changxin	Linhai	Qingyuan	Jindong	Dongtou
Anji	Gongshu	Tiantai	Qingtian	Qujiang	Lucheng
	Wuxing	Panan	Jingning	Pujiang	Ninghai
	Binjiang	Yuyao	Taishun	Lanxi	Dinghai
	Linping	Haishu	Yongjia	Yiwu	Daishan
	Yuhang	Xianju	Liandu		Shengsi
	Deqing	Zhuji	Yunhe		Yinzhou
	Xiuzhou	Cixi	Jinyun		Yuhuan
	Nanhu		Wuyi		Sanmen
	Nanxun				Leqing
	Haining				Luqiao
	Pinghu				Ouhai
	Jiashan				Ruian
	Keqiao				beilun
	Haiyan				Putuo
	Xihu				

Table 1. Geomorphologic dispersion of mosquito vector ecology monitoring counties (cities and districts) in Zhejiang Province, 2023.

pairwise comparisons between groups. *P*-values were adjusted using the Bonferroni correction, which divided the original alpha (α, e.g., 0.05) by the number of comparisons to ensure a more conservative threshold for statistical significance. The test-level corrected α' values were determined as follows: 0.003 for landscapes, 0.005 for habitats, and 0.002 for months. In this analysis, a *P* value less than the corresponding α' value was considered to indicate a statistically significant difference.

Subsequently, regression models were conducted to examine the relationship between multiple variables and the number of female mosquitoes of each species captured by mosquito trapping lights. All multivariable generalized linear models were run using Stata 16.0 software. Before establishing the regression model, we used the "sum" instruction to conduct the dispersion trend analysis of the count data for the number of distinct mosquito species caught by mosquito trapping lights in all habitat sites in Zhejiang between April and November 2023, the results were presented using descriptive statistical indicators, including mean ($\overline{x}$), standard deviation (s), minimum (*Min.*) and maximum (*Max.*). When data were over-dispersed, such as when the standard deviation was greater than the mean, this indicated that negative binomial regression models should be used for establishing multivariate regression of count data, rather than using Poisson's regression models. Next, we performed models with the "nbreg" instruction, factors that were found to have a statistically significant effect in the single-factor statistical analysis were included in the model as independent variables, and the number of each female mosquito species captured by mosquito trapping lights in each habitat was used as dependent variable. Alpha tests were used to certify for overdispersion of the count data again, when the 95% confidence interval of the Alpha value did not cover 0, it was indicated that negative binomial regression models should be used rather than Poisson's regression. Then, we evaluated the impact of each variable on the number of each female mosquito species captured by mosquito trapping lights in each site using the positive or negative signs of the regression coefficients (β) and the value of the incidence rate ratios (*IRR*).

Results
General information
A total of 12,011 mosquito trapping lights were deployed in 2023, and a total of 145,438 female mosquitoes were captured, including 59,843 *Culex(Cx.) quinquefasciatus* (41.15%), 74,534 *Cx. tritaeniorhynchus* (51.25%), 2,605 *Aedes(Ae.) albopictus* (1.79%), 6,861 *Anopheles(An.) sinensis* (4.72%), 1,575 *Armigeres(Ar.) subalbatus* (1.08%), and 20 other mosquito species (0.01%). The dominance index (D) for *Cx. quinquefasciatus* and *Cx. tritaeniorhynchus* exceeded 10%, thereby designating these species as the dominant mosquito species in Zhejiang Province.

Single-factor statistical analysis in mosquito population composition

The chi-square test for multiple independent samples revealed significant variations in mosquito composition ratios based on landscape ($\chi^2 = 16{,}717.174$, $P < 0.001$), habitat ($\chi^2 = 66{,}366.498$, $P < 0.001$), and month ($\chi^2 = 19{,}769.867$, $P < 0.001$) (Table 2), revealing landscape, habitat, and month were all factors for the differences in mosquito population composition. The Row × Column Split Method was used to perform further statistical analysis of the mosquito composition for pairwise comparisons between groups. The results demonstrated that the differences in mosquito composition between each group of landscape types, each group of habitat types, and each group of months were all statistically significant ($P < 0.001$).

We found that *Cx. quinquefasciatus* and *Cx. tritaeniorhynchus* were the dominant species across six diverse landscapes in Zhejiang Province. Specifically, *Cx. tritaeniorhynchus* is the most dominant species in the eastern Zhejiang hills, the central Jinqu basin, the southern Zhejiang mountains, and the southeast coastal area of Zhejiang. In contrast, *Cx. quinquefasciatus* is the most dominant species in the western Zhejiang hilly region and the northern Zhejiang plain. Additionally, *Ae. albopictus* exhibited a notably high population and composition percentage in the southeast coastal area. The composition of mosquito species captured by mosquito trapping lights across six varied landscapes in Zhejiang Province is depicted in Fig. 1.

Urban residential areas, parks, and hospitals show similar composition of the top three mosquito species, with *Cx. quinquefasciatus* being the most dominant, followed by *Ae. albopictus* and *Cx. tritaeniorhynchus*; In park habitats, the number and composition percentage of *An. sinensis* and *Ar. subalbatus* mosquitoes are higher compared to those found in urban residential areas and hospitals; Both peasant households and livestock sheds exhibit high mosquito populations, with *Cx. quinquefasciatus* being the predominant species in peasant households and *Cx. tritaeniorhynchus* in livestock sheds. The number of *An. sinensis* and *Ar. subalbatus* are higher in these rural settings than in other three habitats.

Negative binomial regression analysis of factors influencing mosquitoes capture numbers across different species

The dispersion analysis of the number of various mosquito species captured by mosquito trapping lights

The analysis revealed an over-dispersion phenomenon in the catch numbers of all mosquito species, characterized by a mean value that is smaller than the standard deviation (Table 3), revealing the negative binomial regression model, employed in the multivariate analysis, is more suitable than the Poisson regression model.

	Variable	Light number	*Cx. quinquefasciatus*	*Cx. tritaeniorhynchus*	*Ae. albopictus*	*An. sinensis*	*Ar.subalbatus*	Other mosquito species	X^2	*P*
Landscape	Western Zhejiang hilly region	720	1 438(64.66%)	252(11.33%)	255(11.47%)	109(4.90%)	170(7.64%)	0(0.00%)	16 717.174*	< 0.001
	Northern Zhejiang plain	3438	24 667(49.72%)	19 151(38.60%)	401(0.81%)	4 586(9.24%)	801(1.61%)	8(0.02%)		
	Eastern Zhejiang hills	2604	13 893(37.19%)	22 103(59.17%)	477(1.28%)	780(2.09%)	99(0.27%)	0(0.00%)		
	Southern Zhejiang mountains	1360	4 153(39.68%)	5 660(54.09%)	153(1.46%)	300(2.87%)	192(1.83%)	7(0.07%)		
	Central Jinqu basin	1296	2 832(16.65%)	13 651(80.26%)	121(0.71%)	362(2.13%)	40(0.24%)	2(0.01%)		
	The southeast coastal area of Zhejiang	2593	12 860(44.69%)	13 717(47.67%)	1 198(4.16%)	724(2.52%)	273(0.95%)	3(0.01%)		
Habitat	Urban residential area	2592	8 695(91.98%)	197(2.08%)	484(5.12%)	35(0.37%)	40(0.42%)	2(0.02%)	66 366.498	< 0.001
	Park	2395	8 523(88.03%)	374(3.86%)	645(6.66%)	54(0.56%)	82(0.85%)	4(0.04%)		
	Hospital	2469	9 415(94.40%)	217(2.18%)	269(2.70%)	43(0.43%)	28(0.28%)	2(0.02%)		
	Peasant household	2827	12 170(81.99%)	1 258(8.47%)	670(4.51%)	446(3.00%)	298(2.01%)	2(0.01%)		
	Livestock shed	1728	21 040(20.73%)	72 488(71.43%)	537(0.53%)	6 283 (6.19%)	1 127(1.11%)	10(0.01%)		
Month	April	1496	2 522(88.06%)	182(6.35%)	52(1.82%)	57(1.99%)	47(1.64%)	4(0.14%)	19 769.867*	< 0.001
	May	1495	5 980(79.03%)	1 042(13.77%)	164(2.17%)	240(3.17%)	140(1.85%)	1(0.01%)		
	June	1493	11 709(45.84%)	11 550(45.22%)	302(1.18%)	1 696(6.64%)	283(1.11%)	1(0.00%)		
	July	1504	15 864(31.24%)	32 048(63.11%)	760(1.50%)	1 746(3.44%)	364(0.72%)	2(0.00%)		
	Augest	1524	8 858(34.29%)	14 706(56.93%)	458(1.77%)	1 598(6.19%)	210(0.81%)	1(0.00%)		
	September	1502	5 919(29.08%)	12 773(62.76%)	516(2.54%)	925(4.54%)	215(1.06%)	5(0.02%)		
	October	1503	5 182(62.49%)	2 067(24.93%)	246(2.97%)	555(6.69%)	240(2.89%)	2(0.02%)		
	November	1494	3 809(90.56%)	166(3.95%)	107(2.54%)	44(1.05%)	76(1.81%)	4(0.10%)		

Table 2. Mosquito population composition and single-factor statistical analysis. *represents the statistical value of the result, excluding 'other' mosquito species.

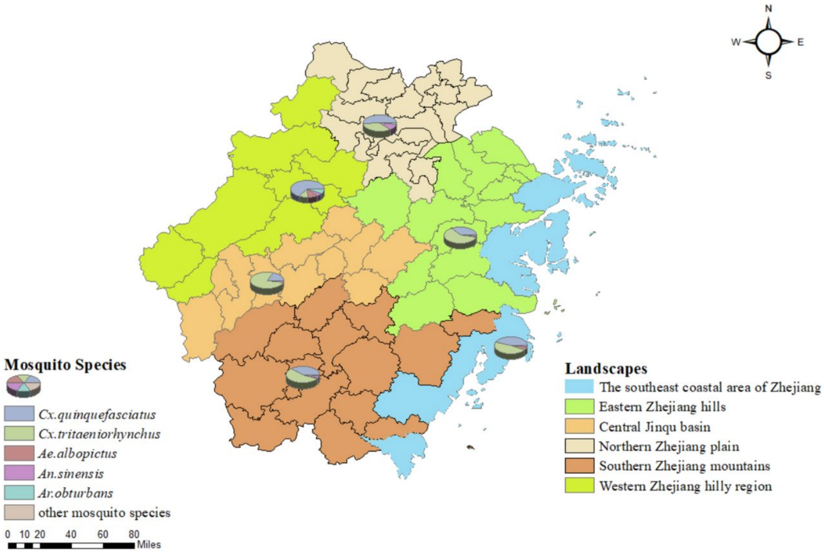

Fig. 1. Composition of mosquito species captured by mosquito trapping lights across six distinct landscapes in Zhejiang Province, China, 2023 (The graph was created using ArcMap GIS 10.7 and is based on a standard map that was downloaded from the National Surveying, Mapping and Geographic Information Administration of China's Standard Map Service website with approval number GS(2024)0650. Tianditu.gov.cn is the URL of the Standard Map Service System's website.)

Mosquito species	$\overline{x}$	*s*	Min	Max
Cx. quinquefasciatus	17.167	116.875	0	5992
Cx. tritaeniorhynchus	21.381	292.953	0	8221
Ae. albopictus	0.747	4.058	0	187
An. sinensis	1.968	29.732	0	1183
Ar. subalbatus	0.452	4.143	0	136
Other mosquitoes	0.006	0.093	0	3

Table 3. Descriptive analysis of the number of different mosquito species captured by mosquito trapping lights in Zhejiang Province, 2023. Abbreviations: mean ($\overline{x}$), standard deviation (*s*), minimum (*Min.*) and maximum (*Max.*)

Negative binomial regression analysis of factors affecting the number of *Cx. quinquefasciatus* mosquito

The number of *Cx. quinquefasciatus* mosquitoes caught by mosquito trapping lights in each site were used as the dependent variable in a negative binomial regression analysis. The factors that were found to have a statistically significant effect on the composition of mosquito species in the results of the single-factor statistical analysis were included as independent variables in the negative binomial regression model. These variables included the month (June as the control dummy variable), number of lights in each habitat site, landscape (the western Zhejiang hilly region as the control dummy variable), and habitat (livestock shed as the control dummy variable). The results of the negative binomial regression analysis showed that the regression modeling was valid ($\chi^2 = 1\,491.70$, $P < 0.001$) and the 95% confidence interval of the Alpha value did not contain 0, which once again confirmed that the use of the negative binomial model was more appropriate than the Poisson model for analyzing the factors affecting the number of *Cx. quinquefasciatus* mosquitoes captured by mosquito trapping lights.

Month, the number of lights, landscape, and habitat all influenced the number of *Cx. quinquefasciatus* caught by mosquito trapping lights ($P < 0.001$). Examining the positive or negative signs of the regression coefficients and the value of *IRR* reveals that (Table 4),

Month: the number of *Cx. quinquefasciatus* species in 4–11 months was lower than in June, except in July ($IRR < 1$);

Light: the number of lights positively influenced the number of *Cx. quinquefasciatus* captured ($IRR = 1.120$, $P < 0.001$), meaning that the number of *Cx. quinquefasciatus* captured increased by 1.120 times for each additional light.

Landscape: other landscapes had a higher number of *Cx. quinquefasciatus* captured than the western Zhejiang hilly region ($IRR > 1$);

Habitat: the number of *Cx. quinquefasciatus* captured in all other habitat types was lower than livestock shed habitat($IRR < 1$).

Variable		β	SE	Z	P	IRR	IRR 95%CI	
							P_{25}	P_{75}
Month								
	April	− 1.550	0.088	− 17.620	< 0.001	0.212	0.179	0.252
	May	− 0.672	0.086	− 7.820	< 0.001	0.511	0.432	0.605
	July	0.007	0.086	0.080	0.939*	1.007*	0.851	1.191
	August	− 0.485	0.086	− 5.670	< 0.001	0.616	0.521	0.728
	September	− 0.781	0.086	− 9.090	< 0.001	0.458	0.387	0.542
	October	− 0.883	0.086	− 10.240	< 0.001	0.414	0.349	0.490
	November	− 1.078	0.087	− 12.350	< 0.001	0.340	0.287	0.404
Number of lights		0.114	0.010	11.480	< 0.001	1.120	1.099	1.142
Landscape								
	Northern Zhejiang plain	1.389	0.090	15.420	< 0.001	4.007	3.359	4.781
	Eastern Zhejiang hills	1.350	0.097	13.900	< 0.001	3.859	3.190	4.668
	Southern Zhejiang mountains	0.447	0.094	4.740	< 0.001	1.563	1.300	1.880
	Central Jinqu basin	0.282	0.100	2.820	< 0.001	1.326	1.090	1.613
	The southeast coastal area of Zhejiang	1.261	0.090	14.070	< 0.001	3.531	2.962	4.209
Habitat								
	Urban residential area	− 0.973	0.073	− 13.250	< 0.001	0.378	0.327	0.436
	Park	− 0.907	0.073	− 12.400	< 0.001	0.404	0.350	0.466
	Hospital	− 0.902	0.074	− 12.180	< 0.001	0.406	0.351	0.469
	Peasant household	− 0.730	0.073	− 10.000	< 0.001	0.482	0.418	0.556
Constant		2.507	0.108	23.120	< 0.001	12.268	9.919	15.173
Alpha		1.509	0.038	–	–	–	1.437	1.585

Table 4. Negative binomial regression analysis of factors affecting the number of *Cx. quinquefasciatus* mosquito captured by mosquito trapping lights (N = 3486). Control dummy variables: June, the western Zhejiang hilly region, livestock shed; * denotes $P > 0.05$. Abbreviation: The number of mosquito vector ecology monitoring sites in Zhejiang Province from April to November 2023(N); The regression coefficient(β);Standard error(*SE*);Incidence Rate Ratio(*IRR*);The 95% confidence interval(95% *CI*).

Negative binomial regression analysis of factors affecting the number of *Cx. tritaeniorhynchus* mosquito

The dependent variable was the number of *Cx. tritaeniorhynchus* captured by mosquito trapping lights in each site, and the independent variables were the month (July as the control dummy variable), number of lights in each habitat site, landscape (the Southern Zhejiang Mountains as the control dummy variable), and habitat (livestock shed as the control dummy variable). These variables were included in the negative binomial regression model because they were statistically significant to the mosquito species composition in the results of single-factor statistical analysis.

It was proven that the negative binomial model is a better fit than the Poisson model for examining the factors influencing the number of *Cx. tritaeniorhynchus* mosquitoes collected by mosquito trapping lights in the current study since the 95% confidence interval of the Alpha value did not contain 0. The value of $\chi^2 = 716.21$, $P < 0.001$, proved that the negative binomial regression model was valid.

Month, number of lights, landscape, and habitat all affected the number of *Cx. tritaeniorhynchus* mosquitoes captured by mosquito trapping lights ($P < 0.05$), and according to the positive and negative regression coefficients and the value of the *IRR* indicators of the respective variables(Table 5), it can be seen that,

Month: The number of *Cx. tritaeniorhynchus* mosquitoes captured in other months was less than that in July ($IRR < 1$), except August and September;

Light: the amount of *Cx. tritaeniorhynchus* mosquitoes collected by mosquito trapping lights in each site were influenced by the number of lights($P < 0.05$).

Landscape: the number of *Cx. tritaeniorhynchus* captured in other landscapes by mosquito trapping lights were lower than in the southern Zhejiang mountains($IRR < 1$).

Habitat: the number of *Cx. tritaeniorhynchus* caught by mosquito trapping lights in other habitats were less than in the livestock shed habitat. ($IRR < 1$).

Negative binomial regression analysis of factors affecting the number of *Ae. albopictus* mosquito

The dependent variable was the number of *Ae. albopictus* captured by mosquito trapping lights in each site, and the independent variables were the month (July as the control dummy variable), number of lights, landscape (the central Jinqu basin as the control dummy variable), and habitat (hospital as the control dummy variable). These variables were included in the negative binomial regression model because they demonstrated statistically significant effects on the composition of mosquito species in the results of single-factor statistical analysis.

Variable		β	SE	Z	P	IRR	IRR 95%CI	
							P25	P75
Month								
	April	− 3.801	0.422	− 9.000	< 0.001	0.022	0.010	0.051
	May	− 2.501	0.362	− 6.910	< 0.001	0.082	0.040	0.167
	June	− 1.147	0.331	− 3.470	0.001	0.318	0.166	0.607
	August	− 0.186	0.321	− 0.580	0.564*	0.831*	0.442	1.559
	September	− 0.524	0.323	− 1.620	0.105*	0.592*	0.315	1.115
	October	− 1.694	0.339	− 5.010	< 0.001	0.184	0.095	0.357
	November	− 3.914	0.409	− 9.570	< 0.001	0.020	0.009	0.044
Number of lights		− 0.186	0.063	− 2.950	0.003	0.830	0.734	0.940
Landscape								
	Western Zhejiang hilly region	− 1.157	0.384	− 3.020	0.003	0.314	0.148	0.667
	Northern Zhejiang plain	− 1.302	0.303	− 4.300	< 0.001	0.272	0.150	0.493
	Eastern Zhejiang hills	− 0.720	0.352	− 2.050	0.041	0.487	0.244	0.970
	Central Jinqu basin	− 1.002	0.332	− 3.020	0.003	0.367	0.192	0.704
	The southeast coastal area of Zhejiang	− 0.667	0.294	− 2.260	0.024	0.513	0.288	0.914
Habitat								
	Urban residential area	− 6.015	0.302	− 19.930	< 0.001	0.002	0.001	0.004
	Park	− 5.249	0.293	− 17.920	< 0.001	0.005	0.003	0.009
	Hospital	− 5.822	0.290	− 20.110	< 0.001	0.003	0.002	0.005
	Peasant household	− 4.510	0.281	− 16.060	< 0.001	0.011	0.006	0.019
Constant		7.078	0.408	17.350	< 0.001	1185.627	533.074	2636.990
Alpha		19.346	1.111	–	–	–	17.286	21.652

Table 5. Negative binomial regression analysis of factors affecting the number of *Cx. tritaeniorhynchus* mosquito captured by mosquito trapping lights (N = 3486). Control dummy variables: July, the southern Zhejiang mountains, livestock shed; * denotes $P > 0.05$.

The results of negative binomial regression analysis showed that the regression modeling was valid ($\chi^2 = 507.10$, $P < 0.001$), and the 95% confidence interval of the Alpha value did not contain 0, which confirmed that the use of the negative binomial model would be more appropriate than Poisson model in this analysis.

Landscape, habitat, number of lights, and month all affect how many *Ae. albopictus* mosquitoes are caught with the mosquito trapping light method in each habitat site($P < 0.05$), and according to the positive and negative regression coefficients and the *IRR* indicator values of the respective variables (Table 6), it can be seen that,

Month: except for August and September, the number of *Ae. albopictus* captured in 4–11 months was lower than that of July ($IRR < 1$);

Light: the quantity of *Ae. albopictus* collected was positively correlated with the number of mosquito trapping lights ($IRR = 1.052$, $P = 0.008$), meaning that the number of *Ae. albopictus* captured increased by 1.052 times for each additional light.

Landscape: more *Ae. albopictus* were captured in other landscapes than in the central Jinqu basin ($IRR > 1$), except for the southern Zhejiang mountains; According to the *IRR* value, the southeast coastal area of Zhejiang has the highest number of *Ae. albopictus* mosquitoes collected by mosquito trapping lights across all landscapes, followed by the western and eastern Zhejiang hills.

Habitat: the number of *Ae. albopictus* captured was more in other habitats than in hospitals ($IRR > 1$); Based on the value of *IRR*, there were more *Ae. albopictus* mosquito captured in parks and peasant households.

Negative binomial regression analysis of factors affecting the number of *An. sinensis* mosquito

The number of *An. sinensis* captured by mosquito trapping lights in each site was the dependent variable, while the month (July as the control dummy variable), number of lights, landscape (the western Zhejiang hilly region as the control dummy variable), and habitat (livestock shed as the control dummy variable) were the independent variables. The negative binomial regression model contained all factors identified by single-factor statistical analysis to be statistically significant for mosquito species composition.

The regression model is statistically significant ($\chi^2 = 554.44$, $P < 0.001$). The absence of 0 in the 95% confidence interval of the Alpha value, further confirmed that the negative binomial model would be a better fit than the Poisson model for analyzing the factors affecting the number of *An.sinensis* captured by mosquito trapping lights in each habitat site.

The number of *An. sinensis* collected by mosquito trapping lights was influenced by month, number of lights, landscape, and habitat ($P < 0.05$), and according to the positive and negative regression coefficients and the value of *IRR* of each covariate (Table 7), it reveals that,

Variable		*β*	*SE*	*Z*	*P*	*IRR*	*IRR 95%CI*	
							P25	*P75*
Month								
	April	− 2.586	0.208	− 12.420	0.000	0.075	0.050	0.113
	May	− 1.391	0.170	− 8.170	0.000	0.249	0.178	0.347
	June	− 0.823	0.159	− 5.160	0.000	0.439	0.321	0.600
	August	− 0.293	0.155	− 1.890	0.059*	0.746*	0.551	1.011
	September	− 0.248	0.154	− 1.610	0.107*	0.780*	0.577	1.055
	October	− 1.019	0.163	− 6.240	0.000	0.361	0.262	0.497
	November	− 1.934	0.183	− 10.590	0.000	0.145	0.101	0.207
Number of lights		0.050	0.019	2.640	0.008	1.052	1.013	1.092
Landscape								
	Western Zhejiang hilly region	1.256	0.203	6.180	0.000	3.510	2.357	5.227
	Northern Zhejiang plain	0.510	0.173	2.960	0.003	1.665	1.187	2.335
	Eastern Zhejiang hills	1.207	0.180	6.690	0.000	3.342	2.347	4.759
	Southern Zhejiang mountains	0.024	0.192	0.120	0.902*	1.024*	0.703	1.491
	The southeast coastal area of Zhejiang	1.612	0.166	9.680	0.000	5.011	3.616	6.944
Habitat								
	Urban residential area	0.712	0.144	4.960	0.000	2.037	1.538	2.699
	Park	1.021	0.142	7.200	0.000	2.777	2.103	3.666
	Peasant household	0.793	0.142	5.590	0.000	2.210	1.674	2.918
	Livestock shed	0.663	0.150	4.410	0.000	1.940	1.445	2.604
Constant		− 1.407	0.212	− 6.630	0.000	0.245	0.161	0.371
Alpha		4.015	0.225	–	–	–	3.598	4.481

Table 6. Negative binomial regression analysis of variables affecting the number of *Ae. albopictus* mosquito captured by mosquito trapping lights (N = 3486). Control dummy variables: July, the central Jinqu basin, hospital; *denotes $P > 0.05$.

Variable		*β*	*SE*	*Z*	*P*	*IRR*	*IRR 95%CI*	
							P_{25}	P_{75}
Month								
	April	− 2.951	0.424	− 6.960	< 0.001	0.052	0.023	0.120
	May	− 2.049	0.360	− 5.680	< 0.001	0.129	0.064	0.261
	June	− 0.604	0.316	− 1.910	0.056*	0.547*	0.294	1.015
	August	− 0.403	0.307	− 1.310	0.189*	0.668*	0.366	1.220
	September	− 0.706	0.320	− 2.210	0.027	0.493	0.264	0.924
	October	− 1.387	0.343	− 4.040	< 0.001	0.250	0.127	0.490
	November	− 2.864	0.431	− 6.650	< 0.001	0.057	0.025	0.133
Number of lights		− 0.120	0.052	− 2.320	0.020	0.887	0.802	0.982
Landscape								
	Northern Zhejiang plain	1.819	0.454	4.010	< 0.001	6.168	2.534	15.013
	Eastern Zhejiang hills	0.587	0.485	1.210	0.226*	1.799*	0.695	4.655
	Southern Zhejiang mountains	1.885	0.470	4.010	< 0.001	6.585	2.620	16.547
	Central Jinqu basin	1.033	0.492	2.100	0.036	2.809	1.072	7.361
	The southeast coastal area of Zhejiang	0.975	0.463	2.100	0.035	2.650	1.069	6.568
Habitat								
	Urban residential area	− 5.167	0.318	− 16.260	< 0.001	0.006	0.003	0.011
	Park	− 4.669	0.298	− 15.650	< 0.001	0.009	0.005	0.017
	Hospital	− 4.940	0.303	− 16.300	< 0.001	0.007	0.004	0.013
	Peasant household	− 2.841	0.251	− 11.330	< 0.001	0.058	0.036	0.095
Constant		2.202	0.500	4.410	< 0.001	9.040	3.396	24.065
Alpha		14.991	1.133				12.927	17.385

Table 7. Negative binomial regression analysis of variables affecting the number of *An. sinensis* mosquito captured by mosquito trapping lights (N = 3486). Control dummy variables: July, the western Zhejiang hilly region, livestock shed; * denotes $P > 0.05$.

Variable		β	SE	Z	P	IRR	IRR 95%CI	
							P_{25}	P_{75}
Month								
	May	0.854	0.397	2.150	0.032	2.348	1.078	5.114
	June	1.290	0.386	3.340	0.001	3.633	1.705	7.742
	July	1.673	0.375	4.460	0.000	5.325	2.553	11.107
	August	1.304	0.381	3.420	0.001	3.683	1.746	7.772
	September	1.530	0.384	3.990	0.000	4.618	2.177	9.795
	October	1.485	0.379	3.920	0.000	4.417	2.103	9.277
	November	0.363	0.402	0.900	0.367*	1.437*	0.654	3.161
Number of lights		0.015	0.043	0.340	0.735*	1.015*	0.933	1.104
Landscape								
	Western Zhejiang hilly region	1.440	0.417	3.450	0.001	4.219	1.864	9.549
	Northern Zhejiang plain	1.594	0.357	4.470	0.000	4.924	2.447	9.907
	Eastern Zhejiang hills	0.242	0.395	0.610	0.541*	1.273*	0.587	2.763
	Southern Zhejiang mountains	1.663	0.378	4.400	0.000	5.277	2.514	11.077
	The southeast coastal area of Zhejiang	0.980	0.365	2.680	0.007	2.664	1.303	5.446
Habitat								
	Urban residential area	− 3.447	0.288	− 11.960	0.000	0.032	0.018	0.056
	Park	− 2.715	0.260	− 10.430	0.000	0.066	0.040	0.110
	Hospital	− 3.861	0.310	− 12.460	0.000	0.021	0.011	0.039
	Peasant household	− 1.421	0.245	− 5.800	0.000	0.242	0.150	0.390
Constant		− 1.864	0.466	− 4.000	0.000	0.155	0.062	0.386
Alpha		14.518	1.241				12.279	17.165

Table 8. Negative binomial regression analysis of variables affecting the number of *Ar. subalbatus* mosquito captured by mosquito trapping lights (N = 3486). Control dummy variables: April, the central Jinqu basin, livestock shed; * denotes $P > 0.05$.

Month: Except for June and August, the number of *An. sinensis* mosquitoes captured in 4–11 months was lower than that of July;

Landscape: the number of *An. sinensis* captured in other landscapes were more (*IRR* > 1), except in the eastern Zhejiang hills. The *IRR* value indicated that there were more *An. sinensis* in the northern Zhejiang plain and the southern Zhejiang mountains compared to the western Zhejiang hilly region.

Light: the amount of *An. sinensis* mosquito collected by mosquito trapping lights in each site was influenced by the number of lights($P < 0.05$).

Habitat: The number of *An. sinensis* captured by mosquito trapping lights in urban residential areas, parks, hospitals, and peasant households was lower than that captured in the livestock shed, as indicated by the *IRR* value (*IRR* < 1).

Negative binomial regression analysis of factors affecting the number of *Ar. subalbatus* mosquito

The dependent variable was the number of *Ar. subalbatus* mosquitoes captured in each site, and the independent variables in the negative binomial regression model were the month (April as the control dummy variable), number of lights, landscape (the central Jinqu basin as the control dummy variable), and habitat (livestock shed as the control dummy variable). These factors were those that demonstrated statistically significant effects on mosquito species composition in the results of single-factor statistical analysis.

Regression modeling was valid ($\chi^2 = 318.52$, $P < 0.001$), and the 95% confidence interval of Alpha value did not contain 0, this further confirmed that using negative binomial modeling would be more appropriate than using the Poisson model.

The number of *Ar. subalbatus* mosquitoes captured by mosquito trapping lights in each site depend on month, landscape, and habitat($P < 0.05$). Based on the value of the *IRR* for each variable and the positive and negative regression coefficients (Table 8), it was determined that,

Month: the number of *Ar. subalbatus* mosquitoes captured by mosquito trapping lights in each site from May to November were higher than in April, except November;

Landscape: compared to the number of *Ar. subalbatus* mosquitoes captured by mosquito trapping lights in the central Jinqu basin area of Zhejiang, there were more *Ar. subalbatus* in other landscapes (*IRR* > 1), except the eastern Zhejiang hills; the *IRR* value indicated that the southern Zhejiang mountains, the western Zhejiang hilly region, and the northern Zhejiang plain had more *Ar. subalbatus* mosquitoes.

Habitat: Compared to the livestock sheds, the number of *Ar. subalbatus* mosquitoes captured in other types of habitats were lower(*IRR* < 1); The *IRR* value showed that the number of *Ar. subalbatus* mosquitoes captured by the mosquito trapping light method in the peasant household and park were relatively higher but still less than those captured in the livestock shed habitats.

In summary, this study's negative binomial models are effective ($P<0.001$), statistical analysis shows that factors such as landscape, habitat, number of lights, and month have an impact on the number of mosquito species caught by mosquito trapping lights in each site.

Discussion

This study demonstrates that the mosquito population's composition differs depending on landscapes and habitats. Dominant mosquito species in Zhejiang Province are *Cx. quinquefasciatus* and *Cx. tritaeniorhynchus*. *Cx. tritaeniorhynchus* is the most dominant mosquito species in the eastern Zhejiang hills, the central Jinqu basin, the southern Zhejiang mountains, and the southeast coastal area of Zhejiang. This phenomenon is possibly associated with the distribution of the province's areas for food and cash crop cultivation, the Jinqu Basin, the Dongyang Basin, and the Pujiang Basin are the primary cultivation areas in Zhejiang Province[12], more studies have shown that *Cx. tritaeniorhynchus* is widely distributed in the rice growing area[16,17]. The number of *Ae. albopictus* mosquitoes captured is relatively higher in the southeast coastal area of Zhejiang than in other regions. *Ae albopictus* is environmentally well-adapted[18], and the southeast coastal area of Zhejiang is affected by the ocean and typhoons, with superior rainfall and air temperature and humidity than the inland[12], which provide great conditions for adult mosquito reproduction and larval growth.

The composition of mosquito populations varies by habitat as well. In urban residential areas, parks, and hospitals, the top three dominant mosquito species share a common composition structure, with *Cx. quinquefasciatus* as the most dominant mosquito species, followed by *Ae. albopictus* and *Cx. tritaeniorhynchus*. Compared to urban residential areas and hospitals, parks have a relatively higher number and proportion of *An. sinensis* and *Ar. subalbatus* mosquitoes, this could be because parks have more ecological plant communities[7] and more unclean environments[19] that are conducive to the growth of these mosquitoes. Mosquitoes are abundant in both peasant households and livestock sheds, the most dominant mosquito species in peasant households is *Cx. quinquefasciatus*, while the most dominant species in the livestock sheds *is Cx. tritaeniorhynchus*, this phenomenon may be because *Cx. quinquefasciatus* is commonly known as feeding on human blood, while *Cx. tritaeniorhynchus* prefers the blood of livestock pigs[20]. *Ar. subalbatus* and *An. sinensis* mosquitoes are more numerous in peasant households and livestock sheds than other three types of habitats, this may be due to unclean water in these areas providing ideal breeding circumstances for these two species[19].

The composition of mosquito populations in Zhejiang Province is influenced by a variety of factors, including month, landscape, and habitat, this reflects the spatial and temporal heterogeneity of mosquito population distribution[8] and further indicates that all regions in Zhejiang Province should explore their own mosquito vector prevention and control measures, and take targeted measures to control vectors and vector-borne diseases, thereby reducing the risk of local mosquito-borne disease epidemics and transmission. The number of *Ae. albopictus* or *Cx. quinquefasciatus* species collected in each mosquito collected site was positively correlated with the number of mosquito trapping lights, whereas the number of *Cx. tritaeniorhynchus* and *An. sinensis* captured was negatively correlated, this implied holding all other predictor variables constant, an increasing of one unit in the light count, the number of *Ae. albopictus* or *Cx. quinquefasciatus* species collected in each site was expected to increase while reversing the number of *Cx. tritaeniorhynchus* and *An. sinensis*. These findings were based on the data information provided by the predictive models in our study. However, our models have limitations in explaining the negative relationship between mosquito trapping lights count and the number of *Cx. tritaeniorhynchus or An. sinensis* species collected in each site, which may be due to the omit important explanatory variables in the models leading to an unreasonable interpretation of the regression coefficients.

There are some limitations in this study, first, the mosquito population data was collected from repeated collections each month at the same site, and the current model prediction still needs to be further optimized. Second, the influence factors included in the study are limited by data resources, the other major influence factors on mosquito population are not included, such as temperature, latitude, longitude, and weather data[3,8], we recommend participating in multi-sectoral cooperation and sharing of data to develop more accurate monitoring and early warning platform for the dynamics of mosquito population changes in this rapid advancement period of artificial intelligence; third, mosquito trapping lights used in our study to collect field mosquitoes may have understated the composition of the *Ae. albopictus* population in Zhejiang Province, as they are not sensitive to the capture efficiency of *Ae. albopictus*[21]. We recommend using them in conjunction with BG-Sentinel traps to monitor mosquito populations.

Conclusion

This study introduced a new way of thinking about how to delve deeper to find the underlying information contained in mosquito surveillance data. It statistically analyzed the comprehensive effect of ecological factors, month, and light count on the number of mosquito species captured by mosquito trapping lights in each monitoring site and developed prediction models using negative binomial regressions. To adopt more effective mosquito vector prevention and control methods and lower the risk of local mosquito-borne illness epidemics, each region should implement mosquito vector prevention and control strategies that take into consideration its landscape, habitat type, and seasonal characteristics.

Data availability

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

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Author contributions

W.R. Z. produced the manuscript content, carried out the data analysis and made the map figure. L.Q.M., N.J., and W.J.N. helped with the manuscript text review and editing. G.Z.Y read and approved the final text.

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Declarations

Competing interests

The authors declare no competing interests.

Ethics approval

There was no informed patient consent or medical ethical review involved in this study.

Additional information

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