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ORIGINAL

A survey on the ecological niche characteristics of mosquitoes in mountainous populated areas in Southwest China: a case study of the Lancang River Basin in Western Yunnan Province

Encuesta sobre las características de los nichos ecológicos de los mosquitos en las zonas montañosas pobladas del suroeste de China: estudio de caso de la cuenca del río Lancang en la provincia occidental de Yunnan

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ABSTRACT

This study used the Lancang River Basin in western Yunnan Province as the study region to conduct a survey of mosquitoes that engage in nighttime blood-sucking activities in order to investigate the ecological niche characteristics of mosquitoes in mountainous residential areas in southwest China. The survey in the residential sections of the basin was sampled, classified, identified, and statistically analysed using the lamp trapping method. The findings indicated that we had 180 000 mosquitoes from 46 different genera. Among them, Anopheles sinensis was the next most prevalent species with 10,25 % of the total, followed in numerical order by Culex tritaeniorhynchus, which accounted for 78,80 % of the whole. Anopheles vaginalis, Culex brown-headed, and Aedes annoyance were among the other frequent species. Culex tritaeniorhynchus was the mosquito species with the broadest distribution over latitudinal and altitudinal gradients, out of 46 species. Only 15 % of mosquito species had an ecotope width index that was higher along the altitudinal gradient than it was along the latitudinal gradient, indicating that most mosquito species had relatively modest ecotope widths. The latitudinal dimension of a species' ecotope widths was often larger than the altitudinal dimension.

Keywords: Lancang River; Mosquitoes; Ecological Niche; Culex Tritaeniorhynchus; Ecotope.

RESUMEN

En este estudio se utilizó la cuenca del río Lancang, en el oeste de la provincia de Yunnan, como región de estudio para realizar una encuesta sobre mosquitos que realizan actividades nocturnas de succión de sangre, con el fin de investigar las características del nicho ecológico de los mosquitos en zonas residenciales montañosas del suroeste de China. El estudio en las zonas residenciales de la cuenca se muestreó, clasificó, identificó y analizó estadísticamente mediante el método de trampa con lámpara. Los resultados indicaron la presencia de 180 000 mosquitos de 46 géneros diferentes. Entre ellos, Anopheles sinensis era la especie más prevalente, con un 10,25 % del total, seguida en orden numérico por Culex tritaeniorhynchus, que representaba el 78,80 % del conjunto. Anopheles vaginalis, Culex cabeza marrón y Aedes molestia figuraban entre las demás especies frecuentes. Culex tritaeniorhynchus fue la especie de mosquito con la distribución más amplia a lo largo de gradientes latitudinales y altitudinales, de un total de 46 especies. Sólo el 15 % de las especies de mosquitos tenían un índice de anchura de ecotopo mayor a lo largo del gradiente altitudinal que a lo largo del gradiente latitudinal, lo que indica que la mayoría de las especies de mosquitos tenían anchuras de ecotopo relativamente modestas. La dimensión latitudinal de la anchura del ecotopo de una especie fue a menudo mayor que la dimensión altitudinal.

Palabras clave: Río Lancang; Mosquitos; Nicho Ecológico; Culex Tritaeniorhynchus; Ecotopo.

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INTRODUCTION

In addition to being a component of the food chain, mosquitoes are crucial to the environment because they are disease vectors, which support biodiversity and ecological equilibrium. The attention paid to the ecological traits and ecological niche of mosquitoes has steadily increased with the in-depth research of ecosystems.[1,2,3]

In this work, we examined the species composition and ecological niche traits of mosquitoes in various geographic locations and elevations, drawing on a survey of mosquitoes in the western Yunnan Province's Lancang River Basin. This work aims to highlight the significance of mosquito ecology research, identify the shortcomings of the existing investigation, and suggest avenues and obstacles for future investigation.

In addition to being vital to the food chain, mosquitoes are also carriers of disease. The stability and variety of ecosystems are significantly impacted by their distribution and abundance.[4] Therefore, it is essential to research mosquito ecological traits and behavioural patterns in order to forecast and manage the spread of illness, preserve biodiversity, and evaluate the condition of ecosystems.[5,6,7]

There are several issues with the ecology of mosquitoes being studied today. In complex ecosystems, species confusion and misclassification are common due to difficulties in species identification and classification. The second issue is that the study of mosquito ecological niche characterization has not yet received enough attention. Other issues include small sample sizes and narrowly focused research, which restrict our ability to fully comprehend the ecological adaptations and functional relationships of mosquitoes. Furthermore, irregular sample collection and irregular data processing are examples of flaws in data collecting and analysis methodologies that compromise the validity and objectivity of study findings. Lastly, a major issue is the lack of interdisciplinary interaction. The study of mosquito ecology spans several academic disciplines, necessitating interdisciplinary collaboration and resource sharing. However, the platform and mechanism for current cooperation have not been improved, which has an impact on the scope and depth of the research.[8,9]

This research expands on prior studies of mosquito species diversity in the Lancang River Basin, Yunnan Province, to better understand the large-scale geospatial ecological niche characteristics of mosquitoes in mountainous inhabited areas in southwest China. In the region's various latitudinal and altitudinal gradient zones, we measured, compared, and examined the ecological indicators of mosquito species composition, ecotope width, and ecotope overlap. We have thoroughly examined the ecological features of mosquitoes in large-scale environmental space by characterising the ecological niche characteristics of mosquito species and the relationship with species multiplicity, distribution, and ecological width.

METHOD

Overview of the study area

The Lancang River, which begins on the Tibetan Plateau in China and flows 2,161 km through China, Myanmar, Laos, Thailand, Cambodia, and Vietnam, is the second longest river in Asia.[10,11,12] It is an interior river in China that runs 1,247 kilometres across the western Yunnan region's Hengduan Mountains. It travels across nine latitudinal gradient zones, or latitudes between 21° and 30° N, exhibiting notable regional variations. The Lancang River basin has a wide range of elevations. The highest point is 6,740 metres above sea level at Kagbo Peak of the Meili Snow Mountain in Deqin, northwest Yunnan, and the lowest point is approximately 480 metres above sea level at the confluence of the Nanla and Lancang Rivers in Mengla County, southwest Yunnan. Due to this, the region's vegetation and temperature have undergone significant changes, going from tropical to icy and from low to extremely high mountains, creating a varied natural scene.[13,14,15]

Survey Sampling

The study's geographic focus is the Lancang River basin in the western Yunnan Province's Hengduan Mountains region. The region's latitudinal range is around 23°N, and its altitude ranges from 500 to 3500 metres. The analysis separates the area into various latitudinal and altitudinal gradient zones taking into account the geographical characteristics and the consequences of climate change. The development of big hydroelectric power plants has resulted in the displacement of local towns, particularly in the 22°–24°N region, thus the mosquito survey sample sites were relatively far from the river.[16]

The adult mosquitoes that are active at night and feed on humans in residential settings were the subject of this investigation. From south to north throughout the Lancang River Basin, we selected 30 townships in 12 counties as sampling locations. We spaced representative two to four townships or villages at varying heights at intervals of half a degree of latitude, or roughly 55 kilometres. Collections were made in home yards and animal pens between 19:30 in the evening and 7:30 the following morning. For collection, UV mosquito catching lamps were employed. The township health centre or the nearby CDC received the gathered specimens and used them for cryopreservation, identification, counting, and recording. Additionally, pertinent data were gathered, including average temperature, precipitation, latitude, and altitude. The peak months for local temperatures, the rainy season, and mosquito concentrations were July through September in 2020 and 2022, respectively, when the surveys were carried out and finished.

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Data processing and analysis methods

We conducted data analytics and separated the survey area into latitudinal and altitudinal gradient belts based on the topography and climatic features of the Lancang River Basin in the western Yunnan highlands:

1. Latitudinal gradient bands: based on the average division of horizontal gradient bands per 1 degree of latitude, we separated the survey region into 9 bands (about 60 and 110 kilometres in a straight line). The sample intervals at 21° to 22°, 22° to 23°, 23° to 24°, 24° to 25°, 25° to 26°, 26° to 27°, 28° to 29°, and 29° to 30° north latitude are specifically included in this. Each latitudinal band's data and information will be processed by us.
2. Elevation gradient bands: based on the vertical gradient bands for every 500 metres of height, we separated the survey region into six elevation bands. The sample zones are, in specific, located between 500 and 1000 metres, 1000 and 1500 metres, 1500 and 2000 metres, 2000 and 2500 metres, 2500 and 3000 metres, and 3000 and 3500 metres above sea level. Every elevation band's information and data will be processed by us[17] see figure 1.

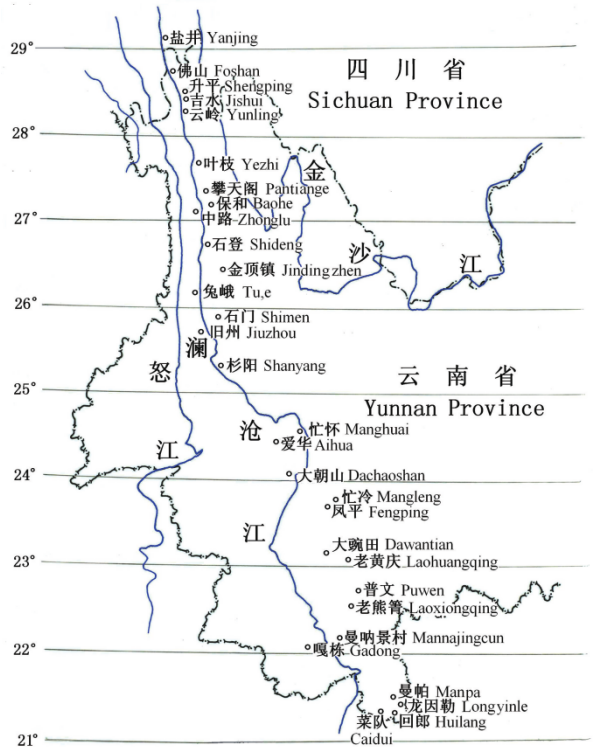

Figure 1. The location of the mosquito sample stations in residential areas in Yunnan Province's Lancang River Basin

To describe the ecology of mosquitoes over various latitudinal and altitudinal gradients, we will employ the following metrics:

- The number of mosquito species found within each latitudinal and altitudinal gradient is known as species richness.
- The ecotope width index measures how well mosquitoes have adapted to their habitat and how well they can use spatial resources.
- The ecological niche overlap index measures how different residential regions, climatic zones, and geographic places converge in terms of how they consume blood resources and how they compete with one another.
- The group-averaged systematic clustering method is used to examine and convey how ecological niches within species overlap or differ from one another at the macro geographic scale of mosquito species.

1. Ecotope width index: Shannon-Wiener index:

$$B_i = -\sum_{i=1}^{n}\left(P_{ij}\ln P_{ij}\right)$$

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2. Ecological niche overlap index: Pianka index:

$$O_{ik} = \frac{\sum_{j=1}^{N} P_{ij} P_{kj}}{\sqrt{\sum_{j=1}^{N} P_{ij}^2 \sum_{j=1}^{N} P_{kj}^2}}$$

Where P_{kj} represents the ratio of individuals of species i and k to the total number of individuals in sample j, and P_i represents the fraction of individuals of species i in the surveyed gradient zone P_{ij}. O_{ik}'s values fall between 0 and 1.

3. Abundance of species: abundance (relative abundance) (A)=100_{ni}/N (n_i= number of individuals of each species N = total number of individuals).

4. The size of the ecological amplitude provides information about the extent of a species' ability to be distributed as well as its spatial distribution along an altitudinal or latitudinal gradient.

MOSQUITO SPECIES AND THEIR DISTRIBUTION

Mosquito species composition and spatial distribution in the Lancang River Basin

After the survey, it was found that there were 180,000 mosquitoes in the Lancang River Basin, belonging to two subfamilies, seven genera and 46 species. Among them, there are 16 species of Anopheles, 15 species of Culex, 11 species of Aedes, and 1 species each of Uranotaenia, Armigeres, Mansonia and Culiseta.[18,19,20]

Regarding the percentage of individuals of each species of mosquito (i.e., relative abundance), Culex tritaeniorhynchus (Cx. tritaeniorhynchus) accounted for 77,87 % of the total number of mosquitoes, making it the numerically dominant species in the area; Anopheles sinensis was the second most dominant species with 10,16 % of the total number of mosquitoes; nuisance species Aedes aegypti (Ar. subalbatus), Anopheles vagabilis (An. wgws), Anopheles palmatus Culex fuscocephala (Cx. fuscocephala) and nuisance species Aedes aegypti (Aedes aegypti) accounted for 5,24 %, 1,83 %, and 1,01 % of the total number of mosquitoes captured, respectively. Furthermore, the other 42 species of mosquitoes were dispersed in relatively small numbers throughout the area and had a species multiplicity of less than 1,00.

46 mosquito species' ecological amplitude in the Lancang River basin, dispersed across a geographic gradient

Distribution of mosquito species' ecological amplitude along a latitudinal gradient

The capacity of the different mosquito species to disperse horizontally over the latitudinal gradient within the nine latitudinal gradient zones between 21° and 30° N latitude varied significantly, as indicated by the data in table 1. The most widely dispersed species in the examined area were Culex tritaeniorhynchus (Cx. tritaeniorhynchus) and Culex pipiens quinquefasciatus (Cx. pipiens quinquefasciatus), which were found to be distributed in all nine latitudinal gradient bands; Anopheles multispecies (Cx. sinensis) and Anopheles sinensis While the majority of other mosquito species, including the majority of Aedes species, a small number of Anopheles species, and individual species of Anopheles vexillifer and Culex, are distributed in only one latitudinal gradient zone and have narrower horizontal distribution ranges, Anopheles sinensis and Anopheles multispecies (Cx. sinensis) can be found in 68 latitudinal gradient zones and have relatively wide ecological distribution ranges.

Table 1. In the Lancang River Basin in Yunnan, China, mosquito composition and species multidimensional dispersion along a latitudinal gradient

Mosquito composition and distribution			Latitude gradient and distribution of species abundance(%)								
Species	**Total**	**Ratio(%)**	**21°**	**22°**	**23°**	**24°**	**25°**	**26°**	**27°**	**28°**	**29°**
1.Ar.subalbatus	1800	1,00 %	0,51	0,18	2,33	9,26	1,21	0,56	1,15	21,03	-
2.An.kunmingensis	230	0,12	-	-	-	-	-	0,04	2,35	0,05	-
3.An.gigas.baileyi	10	0,01	-	-	-	0,06	-	0,02	-0,04	-0,16	-
4.An.maculatus	271	0,14	0,05	0,01	2,48	2,86	0,01	0,25	0,03	0,11	-
5.An.minimus	1085	0,55	2,21	-	2,56	12,03	-	-	-	-	-
6.An.culicifacies	305	0,15	-	-	0,35	0,12	0,31	0,33	0,95	0,21	-
7.An.splendidus	40	0,01	0,01	0	0,55	-	-	-	-	-	-
8.An.tessellatus	335	0,18	-	0,18	1,20	5,22	-	-	-	-	-

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9.An.sinensis	18291	10,02	7,51	11,03	9,56	12,54	2,21	7,58	1,45	1,56	-
10.An.subpictus	85	0,06	-	-	0,01	-	-	-0,03	-	-	-
11.An.pattoni	8	0	-	-	-	-	-0,23	-	-	-	-
12.An.philippinensis	133	0,06	0,05	-	1,74	-	0,10	-	-	-	-
13.An.annula	241	0,11	-	-	-	0,05	-	-	-	-	-
14.An.lindesayi	3	0	-	-	0,01	0,06	-	-	-	-	-
15.An.kochi	235	0,12	0,58	0,08	0,24	-	-	--	-0,26	-	-
16.An.barbirostris	90	0,05	0,32	0,00	-	-	-	-	-	-	-
17.An.vagus	9436	5,21	23,52	3,48	0,21	4,15	0,12	-	0,22	-	-
18.Ae.vexans	748	0,44	1,82	0,12	0,38	0,12	0,06	0,15	0,33	0,04	-
19.Ae.lineato pennis	20	0,01	0,06	-	-	0,05	-	-	-	-	-
20.Ae.albolateralis	7	0,01	-	-	0,15	-	-	-	-	-	-
21.Ae.albopictus	5	0,01	-	0,01	-	-	0,02	-	-	0,22	-
22.Ae.oreophilus	6	0,01	-	-0,02	-	-	-0,01	-	-	-	-
23.Ae.formosensis	5	0,01	-	-	0,12	-	-	0,01	-	-	-
24.Ae.assamensis	5	0,01	0,01	-	-	0,04	-	-	-	-	-
25.Ae.pseudalbopictus	5	0,01	-	-	-	0,25	-	-	-	-	-
26.Ae.yunnanensis	11	0,01	-	-	-	-	-	-	0,78	-	-
27.Ae.yunnandalei	6	0,01	0,04	0,31	-		-	-	-	-	-
28.Ae.niveoides	20	0,01	-	-0,01	-	0,20	-	-	0,15	-	-
29.Cx.halifaxia	77	0,05	-	0,01	0,22	0,12	-	-	-	0,05	-
30.Cx.fuscanus	16	0,01	0,01	0,01	-	-	-	-	0,01	-	-
31.Cx.nigropunctatus	50	0,02	0,01	0,06	0,78	-	-	-	-	-	-
32.Cx.annulus	772	0,41	0,40	0,25	0,66	0,01	0,72	0,54	0,22	-	-
33.Cx.bitaeniorhynchus	50	0,02	0,05	0,01	0,11	0,44	-	0,02	0,05	-	-
34.Cx.tritaeniorhynchus	140244	77,98	53,27	82,32	70,98	29,31	82,66	92,22	82,12	60,58	55,21
35.Cx,whitmorei	35	0,04	0,07	0,03	0,03	-	-	-	-	-	-
36.Cx.pseudovishnui	470	0,28	0,025	0,22	0,14	2,87	-	0,45	0,32	-	-
37.Cx.heileri	285	0,15	-	-	-	0,22	0,01	1,24	0,42	0,65	1,03
38.Cx,pipiengs quinquefasciatus	1052	0,55	0,06	0,06	1,34	2,87	0,24	0,66	3,71	12,84	44,74
39.Cx.sinenis	40	0,02	0,01	0,03	0,08	-	0,01	0,08	-	0,11	-
40.Cx.fuscocephalus	3298	1,81	8,15	1,04	1,47	6,58	-	-	-	-	-
41.Cx.mimeticus	14	0,01	-	-	-	0,30	-	0,04	0,05	-	-
42.Cx.tianpingensis	2	0,01	-	-	-	-	-	0,02	-	-	-
43.Cx.gelidus	100	0,05	0,15	0,01	0,08	1,75	-	-	-	-	-
44.Ur.nivipleura	4	0,01	-	0,01	0,02	-	-	-	-	-	-
45.Ma.uniformis	45	0,02	0,08	0,02	-	-	-	-	-	-	-
46.Cu.niveitaeniata	8	0,01	-	-	-	-	-	-	0,17	-	-

Table 2. Mosquito composition and species richness distribution in the Lancang River Basin, Yunnan Province, China, along the altitudinal gradient

Mosquito composition and distribution			**Distribution of altitudinal gradients and species multiplicity (%)**					
Species	**Total**	**Ratio (%)**	**500m**	**1000m**	**1500m**	**2000m**	**2500m**	**3000m**
1.Ar.subalbatus	1800	1,02	0,30	0,75	0,22	6,23	0,21	1,78
2.An.kunmingensis	230	0,12	-	-	0,04	3,41	0,92	-
3.An.gigas.baileyi	10	0,01	-	-	-	0,07	0,22	1,75
4.An.maculatus	271	0,16	0,12	0,04	0,25	0,08	-	-
5.An.minimus	1085	0,62	0,78	0,04	0,86	-	-	-

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6.An.culicifacies	305	0,16	0,03	0,04	0,56	-	-	-
7.An.splendidus	40	0,02	0,03	0,02	0,01	-	-	-
8.An.tessellatus	335	0,18	0,17	0,38	0,01	-	-	-
9.An.sinensis	18291	10,12	9,51	12,03	10,56	11,54	0,81	0,15
10.An.subpictus	85	0,07	-	-	0,01	-	-	-0,03
11.An.pattoni	8	0,01	-	-	-	-	-0,23	-
12.An.philippinensis	133	0,08	0,05	-	1,74	-	0,10	-
13.An.annula	241	0,12	-	-	-	0,05	-	-
14.An.lindesayi	3	0,01	-	-	0,01	0,06	-	-
15.An.kochi	235	0,13	0,58	0,08	0,24	-	-	--
16.An.barbirostris	90	0,04	0,32	0,00	-	-	-	-
17.An.vagus	9436	5,21	9,66	0,62	0,21	4,15	0,12	-
18.Ae.vexans	748	0,42	1,82	0,05	0,88	0,08	0,15	0,33
19.Ae.lineato pennis	20	0,01	0,67	-	-	0,05	-	-
20.Ae.albolateralis	7	0	0,03	-	0,15	-	-	-
21.Ae.albopictus	5	0	-	-	-	-	0,02	-
22.Ae.oreophilus	6	0	-	-	-	-	-0,01	-
23.Ae.formosensis	5	0	-	0	0,12	-	-	-
24.Ae.assamensis	5	0	0	-	0,01	0	-	-
25.Ae.pseudalbopictus	5	0	-	-	-	0,03	-	-
26.Ae.yunnanensis	11	0,01	-	-	-	-	-	-
27.Ae.yunnandalei	6	0	0,04	0,31	-		-	-
28.Ae.niveoides	20	0,01	-	-0,01	-	0,20	-	-
29.Cx.halifaxia	77	0,06	-	0,01	0,22	0,12	-	-
30.Cx.fuscanus	16	0,01	0,01	0,01	-	-	-	-
31.Cx.nigropunctatus	50	0,02	0,01	0,06	0,78	-	-	-
32.Cx.annulus	772	0,41	0,40	0,25	0,66	0,01	0,72	-
33.Cx.bitaeniorhynchus	50	0,02	0,05	0,01	0,11	0,44	-	-
34.Cx.tritaeniorhynchus	140244	77,98	53,27	82,32	70,98	29,31	82,66	64,22
35.Cx,whitmorei	35	0,04	0,07	0,03	0,03	-	-	-
36.Cx.pseudovishnui	470	0,24	0,025	0,22	0,14	2,87	-	0,45
37.Cx.heileri	285	0,16	-	0,01	0,03	4,12	1,05	-
38.Cx,pipiengs quinquefasciatus	1052	0,52	0,06	0,06	1,34	2,87	0,24	0,66
39.Cx.sinenis	40	0,02	0,01	0,03	0,22	-	-	-
40.Cx.fuscocephalus	3298	1,82	3,30	0,63	0,01	0,28	-	-
41.Cx.mimeticus	14	0,01	-	-	-	0,30	-	0,04
42.Cx.tianpingensis	2	0,01	-	-	-	0,03	0,06	-
43.Cx.gelidus	100	0,04	0,06	0,14	-	-	-	-
44.Ur.nivipleura	4	0	0	0,01	-	-	-	-
45.Ma.uniformis	44	0,02	0,08	-	-	-	-	-
46.Cu.niveitaeniata	8	0	-	-	-	-	0,13	1,78

Distribution of mosquito species ecological amplitude along an altitudinal gradient

Based on the data presented in table 2, it is evident that there were differences in the vertical distribution ability of the 46 species of mosquitoes found in the six altitudinal gradient zones in the Lancang River Basin between 500 and 3000 metres above sea level. Specifically, the three species of Culex tritaeniorhynchus, Aedes aegypti, and Culex invasiveus were able to distribute within the survey area across all six altitudinal gradient zones, exhibiting the widest range of vertical distribution. These were followed by 10 species of mosquitoes, including Anopheles multispecies, Anopheles sinensis, Anopheles puncturei, and Culex annularis, which were able to distribute in four to five altitudinal gradient zones. While some mosquito species, including some Aedes

species, some Anopheles species, Culex species, and A. mansoni, were only found to be distributed in one altitudinal gradient zone, with a narrower vertical distribution range, Aedes aegypti, Anopheles sinensis, Aedes aegypti, and ten other species of mosquitoes were able to be distributed in four to five altitudinal gradient zones, with a relatively wide vertical distribution range.

46 mosquito species' spatial ecological niche widths in the Lancang River basin

Mosquito species' spatial ecological niche breadth at a gradient in latitude

Table 3 shows that Culex tritaeniorhynchus and Anopheles sinensis had the highest ecotope width indices, followed by Culex tritaeniorhynchus and Anopheles nuisance mosquitoes. Other species with high ecotope width indices included Anopheles vaginalis and Anopheles palustris. The ecotope width indices of the remaining mosquito species were either very small or relatively small.

Disparities between latitudinal and altitudinal gradients in mosquito ecological niche width and traits

Table 3. Lists the mosquito species' multiplicity, ecological amplitude, and ecotope width in the Lancang River Basin of Yunnan Province, China

Species composition	Species abundance	latitudinal gradients		Altitude gradient	
		Ecological amplitude	Niche breadth	Ecological amplitude	Niche breadth
1.Ar.subalbatus	1,00	9	0,812	5	0,402
2.An.kunmingensis	0,12	4	0,095	5	0,158
3.An.gigas.baileyi	0,01	4	0,01	5	0,092
4.An.maculatus	0,16	8	0,22	4	0,062
5.An.minimus	0,60	4	0,442	2	0,081
6.An.culicifacies	0,17	5	0,12	5	0,08
7.An.splendidus	0,02	5	0,061	3	0,005
8.An.tessellatus	0,15	4	0,065	3	0,035
9.An.sinensis	10,14	9	1,524	4	0,825
10.An.subpictus	0,04	2	0,022	2	0,013
11.An.pattoni	0,01	1	0,022	1	0,007
12.An.philippinensis	0,06	2	0,088	3	0,016
13.An.annula	0,15	2	0,022	3	0,035
14.An.lindesayi	0,01	1	0,004	1	0
15.An.kochi	0,12	4	0,045	2	0,014
16.An.barbirostris	0,04	3	0,017	1	0,08
17.An.vagus	5,23	5	0,622	2	0,260
18.Ae.vexans	0,42	7	0,155	4	0,099
19.Ae.lineato pennis	0,01	1	0,05	1	0,003
20.Ae.albolateralis	0	1	0,012	1	0,001
21.Ae.albopictus	0	2	0,004	1	0,01
22.Ae.oreophilus	0	1	0,06	2	0,133
23.Ae.formosensis	0	2	0,04	2	0,001
24.Ae.assamensis	0	2	0,003	2	0,001
25.Ae.pseudalbopictus	0,01	1	0,015	1	0,003
26.Ae.yunnanensis	0,01	1	0,041	3	0,151
27.Ae.yunnandalei	0	1	0,05	1	0,001
28.Ae.niveoides	0,01	2	0,022	1	0,02
29.Cx.halifaxia	0,05	6	0,025	3	0,012
30.Cx.fuscanus	0,01	3	0,005	2	0,003
31.Cx.nigropunctatus	0,02	4	0,013	3	0,006
32.Cx.annulus	0,44	6	0,155	5	0,088
33.Cx.bitaeniorhynchus	0,03	5	0,045	4	0,012

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34.Cx.tritaeniorhynchus	77,77	7	2,101	5	1,188
35.Cx,whitmorei	0,03	2	0,089	3	0,003
36.Cx.pseudovishnui	0,25	6	0,18	5	0,082
37.Cx.heileri	0,15	5	0,177	4	0,165
38.Cx,pipiengs quinquefasciatus	0,55	8	0,958	5	0,814
39.Cx.sinenis	0,03	5	0,022	4	0,023
40.Cx.fuscocephalus	1,82	5	0,499	3	0,154
41.Cx.mimeticus	0,01	4	0,024	2	0,006
42.Cx.tianpingensis	0	1	0,004	1	0,012
43.Cx.gelidus	0,05	3	0,088	2	0,016
44.Ur.nivipleura	0	3	0,003	2	0,001
45.Ma.uniformis	0,02	2	0,008	1	0,005
46.Cu.niveitaeniata	0	1	0,012	2	0,079

The ecotope width indices of approximately 85 % (39 species) of the 46 mosquito species in the Lancang River Basin were significantly larger than those of those on the altitudinal gradient, according to the statistical data in table 3; only approximately 15 % (7 species) of the mosquito species on the latitudinal gradient had ecotope width indices smaller than those on the altitudinal gradient. Overall, this illustrates the feature that mosquito species ecotope widths in the Lancang River basin are often greater in the latitudinal than in the altitudinal dimensions.

The latitudinal gradient ecotope width index, however, was found to be smaller than the altitudinal ecotope index of the seven mosquito species (Aedes kunmingensis, Aedes gigas baileyi, Aedes aegypti, Aedes oreophilus, Aedes yunnanensis, and Aedes culex), which were primarily distributed in the areas of Ae. helleri, Cx. tianpingensus, and Ae. niveitaenata rather than in the area of A. culex. The majority of Ae. helleri, Cx. tianpingensus, and Ca. niveitaenata are found in the middle and upper Lancang River, above 26°N latitude and above 1500 metres above sea level. Their geographical characteristics, which include their ability to spread vertically and their tendency towards northward migration at high latitudes, should account for their distinctive spatial distribution characteristics.

Their geographic characteristics and capacity for vertical dispersal should be connected to their spatial distribution traits, which are northward (high latitude) and cool-loving (high altitude). Therefore, in terms of the type of geographic zones, spatial distribution characteristics, and ecotope features, the characteristics and features differ significantly from those of other species that are thermophilic and primarily distributed at lower latitudes and altitudes and that have a latitudinal ecotope width index greater than that of the altitudinal ecotope width index.

In the Lancang River watershed, relationships exist between mosquito species richness and ecological amplitude and niche width

Relationships between ecological amplitude, niche widths, and the number of mosquito species

The Lancang River Basin is home to 46 different species of mosquitoes, the most common of which is Culex tritaeniorhynchus, which has the widest ecological amplitude, the greatest number, a distribution that encompasses all latitudinal and altitudinal gradient zones, and the highest spatial ecological niche width index. Anopheles sinensis, which was present in the majority of the latitudinal and altitudinal gradient zones and had a comparatively high ecological niche index, was the next most common and extensively dispersed species. Additional species with increased ecological amplitude, abundance, and ecotope width index included Culex tiringiensis and Aedes nuisancei.

Even with significant ecological amplitude, certain mosquito species, including Aedes aegypti, exhibited very small ecotope width indices because of low species richness. Conversely, although having tiny ecological amplitudes, several species, such Anopheles vaginalis and Culex brown-headed mosquitoes, exhibited relatively high ecotope width indices due to their high species richness. Because of their limited ecological amplitudes and poor species richness, the majority of mosquito species exhibited low or extremely low spatial ecotope widths.

Overall, these circumstances show how the Lancang River Basin's mosquito population's species richness, ecological amplitude, and ecological niche breadth index are correlated. In addition, these dominant species like Culex tritaeniorhynchus and Anopheles sinensis—had bigger geographic distributions, better ecological adaptation, and stronger geographical resource utilisation. These species also have larger ecotope widths. [21,22,23,24]

The Lancang River basin's mosquito species' ecological niche overlap status and spatial distribution pattern

Along a latitudinal gradient, ecological niche overlap and patterns of spatial distribution among mosquito species

46 species of mosquitoes on the latitudinal gradient were clustered based on the ecological niche overlap values; the findings indicated that the species could be divided into three main categories and five groups (Figure 2). They demonstrated the trend of the mosquito fauna along the latitudinal gradient in the Lancangjiang River Basin, as well as the composition of the community and its spatial distribution pattern. They also expressed the convergence, divergence, or difference among various mosquito species in the selection of geoclimatic and breeding environments and the utilisation of spatial and blood resources under the large-scale environmental and spatial conditions.

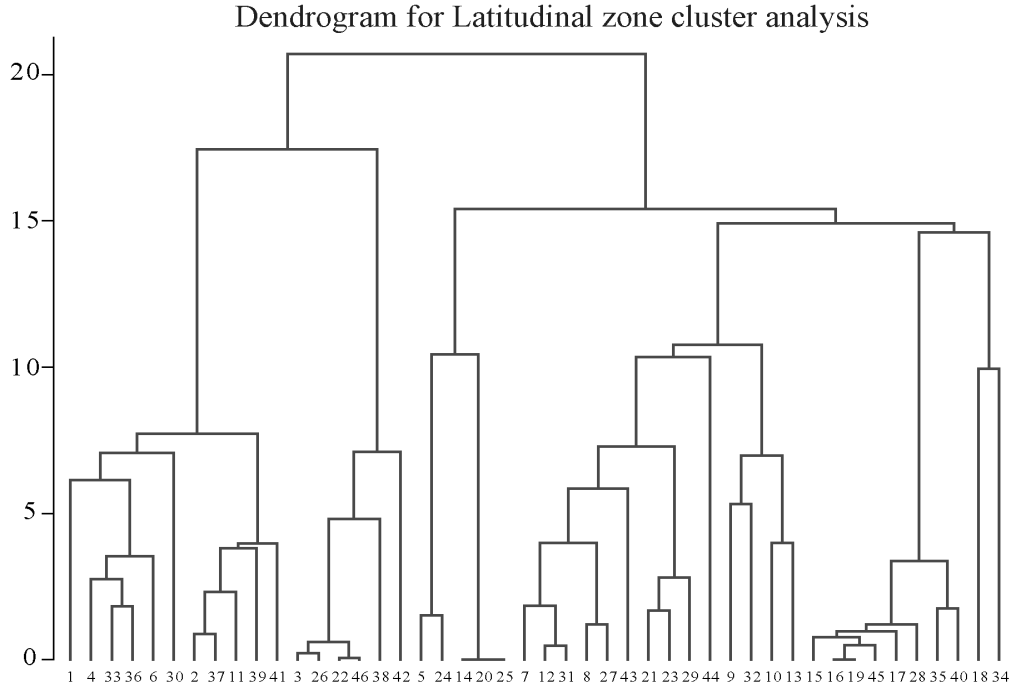

Figure 2. Overlapping ecological niches of 46 species of mosquitoes along the latitudinal gradient in the Lancang River Basin, Yunnan Province, China

Spatial distribution patterns and overlap of ecological niches among mosquito species along an altitudinal gradient

The values of ecological niche overlap among 46 mosquito species varied significantly across the six altitudinal gradient zones of the Lancang River basin. Just 34 pairs, or 3,29 % of the total of 1035 overlapping pairs, overlapped completely, while 223 pairs, or 21,55 % of the total, did not overlap at all. The degree of overlap varies within the range of overlap values between 0,001 and 1,00: 334 pairs (32,27 % of the total) have overlap values less than 0,25; 172 pairs (16,62 % of the total) have overlap values between 0,25 and 0,50; 126 pairs (12,17 % of the total) have overlap values between 0,50 and 0,75; and 180 pairs (17,39 % of the total) have overlap values less than 0,25.

Approximately 80 % of the species exhibit ecological niche overlap, with 29,56 % of the pairs having an overlap of greater than or equal to 0,50. These statistics indicate that 48,89 % of the total number of pairs had an overlap of less than 0,50 see figure 3.

Based on the clustering results of the ecological niche overlap values among 46 mosquito species on the altitudinal gradient, they can be categorized into three major categories and five groups. This result reflects the pattern and characteristics of the overlapping distribution of ecological niches of different mosquito species under large-scale environmental spatial conditions, as well as the similarities, differences and differentiation in the degree of selection of geo-climatic, habitat and breeding environments, spatial utilization and utilization of blood source resources. This result further demonstrated the trend of mosquito fauna changes along the altitudinal gradient in the Lancang River basin, as well as the composition and spatial distribution pattern of the communities.

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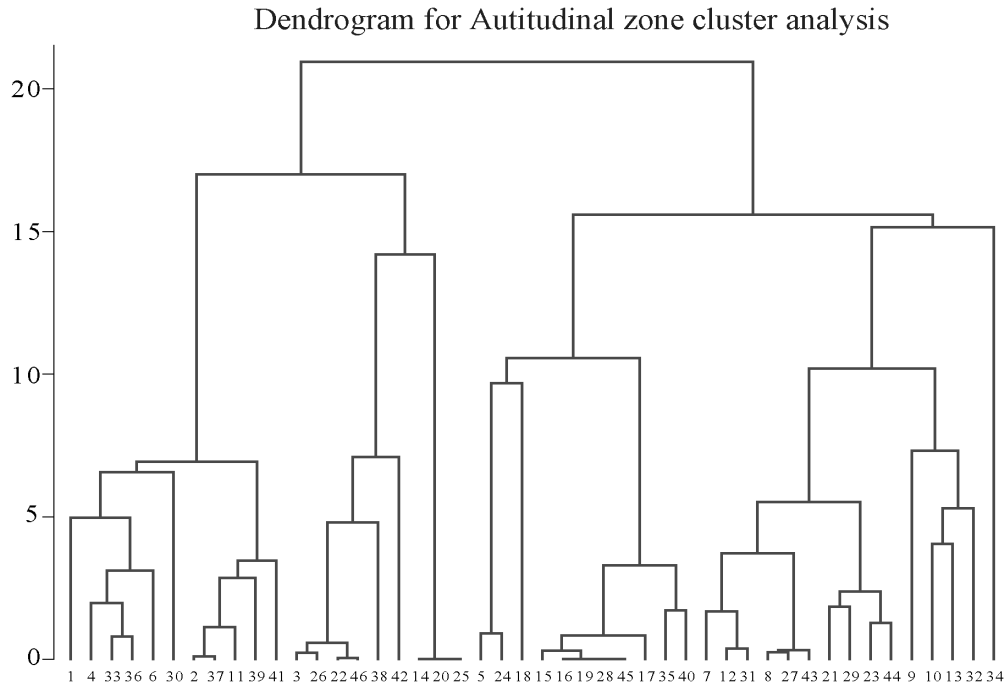

Figure 3. Overlapping ecological niches of 46 species of mosquitoes along the altitudinal gradient in the Lancang River Basin, Yunnan Province, China

CONCLUSIONS

The observation and analysis of mosquitoes in the Lancang River Basin revealed notable variations in the geographical distribution and ecological niche attributes of several mosquito species. Higher species multiplicity and ecological amplitude were shown by dominant species like Culex tritaeniorhynchus and Anopheles sinensis, indicating a greater degree of adaptability to a variety of habitats. Conversely, certain other species, while widely dispersed along particular latitudinal and altitudinal gradients, exhibited comparatively lower species richness and narrower ecological niche width. This shows that various mosquito species have varying capacities for environmental adaptation and the utilisation of geographical resources. These results are critical to a better understanding of the ecosystem's stability, the danger of disease transmission, and the ecological traits of mosquitoes in the Lancang River basin. A scientific foundation for the prevention and management of diseases spread by mosquitoes will be provided by future research that delves deeper into the ecological adaption processes of mosquitoes and their reactions to various environmental changes.

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CONFLICT OF INTEREST

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Conceptualization: Hanyang Xue.
Data curation: Hanyang Xue.
Formal analysis: Hanyang Xue.
Acquisition of funds: Hanyang Xue.
Research: Hanyang Xue.
Methodology: Hanyang Xue.
Project management: Hanyang Xue.
Resources: Hanyang Xue.
Software: Hanyang Xue.
Supervision: Hanyang Xue.
Validation: Hanyang Xue.
Display: Hanyang Xue.
Drafting - original draft: Hanyang Xue.
Writing - proofreading and editing: Hanyang Xue.