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ORIGINAL RESEARCH ARTICLE

Impact of ecological migration village construction on vector mosquito and mosquito-borne disease in the southern Yunnan Province, China

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Abstract

To evaluate the influence of ecological migration village construction on mosquito vector populations and mosquito-borne diseases in southern Yunnan Province. Two vicinal villages in Mengla County, the southern part of Yunnan Province, a native village, and a newly built village, were selected as study sites. Malaria and Japanese Encephalitis vector mosquito population divergence between the two villages were studied. Malaria and Japanese Encephalitis (JE) cases in the two villages were also compared. *Anopheles minimus* was the dominant population in houses in the newly built village, and *An. jeyporiensis* dominated the native village. Accordingly, there were nine malaria cases in the new village compared with zero cases in the native village. *Culex tritaeniorhynchus*, the chief JE vector in the study area, displayed no difference between the two villages; however, there was a higher density of the local secondary JE vector (*Cx. pseudovishnui*) in the native village than in the new one. The JE cases in the villages corresponded to zero. From the vector-borne disease perspective, our results suggest that local community should pay more attention to malaria and *An. minimus* during the construction of an ecological migration village in the new Chinese Western Developing Plan (CWDP) in southern Yunnan Province.

Keywords Mosquito vectors · Mosquito population · Ecological migration · Disease · Yunnan · China

Introduction

The Chinese Western Development Plan (CWDP) in Yunnan Province was first implemented in 2000, and an advanced new CWDP was also conducted in 2019 (Song). Ecological migration is an essential part of the CWDP (Wei 2002) to overcome poverty in the latest version of the CWDP in 2019(Song 2019). When immigrants left their original villages and moved to newly framed villages, they exploited the aboriginal environment in the newly built villages, and such immigration resulted in typical human disturbance of local ecosystems (Wang 2000; Zeng et al. 2000). This type of ecological disturbance will result in changing of mosquitoes breeding and habits, which will affect the local mosquito species composition, population dynamics and mosquito-borne disease epidemic (Lu 2003; Meyer et al. 2016; Loaiza et al. 2019).

Malaria and Japanese B Encephalitis (JBE) were major mosquito-borne diseases in Yunnan Province (Wang and Zhuang 1997; Gu and Zheng 2001; Wang et al. 2004; Su et al. 2005). Before the last malaria case in the province (Zhao et al. 2020), an increase in malaria cases in the new exploitation region was observed in Yunnan Province (Che et al. 1992; Sun et al. 2001), and the JBE was also a major mosquito-borne disease in Yunnan Province (Liu et al. 2021). However, the influence of village exploitation on mosquito vector populations and mosquito-borne diseases has yet to be well-studied. In this paper, the mosquito vector populations and mosquito-borne disease cases in the two villages were compared to provide insight into the influence of new

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village exploitation on mosquito vector and mosquito-borne disease in the southern Yunnan Province and offer a clue for the residents' health protection during new version CWDP.

Materials and methods

Study sites. Two villages were selected as the study sites in Molong town of Mengla County in the Xishuangbanna district of Yunnan Province: a new village and an old village. The distance between the two villages is 6 km, and the two villages share similar environmental characteristics. First, the two villages have the same agricultural patterns: tea trees and rubber plants are planted on the hillside, and the rice field lies on flat land with an irrigation ditch running across. Second, the houses of the two villages are built on the hillside with a house belonging to classical Ganlan-style architecture (Huang 2006). In the native village, without any exploitation action, two hundred and forty-five Miao minority people were living in 50 houses. However, the new village is a newly forming immigration village with fifty-six houses and two hundred and sixty-seven Kucong minority people dwelling in these areas previously in remote mountains. In the new village, the virgin forest on the hillside was felled for tea and rubber plants during the study period. In addition, rice fields and irrigation ditches have been developed on flat land.

Mosquito sample. In each village, eight houses along the edge of the villages were randomly selected as trap sites, and adult mosquitoes were sampled using light traps (New Standard Miniature Light Traps 512 6 V 150Am, John W. Hock, USA) in each house. Light traps were turned on at 1700 h, and the sampled mosquito was retrieved at 0700 h the following day. Mosquitoes were anaesthetized with ether and identified based on their morphology (Lu et al. 1997). Mosquitoes were sampled from June to October in one year, and seven consecutive night trappings were conducted in the middle of each month.

Malaria and Japanese Encephalitis cases survey. During the study, febrile patients asked for treatment in a local village clinic underwent a Plasmodium test with a blood film (Trape 1985). The confirmed cases were treated with antimalarial agents. Borderline JE cases were sent to a local county hospital for clinical diagnosis and treatment.

Data analysis

Analysis of mosquito population density. The density of the mosquito population was measured using light trap density (LD), which was calculated according to the following formula:

$$LD = Ni/L,$$

where *LD* represents the mosquito density in the light traps, *Ni* is the number of mosquitoes in the light traps, and *L* is the number of lights.

Analysis of mosquito population dominance. Domination of the mosquito species population was measured using the Berger-Parker (Berger and Parker 1970) dominant index (d), which was calculated using the following formula:

$$d = \mathrm{Ni/N},$$

where d is the dominant index, N is the total number of mosquitoes of all species, and *Ni* is the number of individual mosquitoes of a species.

Grading dominance of mosquito species. Mosquito species were graded according to their population dominance as follows: predominant species ($d \geq 0.1$), common species ($0.1 \geq d \geq 0.01$), and rare species ($d \leq 0.01$) (Peng and You 1996).

Statistical analysis

Between the two villages, t-test was used to compare the vector density in individual trapped month as well as total study period two-by-two, and the infection rate of malaria and JE were compared with Fisher's Exact test.

Ethical considerations

The survey of malaria and Japanese Encephalitis was conducted by local CDC (Center of Disease and Control) during the study period, and we didn't know the identity of the participants and positive patients. During the mosquito trapping, the houses' owner information was not collected too.

Results

Mosquito species composition

A total of 2,530 mosquitoes were identified in two villages using light traps. Three malaria mosquito vectors namely: *Anopheles minimus* (Theobald, 1901) (26.60%), *An. sinensis* (Wiedemann, 1828) (6.64%) and *An. jeyporiensis* (James, 1902) (17.31%) and two *Japanese Encephalitis* vectors, *Culex tritaeniorhynchus* (Giles, 1901) (4.90%) and *Cx. pseudovishnui* (Colless, 1957) (6.84%) were identified. In new village, the mosquito vectors and their proportions were *An. minimus* (47.39%), *An. sinensis* (9.25%), *An. jeyporiensis* (5.48%), *Cx. tritaeniorhynchus* (6.00%) and *Cx. pseudovishnui* (3.43%); while, the proportion of vectors

Table 1 Malaria vectors population comparison in the total investigation period

	Villages	Species		
		An. minimu	*An. sinensi*	*An. jeyporiensi*
d	New Village	0.48	0.09	0.06
	Native village	0.09	0.04	0.27
LD	New Village	553	108	64
	Native village	120	60	374
T-test of LD	t	-3.622	-1.883	3.257
	Sig.	0.011*	0.109	0.017*

Note: d is the mosquito population dominant index; LD is the light trap mosquito population density;

* Mean mosquito population difference is statistically significant (*)

in native village were *An. minimus* (8.80%), *An. sinensis* (4.40%), *An. jeyporiensis* (27.44%), *Cx. tritaeniorhynchus* (3.96%) and *Cx. pseudovishnui* (9.76%).

The dominance index of malaria vectors is presented in Table 1. Thus, *An. minimus*, *An. sinensis*, and *An. jeyporiensis* comprised the malaria vector phase of the mosquito community at the study sites. *An. minimus* was the predominant malaria vector in the new village ($d = 0.48 > 0.1$) during the *An. jeyporiensis* was predominant in the native village ($d = 0.27 > 0.1$). We compared three malaria vector population densities between the two villages. The density of *An. minimus* in the new village was higher than those in the native village (sig. = 0.011), and the density of *An. jeyporiensis* in the new village was lower than in the native village (Sig. = 0.017). The density difference for *An. sinensis* was not significantly different (sig. =0.109) for the two villages.

Monthly vector population dynamics in the study areas. During the study period, the densities of *An. minimus*, *An. sinensis*, and *An. jeyporiensis* between the two villages were compared using a t-test in each month. Table 2 presents the results. The density difference of *An. minimus* in June between the two villages was significant (Sig. =0.012). The difference was not significant in the other months (Sig.>0.05). However, the density difference of *An. jeyporiensis* in July and June between the two villages is significant (Sig. <0.05); however, the difference was not significant in the other months (Sig.>0.05). In addition, the density difference of *An. sinensis* between the two villages was insignificant each month (Sig.>0.05).

Japanese B Encephalitis mosquito vector populations in the study area.*Cx. triaeniorhynchus* and *Cx. pseudovishnui* were the two JE mosquito vectors found in the area (Table 3). According to the dominance index, the Japanese Encephalitis vectors were both common species in two villages (not the predominant species in the local mosquito community ($0.01 < d < 0.1$). Therefore, these two vectors comprised the *Japanese Encephalitis* vector phase in the study area. The density difference of *Cx. pseudovishnui* between the two villages was significant (Sig. =0.03), and the density of *Cx. pseudovishnui* in the native village were higher than in the new village (Sig. =0.03).

Monthly Japanese Encephalitis mosquito density variation in the study area. The densities of the two Japanese Encephalitis vectors were also compared for each month. A comparison of the results is presented in Table 4. From Table 4, we can see that *Cx. tritaeniorhynchus* density showed no significant differences between the two villages throughout each month (Sig.>0.05). However, *Cx. pseudovishnui* density differences were substantial in June and October (Sig. <0.05). Furthermore, the difference *in Cx. pseudovishnui* between the two villages was not meaningful in other months (Sig.>0.05).

Malaria and Japanese Encephalitis cases in study area. Table 5 shows the malaria and Japanese Encephalitis cases that occurred during our study period. Japanese Encephalitis cases could not be detected in the two villages during the study period. Similarly, the number of malaria cases in the native village was zero. As for the new village, a total of nine malaria cases (four were diagnosed in June and five in July) were documented during the study period. Moreover, malaria cases in the new village accounted for 3.37% of the village population. As Table 6 shows, there is a significant difference in malaria infection rates between the two villages (Fisher test, Exact Sig. =0.004).

Discussion

In new immigration villages in the southern part of Yunnan Province, the immigrating people inevitably changed their original environment to establish agriculture and living systems. Thus, the virgin forest and shrubbery were removed to gain more developing areas, and irrigation and municipal water systems were built to create habitation and

Table 2 Malaria vectors comparison in each investigation month

	Jun		Jul		Aug		Sep		Oct	
	t	Sig.	*t*	Sig.	*t*	Sig.	*t*	Sig.	*t*	Sig.
An. minimu	-4.816	0.012*	-1.039	0.339	-0.692	0.515	-1.456	0.240	-1.198	0.276
An. sinensi	-0.666	0.530	-1.091	0.317	-0.211	0.840	-0.409	0.697	-1.299	0.242
An. jeyporiensi	2.471	0.048*	4.025	0.007*	1.637	0.153	1.795	0.123	2.060	0.085

Note: * mean the mosquito population difference is statistically significant (*)

Table 3 JE vectors comparison in the total investigation period

	Village	Species	
		Cx. triaeniorhynchu	*Cx. pseudovishnu*
d	New Village	0.06	0.03
	Native village	0.04	0.098
LD	New Village	70	40
	Native village	54	133
T-test of LD	*t*	-0.778	4.841
	Sig.	0.483	0.03*

Note: d is the mosquito population dominant index; LD is the light trap mosquito population density;

* Mean the mosquito population difference is statistically significant (*)

Table 6 Malaria cases comparison between the new village and native village

	Village	Infection cases	Non-infection cases
Number of people	New Village	9	258
	Native village	0	245
Fisher-test	Exact Sig.	0.004*	

Note: * mean the infection rate difference between two villages is statistically significant (*)

agricultural facilities (Zeng et al. 2000; Wu et al. 2002). All these village-building actions changed the original mosquito vector breeding sites and the epidemiological cycle of local mosquito-borne diseases (Benitez et al. 2021). Therefore, establishing new migration villages would inevitably lead to the proliferation of mosquito vector species and mosquito-borne diseases in local villages.

For *An. minimus*, the major malaria vector in southern Yunnan Province, there is higher *An. minimus* density in the new village than that in the native village. The larva of *An. minimus* primarily lives in sluggish streams, and the flow velocity of the stream is the crucial factor for its breeding density in streams (Ismail et al. 1978). In the native village, the umbrageous vegetation along the current direction is a disadvantage for breeding *An. minimus* larva; while in the new village, the environment became suitable for producing in the streams after the virgin forest was felled. In newly formed immigration villages, irrigation and living water systems were established, providing breeding sites for *An. minimus* (Chen et al. 1989). For this reason, *An. minimus* dominated in the new village, and the density diverges between villages were also significant. An increase in the malaria vector density after the construction of irrigation and drinking water systems has also been noted in other studies (Amerasinghe and Ariyasena 1990; Mouchet and Carnevale 1997; Yohannes et al. 2005). Furthermore, higher *An. minimus* density in new villages than in the native villages means that the immigrant people have more chance of being bitten and getting malaria infection than those in native villages.

For the other malaria vector, the density of *An. jeyporiensis* in the new village was lower than that of the native village. *An. jeyporiensis* is the second malaria vector in the study area and would like to breed in well-forested environment villages (Mishra and Singh 1997). This favorite landscape could be discovered in the native villages because there was no vegetation-removing action. But in the new immigration village, the virgin forest and shrubbery had been erased. These should be the reason for lower *An. jeyporiensis* density in the new village could also be explained by *An. jeyporiensis* population significant diversification between villages.

The density difference of *An. jeyporiensis* and *An. minimus* was significant in the particular period in this study. The rainfall in the study region may account for the difference because the mosquito density development relates closely to the rain in two back-back directions. First, the rain could produce a fitted breed site for mosquito larvae, while the climax rainfall would decrease mosquito density by washing against breeding site in the stream. At study sites, the rainfall climax typically appears in July and August. So, the rainfall is suitable for Anopheles larva breeding in June. Thus, the density and significant difference of *An. jeyporiensis* and *An. minimus* in June here should result from diverging breeding environment facts for anopheles in two villages. The *An. jeyporiensis* breeding sites are more stable than that of *An. minimus* (Lu and Liu 1990; Vythilingam et al. 2003), which answers why another density difference of *An. jeyporiensis* we could view from Table 2 in July.

For the JBE vectors, the significantly different density of *Cx. pseudovishnui* between the original and newly built village could be seen in the present study. *Cx. pseudovishnui* is the second JBE vector in the southern part of Yunnan Province, and the temporary, clear water is a preferred breed site for *Cx. pseudovishnui* (Lu et al. 1997). In the native village, the humans produced more temporary, clear water than in the new village, which may account for the higher density of *Cx. pseudovishnui* in the native village than that

Table 4 JE vectors comparison in each investigation month

	Jun		Jul		Aug		Sep		Oct	
	t	Sig.	*t*	Sig.	*t*	Sig.	*t*	Sig.	*t*	Sig.
Cx. triaeniorhynchu	0.468	0.656	0.6	0.570	-0.447	0.670	-1.720	0.136	1.732	0.134
Cx. pseudovishnu	3.252	0.047*	2.068	0.084	2.2	0.107	0.067	0.949	3.520	0.013*

Note: * mean the mosquito population difference is statistically significant (*)

Table 5 Malaria and JE cases monthly comparison in investigation year

	Village	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Malaria	New Village	0	0	0	0	0	5*	4*	0	0	0	0	0
	Native village	0	0	0	0	0	0	0	0	0	0	0	0
JE	New Village	0	0	0	0	0	0	0	0	0	0	0	0
	Native village	0	0	0	0	0	0	0	0	0	0	0	0

Note: * mean there were disease cases in the village (*)

in the immigration village. Because of the rainy season and breeding sites difference, the difference between *Cx. pseudovishnui* between villages was signed in June, and the reason for its breeding inclination. The significant difference in October requires further investigation.

It's worth noting that there were non-significant differences between *An. sinensis* and *Cx. triaeniorhynchus* density between two types of villages in the results. *An. sinensis* and *Cx. triaeniorhynchus* is the crucial vector of malaria and JBE in China, respectively, as they breed principally in the big clear water body in Yunnan Province, especially in rice fields (Dong et al. 2004). To improve immigration, the local government reclaimed rice fields in advance for immigration villagers (Wen et al. 2005), which resulted in non-significant different breeding sites for these two vectors between two types of villages in the study area.

The mosquito-borne disease cases difference between the two villages with the mosquito-vector density diversity in the study area was significant. In the study site, *An. minimus* was the chief malaria vector that determined the malaria epidemic in the local area during *An. sinensis* and *An. jeyporiensis* are secondary malaria vectors that could not decide local malaria epidemic (Dong 2000). In the study area, *An. minimus* density was high in the immigration village, and the difference between *An. minimus* between the two villages was significant in June. Accordingly, there were five malaria cases in the new village in June and four cases in July, while there was no malaria case in the native village. New village building resulted in higher malaria vector density and malaria cases than those in the native village noticed by other researchers (Smith 1981; Adak et al. 1994; Manga et al. 1995; Patz et al. 2000). Similarly, *Cx. tritaeniorhynchus* was the primary JBE vector and *Cx. pseudovishnui* was only the second JBE vector in Yunnan Province (Zhang et al. 1999). Between the two types of villages, the non-significant disparity in the density of *Cx. tritaeniorhynchus* and significant density difference conformed well with the similar JBE epidemiology.

Since the CWDP started in 2000 in Yunnan Province (Huang 2000), the adverse effect of the CWDP on the environment (Yang 2001), villages (Yang et al. 2018), and health (Chen et al. 2004) have been reported. With the advancement of the new CWDP beginning in 2019 and the comprehensive poverty alleviation in the southern part of Yunnan province, more and more remote mountains or border villages have been exploited, like the new-built village in this study. Although the last malaria case was detected in Yunnan (Zhao et al. 2020) and China announced malaria-free in 2021 (Who 2021), the risk of malaria breaking out still exists originally from imported malaria through borderline and existing mosquito vectors (Liu and Liu 2021). This study's results confirmed that the mosquito vector density could be high and lead to malaria cases in case of environmental change and malaria importing, even though the present study finished before WHO certified malaria-free in China. Thus, this study cautioned the new CWDP from the standpoint of mosquito-borne disease epidemiology.

Author contributions M.D. Liu analyzed and interpreted the field data regarding pig, pigsty, and environmental features and was the major contributor to writing the manuscript. C.X. Li identified the mosquito caught in the houses and analyzed the field data of the mosquitoes. X.ZH. Wang and Y.D. Dong performed the mosquito trapping and field landscape investigation. T.Y. Zhao designed the study, planned the fieldwork, and directed the procedures. All authors have read and approved the final version of the manuscript.

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

Code Availability Not applicable.

Declarations

Conflicts of interest/Competing interests On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

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