Trends in Parasitology

Review

Anopheles Vectors in Mainland China While Approaching Malaria Elimination

Shaosen Zhang,[1,2,3,4] Shaohua Guo,[1,5] Xinyu Feng,[1] Aneta Afelt,[6] Roger Frutos,[2,3] Shuisen Zhou,[1,*] and Sylvie Manguin[4]

China is approaching malaria elimination; however, well-documented information on malaria vectors is still missing, which could hinder the development of appropriate surveillance strategies and WHO certification. This review summarizes the nationwide distribution of malaria vectors, their bionomic characteristics, control measures, and related studies. After several years of effort, the area of distribution of the principal malaria vectors was reduced, in particular for *Anopheles lesteri* (synonym: *An. anthropophagus*) and *Anopheles dirus* s.l., which nearly disappeared from their former endemic regions. *Anopheles sinensis* is becoming the predominant species in southwestern China. The bionomic characteristics of these species have changed, and resistance to insecticides was reported. There is a need to update surveillance tools and investigate the role of secondary vectors in malaria transmission.

Trends

Malaria is drastically declining in China, and the country is approaching malaria elimination.

The history and epidemiology of malaria in China have been well documented since 2010, but the involvement of malaria vectors has, by comparison, received less attention.

In China, areas with active malaria transmission, and the geographic distribution of its main vectors, were reduced, following the launch of the national malaria elimination program in 2010.

Changes to mosquito behavior, ecology, and insecticide susceptibility induced by environmental changes and control interventions should be further evaluated to secure malaria elimination in China by 2020.

An Overview of Malaria in Mainland China

Malaria is one of the most important vector-borne diseases in the tropical and subtropical belt. Although significant progress has been made on malaria control in several countries, it is still on the list of top health threats to humans, causing 429 000 deaths worldwide in 2015 (WHO, World Malaria Report 2016Appendix A. Without a vaccine, **vector control** (see Glossary) is considered as a key intervention for malaria control and **elimination** [1]. Therefore, for implementing appropriate and targeted vector control strategies as malaria elimination approaches, it is crucial to better understand the distribution and bionomics of malaria vectors [2,3].

Malaria has been endemic in China for more than 4000 years, and in 1949, transmission occurred in 80% of the counties. After the establishment of the People's Republic of China, malaria prevalence decreased drastically from 1553.85/100 000 in 1960 to 1.1/100 000 in 2009 [4,5]. In 2010, the Chinese government launched the national malaria elimination program with the goal of reaching elimination by 2020 (Action plan of China malaria elimination (2010–2020)Appendix A. Since then, a number of articles have been published about malaria control and elimination in China [4,6,7], but, in comparison, information on malaria vectors in China has suffered from a lack of consideration. Moreover, the absence of information on malaria vectors is also a problem for policy makers and researchers to develop strategies for malaria surveillance, risk assessment, and other studies at the elimination stage [3,8,9].

[1]National Institute of Parasitic Diseases, Chinese Centre for Disease Control and Prevention; Key Laboratory of Parasite and Vector Biology, MOH; WHO Collaborating Centre for Tropical Diseases, National Centre for International Research on Tropical Diseases, Shanghai, China
[2]Université de Montpellier, IES-Institut d'Electronique et des Systèmes, UMR5214, CNRS-UM, 860 rue de Saint-Priest, Bât 5, 34095 Montpellier, France
[3]Cirad, UMR 17, Intertryp, Campus

international de Baillarguet, 34398 Montpellier, Cedex 5, France
[4]Institut de Recherche pour le Développement (IRD France), LIPMC, UMR-MD3, Faculté de Pharmacie, 34093 Montpellier, France
[5]Jiading District Center for Disease Control and Prevention, Shanghai, China
[6]Interdisciplinary Center for Mathematical and Computational Modelling, University of Warsaw, Prosta 69, 00-838, Warsaw, Poland

*Correspondence: shuisenzhou@126.com (S. Zhou).

Malaria is transmitted by mosquitoes of the *Anopheles* genus, which comprises 60 species and/or complexes formally recognized in China. Of those, 14 are able to transmit human malaria parasites. Among these 14 species/complexes, the following eight taxa were reported as predominant malaria vectors in China: *An. sinensis*, *An. lesteri* (synonymy with *An. anthropophagus*), *Anopheles minimus* s.l. (including *Anopheles minimus* and *Anopheles harrisoni*), *An. dirus* s.l. (including *Anopheles dirus* and *Anopheles baimaii*), *Anopheles liangshanensis* (synonymy with *An. kunmingensis*), *Anopheles messeae*, *Anopheles sacharovi*, and *Anopheles pseudowillmori* [10–14]. However, after several decades of malaria control efforts, in addition to changes in land use and land cover, some of the *Anopheles* mosquitoes were no longer found or reported according to national malaria surveillance reports [15]. Only four species/complexes have been considered as predominant malaria vectors throughout the country since the beginning of the 21st century, that is, *An. sinensis*, *An. lesteri*, *An. minimus* s.l. and *An. dirus* s.l. Furthermore, *An. pseudowillmori* from the Maculatus Group has been considered as a potential malaria vector in Tibet since 2006 [16]. Hence, this review focuses mostly on these five latter taxa, and on their bionomics (ecology and behavior), distribution and control, during the period 2000–2016, as China approaches malaria elimination.

Geographic Distribution of Malaria Vectors

In mainland China, 24 provinces with previous local malaria transmission reported the presence of *Anopheles* mosquitoes (Figure 1A–E) [12,17]. However, after comprehensive malaria control measures and efforts, the **endemic areas** of *An. lesteri* or *An. dirus* s.l. were drastically reduced [18–22] (Figure 1B,C). Meanwhile, *An. minimus* s.l. was only reported in limited areas [18,23–26] (Figure 1D). These data fit well with malaria prevalence trends in the progress of elimination (Figure 2A–D) [4,27]. The elimination process has been very efficient since its implementation in 2010, as presented in Figure 2C,D.

Hyrcanus Group

Two species within the Hyrcanus Group were confirmed as malaria vectors in China, *An. sinensis* and *An. lesteri* (synonym: *An. anthropophagus*) [12,28,29]. *An. sinensis* is still the most widespread species distributed all over the country with records from northeast (Liaoning Province) to southwest (Yunnan Province) (Figure 1A). Moreover, ecologically suitable areas for *An. sinensis* were modelled, in prospective simulations, to expand along with climate change [30–32]. *An. lesteri* was considered as the **principal malaria vector** in the area ranging from 22°N to 33°N [17,29]. The most northern location where *An. lesteri* was identified is Liaoning Province (around 42°N) [33]. However, after several years of malaria control, as well as environmental changes, the distribution of *An. lesteri* is shrinking, and it even disappeared from some provinces, such as Fujian Province in the southeast and Yunnan Province in the southwest of China [21,34–36] (Figure 1B).

Dirus Complex

The Dirus Complex is now composed of eight sibling species throughout its geographic distribution [37]. Two are present in southern China (Figure 1C), that is, *An. dirus* (former *An. dirus* species A) reported in Hainan and *An. baimaii* (former *An. dirus* species D) collected in Yunnan below 23°N [14,38,39]. This complex is known to play a major role in malaria transmission in both China and southeast Asia [37,40]. Unfortunately, there is no information on their specific role in malaria transmission in China as molecular tools for species identification have not yet been implemented within the national malaria control program.

Minimus Complex

Based on molecular identification, the Minimus Complex consists of two sibling species, *An. minimus* and *An. harrisoni* [41,42]. *An. harrisoni,* named in 2007, was the former *An. minimus* C, whereas *An. minimus* was previously known as species A. In China, the literature referred almost exclusively to *An. minimus* s.l. (Figure 1D). Molecular identification was seldom processed to differentiate the two sibling species for malaria control programs, with few exceptions [41–46]. Regarding their distribution, *An. minimus* and *An. harrisoni* were reported as sympatric in Yunnan Province up to latitude 24.5°N [40,42,47]. In addition, *An. minimus* occurs eastward from Yunnan through southern Guangxi, Hainan, and Guangdong Provinces, whereas *An. harrisoni* occurs northward up to latitude 32.5°N to northern Guangxi, Guizhou, and Sichuan Provinces [42]. *An. minimus* was identified as the principal malaria vector throughout its distribution range [26,40,47–50], while *An. harrisoni* seems to play a secondary role in malaria transmission [42].

Maculatus Group

Out of the eight species of the Maculatus Group, four have previously been recorded in southern China, that is, *An. maculatus*, *An. pseudowillmori*, *An. willmori,* and *An. sawadwongporni* [12,13]. All four are known as malaria vectors in southeast Asia [48,49]. *An. pseudowillmori* has recently been identified as a potential malaria vector along two international border areas (Figure 1E), in Tibet (China–India border) [16,51], and in Yunnan (China–Myanmar border) [50,52,53]. Very limited information is available on the occurrence of these species in China, and more studies are required to define their specific role in malaria transmission.

Bionomics of Larval and Adult Stages

Bionomic traits, including trophic behavior, biting, and resting behaviors, and preferential breeding sites, are key indicators for monitoring the role of *Anopheles* mosquitoes in malaria transmission. Most larval ecological studies focused on four taxa, *An. sinensis*, *An. lesteri*, *An. minimus* s.l., and *An. dirus* s.l. These taxa share a common preference for shaded breeding sites, and in some areas they could be found sympatrically [13,17,33,54] (Table 1). *An. sinensis* and *An. minimus* s.l. displayed changes in both **host preference** and resting behavior. These changes were attributed to human intervention and environmental modification. *An. sinensis* could shift from zoophilic to **anthropophilic** behavior in areas where the number of cattle decreased [54–57]. The proportion of **endophilic** *An. minimus* s.l. diminished in areas with **indoor residual spraying (IRS)** [26,45,46], a trait also described in Central Vietnam [58]. However, very limited information was available on *An. pseudowillmori* for both larval and adult stages.

Vector Control Efforts and Challenges

Vector Control and Insecticide Resistance

Vector control is one of the key interventions to control and possibly eliminate malaria transmission [59]. China has developed its vector control strategies in line with WHO guidelines. These strategies were locally tailored, considering *Anopheles* taxa, the intensity of transmission, and species of *Plasmodium*. In Central China, where *An. sinensis* is the predominant vector and *Plasmodium vivax* is the predominant parasite, the use of door and window screens, as well as mosquito repellent, was recommended in addition to environmental reforming measures, such as intermittent irrigation in rice fields [11,17,29]. Chemical treatments, such as indoor residual spraying (IRS), **insecticide-treated nets (ITNs)** and **long-lasting insecticidal nets (LLINs)** were used mainly in southern China, in particular Yunnan and Hainan where *An. minimus* s.l. and *An. dirus* s.l. are the predominant vectors with both *Plasmodium falciparum* and *P. vivax* as the main parasites [17,29]. However, these chemical interventions were not conducted uniformly but only in selected foci and populations [17] (Action plan of China malaria elimination 2010–2020Appendix A. In addition, a biological vector-control approach based on *Bacillus thuringiensis* var. *israelensis* (Bti) was also explored in Henan and Hubei Provinces in Central China and was found to be effective against larvae of *An. sinensis* and *An. lesteri* [29,60,61].

Glossary

Anthropophilic: mosquitoes showing a preference for feeding on humans, even when nonhuman hosts are available.
Endemic area/region: an area in which there is an ongoing, measurable incidence of malaria infection and mosquito-borne transmission over a succession of years.
Endophagy: tendency of mosquitoes to blood-feed indoors. Antonym: exophagy.
Endophily: tendency of mosquitoes to rest indoors; usually quantified as the proportion resting indoors versus outdoors. Antonym: exophily.
Exophagy: tendency of mosquitoes to feed outdoors; usually quantified as the proportion of biting hosts outdoors versus indoors. Antonym: endophagy.
Exophily: tendency of mosquitoes to rest outdoors, usually quantified as the proportion resting outdoors and indoors. Antonym: endophily.
Host preference: tendency of female *Anopheles* mosquitoes to blood-feed on a specific host species.
Human landing catch: a method for collecting vectors as they land on human individuals. The purpose is to monitor exposure of the human population to vector populations and define the anthropophilic index of the vector species.
Indoor residual spraying (IRS): operational procedure and strategy for malaria vector control involving spraying indoor surfaces of dwellings with a residual insecticide to kill or repel endophilic mosquitoes.
Insecticidebioassay: in applied entomology, experimental testing of the biological effectiveness of an insecticide by deliberately exposing insects to it.
Insecticide resistance: property of mosquitoes to survive after an exposure to a standard dose of insecticide.
Insecticide-treated net (ITN): a mosquito net that has been treated by dipping it into a WHO-recommended insecticide formulation. To ensure its continued insecticidal effect, the net should be retreated periodically.
Long-lasting insecticidal net (LLIN): a factory-treated mosquito net made of material into which insecticide is incorporated or bound

Insecticide resistance is a key indicator in malaria surveillance and in the assessment of vector-control efficiency. It is commonly monitored by **insecticide bioassay**, either by determining LC_{50} (50% lethal concentration) or by using uniform diagnostic doses [62–65]. In China, the diagnostic dose was adopted as a common method in line with WHO recommendations but with modified concentrations depending on local cases of insecticide resistance [66]. A first set of recommendations was related to the test procedures for insecticide resistance monitoring in malaria vector mosquitoes [67]. A second set addressed the pesticide evaluation scheme (WHO Pesticide Evaluation Scheme, 2016Appendix A). The criteria used in China for each insecticide are reported in Table 2, and the geographic distribution of insecticide resistance in *An. sinensis* is summarized in Figure 1F. *An. sinensis* resistance to insecticides was monitored from north to south, covering the geographic distribution of the species in China [65] (Figure 1F). Resistance to organochlorine was reported in Hubei Province, as well as to dichlorodiphenyltrichloroethane (DDT) [68]. Resistance to organochlorine in this species was also reported in Liaoning and Jiangsu Provinces, and to pyrethroids, such as deltamethrin, in Jiangsu [69]. *An. lesteri and An. dirus* s.l. have been reported to be still susceptible to these insecticides [62,66]. Resistance to insecticides in *An. minimus* s.l. was monitored only in southern China, where this vector is present (Figure 1F). Although resistance to DDT was recorded in one area of Yunnan, in other regions, *An. minimus* was found to be still susceptible to the insecticides tested, including malathion, deltamethrin, and permethrin [62]. Limited information is available on *An. pseudowillmori*, but it suggests the absence of resistance at the genome level [70].

Although very little insecticide resistance has been reported in China, the ability of vectors to develop diverse resistance mechanisms to insecticides has been well documented worldwide [71,72]. The capacity of vectors to develop resistance to insecticides will undoubtedly pose a major obstacle to malaria control and elimination in China in the future, especially in the case of the widely distributed *An. sinensis* (Figure 1A).

Evolution of Mosquito Behavior

All front-line vector-control methods currently used in China (e.g., ITNs, IRS), as well as in other regions of the world, are based on the stereotypical view that vectors bite and rest primarily inside houses. This assumption is based on the early characterization of *Anopheles* behaviors of feeding and resting almost exclusively indoors [11]. However, even these endophilic species feed outside to some degree, and may do so increasingly in response to domestic insecticide interventions [73,74].

Documented examples of adaptable vector behaviors that could impact interventions were reviewed by Durnez and Coosemans in 2013 [75]. They, for instance, reported that the declining efficiency of ITNs and IRS was attributed to changes in mosquito behavior, such as host-species preferences (from anthropophilic to zoophilic) [58,76,77] and feeding preference (from **endophagy** to **exophagy**, or in the early evening when people are not protected in their houses or under bed nets) [74,78,79]. During the 1970s, several records of mosquitoes shifting from feeding inside to feeding outside, and from human to animal hosts, were reported in response to indoor insecticide use (DDT spraying and DDT-treated mosquito nets) [80,81]. It is still unknown whether these behavioral shifts were a consequence of phenotypic plasticity or evolutionary change within mosquito populations. Regardless of the mechanism, such behavioral plasticity limits contact between vectors and insecticides, thus diminishing the effectiveness of interventions [82,83]. With respect to China, no monitoring of behavioral change was conducted and no records are available.

Effect of Environmental Changes

Climate and environmental changes are driving the expansion of numerous vector species and the intensification of pathogen transmission in many locations [84]. Specific examples include

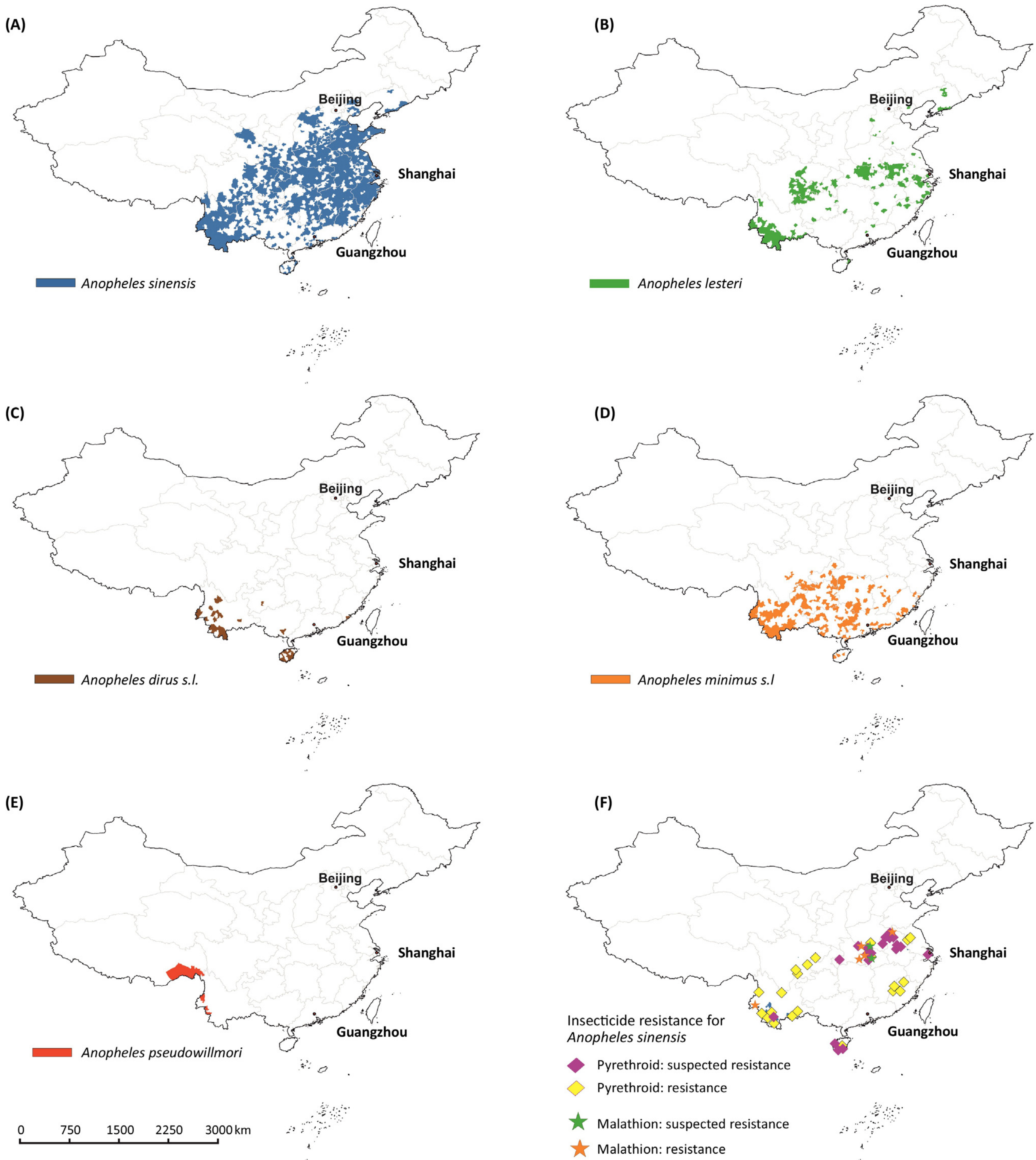
around the fibers. The net must retain its effective biological activity for at least 20 WHO standard washes under laboratory conditions, and 3 years of recommended use under field conditions.

Malaria elimination: interruption of local transmission (reduction to zero incidence) of a specified malaria parasite in a defined geographical area as a result of deliberate control activities. Continued measures to prevent re-establishment of transmission are required.

Principal or main vector: the species of *Anopheles* mainly responsible for transmitting malaria parasites at a regional scale or/and all year-round.

Secondary vector: species of *Anopheles* that plays a local or seasonal role in malaria transmission compared to the principal vector – although capable of maintaining malaria transmission at a reduced level.

Vector control: measures of any kind against malaria-transmitting mosquitoes, intended to limit their ability to transmit the disease.



Trends in Parasitology

Figure 1. Geographic Distribution of Predominant Malaria Vectors and Their Resistance to Insecticide in China. Distribution of (A) *Anopheles sinensis*, (B) *Anopheles lesteri*, (C) *Anopheles dirus* s.l., (D) *Anopheles minimus* s.l., and (E) *Anopheles pseudowillmori*. (F) Resistance of *Anopheles sinensis* to insecticides. On the map, pyrethroid refers to deltamethrin and permethrin, the two major pyrethroid insecticides used in malaria vector control. Data based on literature search for the period 2000–2016.

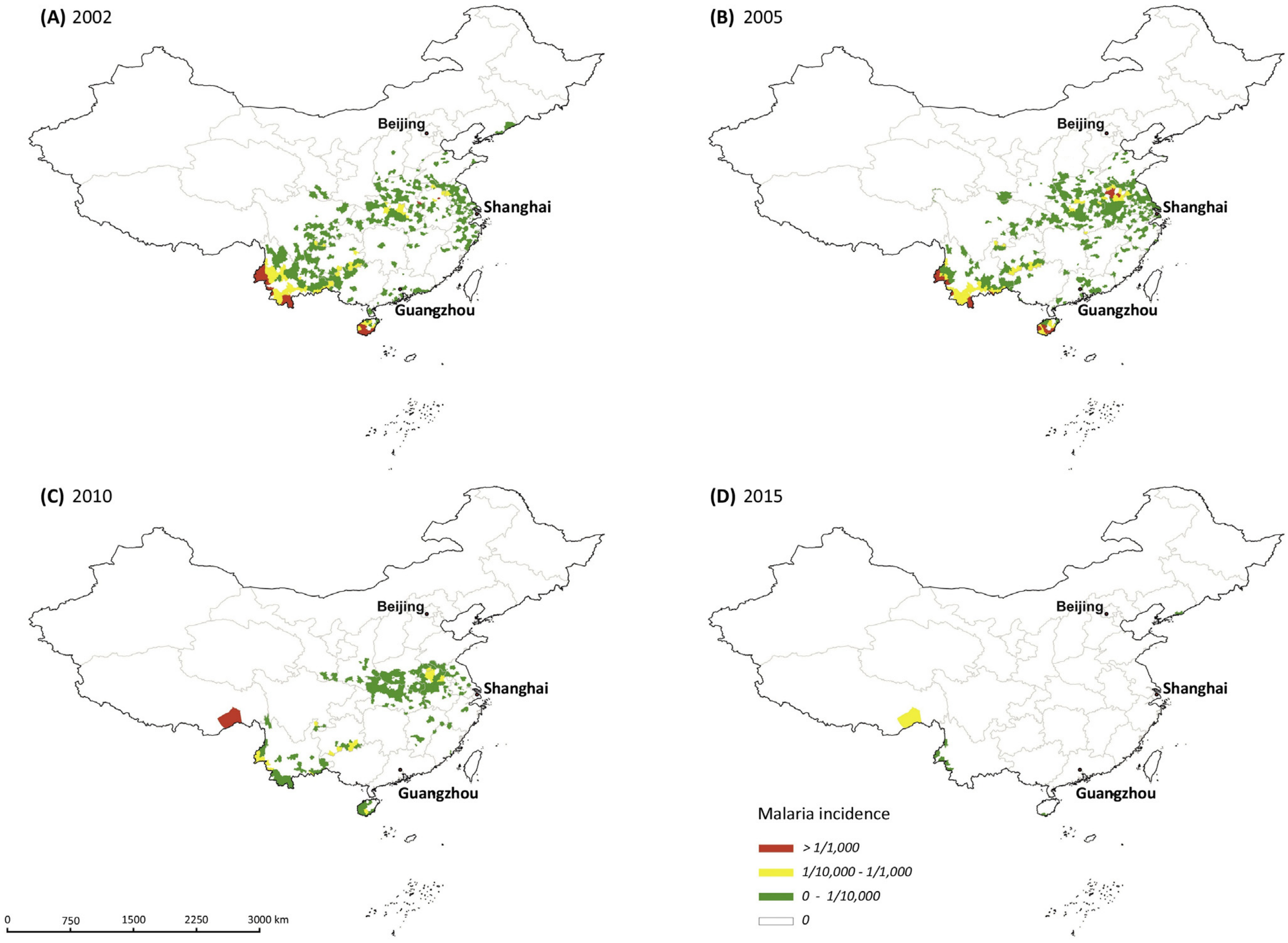


Figure 2. Evolution of Local Malaria Transmission in China from 2002 to 2015. (A) In 2002. (B) In 2005. (C) In 2010. (D) In 2015. Data from the national malaria annual report in China [27,102–105].

deforestation, which has prompted an increase in the human-biting rate of formerly zoophilic vectors in several parts of the tropics and the instigation of new malaria epidemics [85,86]. Historical and forecasted rises in temperature have also been involved in the spread of malaria into new habitats and regions [32,87]. Although climate change is suspected to also play a role in vector distribution in China, this is poorly documented. Only one work has investigated this issue in China and reported a correlation [32]. In this study, the potential impact of climate change on four dominant malaria vectors (*An. dirus* s.l., *An. minimus* s.l., *An. lesteri*, and *An. sinensis*) was assessed by species-distribution models. The environmentally suitable area (ESA), which incorporated the effect of land use and climate, was introduced as the indicator to predict the distribution of malaria vectors. The findings, established on simulation-based estimation, suggest that urbanization and global climate change would increase the ESA for *An. lesteri* and *An. sinensis*, while this increase would be limited for *An. dirus* and *An. minimus* because bioclimatic variables overwhelmed land use variables for these two species [32]. Mitigating against the detrimental impacts of environmental change on malaria transmission will be particularly difficult when public health goals conflict with economic development: for example, the removal of livestock from the landscape caused the formerly zoophilic *An. sinensis* to switch its feeding target from livestock to humans. Such change was considered

Table 1. Bionomics of Malaria Vectors in China

Species	Breeding sites				Resting behavior	Biting behavior			Seasonal fluctuation (peak season of abundance)	Refs
	Preferred	Second option	Third option	Not suitable		Place	Preferred blood source	Peak time of blood-seeking activity at night		
Anopheles sinensis	Rice field	Canal, ditch	Pond	Fishpond	Exophily[a]	Endophagy[a]	Zoophily (1st option) Anthropophily (2nd option)	8 p.m.–9 p.m.[b] 5 a.m.–6 a.m.[b]	July–August	[55,56,98,99,106–109]
Anopheles lesteri	Heliophobic, canal, ditch	Rice field	Filter well	Fishpond	Endophily[a]	Endophagy	Anthropophily[c]	1 a.m.–2 a.m.	August–September	[11,12,20,33,110,111]
Anopheles dirus s.l.	Heliophobic stream in forest	Pit with water	Footprint of cattle	–	Exophily	Endophagy and exophagy[a]	Anthropophily	11 p.m.–1 a.m.	June–July	[11,12,17,18,50,112]
Anopheles minimus s.l.	Heliophobic stream	Canal, ditch	Rice field	Big pool	Endophily	Endophagy	Zoophily/ Anthropophily[d]	10 p.m.–12 p.m.	June–July and September–October April–June[d]	[13,26,45,46,113]
Anopheles pseudowillmori[e]	Rice field, pond, ditch, *etc*	–	–	–	Exophily	Endophagy	Semi-zoophily and semi-anthropophily	11 p.m.–2 a.m.	–[e]	[12,16,50,51,53,114,115]

[a]See Glossary.
[b]There are two peaks during the night. The first peak appears at the first hour after sunset, and the second peak 1 hour before sunrise. The exact time is not the same from east to west because of the time difference.
[c]It has been reported to be zoophilic in Southern China, for example, Hainan [20], Guangdong [110].
[d]Reported especially in Hainan.
[e]*Anopheles pseudowillmori* was reported only in Yunnan[53] and Linzhi Districts, Tibet[16], although it is considered as the potential malaria vector in these areas (especially in Tibet). Its involvement in malaria transmission is still under investigation.

Table 2. Concentration (CO%) and Time of Exposure (min) to Monitor Resistance to Four Insecticides, According to Chinese or WHO Guidelines

Insecticide	China		WHO		Refs
	CO (%)	Time (min)	CO (%)	Time (min)	
DDT	4	60	4	60	(i) Test procedures for insecticide resistance monitoring in malaria vector mosquitoes, WHO 2016, pp.15–16, http://www.who.int/malaria/publications/atoz/9789241511575/en/; (ii) WHO Pesticide Evaluation Scheme, 2016, http://www.who.int/whopes/resistance/en/Diagnostic_concentrations.pdf?ua=1 [62,66]
Malathion	3.2	60	5.0	60	
Deltamethrin	0.01	30	0.05	30	
Permethrin	0.1	30	0.75	30	

as one of the key factors of vivax malaria re-emergence in the central part of China in 2006–2008 [7,57,88]. A similar situation was reported for *An. aquasalis* in the Demerara River estuary of Guyana [89]. Irrigation and dam constructions have also been linked to an increase in malaria risk, although the nature of the effect varies substantially between epidemiological, entomological, and socioeconomic settings [90,91]. While environmental changes enabling poverty reduction are essential to economic development, sustaining malaria elimination will require a clearer mechanistic understanding of the impacts of both vector control and concurrent changes in natural resource management and land use [92].

Facing the Challenges

Updating Knowledge on Malaria Vectors

To manage the challenges related to malaria elimination mentioned above, it is crucial to have updated knowledge on malaria vectors, especially on accurate species identification. This is particularly important when considering that most malaria vectors belong to complexes in which sibling species are morphologically indistinguishable. Ecological characteristics are also key elements to capture in order to implement appropriate control interventions. It is therefore necessary to upgrade the tools for entomological surveillance according to bionomic changes of malaria vectors. Recent publications on the distribution and bionomics of malaria vectors worldwide are good examples of the global knowledge on *Anopheles* mosquitoes [40,47,93–96]. These reviews also updated information on malaria vectors in China, but there are still several knowledge gaps that must be filled. These include, in particular, the influence of behavioral changes of the main vectors on malaria transmission, and the precise distribution and role of sibling species, as well as **secondary vectors**. The focus given to main malaria vectors until recent years has left the secondary ones in the shade, and a real effort should now be given to these secondary vectors in China, and more widely in southeast Asia, as their involvement in malaria transmission must be better framed and analyzed. In addition, there is a need for a nationwide map of the distribution of current malaria vectors based on high-quality surveillance data, including molecular identification of sibling species and the GPS locations of mosquito-collecting points, as done in Thailand for instance [94]. This will be essential for both malaria elimination certification by WHO (WHO: *Eliminating Malaria*, 2016, pp. 22–23Appendix A) and the development of a surveillance strategy at the postmalaria elimination stage.

Updating Surveillance Tools

Entomological survey is the only way to get pertinent information on malaria vectors and to monitor their behavior and their role in malaria transmission. However, the methodology and tools used today, such as light trap, **human landing catch**, cow bait collection, and larval collection, are labor-intensive and time-consuming. In addition, the study sites selected for these investigations are in need of a precise method, which will provide data-based criteria other than experience-based criteria. In this regard, remote sensing, geographic information system, and spatial analysis approaches represent good candidates. Such approaches have been developed since the late 1980s with the objective of establishing host–vector–parasite relationship models allowing for more precise spatiotemporal surveillance of vectors and disease. They were carried out to map the geographic distribution of *Anopheles* mosquitoes in endemic malaria areas such as Belize, Mexico, French Guiana, Brazil, and China [97–101], providing good examples for efficient vector surveillance in further studies.

Concerning the emergence of insecticide resistance, which is a dynamic process, assessing its impact on the efficacy of interventions is an essential but difficult task. In China, although the national malaria surveillance program adopted the monitoring of insecticide resistance since the beginning of the program in 2005, data have been collected from selected fixed sentinel sites. Hence, the surveillance data could only present the status of mosquito populations in limited areas. In a country as large as China, both environmental and socioeconomic developments are highly diverse. Moreover, data sharing on resistance and insecticide use between national health and agriculture departments does not really take place. Data availability and interoperability are still largely missing elements in insecticide resistance management and need to be considered with more attention in future studies. In addition, malaria foci in China, as well as in southeast Asia, are mainly spread along international borders. Their elimination will gain in efficacy if a task force is created with partners and malaria managers from neighboring countries, working in coordination to prevent malaria transmission.

Concluding Remarks

Since the launch of the national malaria elimination program in 2010, malaria prevalence and the distribution zones of the main malaria vectors in mainland China have decreased. However, to achieve malaria elimination by 2020, there is a need to evaluate and follow-up on the behavioral changes of *Anopheles* species in China, driven by both environmental changes and control interventions, and to update the tools for entomological surveillance (see Outstanding Questions). For instance, the role of secondary malaria vectors, like *An. sinensis* in Yunnan, should be monitored with close scrutiny. *An. sinensis,* which settles in rice fields, may represent a major risk for malaria elimination. With *An. sinensis* being an important vector locally, agriculture, and thus the key sector of food production, may also turn into a threat for malaria elimination. A crucial issue for the coming 5 years will therefore be to monitor possible vector replacement but also to investigate potential competition between key societal and economic sectors, such as public health and agriculture, to avoid the occurrence of competitive trends. These studies must bring information to national and international policy makers. They must develop national and international guidelines and decisions on the proper actions to take in order to prevent sectorial competition and to ensure the successful implementation of malaria elimination. Another risk to consider and assess is the reintroduction at postmalaria elimination phase, and proper monitoring and preventive actions will be required. The index of receptivity, which represents the capacity of a given area to be favorable to malaria transmission, should be adopted as an indicator for malaria surveillance. The ecological behavior, such as trophic behavior, biting, and resting behaviors, are in need of further investigation and routine monitoring to assess the potential risk of reintroduction. This is particularly important along international border areas, where one country has achieved malaria elimination while the other neighbor still has local malaria transmission. Molecular techniques, such as PCR, should be routinely implemented to identify vector species and populations and to investigate their respective role in malaria transmission, especially for sibling species such as those of the Minimus and Dirus Complexes.

Outstanding Questions

What is the distribution of the main malaria vectors in China, after several years of malaria control efforts?

What is the current insecticide resistance status of the main malaria vectors in China?

Did environmental change and/or control efforts alter the bionomics of malaria vectors in China?

Do the changes in bionomic characteristics of the main malaria vectors challenge the elimination process? How could we manage these challenges?

What is the role of secondary malaria vectors on malaria transmission in China?

Do we have any of the right tools to monitor the shift in malaria vectors with respect to both population density and bionomics?

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Resources

[i]www.who.int/malaria/publications/world-malaria-report-2016/report/en/

[ii]www.moh.gov.cn/mohbgt/s10788/201005/47529.shtml

[iii]www.nhfpc.gov.cn/zwgk/wtwj/201304/15a4cc7a40b0452191fe409590ca99d8.shtml

[iv]www.who.int/whopes/resistance/en/Diagnostic_concentrations.pdf?ua=1

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