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Malaria Vector Surveillance Report, South Africa, January–December 2022

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Summary

Malaria in South Africa is seasonal and primarily occurs in the Limpopo, Mpumalanga, and KwaZulu-Natal Provinces. Control of malaria vectors is achieved by indoor spraying of residual insecticides (IRS) and limited larval source management. As the country progresses towards malaria elimination, enhanced vector surveillance is necessary in order to obtain comprehensive knowledge of the distribution and density of both primary and secondary vectors responsible for the ongoing residual malaria transmission. This report summarises malaria vector surveillance conducted in 2022 by the provincial malaria control entomology teams in collaboration with partner institutions. The surveillance revealed the presence of four malaria vector species — *Anopheles arabiensis* (n=1,663, 26%), *An. merus* (n=462, 7%), *An. parensis* (n=878, 14%), and *An. vaneedeni* (n=110, 2%). These contribute in varying degrees to ongoing residual malaria transmission in South Africa. Collections also included several closely related non-vector *Anopheles* species. The specimens analysed were collected from KwaZulu-Natal (54%, n=3,442), Mpumalanga (9%, n=601), and Limpopo (37%, n=2,381) provinces. The surveillance information by province and district/municipality supports the ongoing implementation of an IRS-based vector control strategy. In terms of cost and labour effectiveness, we suggest that spraying operations can be stratified by a high rate of proactive coverage in medium-incidence areas (these are the highest incidence districts in South Africa) and along the borders of Mozambique and Zimbabwe, proactive targeted spraying in low-incidence areas, and reactive focal spraying in very low-incidence areas in response to local cases. The completion of proactive spraying should ideally be before the onset of each malaria season. Given that all sporozoite-positive (and therefore malaria-infective) adult *Anopheles* females collected in recent years were found resting outdoors, larval source management, including the treatment of winter breeding sites, should continue to be

used and scaled up as a complimentary method to enhance the effect of IRS in areas where locally acquired cases occur and in other receptive areas at risk for malaria.

Introduction

South Africa's malaria-affected areas include the low-altitude border regions of Limpopo, Mpumalanga, and KwaZulu-Natal (KZN) Provinces. These regions typically experience active malaria transmission, especially during the peak malaria season that spans the summer months of November to April. Malaria incidence in South Africa is generally low, with fewer than 5 000 local cases reported annually.[1]

South Africa's malaria-endemic provinces have developed well-coordinated malaria control operations, including routine vector control, which is primarily based on the application of indoor residual insecticide spraying (IRS) and, to a lesser extent, larval source management.[2] Although IRS has proven efficacy spanning many decades, residual malaria transmission continues and is likely caused by outdoor feeding and resting *Anopheles* vector mosquitoes that are less susceptible to indoor application of insecticides.[3,4,5] In addition, populations of the major malaria vector species, *Anopheles funestus* and *An. arabiensis*, have developed resistance to insecticides, especially in northern KwaZulu-Natal Province.[2,6] The pyrethroid resistance phenotype in *An. arabiensis* in this region is currently of low intensity and is not considered to be operationally significant yet. This is in contrast to the pyrethroid-carbamate resistance profile in *An. funestus* that is of high intensity, highly significant epidemiologically, and was at least partly causative of the malaria epidemic experienced in South Africa during the period 1996-2000.[7]

Residual malaria transmission and insecticide resistance in vector populations within South Africa's borders necessitate ongoing and enhanced vector surveillance to inform best practices for control and elimination. This is especially pertinent in terms of South Africa's malaria elimination agenda.[8] Currently, surveillance is routinely conducted by the entomology teams of Mpumalanga, KwaZulu-Natal, and Limpopo Provinces with support from partner institutions including the National Institute for Communicable Diseases (NICD), the Wits Research Institute for Malaria (WRIM) of the University of the Witwatersrand, the UP Institute for Sustainable Malaria Control (UP ISMC) of the University of Pretoria, and the South African Medical Research Council (SAMRC).

This report summarises malaria vector surveillance in South Africa in 2022 based on specimens referred to the Vector Control Reference Laboratory (VCRL) of the Centre for Emerging Zoonotic and Parasitic Diseases (CEZPD), NICD, as well as specimens collected and analysed by personnel from the University of Pretoria Institute for Sustainable Malaria Control.

Methods

Anopheles mosquitoes were collected from sentinel sites in KwaZulu-Natal, Mpumalanga, and Limpopo Provinces (Figure 1). These specimens were either collected by the VCRL and UP ISMC, or referred to the VCRL by partner institutions and provincial malaria control programme entomology teams from January - December 2022.

Adult *Anopheles* mosquitoes were collected in human-baited net traps, human landing catches, house searches, animal shelters, including cattle kraal, CDC and Encephalitis Vector Survey (EVS) traps, CO_2-baited tent traps, swarm nets, and outdoor clay pots, drums, disused black plastic sheets, modified buckets, and discarded tyres. Other specimens were collected as larvae and reared as adults before analysis. Collections were done at several sentinel sites (Figure 1). Preservation of adult specimens was by desiccation on silica gel in 1.5ml microcentrifuge tubes. Initial morphological identification of each specimen was by VCRL, partner institutions, or provincial malaria control programme personnel. Specimens identified as members of the *An. gambiae* complex or *An. funestus* group were subsequently identified as species using standard polymerase chain reaction (PCR) assays [9,10,11] by VCRL and UP ISMC personnel. The VCRL is a SANAS-accredited laboratory, and specific tests based on the ISO 17025:2017 standard ensured the quality of results for all specimens received and processed at the VCRL.

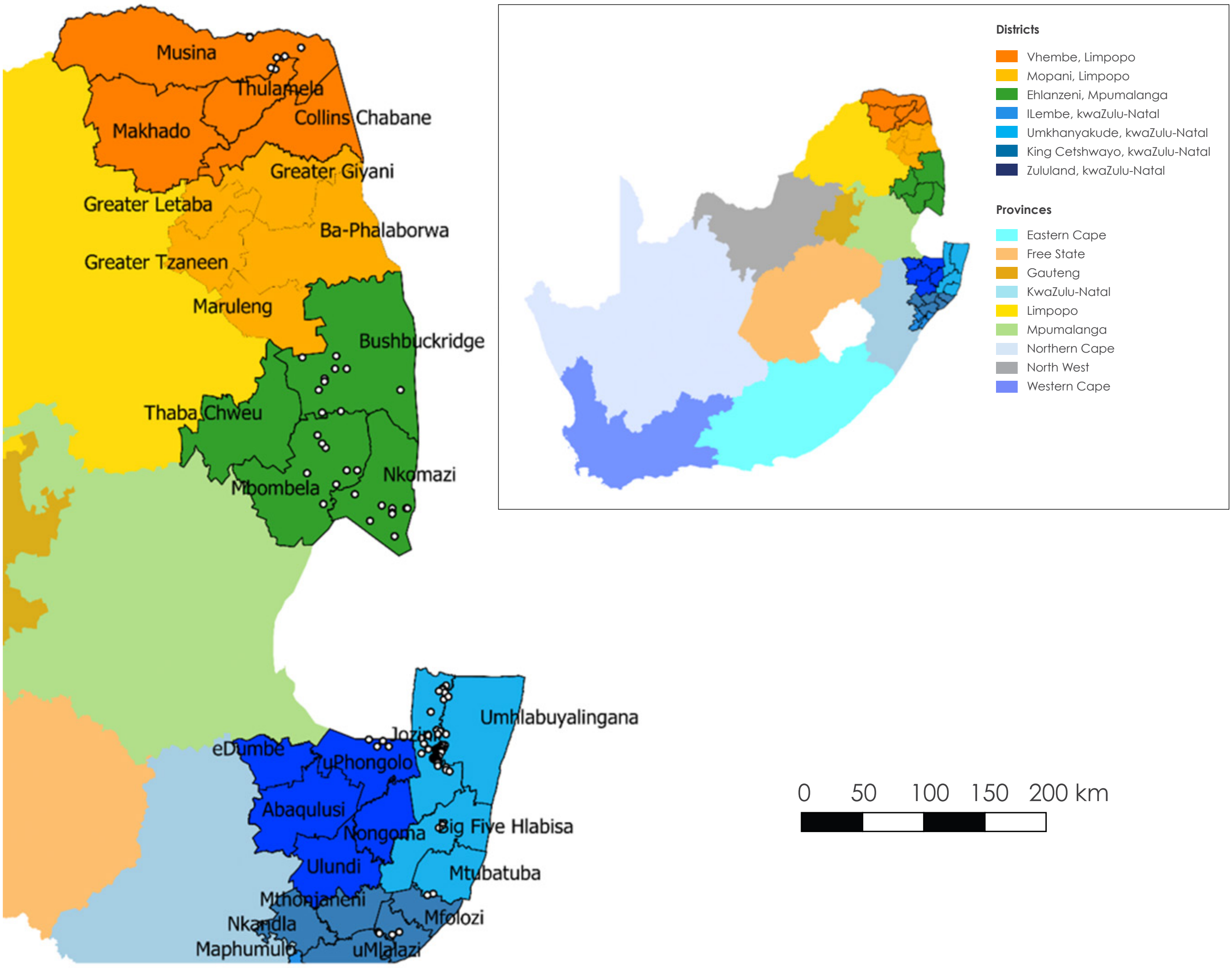


Figure 1. Sentinel sites (white dots) in KwaZulu-Natal, Mpumalanga, and Limpopo Provinces from which *Anopheles* specimens were collected, South Africa, 2022. All maps were created using QGIS Geographic Information System. Open Source Geospatial Foundation Project. http://qgis.org

Results

In total, 6 424 *Anopheles* mosquitoes were collected from Ilembe, Umkhanyakude, King Cetshwayo, and Zululand districts of KwaZulu-Natal Province, the Ehlanzeni district of Mpumalanga Province, and the Vhembe district of Limpopo Province sentinel sites. Most of the specimens were collected from KwaZulu-Natal (54%, n=3,442), followed by Limpopo (37%, n=2,381), and Mpumalanga (9%, n=601) Provinces (Table 1). These were subsequently clustered as either the *An. gambiae* complex (36%, n=2,297), the *An. funestus* group (20%, n=1,309), or other *Anopheles* species (44%, n=2,818). *Anopheles arabiensis* predominated the collections (26%, n=1,663), especially in KwaZulu-Natal Province, although substantial numbers of *An. rufipes* (17%), *An. parensis* (14%), *An. pretoriensis* (8%), and *An. merus* (7%) were also collected. *Anopheles* merus and *An. rufipes* predominated the collections from Mpumalanga and Limpopo Provinces, respectively (Table 1).

Table 1. Numbers of *Anopheles* specimens collected by species and province from different sentinels in South Africa, 2022.

***Anopheles* species complex, group, or other**	**Species**	**KwaZulu-Natal**	**Mpumalanga**	**Limpopo**	**Total**
***An. gambiae* complex**	*An. arabiensis*	*1,590*	*73*		*1,663*
	An. merus	*142*	*320*		*462*
	An. quadriannulatus	*38*	*109*	*25*	*172*
***An. funestus* group**	*An. leesoni*	*17*		*48*	*65*
	An. parensis	*869*		*9*	*878*
	An. rivulorum	*110*	*18*	*33*	*161*
	An. rivulorum-like			*95*	*95*
	An. vaneedeni	*88*	*16*	*6*	*110*
Other *Anopheles* species	*An. caliginosus*	*0*	*1*		*1*
	An. coustani	*61*	*27*	*84*	*172*
	An. cydippis			*2*	*2*
	An. demeilloni	*11*	*1*	*39*	*51*
	An. flavicosta			*3*	*3*
	An. gibbinsi			*80*	*80*
	An. listeri			*130*	*130*
	An. longipalpus		*2*		*2*
	An. maculipalpis	*15*	*4*	*1*	*20*
	An. marshallii group	*316*	*1*		*317*
	An. nili			*82*	*82*
	An. pharoensis	*52*		*1*	*53*
	An. pretoriensis	*19*	*20*	*499*	*538*
	An. rhodesiensis			*121*	*121*
	An. rufipes	*38*	*9*	*1029*	*1076*
	An. squamosus	*36*		*2*	*38*
	An. tenebrosus	*40*		*80*	*120*
	An. theileri			*12*	*12*
Total		*3,442*	*601*	*2,381*	*6,424*

Collections of the malaria vectors *An. arabiensis* and *An. merus* (members of the *An. gambiae* species complex) were from sentinel sites in the KwaZulu-Natal and Mpumalanga Provinces (Figure 2). In KwaZulu-Natal Province, populations of these species were in the Jozini and Big Five Hlabisa municipalities of the Umkhanyakude District, the uPhongolo municipality of Zululand District, and the uMfolozi, uMhlathuze, and uMlalazi municipalities of the King Cetshwayo District. In Mpumalanga Province, these species were in Bushbuckridge, Mbombela, and Nkomazi municipalities of the Ehlanzeni District.

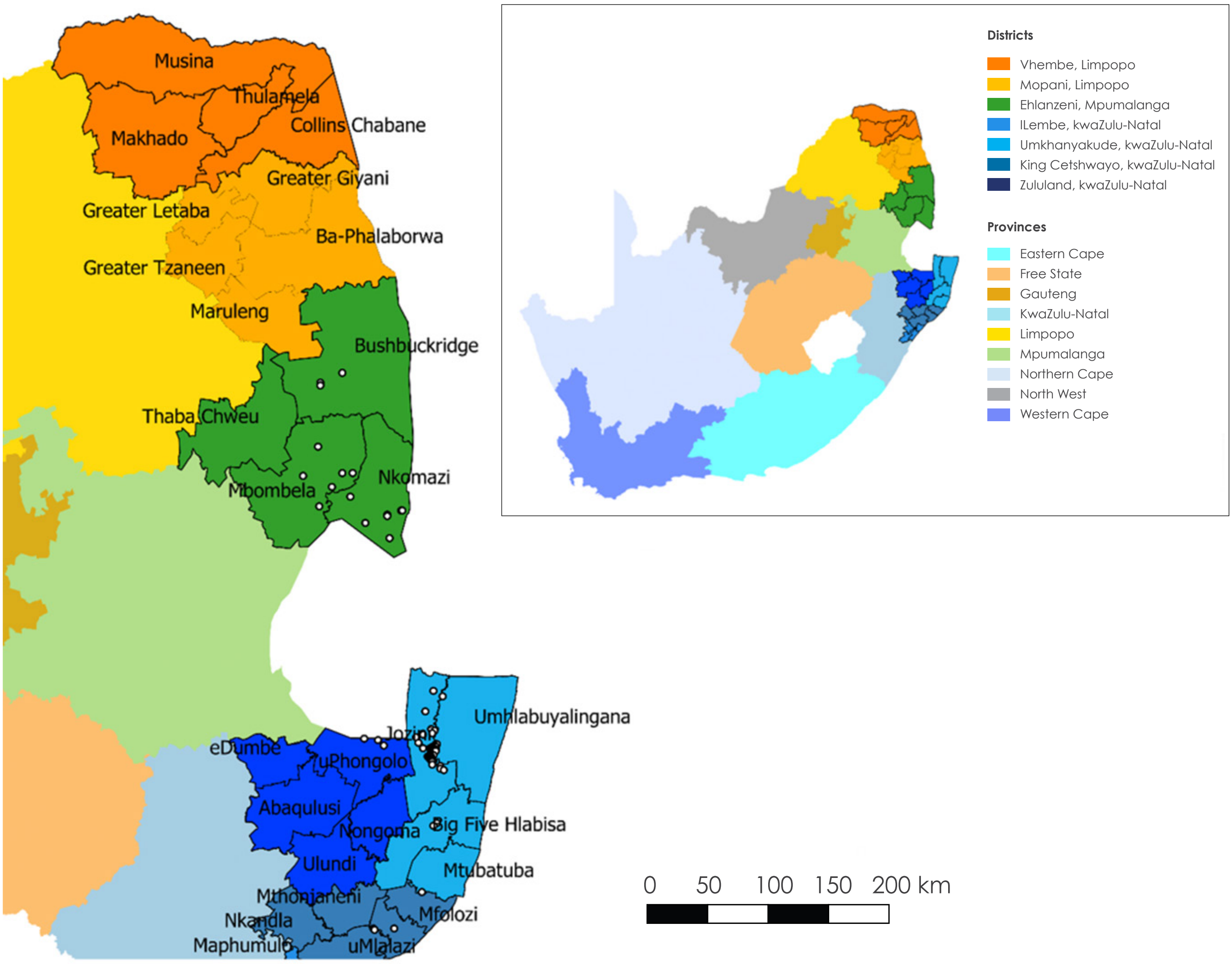


Figure 2. Sentinel sites (white dots) in KwaZulu-Natal, Mpumalanga, and Limpopo Provinces that yielded samples of *Anopheles arabiensis* and *An. merus* (*Anopheles gambiae* complex), South Africa, 2022.

Samples of the potential secondary malaria vector species *An. vaneedeni*[3] came from sentinel sites in all three endemic provinces, while collections of *An. parensis*, also a potential secondary vector[12], were from the KwaZulu-Natal and Limpopo Provinces (Table 1). Other potential malaria vector species within the *An. funestus* group that were collected from sentinel sites in these three provinces included *An. leesoni* and *An. rivulorum*[13] (Table 1). Collection site localities for all known and suspected vector species within the *An. funestus* group are indicated in Figure 3. Specimens of these species came from the Jozini, Umhlabuyalingana, and Mtubatuba municipalities of the Umkhanyakude District, the Uphongolo municipality of Zululand District, KwaZulu-Natal Province, the Nkomazi and Bushbuckridge of the Ehlanzeni District of Mpumalanga Province, and the Musina and Thulamela municipalities of the Vhembe District of Limpopo Province.

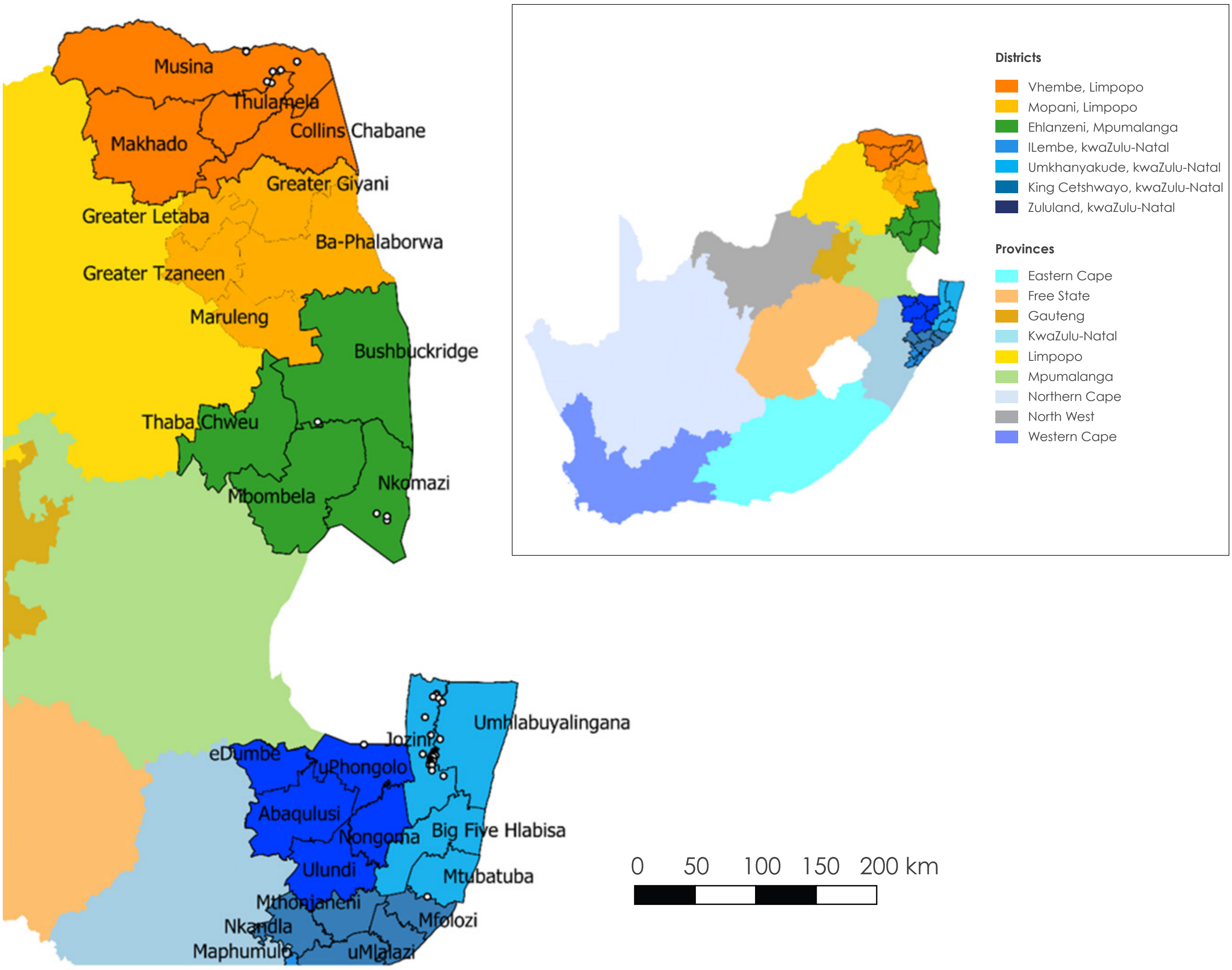


Figure 3. Sentinel sites (white dots) in KwaZulu-Natal, Mpumalanga, and Limpopo Provinces from which *Anopheles funestus* group samples of the known and potential secondary malaria vectors *An. vaneedeni*, *An. parensis*, *An. Rivulorum*, and *An. leesoni* were collected, South Africa, 2022.

Anopheles coustani, *An. demeilloni*, *An. longipalpis*, *An. marshallii* group, *An. nili*, *An. pharoensis*, *An. pretoriensis*, *An. rufipes*, *An. squamosus*, *An. Tenebrosus*, and *An. theileri* are incriminated as malaria vectors in other regions of Africa[13-20] but not in South Africa. Figure 4 shows the distribution of these potential vector species. Specimens of these species were collected in the Jozini and Umhlabuyalingana municipalities in the Umkhanyakude District, as well as in the uPhongolo municipality of the Zululand district of KwaZulu-Natal Province, in the Bushbuckridge and Nkomazi municipalities of the Ehlanzeni District of Mpumalanga Province, and in the Musina and Thulamela municipalities of the Vhembe district of Limpopo Province.

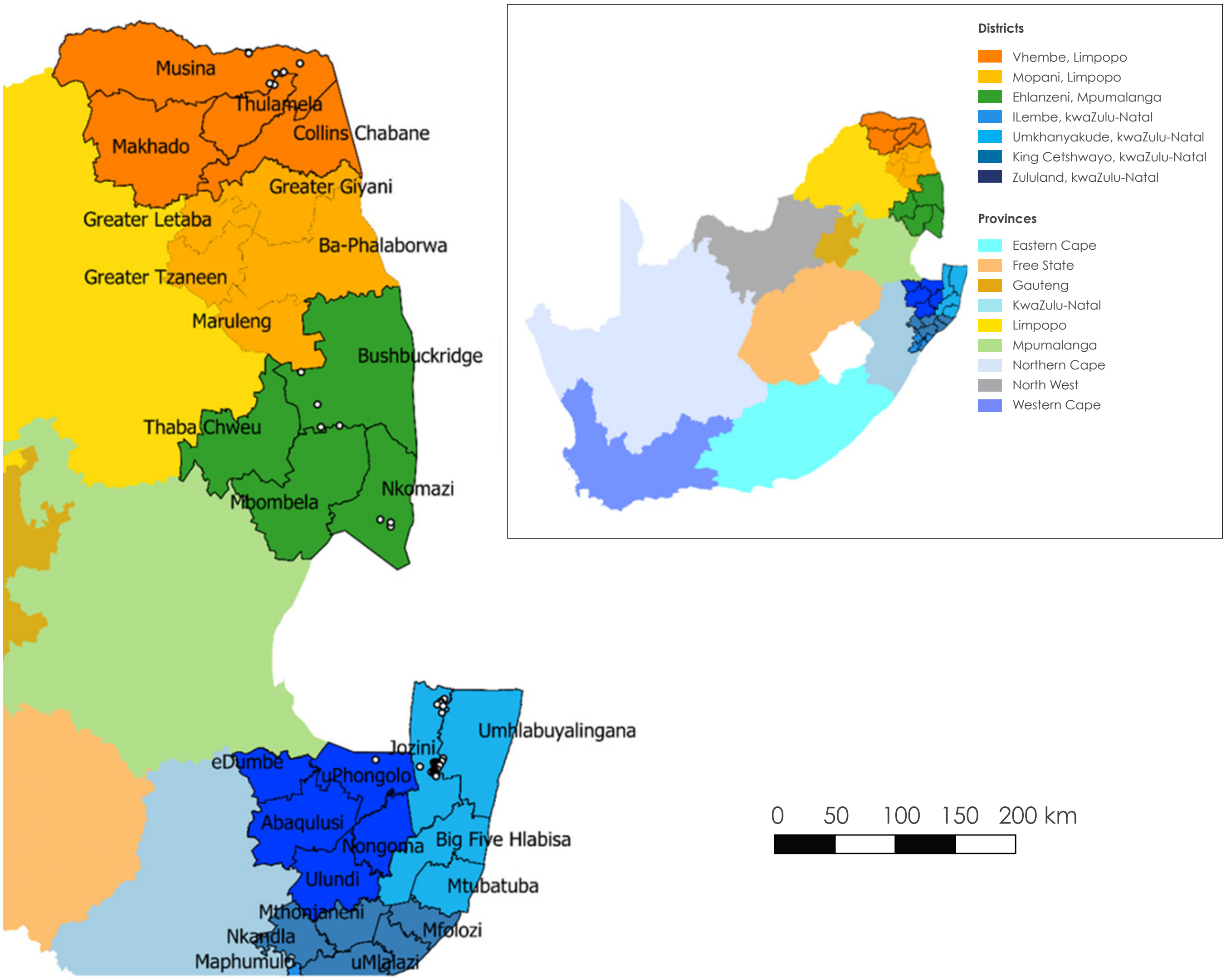
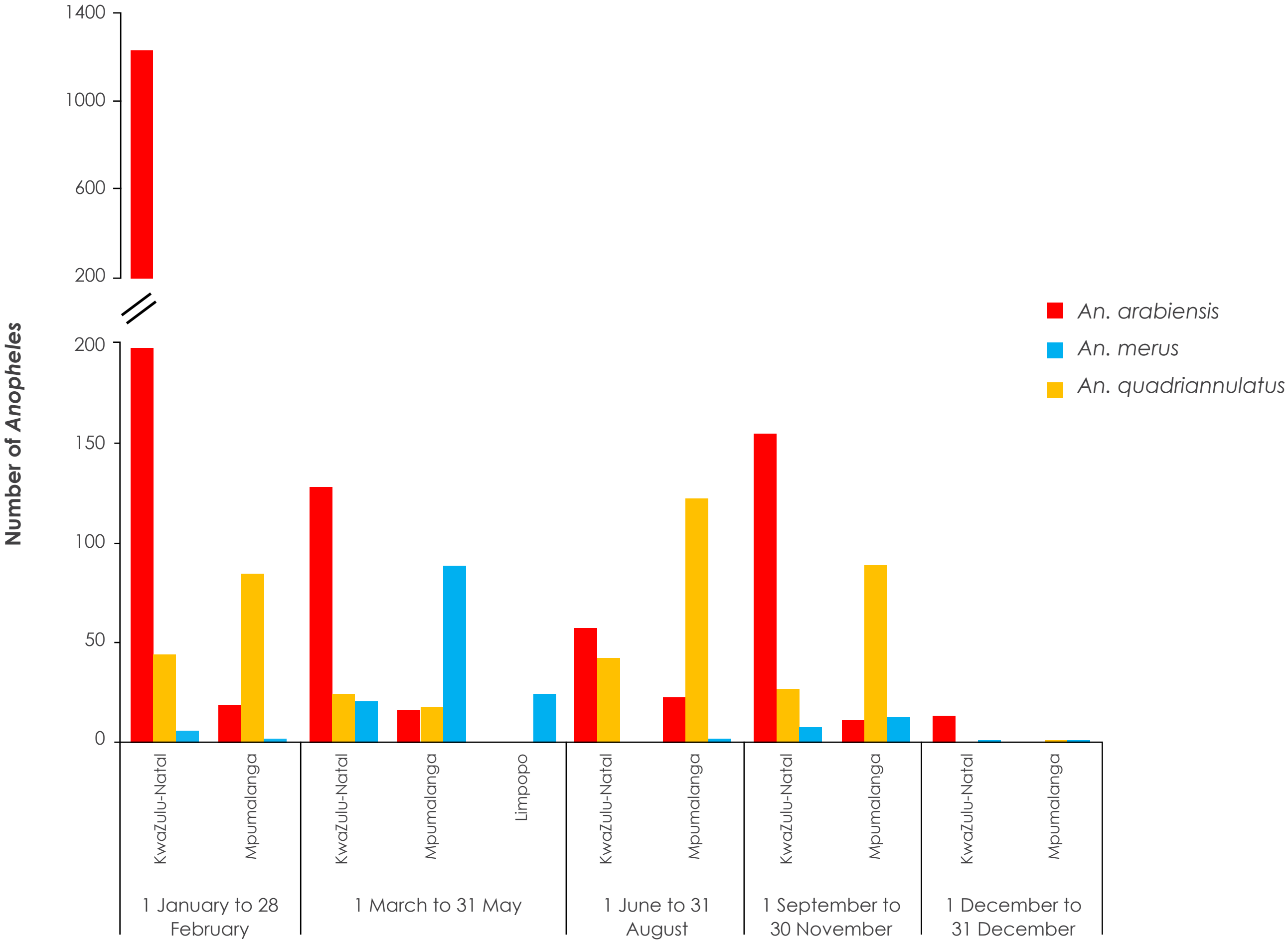


Figure 4. Sentinel sites (white dots) in KwaZulu-Natal, Mpumalanga, and Limpopo Provinces from which samples of miscellaneous *Anopheles* species (species not belonging to the *An. gambiae* complex or *An. funestus* group) were collected. These sites included the collection of potential secondary malaria vectors *Anopheles coustani*, *An. demeilloni*, *An. longipalpis*, *An. marshallii* group, An. nili, *An. pharoensis*, *An. pretoriensis*, *An. rufipes*, *An. squamosus*, *An. Tenebrosus*, and *An. theileri*, South Africa, 2022.

The number of anophelines collected by species during specific seasons was highly variable across the three endemic provinces. *Anopheles arabiensis* was prevalent throughout the year in KwaZulu-Natal Province, while *An. merus* was particularly prevalent during summer (January to February), winter (June to August), and spring (September to November) in Mpumalanga Province (Figure 5). *Anopheles quadriannulatus* predominated the *Anopheles gambiae* complex collections from Limpopo Province during autumn (March to May). Of the *An. funestus* group, *An. parensis* was most common during summer and autumn in KwaZulu-Natal Province. *Anopheles vaneedeni* predominated in Mpumalanga Province during summer (January to February), while *An. rivulorum* was prevalent during autumn. *Anopheles rivulorum-like* dominated the collections in Limpopo Province during autumn and spring (Figure 6). Miscellaneous *Anopheles* species collections in KwaZulu-Natal Province indicate that *An. marshallii* group predominated throughout the year (Figure 7). *Anopheles coustani* was predominant in summer (January to February) and autumn, while in spring, *An. pretoriensis* predominated the collections of miscellaneous species in Mpumalanga Province. *Anopheles gibbinsi* and *An. rufipes* predominated the miscellaneous species in autumn and spring, respectively, in Limpopo Province.



***An. gambiae* complex species collected during specific months**

Figure 5. Distribution (in absolute numbers) of *Anopheles gambiae* complex specimens collected by species, province, and season, South Africa, 2022. Summer = 1 January to 28 February and December; Autumn = 1 March to 31 May; Winter = 1 June to 31 August; Spring = 1 September to 30 November.

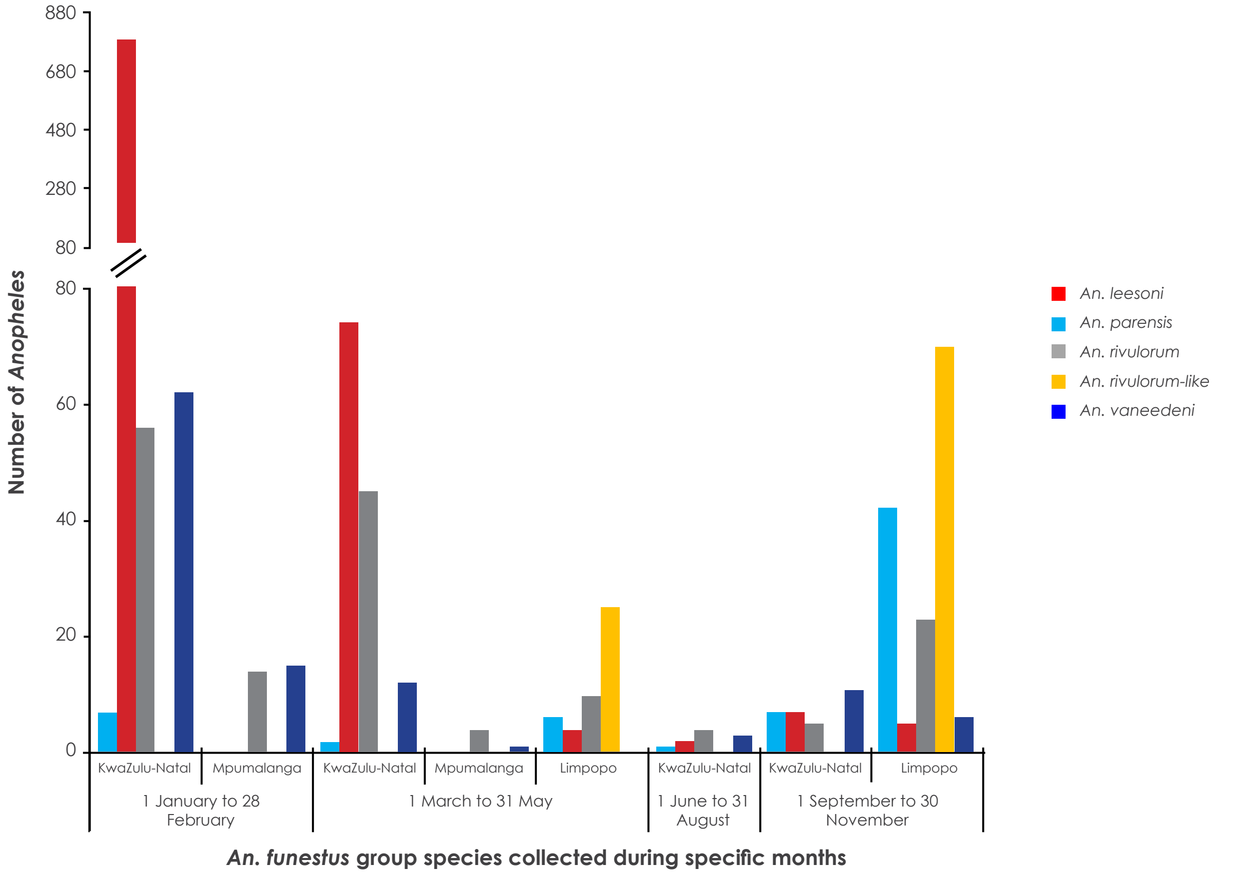


Figure 6. Distribution (in absolute numbers) of *Anopheles funestus* group specimens collected by species, province, and season, South Africa, 2022. Summer = 1 January to 28 February; Autumn = 1 March to 31 May; Winter = 1 June to 31 August; Spring = 1 September to 30 November.

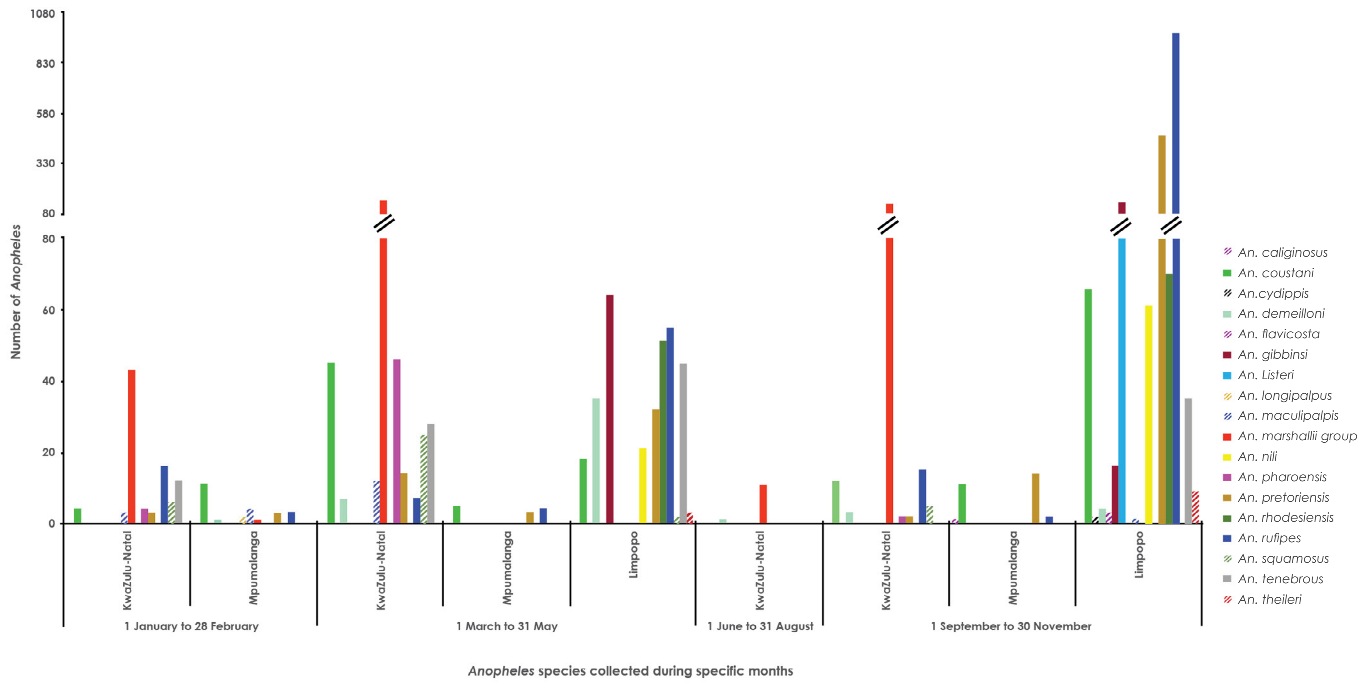


Figure 7. Distribution (in absolute numbers) of miscellaneous *Anopheles* specimens collected by species, province, and season, South Africa, 2022. Summer = 1 January to 28 February and December; Autumn = 1 March to 31 May; Winter = 1 June to 31 August; Spring = 1 September to 30 November.

The *Anopheles* specimens collected in 2022 were sampled as either larvae or adults. In KwaZulu-Natal Province, 94% of the species were collected as adults, while in Limpopo and Mpumalanga, 51% and 33% of *Anopheles* species were collected as adults, respectively. In all three provinces, CO_2-baited tent traps were used to collect adult mosquito specimens. CO_2-baited tent traps were most effective in Limpopo, where 74% (n=880) of the mosquitoes were sampled using this method. So was Mpumalanga, where 35% (n=59) of the specimens were also derived from this sampling method. In contrast, clay pots were the most effective sampling method in KwaZulu-Natal Province (54%, n=1,673), followed by discarded tyres (27%, n=839).

Collections of adult *An. gambiae* complex mosquitoes, especially *An. arabiensis* and *An. merus*, were from clay pots, CO_2-baited tent traps, human-landing catches, cattle kraal posts, drums, male swarms, discarded tyres, human-baited net traps, animal shelters, and disused black plastic sheeting (Table 2). Collections of adult *An. funestus* group including *An. parensis*, *An. vaneedeni*, *An. Rivulorum*, and *An. leesoni*, were from all the collection methods listed in Table 2, with the exception of indoor collections.

Collections of the potential secondary malaria vectors Anopheles coustani, *An. demeilloni*, *An. longipalpis*, *An. marshallii* group, *An. nili*, *An. pharoensis*, *An. pretoriensis*, *An. rufipes*, *An. squamosus*, *An. Tenebrosus*, and *An. theileri* were from clay pots, CO_2-baited tent traps, human-landing catches, CDC light traps, EVS traps, cattle kraal posts, indoor searches, modified buckets, discarded tyres, and animal shelters (Table 2).

Table 2. Numbers of adult *Anopheles* specimens by species and sampling method from the malaria-endemic provinces of South Africa, 2022.

***Anopheles* species complex, group, or other**	**Species**	**Clay pots**		**CO_2 tent traps**			**Human landing catches**		**CDC-light traps**	**EVS traps**	**Cattle kraal posts**		**Drums**	**Indoor searches**	**Male swarm**		**Modified buckets**	**Discarded Tyres**	**Human-baited net trap**	**Animal Shelters**	**Black plastic sheet**
		KZN	**MP**	**KZN**	**MP**	**LP**	**KZN**	**MP**	**LP**	**LP**	**KZN**	**MP**	**KZN**	**KZN**	**KZN**	**MP**	**KZN**	**KZN**	**KZN**	**KZN**	**KZN**
***An. gambiae* complex**	***An. arabiensis***	914	8	2	1		9	3			64	3	6		21		22	382	1	17	11
	An. merus	41	7	2	20		9	17			13	1	2		4	30		33	1		
	An. quadriannulatus	2	1			20		1	1	4	5										
***An. funestus* group**	***An. leesoni***	7				30			14	4	1		1				1	4		2	
	An. parensis	405		1		1			3	3	21		3				3	382		18	14
	An. rivulorum	24		20	5	8		3	8	1	11	10						14		40	
	An. rivulorum-like					54			24	8											
	An. vaneedeni	45	3	5	6	2		5	3	1	13					2		18		2	
Other *Anopheles* species	***An. caliginosus***							1													
	An. coustani	1		12	12	60		13	8	1	4										42
	An. cydippis					2															
	An. demeilloni	5			1	9			3	24									3		
	An. flavicosta								3												
	An. gibbinsi					74				5											
	An. Listeri					51				1											
	An. longipalpus				2																
	An. maculipalpis	13		2	2	1		1				1									
	An. marshallii group	180		8	1												3	3	2		
	An. nili					61															
	An. pharoensis	7		38		1					2										3
	An. pretoriensis			3	3	195			19	11							1	1			14
	An. rhodesiensis					33			2	10											
	An. rufipes	6		31	6	207			113	18	5						1	1			
	An. squamosus	7		23							6										6
	An. tenebrous	16		16		64			11	5				4					1		
	An. theileri					7				3											

Discussion

Malaria vector surveillance in 2022 in the KwaZulu-Natal, Mpumalanga, and Limpopo provinces of South Africa revealed 17 *Anopheles* species of interest in malaria transmission. The collections included species previously incriminated as vectors in South Africa (*An. arabiensis*, *An. parensis*, and *An. vaneedeni*),[3,4,12] as well as species incriminated as vectors in other African localities (*An. merus*, *An. leesoni*, *An. rivulorum*, *An. coustani*, *An. demeilloni*, *An. longipalpis*, *An. marshallii* group, *An. nili*, *An. pharoensis*, *An. pretoriensis*, *An. rufipes*, *An. squamosus*, *An. tenebrosus*, and *An. theileli* [13-20]).

The major vector, *An. arabiensis*, was the predominant species collected during 2022, accounting for 46% of the specimens collected from KwaZulu-Natal Province. This species was also present in Mpumalanga Province, accounting for 12% of the specimens collected, and is likely present in Limpopo Province, although no specimens were collected in 2022. *Anopheles arabiensis* is currently the major malaria vector in South Africa, following the near eradication of *An. funestus* by intensive IRS campaigns over the last two decades.[2,21] Since *An. arabiensis* females are at least partially inclined to feed and rest outdoors, they are less susceptible to control by IRS.[4,5] This species is therefore the primary vector of residual malaria in South Africa,[4] but not the only contributor.

Collections of *An. merus* were from KwaZulu-Natal and Mpumalanga Provinces, with the highest numbers coming from Mpumalanga Province, similar to collections from 2019 to 2021. Although *An. merus* has not been directly implicated in malaria transmission in South Africa, its confirmed vector status in other regions, such as southern Mozambique (sporozoite rates for *An. merus* in the Boane District being 4.2%),[22] suggests that it is most likely an important secondary malaria vector in South Africa. This species is primarily a coastal saltwater breeder, although it has also been collected from freshwater larval habitats in southern Africa, including sites in South Africa.[23]

Anopheles parensis and *An. vaneedeni* have been implicated as secondary malaria vectors in South Africa,[3,12] while other members of the *An. funestus* group (*An. rivulorum* and *An. leesoni*) have been implicated as secondary malaria vectors in East Africa.[13] Collections of *An. vaneedeni* and *An. rivulorum* were from all three endemic provinces, while *An. parensis* and *An. leesoni* were detected in KwaZulu-Natal and Limpopo Provinces. *Anopheles vaneedeni* likely contributes to residual malaria transmission in South Africa given its tendency to rest outdoors and to feed on humans, amongst other vertebrate hosts.[3] *Anopheles parensis* is primarily zoonotic and may rest indoors and outdoors. This species will also occasionally feed on humans[24] and can potentially contribute to residual malaria transmission in South Africa.

The major vector *An. funestus s.s.*, the predominant malaria vector species in neighbouring Mozambique and Zimbabwe, was not detected in South Africa in 2022. This can be attributed to year-on-year IRS programmes in the malaria-endemic provinces. Ongoing vigilance for the presence of this species is, however, important. This is because *An. funestus* is an efficient malaria vector that can cause outbreaks and epidemics in comparatively short time frames, exacerbated by high-intensity pyrethroid resistance in most populations of this species in south-eastern Africa.

Other species that occur in South Africa and that have been incriminated as malaria vectors in various African localities include *An. coustani*, *An. demeilloni*, *An. longipalpis*, *An. marshallii* group, *An. nili*, *An. pharoensis*, *An. pretoriensis*, *An. rufipes*, *An. squamosus*, *An. tenebrosus*, and *An. theileri*.[13-20] It is possible that one or more of these species plays a role in residual malaria transmission in South Africa. *Anopheles coustani*, *An. demeilloni*, *An. pretoriensis*, and *An. rufipes* were present in all three endemic provinces in South Africa in 2022.

Anopheles population densities tend to fluctuate between seasons, as indicated in the collection data for 2022. They are generally highest during the late summer months, congruent with increased rainfall[4], and translate into higher malaria transmission rates during summer and especially late summer.

Collections of the *Anopheles* species incriminated as vectors in South Africa, *An. arabiensis*, *An. parensis*, and *An. vaneedeni*, were predominantly from clay pots. Collections of other potential secondary vectors were predominantly from CO_2 tent traps, clay pots, discarded tyres, and EVS traps. These data show that collection methods targeting adult mosquitoes yield greater critical surveillance information than exclusive reliance on larval collections, especially in terms of vector species assemblage (risk and receptivity) and vector incrimination.

The urban malaria vector *An. stephensi* has not been detected in southern Africa to date, but is nevertheless increasing its range in Africa.[25] This species is endemic to South-East Asia and parts of the Arabian Peninsula and has recently been detected in the horn of Africa, Sudan, and most recently in East and West Africa. *Anopheles stephensi* generally breeds in clean, potable water, and adult females take blood from humans and livestock. It's mode of spread into Africa is evidently shipping, and based on an analysis of global shipping networks, South Africa is at risk of importing this species.[26] Vigilance for *An. stephensi* in east coast seaports and urban and peri-urban areas of malaria-endemic districts is therefore indicated.

The occurrence of primary and secondary vector species in all three of South Africa's malaria-endemic provinces shows that the affected districts/municipalities remain highly receptive to malaria despite ongoing IRS operations each year. During 2022, Limpopo Province recorded the highest number of local malaria cases, primarily in the Mopani and Vhembe districts, yet the major vector species *An. arabiensis* and *An. funestus* were not detected. This suggests that secondary vector species play an especially important role in ongoing malaria transmission in Limpopo Province, which is likely true for the other endemic provinces as well, but to a lesser extent. To date, only *An. funestus s.s.* is historically implicated in malaria transmission in Limpopo Province, although this species was not detected in 2022. The entomological drivers of malaria transmission in this province are yet to be fully determined.

Conclusions

Several malaria vector species occur in the north-eastern lowveld regions of South Africa, with their relative abundances remaining comparatively high through the dry winter months in some instances. These data indicate a high receptivity for malaria and therefore, a high risk of resurgence in endemic areas currently cleared up or at very low incidence. Despite co-ordinated provincial IRS programmes that usually achieve high spray coverage rates (80% or more of targeted structures in endemic areas), populations of these species persist and at least three of them - An. arabiensis, An. vaneedeni, and An. parensis – have previously been implicated in ongoing residual transmission in South Africa (An. merus is also a highly likely contributor). The reasons for this are multiple and certainly include outdoor-biting and outdoor-resting components of these species. The vector surveillance information by province and district/municipality from 2022 supports the ongoing implementation of a stratified IRS-based vector control strategy supported by larval source management for the control of residual malaria.

We recommend:

- Maintenance of malaria vector surveillance in South Africa's endemic provinces on a weekly to monthly basis, especially during summer and autumn, by provincial entomology teams with the support of partner institutions (NICD, UP ISMC, SAMRC, and WRIM).
- Prioritisation of insecticide susceptibility data, especially for populations of major vector species. Collection of susceptibility data should be annual and conducted in collaboration with partner institutions. Priority insecticides include deltamethrin, pirimiphos methyl, DDT, and clothianidin, if possible.
- Emphasis on the collection of adult *Anopheles* mosquitoes using an array of proven methods. This necessarily involves night-time collections by surveillance teams and personnel of partner institutions. Larval collections, conducted during the day, are also important, primarily for the detection and geolocation of breeding sites.
- Biannual vector surveillance (by provincial entomology team personnel) in those districts or municipalities in endemic provinces that are currently malaria-free. This provides important information on malaria receptivity and the risk of re-introduction.
- Annual sampling (by provincial entomology team personnel and partner institutions) of aquatic stage mosquitoes from potential *An. stephensi* breeding sites, especially in east coast seaports as well as urban and peri-urban areas in malaria-endemic districts.
- Use of the provincial DHIS2 systems for the collation of vector surveillance data. Senior entomology team members, with the support of information officers, can do this. Partner institutions are strongly encouraged to share their surveillance data with the national and provincial control programmes by uploading pertinent data to the DHIS2 databases.
- Stratification of annual IRS-based vector control operations by a high rate of proactive coverage in medium-incidence areas (these are the highest incidence districts in South Africa) and along the borders of Mozambique and Zimbabwe, proactive targeted spraying in low-incidence areas, and reactive focal spraying in very low-incidence areas in response to local cases. Proactive spraying should achieve a high rate of coverage (>95%) in areas of active transmission based on incidence data from preceding malaria seasons and the occurrence of major and secondary vector species.
- Completion of IRS activities, as conducted by provincial malaria control personnel, before the onset of each malaria season, i.e. October – November.
- Larval habitats mapping and characterisation to facilitate larviciding
- Scaling up of larviciding, including the treatment of winter breeding sites, as a complimentary method to enhance the effect of IRS in areas where locally-acquired cases occur and in other receptive areas at risk for malaria.[27]
- Maintenance and revision of insecticide resistance management practices that hinge on vector surveillance information and the market availability/affordability of third-generation insecticides. These include products containing one or a combination of the following active ingredients: pyrethroids, pirimiphos methyl, and clothianidin.

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Conflicts of interest

The authors declare no conflicts of interest

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