Review of the ecology of malaria vectors in the WHO Eastern Mediterranean Region

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On the basis of published records and unpublished reports to WHO, the author reviews the information available on the ecology of 15 anopheline malaria vectors occurring in areas of the WHO Eastern Mediterranean Region where attack measures are being applied. The information, which is still incomplete, relates chiefly to the period since 1956, the year when the malaria eradication programme in the Region was launched. An attempt is made to evaluate the control measures undertaken so far, and to provide data on the sensitivity to insecticides, behaviour, and mortality of vector populations.

This paper reviews recent information on the ecology of malaria vectors in the area designated by the World Health Organization as the Eastern Mediterranean Region, with special reference to technical problems. Earlier information can be found in older literature (11, 15, 19). The review mainly covers the principal and some additional malaria vectors on which information is available in published and unpublished reports from countries with a malaria eradication or control programme under way. Vectors in countries with programmes in the maintenance phase (Israel and Lebanon) or where malaria has been eradicated (Cyprus) are not included, since the potential of former vectors in such areas is outside the scope of this paper.

The area under discussion contains fauna of three zoogeographical regions—the Ethiopian, the Palaearctic and the Oriental regions. As far as possible the review follows this sequence, starting with vectors occurring in the southernmost part of the area and then discussing those of the north and north-east.

*Anopheles gambiae* Giles

This is the most important malaria vector of the Ethiopian zoogeographical region. In Democratic Yemen, Ethiopia, Saudi Arabia, Somalia, Sudan, and Yemen, *A. gambiae* can be found throughout the year in riverine areas or areas with permanent sources of water, though at much reduced densities during the dry season. Even in areas with limited sources of water, as in Saudi Arabia, Somalia, and Sudan, *A. gambiae* can persist throughout the dry season at a very low density, breeding in the ecologically most suitable sites. These may be termed “mother foci”, from which *A. gambiae* spreads during the rainy season to the surrounding areas that are dry during the arid season. According to Davidson, species B is the only member of the *A. gambiae* complex that has so far been identified from Saudi Arabia, Democratic Yemen, Sudan, and Ethiopia, although there is a single record of species C from Ethiopia (G. Davidson and G. B. White, personal communications, 1973). In climatically favourable years, severe malaria epidemics may develop, as happened in 1950/51 and 1957/58 in Saudi Arabia.

Fontaine et al. (4) reported an epidemic in Ethiopia in 1958 that struck areas at altitudes of 1600–2150 m and concluded that *A. gambiae* was the only vector involved. The main precipitating cause was the unusual weather in that year; rainfall exceeded all previous records while temperature and humidity were abnormally high. Working near Nazareth at an altitude of 1600–1800 m in 1964/65, in an unsprayed area where the parasite rate ranged

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2 The WHO Eastern Mediterranean Region comprises the following countries: Afghanistan, Bahrain, Cyprus, Democratic Yemen, Egypt, Ethiopia, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libyan Arab Republic, Oman, Pakistan, Qatar, Saudi Arabia, Somalia, Sudan, Syrian Arab Republic, Tunisia, United Arab Emirates, and Yemen.

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between 2.8% and 31.9%, Rishikesh a reported sporozoite rates as low as 0.11–0.31% in 4,513 A. gambiae females dissected. A review of anopheline mosquitoes in Ethiopia by O’Connor (21) quotes many negative results of dissections of A. gambiae carried out by several workers in different parts of the country; an exception was one record of higher gland infection, found in 3 out of 100 A. gambiae dissected in Welo Province by Rice in 1955/56. Krafur (13), working in a savannah area extending along the River Baro at Gambela, recorded an average sporozoite rate of 2.89% in the wet season and 0.37% in the dry season. Using the parous rate and the immediate and delayed sporozoite rate to calculate the theoretical daily survival for A. gambiae and A. funestus, he arrived at estimated values of 0.89 for the wet season and 0.79 for the dry season.

In the area under the attack phase of the malaria eradication programme in Ethiopia, where operations began in 1966/67, A. gambiae house-resting and biting densities have been much reduced, except in instances when operational defects, mainly related to human ecology, were involved. Jolivet (unpublished report to WHO, 1959) reported that some A. gambiae were found resting in a sugar-cane plantation near breeding places during the day, but no details on the density and the abdominal stages were given. From observations made in Nazareth, Rishikesh a concluded that the species is highly endophilic. His data on the blood digestion stages of house-resting populations suggest, though, that a proportion of females leaves the indoor resting shelter before the completion of the gonotrophic cycle. However, box shelters used for sampling outside resting populations did not yield a significant number of A. gambiae.

Outdoor resting of species B was observed by Haridi (9) in July–October 1967 in the Khashm El Girba area, Kassala Province, Sudan. The area of observation had been under DDT house spraying since 1964 and a high incidence of malaria was recorded during the period of study. Of 432 females collected from outside natural shelters in September and October, 57% were bloodfed and the fed/gravid ratio was 2:1. Of 125 females caught at these shelters that had taken bloodmeals, 26% contained human blood, 70% cattle blood and the remainder blood of other vertebrates. It is not known whether the females found positive for human blood had escaped from human habitations or had fed on people sleeping outside with their cattle. Two individuals positive for sporozoites were detected among 56 females collected from outside shelters. At the same time, the parous rate among 54 females collected from outside shelters was 57%, giving a probability of daily survival of 0.758 assuming that the gonotrophic cycle of the outside resting population was 2 days. The outside resting of A. gambiae coincided with a large exodus from sprayed houses, as demonstrated by window trap observations, with a survival rate of 88–94%. The species was found to be susceptible to DDT. The indoor density also markedly increased during September and October; a fed/gravid ratio of 3.5:1 was found and one sporozoite-positive female was detected among 11 parous females dissected. Haridi suggested that the exodus of mosquitoes from sprayed houses and the high survival rate may have been partly attributable to a natural behaviour pattern of A. gambiae species B in this part of Sudan, or a result of the irritant effect of DDT. The high survival rate could also be explained by the ageing of DDT deposits or by inadequate spraying and the presence of unsprayable objects, suggesting that in view of the partial exophily of A. gambiae and irritant effects of DDT, only active deposits of the insecticide would be effective in producing a high mortality. Haridi concluded that the epidemiological significance of outdoor resting populations should not be overlooked and further observations should be made to identify the ecological conditions favoured by such populations in different parts of Sudan.

The dry season biology of a member of the A. gambiae complex (probably species B) and its resurgence in seasonally waterless areas has been investigated in Sudan (21). In the White Nile valley, the species was found to maintain itself by low-level breeding; larvae, male mosquitoes, and parous females were found throughout the dry seasons of 1966 and 1967. In contrast, in scattered villages of the arid area of Fattasha situated more than 20 km from the Nile Valley, regular sampling through the cool dry and hot dry months of the year failed to detect any A. gambiae except nulliparous females in inhabited and vacant huts, dry wells, and animal burrows. In the females collected from November to April, the ovaries did not develop beyond Christophers’ stages II and III and the stomachs contained small amounts of fresh or old blood. Normal development of the ovaries was observed during the favourable season. Evidently the female A. gambiae population can adapt to the severe drought and heat

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of the arid zone in Sudan by continuing to feed, but ovarian development is extremely retarded.

The first confirmed record of DDT resistance in *A. gambiae* in East Africa came from El Guneid sugar estate, Sudan, in January and March 1970, and the mode of inheritance of the resistance was studied by Haridi (10). The same mosquito population also showed a pronounced resistance to dieldrin. Previously, HCH had been sprayed in this locality, being replaced by DDT in 1969. It seems that high selection pressure had been created by pesticides used on cotton crops before the sugar-cane was planted and in cotton plantations still surrounding the estate. The area was carefully sprayed with DDT in August 1970 in an attempt to determine the practical implications of DDT resistance in this population. With 4 hours’ exposure to 4% DDT in September 1970, the lowest mortality was 76%, while trap mortality was about 24%, gravid females forming a large proportion of exit trap collections. The man-biting density was as high as 27 per man per night, and the indoor resting density was estimated to be about 60 per man-hour of searching. Further instances of DDT resistance in *A. gambiae* in other parts of Sudan were reported to WHO in 1971 and 1972.

*Anopheles funestus* Giles

Next to *A. gambiae*, this is the second most important malaria vector in the Ethiopian zoogeographical region. It occurs in Ethiopia, Somalia and Sudan, though information from these countries on its ecology and behaviour is fragmentary. In Ethiopia, although it is present in most areas occupied by *A. gambiae*, its density is usually much lower, except in certain areas where favourable breeding conditions prevail (20). From observations in Ethiopia, Rishikesh a concluded that *A. funestus*, like *A. gambiae*, is highly endophilic and acts as an additional vector. No gland infection was found in 339 females dissected. The species responds to residual house spraying with DDT. Limited susceptibility tests recently carried out in Ethiopia showed that it is susceptible to DDT but a low level of resistance to dieldrin was encountered. Krafsur (14), reviewing his investigations in the Gambela area, determined the vectorial status of *A. gambiae*, *A. funestus* and *A. nili* on a seasonal basis by multiplying estimates of their man-biting rates by their seasonal sporozoite rate. *A. funestus* was the predominant vector, followed by *A. nili* and *A. gambiae*.

*Anopheles pharoensis* Theobald

*A. pharoensis* is widely distributed in Ethiopia, Somalia and Sudan and also extends into Egypt. Jolivet (unpublished report to WHO, 1959) mentions that one infected specimen was found in Ethiopia by Ovassa. Rishikesh b could not detect any gland infection in 2,577 females of this species dissected in Ethiopia, and he considers that it is less endophilic than *A. gambiae*. In Sudan, where it has not been incriminated as a vector so far, it was found resting indoors and outdoors, and was often encountered on shaded vegetation around houses.

In Egypt, *A. pharoensis* was first reported as a vector by Barber & Rice (2), who found a sporozoite rate of 0.33% in 1,513 specimens dissected during a malaria outbreak. The species was further studied from 1959 to 1962 in the southern part of the Nile Delta by Zahar et al.c Baseline observations showed that it bites man and animal indiscriminately both indoors and outdoors. A human blood index of 32.1% was recorded in an area with a man/animal ratio of 1:7. The partial exophily of this species was demonstrated by using outlet window traps and by the collection from rice plants of blood-fed females with a human blood index of 19.4%. In a study of the age grouping of this vector by Polovodova's technique in samples collected in window traps in an unsprayed area, the highest numbers of dilatations observed were 3 and 4, each occurring in 0.05% of 1,980 females dissected during 1960–1962. Dry climatic conditions in June do not favour the species' survival.

Longevity markedly increases with the increase of the relative humidity from July to September. After September, a decline in vector output and density occurs as the rice fields dry up, leading to a temporary imbalance in the proportions of nulliparous and parous mosquitoes.

The paucity of aged individuals shows that though *A. pharoensis* attains very high biting densities during the favourable season, females of epidemiologically dangerous age are still scarce in the population. This may explain the low infectivity and the low degree of malaria transmission effected by this species. The intensity of transmission may vary from place to place and from year to year depending on the relative humidity and the size of the reservoir of infective

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a Rishikesh, N., *op. cit.*

b Rishikesh, N., *op. cit.*

cases. Rice cultivation is a very important factor in producing an increase of breeding of *A. pharoensis* and in raising relative humidity, thus favouring the adults' survival.

*A. pharoensis* was reported to be susceptible to DDT before 1959 by Zahar (30), and was later found to be resistant to both dieldrin and DDT. Double resistance also appeared in *A. pharoensis* from unsprayed areas; it was probably related to the extensive use of chlorinated hydrocarbon insecticides for control of cotton pests.

Starting the first cycle in June 1960, a limited scale field trial was carried out in Egypt in order to evaluate the impact of DDT spraying on malaria transmission when applied at a dose of 2 g of technical DDT per m² once a year for a period of 3 years. Under the influence of insecticidal attack, the overall parasite rate dropped in 1960 to 20% of that of 1959. This indicated an adequate regression during the first year which, if maintained, would ultimately have resulted in a diminution of malaria to a very low level (17). There was evidence that the insecticide was starting to wear off in September 1960, when 4 infants born after spraying became positive. Except for that temporary reversal, reflecting operational defects, the overall picture of the year was generally satisfactory. The control of vector longevity was satisfactory when the average trap mortality was 70% or more; it became unsatisfactory when the average was below about 54%. In terms of probability of survival through one day (16), results were adequate as long as this index was kept below 0.5. Taking the data on satisfactory response in 1960 as a basis for assessment, the appropriate critical value for survival through the extrinsic cycle might be approximately 0.002.

In 1961, the second year of the trial, the crude parasite rate showed a much smaller decline, indicating a less favourable response. It fell only from 2.37% to 1.87%, the latter level being equal to 16% of the baseline level, instead of the 4% that would have been expected after 2 years of attack had the initial rate of decrease been maintained. Trap mortality was only slightly over half the 70% level required for satisfactory control. Vector probability of survival through one day increased to 0.62 and through the extrinsic cycle to 0.013, i.e., over six times the critical value of 0.002 suggested on the basis of the data of satisfactory response. In 1962, the third year of attack, the general parasite rate fell to 4.5% of the original 1959 level, compared with the level of 0.4% expected had satisfactory control been continuously maintained. That rate of decline implied further low-grade transmission in the sprayed area in the third year of attack. The critical levels for the probability of vector survival through one day through the extrinsic cycle were exceeded. The trap mortality was only 41.8%, again much inferior to the 70% level required for satisfactory control. This unsatisfactory control coincided with a deterioration in the susceptibility of *A. pharoensis* to DDT, which was determined periodically throughout the study. Further observations confirmed the ineffectiveness of two rounds of DDT spraying, each at 2 g/m², in the same trial area in 1963. However, it was not certain whether this was the main factor responsible for continued transmission, or if outdoor biting and outdoor resting of the vector population had played a role.

*Anopheles sergenti* Theobald and *A. multicolor* Camouflu

*A. sergenti* is an important vector of malaria in the oases and in Fayoum Province in Egypt, and in the Libyan Arab Republic. In the eastern part of the Region, it is recorded from Iran, Iraq, Jordan, Saudi Arabia, and some pockets in the Syrian Arab Republic. Eradication was attempted at the Kharga and Dakhla oases, Egypt, by an intensive larviciding campaign from 1946 to 1948, which resulted in a fall in the parasite rate from 13.5% to 0.3%. The return of this species to 3 oases was observed in 1951 (8), indicating that eradication had not been achieved.

There has been little investigation of the bionomics and behaviour of *A. sergenti* in the Libyan Arab Republic and Tunisia. It is quite likely that it was the vector responsible for the malaria outbreaks of 1964 and 1965 observed in Ghat and Barakat, on the Libyan southern border. It was recently found to be responsible for malaria transmission in the southern part of Tunisia (Wernsdorfer and Iyengar, unpublished reports to WHO, 1969–1971). The role of *A. multicolor*, where it exists with *A. sergenti* or alone

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in these oases, remains unknown. *A. multicolor* has not been incriminated in nature, but is suspected to be a vector on epidemiological grounds as it has been found alone in some oases where malaria is transmitted.

Farid (3) reviewed the situation of *A. sergenti* in relation to malaria in Western Asia. His observations in the Jordan valley during 1949–1952 showed that despite 2 cycles of DDT and HCH residual spraying in 1951, malaria transmission continued in 4 out of 12 villages. A malaria outbreak was observed in 1952 at El-Gurm, where a 55.3% overall parasite rate and a 38% infant parasite rate were recorded. No adult *A. sergenti* were found in sprayed premises but they were abundant in caves and fissures in the neighbouring hills. One sporozoite-positive specimen was detected in a sample from the caves. Antilarval measures were then introduced to supplement residual house spraying. Dieldrin was used as a larvicde until resistance to it was discovered in the Jordan Valley (Garrett-Jones, unpublished WHO document, 1958), when it was replaced by DDT. Singh & Gad (27) reported some tolerance to DDT in *A. sergenti* larvae, which was attributed to low temperatures during the cold season. Davidson (unpublished report to WHO, 1967) succeeded in raising a self-perpetuating colony of *A. sergenti* from egg batches sent from Fashikha in the Jordan Valley in May 1967. Tests made with samples from this colony indicated that the species was still resistant to dieldrin, while tolerant to DDT. This was probably slightly enhanced tolerance to DDT in the dieldrin-resistant strain selected to near homozygosity. According to reports to WHO, DDT house spraying supplemented by larviciding with DDT/diesel oil and later with temephos *a* have given satisfactory control of *A. sergenti* and consequently no malaria transmission has taken place.

In Saudi Arabia, larviciding of all potential breeding places of *A. sergenti* using Paris green in suspension at a dosage of 0.15 g of Paris green per m² did not give satisfactory control during 3 years' operations in Khaiber oasis. The output of adults remained high and malaria transmission continued (Zahar, unpublished report to WHO, 1967).

*Anopheles labranchiae* Falleroni

This is a palearctic species with a limited distribution along the North African littoral. It has been reported from the north-western part of the Libyan Arab Republic, which represents the eastern limit of its distribution in northern Africa. In Tunisia it is the principal malaria vector in a large part of the country, particularly in the northern governorates. Since the initiation of Tunisia's malaria eradication programme *A. labranchiae* has succumbed to DDT house spraying, as shown by its virtually complete absence from hand spray captures and bait captures in properly sprayed areas. In susceptibility tests carried out by Iyengar in 1971 (unpublished reports to WHO), about 12% survival was observed with exposure to 4% DDT for 1 hour, but an almost complete kill was obtained with 2 hours' exposure to this concentration. Residual spraying together with case detection has succeeded in interrupting malaria transmission in large areas of Tunisia, which have advanced to the consolidation phase.

*Anopheles claviger* Meigen

*A. claviger* is widely distributed in the Middle East. In 1956, when Gramiccia (7) reviewed its position in the area as a vector of malaria on an epidemiological basis, no records of its incrimination in nature in the Eastern Mediterranean Region were available except from Cyprus. In October 1970 an outbreak of malaria occurred in a small village on the outskirts of Aleppo, Syrian Arab Republic, where 58 indigenous cases of *P. vivax* were detected. *A. claviger* was the only anopheline found in this area and dissection of 20 specimens showed 2 females with sporozoite infection. Oil larviciding in wells where it breeds could bring about control of malaria transmission.

*Anopheles pulcherrimus* Theobald and *Anopheles hyrcanus* Pallas

*A. pulcherrimus* occurs in the north-eastern part of the Eastern Mediterranean Region, including eastern Saudi Arabia, the Syrian Arab Republic, Iraq, and Afghanistan. In Saudi Arabia and the Syrian Arab Republic there has been no suspicion that it is responsible for malaria transmission, but in Iraq some epidemiological evidence was found that an outbreak of malaria in a small area was associated with the presence of this species alone (26). However, no dissections were made to provide evidence of its incrimination in nature nor have the observations been followed up.

In the Kunduz area of northern Afghanistan, which has been under the attack phase for a long

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*a* Proposed to the ISO as the common name for *O,O',O'-tetramethyl *O,O'-thiodi-4,1-phenylene phosphorothioate.

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time, *A. superpictus* has not been reported for some 15 years, but *A. pulcherrimus* and *A. hyrcanus* were suspected to be vectors. After 1966 a steady increase was noted in the number of malaria cases in the Kunduz area and attempts were made to detect the vector responsible. Badawy (unpublished reports to WHO, 1969) demonstrated gland infections among wild-caught females of *A. pulcherrimus* and *A. hyrcanus* dissected within 1 day of capture. Entomological investigations indicated that both species had existed in areas sprayed with DDT, biting man and animals in high densities outdoors, particularly during the season when people slept outside. Both species were encountered resting in natural shelters, but *A. pulcherrimus* also uses unsprayed indoor shelters, e.g., those missed during spraying. Susceptibility tests showed that *A. pulcherrimus* remained susceptible to DDT whereas *A. hyrcanus* exhibited marked resistance to this insecticide. Both species showed normal susceptibility to dieldrin. This is in contrast to Paffy’s finding (23) that *A. pulcherrimus* showed pronounced dieldrin resistance in the Eastern Province of Saudi Arabia. In investigations by Zahar (unpublished report to WHO, 1970) in Afghanistan, *A. hyrcanus* appeared to play an important role in malaria transmission during May and part of June, after which *A. pulcherrimus* took over despite DDT spraying. Transmission continued throughout July and August, though at a slower pace during the latter month. Age grouping dissections carried out on outside resting populations of *A. pulcherrimus* in August 1970 indicated a high parasite rate and consequently a high probability of daily survival. Specimens with 4–6 dilatations were also encountered. This provides evidence that *A. pulcherrimus* could withstand adverse conditions in the outside natural resting shelters. A high biting density on man was recorded during the same investigation. In all foci of transmission studied, there were obvious operational deficiencies of DDT coverage in time and space; thus it was difficult to determine whether persistence of transmission was attributable to the exophilic tendency of *A. pulcherrimus* or to operational defects alone. No valid basis has been found for identifying the form of *A. hyrcanus* that occurs in the Kunduz area as *A.h. pseudopictus*; the form has recently been confirmed to be typical *A. hyrcanus* Pallas (29).

*Anopheles superpictus* Grassi

This important palaearctic vector is commonly found in association with *A. sergenti* in Jordan and in north-western Saudi Arabia. In these areas, it has apparently responded to attack measures. It extends further north in the Region, occurring in the Syrian Arab Republic, Iraq, Iran, and Pakistan, where it has been recorded in Baluchistan and south Waziristan. The species has also been recorded in Tunisia.

In the Syrian Arab Republic transmission still persisted in 1965-1966 in the Armala area, Idleb Province, in the north-western part of the country where *A. superpictus* is the principal vector, breeding in hill streams. A household survey by de Zuluet (unpublished report to WHO, 1966) indicated that sleeping outdoors was rare even during summer months. On the other hand, spraying of temporary farm huts built between the 2 spraying rounds in 1966 had been overlooked and these were found to shelter *A. superpictus*. In addition, houses had been plastered after DDT spraying. When total coverage was achieved in house spraying with DDT, *A. superpictus* was brought under control and malaria transmission was interrupted.

In Iran, *A. superpictus* is widely distributed except in the coastal area of Shatt el Arab. In the region of the Caspian Sea, however, its distribution is very restricted. In 1965, it was reported that *A. superpictus* had a similar pattern of seasonal prevalence to *A. fluviatilis*, their density peaks occurring in the spring and autumn. The human blood index for *A. superpictus* was 22.4%. Applying Polovodova’s technique, it was found that the proportion of potentially dangerous females in the *A. superpictus* population, i.e., females having more than 3 dilataions, was 1.5%. This species, together with *A. fluviatilis*, has proved refractory to attack measures. Mesghali (unpublished observations, 1968) pointed out that in some parts of Iran, particularly in Kermanshah and in Kashaf-rud, Khurasan, despite the campaign against malaria, transmission by *A. superpictus* had not been interrupted. The species was almost absent from sprayed dwellings but present in caves and other natural shelters. Of females taken from caves, 4.1% had human blood and 0.9% were sporozoite-positive. *A. superpictus* was reported to be susceptible to dieldrin and DDT despite repeated spraying; it was likewise susceptible to malathion.

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Anopheles fluviatilis James

The vector *A. fluviatilis* also has a wide distribution in the Region. It exists in the central northern part and in the Eastern Province of Saudi Arabia, in Iraq, and in Iran where it occupies the southern slopes and foothills of the Zagros mountains together with *A. stephensi* and *A. superpictus*. Its distribution extends to Pakistan.

The behaviour of *A. fluviatilis* has been studied in some detail in Iran. Age determinations showed that only 1–2.5% of the population of this species could reach a potentially dangerous age, i.e., over 3 dilatations. The data reported included a sporozoite rate of 0.98% and a human blood index of 10%, which appears to be an underestimate. Like *A. superpictus*, *A. fluviatilis* exhibited exophilic behaviour. Mesghali (unpublished observations, 1968) reported that in Jirfot, southern Iran, when the inhabitants were sleeping indoors, 82.6% of the specimens of *A. fluviatilis* caught in outside shelters were found to have fed on man, indicating that they bite indoors and rest outdoors. In the Bandar Abbas area, observations indicated that the species feeds indoors and outdoors, resting both in houses and in outside shelters. Mesghali noted that in view of the absence of baseline information on the behaviour of *A. fluviatilis* and *A. superpictus*, it is difficult to judge whether natural exophily played a role in the pattern of behaviour encountered after spraying. *A. fluviatilis* too is susceptible to DDT, dieldrin and malathion. In Saudi Arabia this species, which has not been incriminated as a vector, was found to be susceptible to DDT (23), but resistant to dieldrin.

In Pakistan, *A. fluviatilis* is found in the foothill regions of the mountainous tracts. Its role in malaria transmission is not clear although it is known to be a vector in the neighbouring countries of Iran and India. Bloodmeals collected from partially sprayed human and animal shelters in the Sind plain gave a human blood index of 5.4%. In unsprayed mountainous areas the index was 11.5% (Akiyama, unpublished reports to WHO, 1968). Malaria was reported to be hypodemic in the area dominated by this species. The classification of abdominal stages of *A. fluviatilis* caught by spray capture indicated that it is highly endophilic in the mountainous areas. Dissection of 434 females of *A. fluviatilis* yielded no sporozoite-positive specimens. In Pakistan the species was found to be susceptible to DDT.

Anopheles d’thali Patton

This species is widespread in semi-arid parts of the Region, but was not considered to be a vector of malaria until gland infections were recently reported.

In Somalia, Rishikesh found 1 specimen with sporozoite-positive glands among 14 females of this species dissected. It is not understood why none of the *A. gambiae* females dissected at the same time showed any gland infection. Of the 14 female *A. d’thali*, the ovaries of 9 were dissected and 8 were found to be parous. The parasite rate in the local human population was about 20%. However, precipitin tests of 11 bloodmeal smears showed no positive reaction to human blood. Observations using baited nets showed that *A. d’thali* mainly bites outdoors. Its incrimination as a malaria vector has not been further confirmed in Somalia.

In Iran, the species is found in association with *A. fluviatilis, A. stephensi*, and *A. superpictus*. Gland infection in *A. d’thali* was reported by Mesghali (unpublished report to WHO, 1967) and this was confirmed by Manoochehri et al. (18). The species was repeatedly found infected during 1965–1967. The sporozoite rates ranged between 1% and 2.1%, while the human blood index ranged from 1% to 25% depending on the area. A high man-biting density was recorded. Age composition showed a parous rate of 11.1–43%. *A. d’thali* was found to rest in both indoor and outdoor shelters. While it is quite susceptible to DDT, it showed some resistance to dieldrin.

Anopheles sacharovi Favre

The palaearctic species *A. sacharovi* is a major vector in the Syrian Arab Republic and in northern Iraq, but in Iran it has a more localized distribution in the central, north-western and south-western areas. At the junction of the Khabur and Tigris rivers on the borders of Iraq, the Syrian Arab Republic and Turkey, swampy areas provide *A. sacharovi* with suitable breeding places. The biting of people sleeping outside during the summer months and the suspected outdoor resting of *A. sacharovi* are thought to be responsible for the persistence of malaria transmission in this ecologically homogeneous border

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\(^a\) Institute of Public Health Research, Teheran, op. cit.


area (de Zulueta, unpublished report to WHO, 1967). Larval tests made at Darik, El Haseke Province, Syrian Arab Republic, in the first week of October 1965 (Cullen, unpublished report to WHO, 1965), indicated that the species was susceptible to DDT.

Soliman (28) reported that in the Syrian Arab Republic *A. sacharovi* was susceptible to DDT and dieldrin in 1958 in unsprayed areas in El Haseke Province and the Rouge valley, Aleppo Province, in which some agricultural pesticides had been applied in 1952, and house spraying with DDT had commenced under the malaria eradication programme in 1956. In June 1960, tests at Haret el Khaleb, Latakia Province, also showed that *A. sacharovi* was susceptible to DDT and dieldrin (Keilany, unpublished report to WHO, 1960). Tests by Thymakis (unpublished report to WHO, 1963) indicated an increased tolerance to DDT; mortality after 1 hour’s exposure to 4% DDT was 84.6% (26 exposed) at Ras el Ain, El Haseke Province, and 87% (23 exposed) at one locality in the Ghab area, Orontes valley, Hama Province. In the latter area, exposure to 4% DDT for 2 hours gave complete mortality.

Focal DDT spraying began in the Ghab area in 1964 and in 1967 this was replaced by total-coverage spraying. Following a marked increase in malaria transmission in that year, *A. sacharovi* was collected in large densities during October in both unsprayed and sprayed premises. Tests made from 3 to 29 October (Oddo, de Zulueta, & Keilany, unpublished report to WHO, 1967) showed 10.5% mortality with 4% DDT after 1 hour, 0–85% after 2 hours, and 28.6% after 4 hours. One-hour exposure to 0.4% dieldrin gave 60–78% mortality and to 0.8% dieldrin gave 76.4–96% mortality. As the temperature during October 1967 was above 20°C, it was assumed that prehibernation adaptation was induced rather by photoperiodic reaction than by temperature, resulting in high tolerance to insecticides in late October.

Observations were repeated in July and August 1968, just before the second round of DDT spraying (Onori & Zahar, unpublished data, 1968). The average mortality obtained with exposure to 4% DDT for 1 hour was 19.1%, for 2 hours 27.1%, and for 4 hours 62.7%. At the time of susceptibility testing, sprayed surfaces showed extensive disturbance from replastering or whitewashing. *A. sacharovi* was found in disturbed and apparently sprayed premises in fair densities and at different stages of the gonotrophic cycle, mostly on unsprayable surfaces, though a few were collected from sprayed walls. The number of indigenous malaria cases increased progressively after the first DDT spraying round of 1968. Window trap observations in apparently sprayed and disturbed premises showed that *A. sacharovi* leaves the house mainly in the empty and gravid states. The average trap mortality was 18%, while the average biting density per man per night was 8 indoors by direct capture and 15 by baited nets outdoors. The average house resting density varied from 6 to 12 individuals per room. Most people in the Ghab sleep outdoors in summer and *A. sacharovi* enters houses during the early hours of the morning after feeding outdoors. Thus, *A. sacharovi* seems to be largely endophilic in that area.

It was difficult to determine to what extent DDT resistance was responsible for persistence of transmission, since large-scale disturbance of sprayed surfaces occurred after the first spraying round. Observations continued after the second DDT spraying round, which was applied in August/September 1968. The results of susceptibility tests carried out in September and October did not vary much from those obtained before the second round of spraying. Spray capture and window trap data indicated that an appreciable proportion of gravid *A. sacharovi* females could still be found in sprayed premises; they constituted 59–82% of the trap collection made during the month following the second spraying round, with an average trap mortality of about 28%. House resting and biting densities tended to increase after a brief reduction following the second round. The presence of such densities, with high survival in window trap catches, shows that the response to the second DDT round was unsatisfactory. Supporting epidemiological evidence indicated that transmission persisted in the area after the second round despite a sharp reduction in the number of cases brought about by mass drug administration (22). When susceptibility to 0.8% dieldrin was tested in August 1968, complete mortality was obtained after 1 hour’s exposure, but tests in September and October showed a few survivors at this exposure (Chang & Keilany, unpublished reports to WHO, 1968). This small survival was attributed to prehibernation tolerance. On the basis of the above investigations it was decided to replace DDT with dieldrin, and commencing in 1969 the areas of DDT resistance received 2 spraying rounds of dieldrin per year.

This regime drastically reduced the density of *A. sacharovi*, as measured by different methods of capture following dieldrin spraying, and tests with 0.8% dieldrin on small insect samples resulted in
either complete mortality or only an occasional survivor. With a small batch of *A. sacharovi* tested in September 1971 there was, for the first time, 25% survival after 1 hour's exposure to 0.8% dieldrin. Tests during July and August 1972 (Keilany, unpublished reports to WHO, 1972) demonstrated without doubt a pronounced dieldrin resistance in *A. sacharovi*. The mortality after 1 hour's exposure to 4% dieldrin was below 10% and there was little difference between the mortalities obtained with dieldrin concentrations ranging from 0.8% to 4%.

*Anopheles stephensi* Liston

The oriental malaria vector *A. stephensi* is present over a fairly large area in the northern and eastern parts of the Region. *A. stephensi mysorensis* has been identified in the Eastern Province of Saudi Arabia (23) and in southern Iran.\(^a\)

In Iran, Iraq, and Saudi Arabia *A. stephensi* is resistant to DDT and dieldrin. The status of resistance in this vector and its operational significance were reviewed by Chang & Ungureanu.\(^b\) As DDT residual house spraying proved still able to curtail the severe malaria epidemic that occurred in Iraq and Iran in 1962-1963, DDT residual spraying was reinstituted in the *A. stephensi* area of southern Iran and Iraq in combination with other measures such as surveillance and larviciding operations, in an effort to interrupt malaria transmission. The susceptibility level of *A. stephensi* to DDT was checked periodically and routine estimation of house resting density by spray capture continued. The results from southern Iran were reported by de Zuluea et al. (31). Susceptibility tests carried out in 1965 and early 1966 indicated no further increase of the resistance level of *A. stephensi*. It was only in November 1966 that an extremely low kill was recorded. The average mortality obtained after 1 hour's exposure to 4% DDT was 1% and 10.2% respectively in the Fao and Shatt al Arab areas of southern Iraq. Even exposure to 4% DDT for 4 hours in Fao Mamlaha did not give more than 2.5% mortality. This locality had received 3 rounds of DDT spraying with excellent coverage. The great increase in the resistance level coincided with a marked increase of *A. stephensi* densities in Basra Liwa. Room densities during August, September and November 1966 were some 10-29 times those recorded during the corresponding months in 1965. The species spread beyond its normal limits of distribution in the country and was found as far away as Kurkuk Liwa in the north of Iraq.

The possibility that several forms of *A. stephensi* existed in southern Iraq and Iran, having a different potential for malaria transmission, was considered by de Zuluea et al. It was noted that in the Fao area transmission had persisted since the reintroduction of DDT house spraying in 1964, whereas in other areas the species existed but transmission had been interrupted or had continued at a very low rate. Laboratory investigations carried out at the Ross Institute of Tropical Hygiene, London, using different strains of *A. stephensi*, produced no evidence of hybrid sterility among 5 populations originating from India (Delhi), Iraq (Fao Mamlaha, Gezira and Baghdad) and Iran (Kazeroun). It was also suspected that more than one type of DDT resistance might exist in *A. stephensi* populations in southern Iraq. Crosses made at the Ross Institute indicated that resistance in colonies from Gezira and Fao Mamlaha was genetically identical. From selection studies, the authors considered that the changes in the pattern of resistance of this species to DDT in southern Iraq might be explained by the existence of genes ancillary to the oligogene common to all populations studied. Absolute homozygosity for all genes does not appear to have been reached, as indicated by the increased mortalities recorded in the same areas of southern Iraq in 1967, which continued to be sprayed with DDT.

Assessment of the malaria situation in southern Iraq indicated an almost equal parasite incidence throughout 1965-1967, during which period the house-resting density of *A. stephensi* was generally low except in 1966. DDT spraying continued during 1968 with no appreciable reduction of malaria transmission. In fact, in that year a malaria outbreak occurred in a group of villages in Basra Liwa. An entomological investigation was carried out during October 1968 in villages where indigenous cases had recently been recorded (Zahar, unpublished report to WHO, 1969). The spraying coverage in the area was estimated during the investigation to be about 84%. In sprayed rooms, *A. stephensi* was captured from unsprayed surfaces but some were found resting on

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sprayed surfaces. The average densities of *A. stephensi* were 5.2 per sprayed room and 6.7 per unsprayed room. Susceptibility tests showed 26.5% mortality with 4 hours’ exposure to 4% DDT among specimens collected from unsprayed shelters. Two nights of window trap collections showed that the maximum exodus of *A. stephensi* from sprayed houses took place 2–3 hours after sunset. Gravid females constituted a large proportion of trap collections, indicating that the mosquitoes were completing their gonotrophic cycle in the sprayed premises. The average density per trap per night was 10 *A. stephensi*. Mortality after a 24-hour holding period in unfed and fed females was 30% and 14% respectively. At the same time, the parous rate recorded in samples collected from sprayed premises was 53%. Assuming that the gonotrophic cycle was 2 days, the probability of daily survival was about 0.726. During dissections, a number of females were found to have 3–6 dilatations, confirming that *A. stephensi* had a high survival rate within sprayed premises. For comparison, a parous rate of 60%, giving a probability of daily survival of 0.775, was recorded in an unsprayed urban area in central Iraq where transmission had occurred. This figure is very close to that estimated for the DDT sprayed area.

In view of the above results, it was decided to replace DDT with malathion in Basra Liwa. Observations throughout 1969–1972 showed a good response under malathion spraying, and *A. stephensi* has become very scarce except where refusals were met with or operational defects occurred. The supporting epidemiological evidence reported to WHO indicated that transmission has been almost interrupted. In 1968, a small area comprising 2 villages was sprayed with propoxur. Indigenous cases started to appear shortly after the second spraying round, giving the impression that transmission continued even though *A. stephensi* could not be found by daytime capture, bait capture, or larval searches. However, observations throughout 1969 confirmed that these cases were relapses that possibly had not received radical treatment previously and that transmission in the area had in fact been interrupted by propoxur spraying.

In Iran, data collected by Kazeroun Research Station before spraying in Kazeroun area showed that the average density of *A. stephensi* per room was 200 and that from June to October the density was higher in human habitations than in stables. The species was observed resting on clothes and straw material and occasionally on walls. From October to December, mosquitoes were often found in stables. They were occasionally collected from pit shelters. However, *A. stephensi* is known to be largely endophilic. In longevity studies, 4.4% of *A. stephensi* dissected were found to have at least 3 dilatations and therefore to be at a potentially dangerous age. The sporozoite rate recorded was 0.51%. Precipitin tests showed a human blood index of 24%. When 2 humans and 1 animal were used in a magoon trap, *A. stephensi* showed a maximum human blood preference of 47% and a minimum of 5%.

Continual evaluation of DDT spraying in 1965–1967 showed that the resistance of *A. stephensi* to DDT was increasing, and that transmission persisted in southern Iran as in southern Iraq. Malathion was therefore tried in Iran, first of all on a village scale. In 1967, it was decided in the littoral and plain areas to spray DDT in one round in the spring and malathion in a second round later in the year. According to a progress report from the Institute of Public Health Research, Teheran, *A. stephensi* density in the coastal area, despite the DDT spraying in the spring, showed a steady increase from June until September. Persistence of transmission was observed in a village in the coastal area, where the density of *A. stephensi* was 15.2 per room and the proportion of dangerous females had reached a maximum in September 1967. Dissection of 136 *A. stephensi* females gave a sporozoite rate of 1.47%. At the same time, 10 cases of *Plasmodium vivax* infection were detected in the village. In October, after applying malathion, a marked reduction in house-resting density was observed. However, since seasonal changes intervened, it was difficult to draw a firm conclusion on the success of the application of malathion in September and October.

In 1968, the regimen of spring DDT and autumn malathion spraying rounds was repeated, though the latter spraying was advanced to start in mid-August. Through the period 1965–1968, susceptibility tests on *A. stephensi* showed a steady deterioration, mortality falling in 1968 to 15.7% after 1 hour’s exposure to 4% DDT. High parous rates were recorded during August (68.8%) and September (79.3%) in 1967, with a probability of daily survival of 0.83 and 0.89

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* Institute of Public Health Research, Teheran, *op. cit.*
respectively before malathion was applied in October 1967. At the same time, the mortality in window trap collections was not more than 7%. The parous rates of 55% and 58% recorded in July and August 1968 during the period following DDT spraying were lower than before. There was a slowly rising trend in the monthly parasite incidence, but at a lower level than in the years when only DDT was applied. Spray catches indicated that the density of vectors in houses was generally low; no mosquitos were captured in night catches or by window traps. It was concluded that under the regimen of 2 annual DDT spraying rounds, there was always a marked building up of the density of A. stephensi combined with increasing longevity, which led to persistence of transmission at a fairly high rate. Under the DDT and malathion regimen, there was a definite shortening in the period of vector activity and high mosquito density, resulting in a much lower rate of transmission. Malathion reduced the A. stephensi population drastically and it was suggested that in view of the increase in the level of DDT resistance, it would be better to replace DDT entirely with malathion (Zahar, unpublished report to WHO, 1969). According to recent reports from Iraq and Iran, A. stephensi remains susceptible to malathion in areas where spraying with this insecticide is in progress.

Quraishi et al. (24) made observations on flight range in Iran by releasing P32-labelled A. stephensi. Since the number of recaptures was very small and variations were numerous, catches could be taken only as indicating a rough trend. The number of mosquitos recaptured was markedly lower at 3–5 km from the point of release than at 1–3 km. Both males and females were able to fly 1.8 km overnight. One female was caught in a village 2.8 km from the point of release within 16 hours of release. In the course of the observations, an attempt was made to determine the daily mortality. This could only be done for the first 6 days because too few marked mosquitos were recaptured thereafter. An attempt was also made to study the duration of the gonotrophic cycle.

In Pakistan, A. stephensi occurs in varying densities in association with A. culicifacies. In the urban area of Karachi, Husain & Talibi (12) reported monthly dissections carried out from 1947 to 1951, during which a total of 23,223 A. stephensi were dissected for gland infection and 9,617 of these were also examined for gut infection, in both cases with negative results. Afridi et al. (1) showed that A. stephensi mysorensis occurs in the Karachi, Sukkur and Hyderabad zones, though the type form was either absent or, if present, occurred in such small numbers that it could not be detected.

Rahman & Muttalib (25), investigating the malaria situation in Karachi city, reported a spleen rate of up to 34.3% and a parasite rate of 15.5%. A. stephensi and A. subpictus were the only anophelines they encountered either as adults or larvae in the different parts of the city surveyed. They found 1 female A. stephensi with sporozoites among 204 dissected during July–August 1966 in Karachi. Further dissections made by Muttalib and Akiyama (unpublished reports to WHO, 1966 and 1967) of 505 A. stephensi and 2,015 A. subpictus collected from the city revealed 6 gland infections (1.18%) in A. stephensi and none in A. subpictus. In April 1967, 1 gland infection was recorded from 328 dissections of A. stephensi.

Susceptibility tests carried out with A. stephensi in Karachi city in 1967–1968 indicated resistance to DDT, but at a much lower level than in Iran and Iraq. The mortality recorded on exposure to 4% DDT for 1 hour ranged from 32.5% to 80% and for 2 hours from 76% to 92%.

Information on A. stephensi in rural areas of Pakistan is given in the section on A. culicifacies below.

A species found at Ras Gharib on the Gulf of Suez, Egypt, was identified as A. stephensi by Gad (5). The identification was checked by Dr P. F. Mattingly of the Department of Entomology, British Museum (Natural History), London, who found it resembling A. dancalicus Corradetti, although he was inclined to consider it as being slightly aberrant A. stephensi. Breeding sites and the ecological conditions in the locality where the species was found were described by this author. The susceptibility of its larvae to DDT, dieldrin, lindane, and malathion was noted by Gad & Kamel (6). There has been no evidence of malaria transmission in the area. However, control of breeding places by oil larviciding was introduced and no material could be obtained for crossing experiments with known strains of A. stephensi to confirm the mosquito’s identity. A. stephensi has also been recorded in the northern part of the United Arab Emirates (see under A. culicifacies).

Anopheles culicifacies Giles

The oriental species A. culicifacies is the principal malaria vector in Pakistan, where it is widely distributed. It has been connected with the unstable type of malaria. Throughout the rural areas of
central and southern Pakistan, it is commonly associated with *A. stephensi*. Prespraying observations showed that the 2 species are found throughout the year. *A. culicifacies* appears in high density in April, declines in May-June, but increases again from July-August to reach a peak in September-October. *A. stephensi* density declines in July but increases again in August, reaching a peak in September. The lowest densities of the 2 vectors are usually encountered during December-February. When the malaria eradication programme began in 1961, DDT residual house spraying was successful in drastically affecting the densities of both vectors. The epidemiological results were satisfactory, so that many zones were switched to the consolidation phase. The 2 species, which are endophilic, were found to be absent or scarce in properly sprayed houses after the application of DDT. However, reports to WHO showed that high densities of both species were encountered wherever there were operational defects, necessitating the continuation of DDT spraying in some areas. Records of susceptibility tests carried out in 1962 indicated that *A. culicifacies* was susceptible to DDT. However, resistance started to appear from 1964 onwards in both species in different zones, and throughout 1967-1972 more records of DDT resistance in both *A. culicifacies* and *A. stephensi* were obtained. This resistance reached a high level in most zones although the generally small sample size in the tests of some 50-60 mosquitoes or even less has not permitted conclusions to be drawn on the resistance level in the mosquito population as a whole (unpublished reports to WHO). No special investigations have been carried out to determine the practical implications of this resistance. However, the epidemiological situation has been studied in areas where malaria transmission has recently flared up. Because of the high level of DDT resistance in both vectors in many areas, HCH has been tried extensively in the North-West Frontier Province in 1972-1974. Recent susceptibility tests with dieldrin have indicated that resistance to cyclodiene insecticides has appeared, and a suitable alternative insecticide is being sought.

In 1968, a survey was carried out in the northern part of the United Arab Emirates, previously known as the Northern Trucial States (Zahar, unpublished report to WHO, 1969). *A. culicifacies* s.l.\(^a\) in association with *A. stephensi* was found in high densities, and was connected with a high endemicity of malaria, the crude parasite rates ranging from 15% to 49%. The parasite formula showed 68.5% *Plasmodium falciparum*, 22.4% *P. vivax* and 9.1% *P. malariae*. *A. culicifacies* and *A. stephensi* were found breeding in wells—the only source of water—and cement basins used for water storage in the rural areas.

\(^a\) The identification of this species was checked by Dr M. T. Gillies, who reported that the form appears to be intermediate between the nominate subspecies and the subspecies *adenensis* but suggested that for the time being it should be referred to simply as *A. culicifacies* s.l.

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RÉSUMÉ

L’ÉCOLOGIE DES VECTEURS DU PALUDISME DANS LA RÉGION OMS DE LA MÉDITERRANÉE ORIENTALE: REVUE DE LA QUESTION

L’auteur passe en revue la documentation disponible sur l’écologie de 15 vecteurs du paludisme de la Région OMS de la Méditerranée orientale.

Les renseignements présentés se rapportent surtout à la période écoulée depuis 1956, date du lancement du programme de lutte ou d’éradication dans cette Région.
Les données concernant l'étude épidémiologique de la situation du paludisme et l'évaluation des mesures d'attaque du point de vue entomologique sont tirées des travaux publiés à ce sujet ou de rapports non publiés adressés à l'OMS. Des indications sur le degré de sensibilité aux insecticides des vecteurs du paludisme, et sur le comportement et la mortalité des populations de vecteurs ayant fait l'objet de mesures d'attaque, sont également fournies dans cette analyse qui renseigne en outre sur l'indice d'anthropophilie, la préférence trophique et la longévité des vecteurs. Les informations relatives à chaque espèce sont plus ou moins complètes, selon l'importance des recherches entomologiques effectuées dans les diverses zones, mais l'article a le mérite de faire apparaître les lacunes de nos connaissances sur l'écologie des vecteurs, ce qui devrait inciter les chercheurs à poursuivre leurs observations ou à entreprendre de nouvelles investigations.

REFERENCES


