Malaria and Mosquitoes

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Most of what is written here has already been published in a Dutch medical journal (Brug, 1938), however I esteem it important enough te bring it to the attention of entomologists and of those who do not understand the Dutch language. By far the majority of the authorities writing about human malaria, if not all of them, are convinced that *Anopheles* only can act as a vector and that non-anopheline mosquitoes are absolutely unfit for this function. It was a great surprise to me and, I suppose, to many others when Williamson and Zain (1937) stated that human malaria-parasites can completely develop in *Culex bitaeniorhynchus*. They found sporozoites of benign tertian as well as those of subtertian in the salivary glands of laboratory-bred mosquitoes if experimentally infected and probably those of quartan too. For me it was an occasion to peruse the literature in order to find out in how far the common thesis "malaria is carried by Anophelines only" has a sound foundation in research.

When Ross (1898) discovered the life-cycle of avian plasmodium he was dealing with the "grey mosquito" (probably *Culex fatigans*) and "brindled mosquitoes" (*Culex taeniatus* type). Human plasmodia did not develop in them, but Ross saw part of the life-cycle in the "dappled winged mosquito", probably an anopheline species. Grassi (1901) demonstrated the complete life-cycle of benign and subtertian parasites in *Anopheles maculipennis* and *A. bifurcatus*. On the other hand he saw no development of parasites from the same origin as those that gave positive results in *Anopheles*, in eight Culicine species. They were : *Culex pipiens, C. penicillaris (Aëdes (Ochlerotatus) caspius), C. albopunctatus (Aë. (Finlaya) geniculatus), C. pulchritarsus (Aë. (Ochl.)), C. Richardii (Mansonia (Coquillettidia)), C. vexans (Aë. (Aedimorphus)), C. nemerosus (Aë. (Ochl.) communis),* and *Theobaldia annulata*. It is true that the number of Culicine specimens belonging to four of the eight species Grassi used was rather small, but at any rate he proved that in the most common Italian species there was no development. As far as quartan malaria was concerned Grassi saw no development in Culicini, but in this case only one of the *Anopheles* he used as controls became infected. The conclusion that human malaria parasites develop in *Anopheles* only, and not in Culicines was rather generally adopted with much enthusiasm.

However, there were some dissentients and amongst them no less than Ross (1908, 1911) and Lavéran (1907). Ross stated that possibly marsh-born mosquitoes other than *Anopheles* might function as malaria-carriers. Lavéran declared sharply: "Il faut dire que ces expériences n'ont porté que sur un petit nombre d'espèces de *Culex* et que en dehors des *Culex* et des *Anophèles* il existe plusieurs genres de Culicides comprenant de nombreuses espèces". As stated Grassi's findings were generally considered as final and very little research has been made since to establish the status of non-anopheline mosquitoes as possible malaria carriers. The authors of handbooks become more and more positive in stating the monopoly of *Anopheles* in this matter. Some authors who were not so quite sure I quote here below:

Stephens and Christophers (1900) found that *Culex* caught in native huts in Sierra Leone contained sporozoites in their salivary glands, but these sporozoites differed morphologically from those found in *Anopheles* and their arrangement in the glands was otherwise.

Berkeley (1901) wrote: "Nor should we feel absolutely sure that none of our native species of *Culex* can exceptionally carry the infection till at least *C. pungens, C. taeniorhynchus* and *C. triseriatus* have been further examined, I have made a dozen or more inoculations with negative result".

Tsuzuki (1902) states: "Ich füge noch hinzu, dass ich weder in Jeso noch in Formosa die Entwicklung des Plasmodium (Menschenmalaria) im Körper der *Culex*-arten konstatieren könnte". Probably this refers to experimental infection with subtertian (Formosa) and benign tertian (Jeso).

Zieman (1902) dissected Culices found in malaria houses without finding any of them infected.

Dutton (1903) wrote: "In fact only a few species of *Culex* have been shown incapable of transmitting the disease".

Lavéran (1907): "Des *Culex de* différentes espéces provenants de larves en captivité nourris sur des malades atteints de de fièvre palustre n'ont jamais été infectés".

Leicester (1908) fed some 100 Culicines belonging to fifteen different species on "good malignant tertain cases"; none of them became infected. However, 16 Anophelines having fed too showed infection neither.

The Commission for the study of malaria in Russia (1915) failed to find Culicines infected with malaria parasites.

Professor Swellengrebel kindly put at my disposition his notes (not published) about a malaria research in Belawan (Deli, Sumatra). Apparently not wholly convinced of the monopoly of *Anopheles* he also dissected Culicine mosquitoes. They were 309 in all belonging to eight different species. 283 of them were *Culex microannulatus* (*C. sitiens*?) and amongst these two had cysts on

their guts with coarse brown pigment and in one of the gnats with black spores too.

Senior-White and Williamson (1927) wrote: "Even the possibility that there may be Culicine mosquitoes whose digestive and bodyfluids resemble those of proved malaria carriers and which are therefore themselves able to transmit malaria must not be entirely excluded".

Nikolaev and Yakovleva (1929) trying to infect the Culicine species *Culex pipiens, Theobaldia alaskensis* and *Aëdes salinellus* with malaria could find neither oocysts nor sporozoites.

Taylor (1930) working in Nigeria, dissected 117 Culicines and examined them for malariaparasites. One very heavy infection with small oocysts was seen in a specimen of *Lutzia tigripes.*

Gibbins (1932) examined in Uganda 102 specimens of *Mansonia uniformis* without finding plasmodia on the stomachs or in the salivary glands.

From this list it appears that serious experiments to prove the thesis that Culicine mosquitoes cannot carry human malaria have only been made by Grassi with eight species, that Ross has experimented with at least two species and Nikolaev and Yakovleva with three species. With *Culex bitaeniorhynchus* experimented upon by Williamson and Zain in all fourteen species. Chanal (1921) studying literature found that eighteen species of Culicines were tested, none showing a trace of development of any human plasmodium. But amongst these eighteen were those of Leicester's experiments, in wich the *Anopheles* too showed no development of the malaria parasites.

At any rate it is quite sure that in view of the tremendous number of Culicine species research in this line has been very insufficient. Edwards (1932) mentions about 1100 species and how many have been described since? It is true that amongst these 1100 species there are many that may be eliminated automatically because they never suck human blood, but even then, there remain some hundreds of species that do not despise human blood at all.

It might be argued that the thesis "Anophelines only carry human malaria" has proved very efficient in malaria control. This is certainly true. Malaria has been controlled by methods directed against *Anopheles.* But the control of malaria is often involuntarily combined with the eradication of non-anopheline species. If the control measures apply to breeding places, Culicine as well as Anopheline mosquitoes may be struck. Ross (1908) as well as Williamson (1927) suspected especially the Culicines breeding together with Anophelines. The conclusion to be drawn from the succes of *Anopheles* control is that undoubtedly *Anopheles* plays the most important rôle in the propagation of human malaria but not that this rôle is exclusive.

The research of the vectors of yellow fever is very instructive in this regard. In the beginning it was assumed that *Stegomyia fas-*

ciata (Aëdes calopus or *Aë. argenteus* or *Aë. aegypti)* was the vector (1900). The results of sanitation directed against this species seemed to confirm this view. The successes were perhaps still greater than in malaria control. Epidemics of yellow fever hardly occurred any more. Afterwards yungle fever was discovered. And, amongst the yungle mosquitoes many species proved to be able to carry yellow fever experimentally. Moreover in nature specimens were found carrying virulent yellow fever virus (Shannon, Whitman and Franca, 1932; Haddow, 1945 and many others). Amongst the latter there were not only species closely related to *S. fasciata* (f.i. *Aë. simpsoni*) but also others systematically rather removed from this species (*Haemagogus* and *Sabethine* species).

It seems not quite impossible that further research on the ability of non anopheline mosquitoes may have similar results. Williamson and Zain have initiated this research. It is of great importance that their experiments with *Culex bitaeniorhynchus* are repeated and that similar experiments are made with the common man-biting Culicini. At present we do not even know with certainty whether *Culex fatigans* can carry malaria, for it is not quite certain that Ross' "grey mosquito" was indeed this species. That the ability to carry a special parasite need not be confined to a single genus of mosquitoes is shown i.a. by *Wuchereria malayi* that develops in *Anopheles barbirostris* as well as in various species of the subgenus *Mansonioides*.

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