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Population Increases in *Culex pipiens fatigans* Wiedemann*

A Review of Present Knowledge

P. F. MATTINGLY [1]

The author reviews the growing body of evidence that urban populations of Culex pipiens fatigans *have increased extensively during recent years in both Africa and Asia. Two main factors seem to be responsible—the spread of urbanization, providing favourable habitats for this essentially urban mosquito; and the increasing use of residual insecticides, leading to disregard of conventional sanitary measures and a consequent proliferation of suitable culicine breeding-places. In addition, it is possible that the use of insecticides may be bringing about a selective destruction of less resistant competitors of* C. fatigans.

Present knowledge of this species is too exiguous to allow of a full understanding of the reasons for its increase, to assess its significance in relation to disease transmission, or definitively to adopt economical and practicable control methods. However, a number of possible lines of approach to this problem are suggested.

During recent years increases in urban populations of *Culex fatigans* have taken place on such a scale as to render their occurrence beyond dispute. It is true that a subjective impression of such increases may arise, for instance, from return to a previous level after temporary reduction by the use of insecticides. Such impressions cannot, however, account for the cases which are here discussed. On the contrary, it is possible, even probable, that massive increases have taken place without the public or even the medical services being aware of them.

As an example, I personally carried out a survey in Kaduna, Nigeria, in 1942 without detecting this species at all. It is true that this was primarily an anopheline survey but culicines were also recorded. Moreover, it was carried out during only a few weeks of the year when *C. fatigans* might not have been present in maximum abundance. Hanney (1960), however, recorded it in densities as high as 760 per room and he has assured me that it would now be quite impossible to fail to detect it both as an adult and in the early stages at all times of the year. Earlier records (Johnston, 1916; Johnson, 1919) confirm my own findings and there can be no reasonable doubt that within the last twenty years this species has pullulated in Kaduna without the fact being recognized.

This being so, it seems at least highly probable that unrecognized increases have also taken place in other West African cities. The only published record of such an increase in this part of the world comes from Freetown, Sierra Leone (Thomas, 1956). Here a survey carried out in 1955 revealed *C. fatigans* in densities far lower than those recorded from Kaduna but, nevertheless, sufficient to excite comment since a careful survey, devoted specifically to house-haunting mosquitos, had entirely failed to reveal its presence in 1931 (Gordon et al., 1932).

According to information given to me by Mr R. Elliott a considerable increase must have taken place in Yaba (Lagos), Nigeria. During the period 1942-46 I found *C. fatigans* there only once. Earlier records (Dalziel, in Macfie & Ingram, 1916) also emphasize its rarity in the Lagos area generally. It seems, however, that it is now very abundant. It is also very abundant in some urban areas in the former French territories (Brazzaville, Yaoundé, Douala, Fort Lamy, Bobo Dioulasso) and, although previous records are lacking, it is difficult to avoid the impression that there have been large post-war increases.

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[1] Principal Scientific Officer, British Museum (Natural History), London, England.

Smith (1958) and Smith & Bransby-Williams [1] have recorded increases in the Pare-Taveta area in East Africa and it is unlikely that these are unique. Joseph et al. (1960) recorded a similar increase in southern India and Wharton (1951) one in Malaya. It is generally acknowledged that there have been large increases in *C. fatigans* in southern Asia as a whole.

CAUSES OF INCREASES

Two factors seem to have been mainly responsible for these increases. They are urbanization and the use of residual insecticides. The two are not always separable. In fact, they seem generally to have acted together, with mutually adjuvant effects. This occurs when, for example, the introduction of residual insecticides leads to the abandonment of conventional sanitary measures, thereby intensifying the effect of the provision of increased breeding facilities resulting from urbanization or industrialization. It may also happen where there is a more direct effect of insecticides, for instance, where the provision of additional breeding-places enables *C. fatigans* to exploit the advantage conferred on it by its greater tolerance for or resistance to insecticides.

Urbanization

The general theme is discussed by Mouchet et al. (1960). Here attention will be paid mainly to its entomological aspects. There are very few records of *C. fatigans* existing independently of man. It has been described as a " wild " mosquito on the Kenya coast (Heisch, quoted by Symes [2]), and Van Someren et al. (1958) have recorded it in the bush in that area and have noted differences in its behaviour there from its behaviour in houses. The same area has, however, been described elsewhere as " semi-urban " (Heisch et al., 1959) and it is possible that this conveys a truer picture of the situation. Some coastal areas seem to offer particularly favourable conditions for *C. fatigans*. The factors responsible are probably related in part to human geography and in part to poor natural surface drainage. Boorman & Service (1960) have a record from a forest in West Africa three miles from the nearest large human settlement, but they give no details.

In many parts of its range *C. fatigans* is not merely man-adapted but very largely urban in its distribution. Hamon (1962) notes a tendency for it to spread into villages in the neighbourhood of Bobo Dioulasso but regards this as of recent origin. This is an important observation because any tendency to spread into rural areas could have an effect, in terms of over-all population density, greatly outweighing the combined effects of purely urban increases. In parts of South-East Asia *C. fatigans* is, or was, largely confined to the neighbourhood of ports and large rivers (Brug & Bonne-Wepster, 1947), suggesting relatively recent human introduction. The same seems also to be true of parts of South America.

That urbanization need not necessarily imply high densities of *C. fatigans* is illustrated by an interesting case brought to my attention by Mr J. Mouchet. In Fort Lamy he recorded indices (? room indices) of *C. fatigans* of the order of 30-50. As against this, in a large town about 1½ miles away on the other (Cameroun) side of the Shari River the corresponding indices were only of the order of 0.1. Clearly there have been factors operating in Fort Lamy, such as nature of water supply, use of insecticides and types of general sanitary measures employed (or not employed) which have led to a local pullulation. It is interesting that this has not been communicated, over such a short distance, to the neighbouring town.

Nor are such pullulations only of recent occurrence. The most dramatic instance recorded in the literature is that described by Afridi & Majid (1938) from the Delhi urban area. Here inefficient disposal of human sewage led to the production of *C. fatigans* on a scale and with forms of behaviour reminiscent of huge natural populations of salt-marsh *Aëdes*.

Having emphasized the urban character of *C. fatigans*, it is, however, necessary to draw attention to some features of its behaviour, even in urban environments, which render it to a certain extent independent of man. Such aspects of behaviour might conceivably offer possibilities of selective control and they cannot fail to be of considerable epidemiological interest and of potential importance with regard to the ultimate effect of control measures. Foremost among them is the occurrence, even in large cities, of ornithophilic strains of *C. fatigans* (Mathis, 1935; Galliard, 1936; Mattingly, in Mattingly et al., 1951; Thomas, 1956). Such ornithophilic strains have a natural advantage over anthropophilic ones in that *C. fatigans* produces many more

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[1] See the article on page 603 of this issue.

[2] Symes, C. B. (1961) *A note on* Culex pipiens fatigans (unpublished working document WHO/Fil/22).

eggs on a meal of bird blood than on one of mammal blood (references in Mattingly et al., 1951).

Hopkins (1952) drew attention to the ability of *C. fatigans* to utilize natural breeding-places and selection for this ability, in combination with ornithophily, could clearly lead to the establishment of predominantly exophilic populations. The potential importance of this form of selection has been much discussed in relation to malaria eradication (see Mattingly, 1962). *C. fatigans* might well be a suitable species in which to study the phenomenon. On the available evidence it would seem that this is to be regarded as a man-adapted, tropical form of *C. pipiens pipiens* which has retained relict biological characteristics of the latter sufficient to enable it to behave to a limited extent as a semi-wild mosquito.

Effect of residual insecticides

The indirect effect of residual insecticides in encouraging neglect of normal sanitary precautions has been noted above. Direct effects have also been claimed and the evidence for these, while not conclusive, is by no means negligible. As a possible mechanism underlying the Freetown increase it was suggested (Mattingly, 1957) that there might have been a selective destruction of competitors less resistant to insecticides. *Culex (Culiciomyia) nebulosus* Theobald was suggested as the most likely competitor. This would be a difficult hypothesis to substantiate without direct experiment, but it is noteworthy that early estimates of relative abundance (Macfie & Ingram, 1916) reveal a well-marked negative correlation between the two species in different parts of West Africa. The same authors' figures of relative abundance in larval samples from Accra and Lagos also show a strongly marked negative correlation. A similar negative correlation appears in their figures for *Culex duttoni* Theobald and *Culex tigripes* Grandpré & Charmoy, a potential competitor and a predator on *C. fatigans* respectively. No such negative correlation appears in their figures for other house-haunting mosquitos (*Anopheles gambiae* Giles, *Culex invidiosus* Theobald, *Aëdes aegypti* Linnaeus, *Aëdes metallicus* Theobald) which would be unlikely, by reason of their breeding preferences, to be competitors of *C. fatigans*. There is evidence that the Freetown increase occurred at least as early as 1947. In some places this would rule out a possible effect of residual insecticides. It appears, however, that DDT was used very early in Freetown, possibly as early as 1945.[1]

[1] Personal communication from Mr R. Elliott.

The population increases which have taken place in Freetown and Kaduna have not been associated with the use of residual insecticides in a planned disease eradication campaign. They have accompanied the employment of the latter as a general sanitary measure. The increases recorded by Smith (1950) and Smith & Bransby-Williams [2] from northern Tanganyika followed directly on a malaria eradication project. In one place the increase was observed only when the discontinuance of spraying was followed, about two years later, by a change in the management of sisal waste with consequent increase in breeding facilities. The other increase, in a different part of the same area, took place progressively during spraying.

One of the best-documented increases took place in Kerala State, India (Joseph et al., 1960). It was associated with an attempt to control Brugian filariasis by means of dieldrin. Here the association with the use of dieldrin seemed so evident that it was recommended that the latter should no longer be used in the area. It seems, however, that the effect was amplified by the presence of a fairly recently established match factory.

Wharton (1958) recorded what appears to be a particularly interesting increase in a rural area in Malaya. This was also associated with a campaign against Brugian filariasis, i.e., against *Mansonioides* mosquitos. It seems to have occurred in a rural area unaffected by industrialization or urbanization. This is not, however, specifically stated and detailed figures are not given. Wharton merely records that " fairly large " numbers of *C. fatigans* were present before spraying and " large numbers " after.

Taking the evidence as a whole, it seems that there is a strong case for further investigation either by a follow-up during a spraying campaign or by means of a controlled field experiment.

EPIDEMIOLOGICAL IMPLICATIONS

The available data [3] are not sufficiently detailed to reveal whether there has been any increase in filariasis which could be related to increases in *C. fatigans*. In many areas our knowledge of the vector status of this species is so slender as to render comparison with the past impossible. We ought to be initiating studies now with an eye to the future.

Wharton (1960) found that an urban strain of *C. fatigans* was about twenty times as efficient a vector of *W. bancrofti* as was a rural strain from

[2] See the article on page 603 of this issue.

[3] Communication from the World Health Organization.

another part of Malaya. This clearly suggests the possibility that increases in population density, by enlarging the area of contact between parasite and vector, could lead to an enhancement of vector status. So also could changes in host preference.

C. fatigans is not usually regarded as a virus vector of any importance, except, perhaps, in the case of St Louis encephalitis in the central United States of America (Chamberlain et al., 1959). It has recently been suspected of complicity in an outbreak of Chikungunya fever in Northern Rhodesia (Rodger, 1961). The evidence is inconclusive, but it is interesting that it includes " a most unusual and unseasonable plague of *C. fatigans* " coinciding with the first appearance of the virus. Here again, as in the case of filariasis, enhancement of vector status resulting from uncontrolled population increases is a possibility which cannot be ignored.

POSSIBILITIES OF CONTROL

Although it might seem, from the closeness of its association with man, that *C. fatigans* would be an easy mosquito to control with residual insecticides, it is, in fact, of all species the most difficult. The very closeness of its association with man has enabled it to profit from his efforts to improve his environment by urbanization and industrialization and its tolerance of organic insecticides, rapidly developing into resistance wherever selection pressures are strong enough, has had a precisely contrary effect to that which was intended. It follows that the prevailing methods of pest reduction are not merely inadequate but positively dangerous and alternative or supplementary measures must be devised.

Reliance can certainly not be placed on new insecticides alone. On the contrary, these could, if employed injudiciously, seriously worsen the situation. Among the newer insecticides DDVP is perhaps the most promising since it seems to provide, in principle, an answer to the particular propensity of *C. fatigans* for avoiding contact with residual insecticides by resting on unsprayed surfaces (Chow & Thevasagayam, 1957). To obviate the risk of resistance, however, it must be employed with caution and then mainly as an adjunct to other measures. It could, in particular, be a useful weapon for tackling the problem of human introduction into areas in which successful reduction has been achieved. This is a major risk in the case of the present species, as may be seen from the work of Charles (1954). In order to employ it effectively it will be necessary to acquire a much more detailed knowledge of the behaviour of *C. fatigans* in houses and other enclosed spaces.

So far as general sanitary measures are concerned, the most important are undoubtedly those concerned with the proper disposal of human sewage and sullage and of industrial waste. These are large problems. On a smaller scale a great deal could certainly be achieved by the proper screening of breeding-places, particularly those which are underground or otherwise covered. In drier areas these may be important dry season refuges (Ansari, 1958) and their denial to *C. fatigans* at this time of year might well be particularly effective. In many parts of its range *C. fatigans* is a markedly seasonal mosquito and a study of the reasons for this in particular areas is an essential preliminary to any well-planned control scheme.

Biological methods for the control of this species have so far received little attention, although in some respects it seems particularly suited to this type of control. Our knowledge of *C. fatigans* genetics is still very rudimentary although it is easily maintained in the laboratory and should therefore be very suitable for study. Genetical methods of control can certainly not be ruled out.

We need to know more of its relationship to other members of the *C. pipiens* complex (see Mattingly et al., 1951; Mattingly, 1957).[1] It is known to hybridize or intergrade morphologically with other members of the complex in some parts of its range and there is some evidence of biological intergradation in others —autogeny in north-west India (Bhatnagar et al., 1958), occurrence at high altitudes in Yunnan (Galliard, 1939), an apparent tendency to undergo gonadotrophic dissociation on the approach of winter in the Transvaal.[2]

No control scheme should be undertaken without a thorough preliminary entomological investigation of population density, preferred breeding-sites, host preferences, vector status and seasonal variations in all or any of these. Certain biological peculiarities of the genus *Culex* could render this a simpler task than with some other groups. Thus it seems that in general birds are the most important, if not the only important, alternative hosts to man (Wharton, 1951; Colless, 1959; Reid, 1961). Avian blood, with its nucleated erythrocytes, can be readily recognized without recourse to precipitin tests. Again the habit of laying the eggs in rafts renders possible a direct

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[1] See also the article by Mattingly on page 569 of this issue.

[2] Personal communication from Dr H. E. Paterson.

estimate of the numbers of females utilizing particular breeding-places.

Nor is a mere preliminary investigation sufficient. Entomological assessment must be maintained throughout the control campaign not only to enable us to evaluate the results of the techniques we have been using but to render possible the most efficient deployment of the many weapons at our disposal in accordance with the demands of a constantly changing situation.

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RÉSUMÉ

Selon une impression générale qui repose sur des données indiscutables, *Culex fatigans* s'est multiplié de façon inhabituelle au cours des dernières années, tant en Afrique qu'en Asie. L'accroissement des populations urbaines de cette espèce a fait l'objet de commentaires scientifiques à maintes reprises. Il y a tout lieu de penser que le même phénomène a passé inaperçu en d'autres régions. A titre d'exemple, on peut citer Kaduna (Nigeria).

L'urbanisation et l'emploi d'insecticides rémanents seraient les deux facteurs responsables principaux de cet accroissement. Le second de ces facteurs peut agir de deux manières: il conduit tout d'abord à abandonner les modes d'assainissement classiques et ensuite, par effet indirect, il opère une destruction élective des individus concurrents les moins résistants. A vrai dire, ce dernier effet reste à prouver. Dans l'un et l'autre cas, le facteur essentiel est la tolérance naturelle élevée de *C. fatigans* et des autres variétés de *C. pipiens* pour les insecticides chlorés; cette tolérance naturelle crée rapidement une résistance.

C. fatigans est surtout un moustique urbain, et la preuve n'a pas été apportée qu'il existe réellement des populations sauvages de cette espèce. Néanmoins, il existe toujours une certaine possibilité qu'il se répande dans les zones rurales. Ce dernier fait, joint à l'augmentation constatée en milieu urbain — qu'elle ait été vérifiée ou simplement présumée — pourrait aboutir à une multiplication massive des moustiques à l'échelle mondiale, ce qui aurait des conséquences considérables pour ce qui est des agents vecteurs et du taux de la filariose.

On connaît assez mal les facteurs qui influent sur les moustiques vecteurs. Certaines données font état de souches ornithophiles bien définies, mais un supplément d'informations apparaît nécessaire. En certaines zones, il est possible que les variations dans le nombre et l'équilibre naturel des insectes vecteurs soient importantes.

Au Sierra Leone, au Tanganyika, en Inde et en Malaisie, on a signalé des augmentations de populations qui sont un effet direct des insecticides rémanents. Dans deux cas, on relève une association avec l'emploi d'insecticides rémanents au cours de projets de lutte contre l'infection tandis que dans deux autres cas, leur emploi comme mesure d'assainissement général est en cause. Dans deux et probablement trois cas, on a la preuve que l'urbanisation a exercé un effet adjuvant. L'accroissement constaté à Freetown, Sierra Leone, a été supposé en relation avec la destruction d'espèces concurrentes, alors qu'il y a de bonnes raisons de penser que la corrélation entre la densité de ces espèces et celle de *C. fatigans* en diverses parties de l'Ouest africain est négative. Toutefois, les preuves directes font défaut.

Il sera difficile d'enrayer la progression à travers le monde de *C. fatigans*. L'amélioration générale du niveau sanitaire sera certainement le moyen d'action le plus efficace. Ceci mis à part, la réduction de la filariose dépend d'une amélioration de nos connaissances relatives à l'état naturel des agents vecteurs et des facteurs qui le conditionnent.

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