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THE POSSIBILITY OF ACTIVE LONG-DISTANCE MIGRATIONS BY ANOPHELES PHAROENSIS THEO.

by

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1. Introduction

What amounts to a new theory of active migration as a developed biological character in certain small insects has recently been formulated and discussed in the literature (Johnson, 1960; Kennedy, 1961). The group in which the character has been most studied is the Aphidae - weak-flying insects in which the great distances covered could not be covered without the aid of wind. But this phenomenon of wind-aided dispersion is no longer regarded as a process of mere passive or mechanical transportation, but as one which is started and terminated by definite changes in the insect's pattern of activity. These changes are held to be due to some physiological mechanism, which itself may be set in motion by particular conditions in the environment.

There is no reason for thinking that the phenomenon occurring in aphids may not occur also in mosquitos. In the latter group the biological value of a migratory habit might be doubtful in any well-watered region, but *a priori* it would seem to be considerable in an arid zone. It is inherently very difficult indeed to prove such an occurrence, but that is not a reason for doubting its possibility if there is circumstantial evidence in its favour. There is at present a fair amount of such evidence, and this has increased since it was reviewed and discussed by Garrett-Jones (1957) with regard to the anopheline mosquitos of the Middle East. Where the possible breeding-grounds for mosquitos are more-or-less widely separated, and where some of them are liable to periodic desiccation, the sudden appearance of mosquitos in numbers, in unlikely places, is more likely to be noticed.

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Recently there came to notice some striking fresh evidence tending to support the view that migrations over very long distances may sometimes be undertaken with the aid of wind by Anopheles pharoensis Theobald. Among the Middle Eastern anophelines of the desert/oasis climatic zone A. pharoensis, which is the principal malaria vector of the lower Nile Valley, is also the species for which there is most earlier evidence of migratory flights (Kirkpatrick, 1925; Garrett-Jones, 1950). The relevant new data to be discussed here are reported by Saliternik (1960) and McKenzie Pollock (1960).

2. The outbreak of malaria in Israel and at Gaza in 1959

In 1959 fresh cases of malaria occurred at a number of points along the Israel Coast and at Gaza, areas from which this disease had been considered as eradicated. The cases were scattered over a strip of territory about 130 kilometres long, from Gaza in the south to Tantura (a settlement some 35 kilometres south of Haifa) in the north. The discovery of the cases and the subsequent findings present features of unusual epidemiological interest.

The data from Gaza, where the outbreak was heaviest, are of only minor interest to this discussion because there is some room for doubt about the identity and origin of the mosquitos which caused the transmission. Routine larvicidal measures were in operation at the relevant time, but the supervision of these was not such as to ensure that no anopheline breeding could occur. It can safely be said, however, that there was not a massive output of vector-mosquitos at Gaza during that year, and that Gaza could not be the place of origin of any "wave" of mosquitos appearing elsewhere. Late in 1959 an entomological survey failed to reveal any anopheline adults or larvae in the Gaza area, while a survey in 1960 of adjoining territory to the south detected breeding by A. multicolor only.

The movement of persons between Gaza and the Egyptian delta may mean that a certain reservoir of malaria parasites in man might often be found at Gaza. Nevertheless the UNWRA authorities considered the area to be free from locally-transmitted cases for several years prior to 1959. In July of that year nine malaria cases were confirmed, and in the subsequent months the incidence rose to reach a peak of 67 cases in October, falling again to 13 in December 1959. Epidemiological investigation showed that 70 out of 85 confirmed cases were fresh ones due to local transmission.

It was reported from Gaza that a strong south-westerly wind blew from 15 to 18 September and that it brought with it an "invasion wave" of mosquitos (unidentified) which attacked the people. For the discussion which follows it should be noted that full moon occurred on 17 September.

We may assume, in view of the prevailing political conditions, that no movement of persons took place in 1959 between the coastal settlements of Israel and any part of the neighbouring Arab countries. Clinical and diagnostic checks on the inhabitants of the settlements, and particularly on new immigrants to Israel, are thorough and frequent. Twelve settlements were affected by the 1959 outbreak of malaria, and the authorities are confident that all but one of these (Ashkelon town in the south, where two cases had been found in 1957) had been completely malaria-free for ten or more years beforehand (Saliternik, 1960). The total number of malaria cases detected in the whole of Israel was 69 in 1957, (Saliternik, 1958/1959) and 36 in 1959. In the latter year 24 cases were confirmed in the coastal plain (i.e. geographically separated from the cases occurring in the hills inland). Upon epidemiological investigation it was shown that 21 of the 24 cases were due to fresh local infection, and only three were relapses.

In six settlements of the Ashkelon District there was a total of nine fresh infections, namely one in July, two in August, five in September and one in November. In six widely-scattered settlements further up the coast there was a total of twelve fresh infections. Two of these occurred in October, while in the remaining ten the onset of fever happened between 6 and 8 August. This simultaneous outbreak was very striking (despite its small scale) in view of the malaria-free record of the settlements. Four of the ten infections happened in members of an evening picnic-party from Haifa, who had visited the locality of Tantura (a settlement without malaria for the preceding 10 years) on 24 July. Saliternik (1960) is satisfied that this fixes precisely the date of those four cases of transmission; and it is clear that isolated infections happened in five other localities on or about the same date.

An examination of meteorological records showed that there was exceptional weather, for the time of year, on the night of 23 July. As at Gaza in September, there was a strong wind from the west or south-west (according to locality) on the coast of Israel; it was accompanied by rain, although July is normally a rainless month. It is also noteworthy that the moon was full on 20 July.

In the Israel coastal plain the routine oiling of all permanent waters is strictly enforced. Following the malaria outbreak a careful survey of possible anopheline breeding places was made in the autumn. Breeding by A. pharoensis was detected in as many as 22 localities, the breeding-places consisting almost entirely of small, temporary collections of water which were not covered by the routine control measures. Such a widespread occurrence of this species would have been remarkable at any time, for in Israel (and formerly in Palestine) it has occurred only rarely, being here considered as at the extreme limit of its potential range. Moreover, when it occurred it had been regarded as a non-vector in that country. The recognized former vectors of malaria in Palestine and in Israel are A. sacharovi, A. claviger, A. superpictus and A. sergenti. The peaks of transmission by these vectors were May-July and October-November (Saliternik, 1958/1959). The first three species are now very scarce in Israel, while A. sergenti (which is held responsible for any cases of transmission in the hills and the rift valley) is not found near the coast. No anopheline other than A. pharoensis was found in the 1959 autumn survey of the coastal plain, and the conclusion is inescapable that this was the species which transmitted the 21 fresh infections.

One further datum should be recorded. Saliternik (1960) submitted samples of the A. pharoensis larvae found in the Ashkelon District to insecticide-susceptibility tests in November 1959, and found them susceptible to DDT

(LC_{50} 0.004 p.p.m.) but resistant to dieldrin (LC_{50} 1.0 p.p.m.). This resistance could possibly be a seasonal effect, or be due to local selection-pressure, as crops in the district were sprayed with gamma BHC in April 1959. However it is most unlikely that A. pharoensis was present in April (or during the time when the BHC would have continued to be a potent selective agent). If the species reached the area only in July it is reasonable to conclude that the invading females were already dieldrin-resistant. Dieldrin resistance in A. pharoensis is fully developed in several parts of the Nile delta (Zahar & Thymakis, 1959).

3. Discussion

Saliternik (1960) characterized the outbreak in Israel as unusual and considered that no definite conclusions could be drawn to explain it, the data being incomplete. McKenzie Pollock suggested that infected mosquitos might have reached Gaza on the wind, originating from some uncontrolled area in the Sinai desert.

Rather long distances covered by A. pharoensis were recorded by Kirkpatrick (1925) and by Low (1925). Low states that, after breeding-places near an army camp at Ismailia, Egypt, were eliminated in 1924, A. multicolor ceased to be found in the camp but A. pharoensis was still present in great numbers. He says the species "used to invade the camp from a marsh, distant about nine kilometres on the Kantara Canal. This lay in the direction of the prevailing wind, and after a strong wind they were always very prevalent". Kirkpatrick mentions the appearance of A. pharoensis in the desert at a distance of 56 kilometres from their nearest possible breeding-places.

Considerably later there was recorded a mass invasion by the same species on army camps in the western desert of Egypt, at a distance of 29 kilometres and upwards from the nearest surface water, which was in the swamps around Alexandria (Garrett-Jones, 1950). A remarkable feature of the observation was the fact that the invasions appeared in the middle of a single night in each of two consecutive months (August and September 1942), the night being that of full moon on each occasion. Everyone in the camps was woken by the bites of the mosquitos, and the pattern of pyrexias which followed these events after an interval of some 15 days suggested that cases of malaria transmission may have occurred. There was no way of confirming this on the spot by laboratory diagnosis.

. The writer is indebted to Dr F. N. Ratcliffe of the Commonwealth Scientific and Industrial Research Organization, Canberra, for an interesting and significant account (in a personal communication) of happenings in Australia which are relevant to the present discussion (see also Ratcliffe et al., 1952). He states that myxomatosis spread rapidly following the liberation of the virus in one area, and that long-distance movements of the vectors must have played an important part in this. The main agent spreading the disease, which "just turned up everywhere", is thought to have been Anopheles annulipes, which was observed in rabbit-burrows about 20 kilometres from the nearest breeding-places just after a "cool change" associated with strong southerly winds. Another but weaker vector, Aëdes theobaldi, is known to disperse in numbers over distances of 64 kilometres within a few days. But the most dramatic evidence was the arrival of myxomatosis in Woody Island, an island with a rabbit-population situated at least 320 kilometres from the nearest rabbit-infested area on the Australian mainland. In Dr Ratcliffe's estimation the only possible explanation of this is that an infected mosquito or mosquitos were carried across this distance with the help of suitable winds. The evidence from Australia constitutes another instance of presumed long-distance wind-aided flights by mosquitos which would probably never have been suspected but for the chance circumstance that they evidently traversed stretches of sea-water and desert.

If it is certain that the 21 fresh infections in Israel were transmitted locally by A. pharoensis, then it might be surmised that the infected mosquitos could have arrived there from the Nile Delta. This would mean flights of up to 280 kilometres, the distance from Port Said to Tantura. There is no nearer place where in 1959 the conditions of malaria prevalence and vector prevalence were such as to offer a more acceptable explanation of the outbreak.

While this hypothesis may be unfamiliar and therefore may appear far-fetched to the malaria epidemiologist, it would be much more readily accepted by the specialist in insect ecology. The matter has to be considered from three angles: the existence of true migratory flights of a distinct type in weak insects; the distances that can be covered in such flights; and the numbers likely to travel and "arrive". Johnson (1960) and Kennedy (1961) have shown that the behaviour of aphids can only be explained on the theory that they have two distinct types of flight, a short-distance type for the fulfilment of their vegetative needs and a long-distance type for the effective dispersal of the species. It is postulated that those species in which the habit of long-distance flight, aided by wind, is developed are liable to undergo physiological change en masse under certain conditions, by which their vegetative responses are inhibited and their locomotor responses activated. They then tend to fly actively in an upward direction (i.e. away from their food supply) to a level where they will be carried a shorter or longer distance by the wind. At some later stage (how determined is not yet known) they revert to their former condition when their vegetative responses are reactivated, causing them to fly downwards in search of food (or of a breeding-place). For a given insect one can think of various external stimuli which might trigger off a physiological change and a consequent migratory flight: the age of the insect, its density at the breeding-site, scarcity of food, atmospheric temperature, diurnal period - to mention but a few. In the case of *A. pharoensis* the stimulus appears to be connected with the occurrence of full moon. We cannot say, however, whether its migrations happen at every full moon, and at no other time.

In one respect it seems that the migrations of *A. pharoensis* do not fit in with Johnson's conception of the phenomenon. Having principally the Aphidae in mind he takes the view that migratory flights are undertaken only by very young insects. While this may well be true of that group, there seems to be no need to apply the same criterion in advance to other groups of insects. The evidence points to such flights being made by vectors of myxomatosis and of malaria after they have taken at least one blood-meal, some of them thereby picking up infection. If moonlight or some other factor unconnected with the insect itself provides the stimulus, it seems most likely to affect simultaneously females of all ages in the population (and possibly males as well). If the A. pharoensis responsible for malaria transmission in Israel came from the Nile delta, some of them must have been almost old enough to carry sporozoites at the time of migration.

On the question of distance covered there should be no difficulty in accepting the proposition that a proportion of migrating mosquitos can make and survive journeys of several hundreds of kilometres. A distance of 300 kilometres would be covered in six hours on a moderate wind of 50 kph in the upper air. Aphids are known to continue in flight for similar periods, while certain locusts and Lepidoptera make intermittent flights extending over many days.

It has been objected that an enormous volume of migration would be necessary to produce the effect observed in Israel. Again we would stress that what might seem enormous numbers to the malariologist would not seem so to the ecologist. This can be simply demonstrated. Let us suppose that the sporozoite rate of A. pharoensis at the origin of the flight was 1 per cent., and that a factor of 10 per cent. is assumed for, respectively, the proportion of the population taking to flight, the proportion arriving in a populated place, and the proportion biting man on arrival. It would then require a population of 100 000 females in the area of production to produce each case of infection in the invasion-area. Ten million females might thus be sufficient to cause an outbreak of 100 new cases in a non-malarious area. Every ecologist will recognize that this hypothetical figure of ten million females is yet a very small population in any insect enjoying a rich breeding-ground to which it is fully adapted, and that an area of a few square kilometres could produce many times this number in the course of, say, one week.

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