THE SEASONAL HISTORY OF *ANOPHELES OCCIDENTALIS* D. & K. IN CALIFORNIA¹

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The control of malarial mosquitoes has been operated for years on the assumption that Réaumur's classical work on the life history of *Culex pipiens* was a suitable basis for the life history of all mosquitoes. It is only within a comparatively few years that ecological studies have been conducted with anopheline mosquitoes to lay the foundation for a more economical and efficient method of control operation than that which followed the old slogan of "Oil or drain all standing water" with no reference to type of breeding place, presence of larvae, or time of year. There is no question in the writer's mind regarding the *success* of a campaign carried out along these lines, but in the light of what we know regarding selective breeding and the limited generations of the insects, the waste in materials, time, and energy of these "shotgun" methods is appalling.

Perhaps the most important field for improvement can be based on the study of the life history. It was the writer's good fortune to be detailed to co-operate in June 1919 with a party of U. S. Public Health Service officers at Chico, California where investigations were being carried on regarding the status of anopheline mosquitoes in the rice fields. In this month he began a weekly collection of all mosquitoes appearing under a highway bridge situated some distance from the nearest rice field. This procedure was maintained by the writer until other work called him away in August after which Mr. W. C. Purdy, special expert of the U. S. P. H. S., made the weekly collections forwarding them to the writer for identification. The bridge under which the collections were made was a modern, concrete, highway structure spanning a natural drainage slough, continually holding water but without a noticeable current in the immediate vicinity of the bridge during most of the year. Mosquito breeding, during the season, was prolific in many parts of the slough. No control measures were undertaken within five miles of the bridge. Collections were made in shell vials containing chloroform or cyanide, the specimens transferred to pill boxes and transported to the laboratory for identification. All mosquitoes resting on the roof or sides of the bridge were taken except on certain occasions when the single collection would have run into the thousands. At such times the distribution of the mosquitoes under the bridge was observed and enough sections

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covered to approximate a half or a quarter, from the identification of which the whole population was estimated. In all, 26,010 mosquitoes were collected and identified in the sixteen months of the project, of which 5,756 were *A. occidentalis* D. & K. Because this species found its optimum breeding conditions in the immediate vicinity of the collection point and its more important bearing upon the malaria question, for as

Fig. 9. Seasonal Occurrence of *A. occidentalis*

the western counterpart of the eastern *quadrimaculatus* Say it is undoubtedly the most important malaria carrier in the West, the above explanation and charts are offered.

The study of the chart of male collection establishes two points (1) that hibernation, indicated by the absence of males starts just after the middle of November and (2) the curves are strongly suggestive of only two generations a year with a possibility of the earliest members of a third overtaking the stragglers of a second during September with the appearance of a possible fourth in October or November. In connection with the first point, "hibernation" is used in a rather loose fashion as no true dormancy occurs in the overwintering females. They frequently change their places of refuge as shown by the fact that we were able to make repeated complete collections beneath the bridge thruout the winter. However, they show no inclination to feed in the open thruout the period, the earliest records of this being in January in unusually warm weather.

In February of each year the females begin to emerge from their overwintering refuges. In the year shown on the chart (1920) this emergence was accomplished gradually, but on the following year the emergence was extremely uniform and striking. About February twentieth communities in many parts of California were deluged with enormous swarms of *A. occidentalis* females which invaded houses, biting viciously even in bright sunlight. By the last of the month, however, they had practically disappeared. During this flight of emergence, the area infested is almost always greater than at any other period of the year, many districts being invaded in February by *A. occidentalis* that are entirely free from them during the remainder of the year. The only explanation at hand is that the unusual length of flight at this time is a biological stimulus to ensure the spread of the species. Females dissected during the winter and at the start of the emergence flight contained round, half grown eggs in the ovaries but those taken later showed fully developed eggs. Some unfed migrants given a blood meal in the laboratory developed mature eggs in approximately 48 hours. This migratory flight from hibernation quarters on the part of the overwintering females is the official opening of the season for *A. occidentalis*. Eggs are deposited and the adult population falls off very rapidly in numbers with adult mosquitoes practically absent in April. From the information at hand, which is limited to a single experiment and the study of the chart of female *occidentalis* collections, it would appear that the overwintering females lay but a single batch of eggs before death overtakes them. Several migrant females were confined in the laboratory in the spring of 1920, and given blood meals whenever they could be

induced to bite. All deposited single batches of eggs and then died despite the utmost care without ovipositing a second time in contrast to the midseason females which frequently deposit two and sometimes three batches of eggs in captivity under similar circumstances. The study of the collection chart of both males and females shows the emergence of the first generation of the year reaching its peak during the first of June and is followed by a rapid decrease in numbers that would have been replaced by a more sustained curve had there been more than one series of deposited eggs. It is interesting to note the three peaks that denote the emergence of first brood males in April, May and early June and hazard at their connection with the three peaks of overwintering females that were abroad in February and March (the emergence from hibernation being unusually gradual during the year in question.)

The individuals of this first generation which began to emerge from pupation in May and June are relatively few in number. This may be due to the small number of eggs deposited by the overwintering females as advanced above, or it may be due to the hazards of life at this time of year. The average low temperature prolongs the larval life of this generation to approximately two months during which time they are constantly exposed to their predaceous and parasitic enemies and to the danger of being washed out by high water, a factor which disposes of many mosquito larvae breeding along the edges of streams fed by melting mountain snows.

Fertilization of the females takes place immediately upon emergence. The males emerge first and may be seen hovering over or near the breeding places in small swarms awaiting the appearance of the females. The universal fertility of captured wild specimens points to a very perfect biological arrangement enabling an infallible fertilization of the female and strengthens Knab's conclusion based on his observation of anopheline mating that the female seeks out a male from the hovering swarm.

The egg deposition of this first generation begins within a few days of its emergence. The average number of eggs deposited in a single laying by *A. occidentalis* is according to Herms and Freeborn, approximately 200 eggs, a much greater number than had previously been supposed. The number of layings can not be estimated with our present technique. The two biological factors that have hindered us in this work are (1) inability to produce copulation with bred specimens in captivity which forced the use of wild material regarding whose previous egg deposition we had no check and (2) inability to keep laying females alive in captivity until their ovaries no longer showed the reappearance of a new batch of eggs following the deposition of the second and on one occasion a third laying. Every attempt was made to reproduce natural conditions in

respect to temperature, humidity, breeding places, and food but death always resulted with one exception before the third deposition and subsequent dissection invariably showed the ovaries filled with eggs which from a biological standpoint would indicate a premature death. The total number of eggs that can be deposited by a single female of this first generation under natural conditions must remain a conjecture at this time. Under laboratory conditions the greatest number of separate layings for *A. occidentalis* was three, with a total deposition of four hundred and ninety-one eggs.

With this propensity for egg laying in mind which under natural conditions is continued thru an unknown number of batches, the ascending curve beginning in late July and reaching its peak in late September is easily foreseen.

The origin of the overwintering females is a difficult point to fix. However, Mitzmain has shown that engorged females are unable to pass the winter successfully. It is to be inferred therefore, that they are the members of the last batch of the season which occurs if we refer to the chart of male collections and estimate the life of the male *occidentalis* at a week, about the fifteenth of November. Whether these individuals are technically stragglers of the second generation represented by the September peak or of a third or fourth generation is at present unknown.

The practical points from a control standpoint in these studies resolve themselves about the time for offensive measures against malarial mosquitoes. After the migratory flight of the overwintering females there follows a rapid decrease in the adult population to the point when practically every living member of the species is in the aquatic larval stage, (early April in the locality represented in the charts.) The drainage, filling or oiling of all breeding places at this period, if carefully done controls, with the exception of the subsequent breeding of foreign invading females, the entire generation that are the progenitors of the summer and fall broods. If this opportunity is neglected, the emerging females capable of depositing many consecutive batches of eggs lay the foundation for an overlapping series of adults and larvae that ensure the survival of the species over a continued campaign directed against the larvae.

Once again during the year man is given his chance to strike a decisive blow against this species. This opportunity comes in California in October or in any locality where hibernation occurs soon after the fall peak of the adult population takes place. At this time, the number of adults are being rapidly depleted but breeding waters are stocked with larvae which will give rise to thousands of females emerging too late to

feed and consequently fitted to overwinter and produce the eggs for the first generation of the next year. Control work pursued as the adults of the fall peak are decreasing and directed against the larvae invariably reduces to the minimum the numbers of overwintering females.

The practicability of these measures is not limited to a theoretical examination of the charts but has been demonstrated in actual field practice in California. In the fall of 1919, the writer had charge of an anti-malarial campaign at Anderson in Northern California, where preliminary work was undertaken in August. By October first, as far as repeated field inspections could determine, control was absolute. The work was continued on permanent ditches until December first during which time no larvae were observed. Work was then discontinued by our project, the responsibilities being assumed by local authorities. On the following spring at the time of the migratory emergence flight in surrounding areas, Anderson was comparatively free, a few adults drifting in from unprotected areas with the result that the individuals of the first brood even if uncontrolled would have been of little sanitary importance.

In the spring of 1921, the abrupt and overwhelming migratory emergence flight so incensed an already educated municipal population in the northern part of California that public clamor demanded immediate action on the part of the health authorities who responded by draining and oiling all breeding places in the municipality, hitherto a notorious malaria center. The first brood never emerged, and by midsummer mosquito control operations were discontinued as no larvae could be found within the area. On previous years when work was started at a later date the entire appropriation for mosquito control was invariably exhausted before the season drew to a close and mosquito control was problematical. This year, however, with work starting at a very early date mosquito control was absolute by midsummer and fully one-half the appropriation which was the same as on previous years, remained in the city treasury.

As *A. punctipennis* Say and *A. pseudopunctipennis* Theobald did not breed in the immediate vicinity of the collection point, the discussion is limited to *A. occidentalis* D. & K. Of these two species above mentioned, little is known concerning their hibernation in California. No records of adult capture during the winter months are at hand nor have their larvae been taken during this period². Control measures directed against *A. occidentalis* as outlined above would control these species as well should they be shown to winter over as larvae.

²Mitzmain has observed overwintering females of *A. punctipennis* in Mississippi.

An interesting feature in the study of these collection data is to be found in a comparison of the first season (1919) with the second season (1920). During 1919 the nearest rice field was some distance away but during the intervening winter the entire area surrounding the bridge was leveled for rice and the collections for 1920 therefore show the rate to be expected from rice fields in that particular vicinity. The writer does not care to comment on this phase of the problem as Mr. W. C. Purdy of the U. S. Public Health Service, who so kindly made the collections upon which these studies are based, already has in preparation a report of this phase of the work which will undoubtedly be published at an early date by his service.

SUMMARY

1. Efficient mosquito-malaria control depends on an intimate knowledge of the life history of the mosquito in question and can not be based on the known life history of another species.

2. In California *A. occidentalis* D. & K. overwinters as an adult female, hibernation beginning about November 15th and terminating in February in a widespread migratory flight.

3. These overwintering females evidently lay but few eggs and have all disappeared by April at which time all the individuals of the species exist as larval forms.

4. The first brood of the year reaches its peak in June. The individuals of this brood have the ability to lay many series of eggs which accounts for the accumulative peak of mosquito population that occurs in September.

5. The species apparently passes thru two generations in a season with the possibility of a third or fourth under the most favorable circumstances.

6. Control work directed against the larvae after the spring migratory flight of overwintering adults and again after the peak is reached in the fall, if carefully done, will hold this species under control.

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