1928. "Notes on Banding Terns at Chatham, Mass., for 1928." *Bull. N. E. B. B. A.*, Vol. IV, No. 4, October, 1928, pp. 125–132.
1929. "Notes on Banding Terns at Chatham, Mass., for 1929." *Bull. N. E. B. B. A.*, Vol. V, No. 4, October, 1929, pp. 144–148.
1930. "Further Banding Notes from Tern Island, Mass." *Bird-Banding*, Vol. I, No. 4, October, 1930, pp. 181–184.
1932. "Report of Tern Banding on Cape Cod During 1932." *Bird-Banding*, Vol. III, No. 2, April, 1932, pp. 63–65.

FORBUSH, E. H.
1925. Birds of Massachusetts and Other New England States, Vol I, pp. 105–126.

BIRD MALARIA AND MOSQUITO CONTROL

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THE purpose of this paper is to point out that a large percentage of birds in nature are infected with a mosquito-borne malaria, and that this fact presents a phase of a problem of wild-life management that has been overlooked almost entirely.

OCCURRENCE OF PLASMODIUM IN NORTH AMERICAN BIRDS

The causative agent of malaria in birds was discovered in 1885, only five years after it was first recognized in man. Although malaria parasites have been reported from many species of birds throughout the world, very little is as yet known of their prevalence among the avifauna or the effects on the avian population.

In its broadest sense, malaria, which originally meant "bad air", may today be interpreted as applying to the diseases caused by the blood-inhabiting protozoa of the family Plasmodidæ. At least three genera of Plasmodidæ have been reported from birds: *Leucocytozoön*, *Hæmoproteus*, and *Plasmodium*. All these forms live within red blood cells. Only one genus—*Plasmodium*—is known to occur in man. There has been much experimental investigation on the *Plasmodium* of birds which has had direct bearing on the human malady. Mosquito transmission was first worked out with birds in India by Ross in 1898. Most of the recent advances in drug treatment of malaria have been tested first in the laboratory on canaries. Studies of avian *Plasmodium*, however, have been mainly with laboratory birds and have not added greatly to our knowledge of the conditions in the wild bird hosts.

Most protozoölogists recognize only three valid species of *Plasmodium* as occurring in man. However, as has been shown recently by Manwell (1935), there are at least eight valid species prevalent

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in birds from North America alone, and several other species have been isolated elsewhere. More than thirty of our North American species of birds have been observed to harbor at least one of these species of *Plasmodium*. No doubt, further study will reveal a more widespread prevalence among our avifauna, with perhaps even added species of the parasite.

In order to understand the importance of *Plasmodium* infections in our wild birds it is necessary to know something of the prevalence within a single species of bird. Although our knowledge is still quite limited, recent studies on a few of our birds present some tangible facts. Most studies have been based merely on the examination of a single blood-smear from a bird. Very little value can be attached to such a method if it is to be interpreted as a picture of the total prevalence of infection. Mostly from studies with canaries, it has been learned that when a bird becomes infected it is usually a week or two before parasites are in the blood in sufficient numbers to be found on examination of the blood film, and in one case—*Plasmodium polare*—the incubation period may be several months. With most of the species the acute infection lasts but a few days, and within a short period the parasites are so few in number in the blood of the infected bird as to be rarely seen by examination of a blood-smear. Relapses are known to occur in experimentally infected canaries, but we have no knowledge of their frequence in the natural infections of the wild birds. Thus it is that *Plasmodium* species can be diagnosed by routine blood-smears only during a short period of the bird's life. However, by injecting some of the blood from a wild bird into a malaria-free canary, the canary will usually develop an acute initial infection which can easily be demonstrated if periodic smears are made every few days. This procedure was tested by Manwell and Herman (1935) with a series of birds captured in the vicinity of Syracuse, New York. The most outstanding of the results obtained was with a series of twenty-nine Song Sparrows (*Melospiza m. melodia*). Only six were diagnosed from blood-smears, but injections into canaries disclosed seventeen—well over fifty per cent—to be infected with at least one species of malaria. This method of procedure gives a closer approximation of the true prevalence of *Plasmodium*.

During the summer of 1936, blood-smears were made from 193 Eastern Red-wings (*Agelaius p. phœniceus*) at the Austin Ornithological Research Station on Cape Cod. Of this number, only seven were diagnosed with *Plasmodium* (Herman, 1938). During the summer of 1937 blood from forty-eight Red-wings was subinoculated into canaries. *Plasmodium* was subsequently diagnosed in at least twenty-nine of these canaries—thus demonstrating a prevalence of well over sixty percent in the Red-wings.

The prevalence of malaria in the Eastern Robin (*Turdus m. migratorius*) is even more striking. As early as 1904, Novy and MacNeal

reported *Plasmodium* to be common in Robins in Ann Arbor, Michigan. All the adult Robins examined in the laboratory of Dr. R. D. Manwell at Syracuse University within the past few years (at least thirteen birds) have been infected with at least one species of *Plasmodium*, and the few adult Robins that have been studied by the author at the Austin Station (seven birds) also have been infected.

EFFECT ON THE BIRDS

The high prevalence of this disease in our wild birds having been determined, the next question which presents itself is the detrimental effects of the disease on the health of the individual. Although fatalities from malaria frequently occur in humans, death is often caused by complications or secondary invaders, particularly pneumonia. Relapses also frequently occur after surgical operation or after a shock or strain of any description. Whether or not an analogous condition prevails in birds is not known. It is known, however, that pneumonia is a common cause of death with birds kept in captivity. It has never been determined whether *Plasmodium* infections in any group of birds is responsible for great losses, such as O'Roke (1934) has shown to be the case with *Leucocytozoön* in young ducks. Nevertheless, so many of the red blood cells of the bird are destroyed by the parasites that the health of the individual must be impaired considerably and the resistance of the bird thus markedly lowered. It must be emphasized that small birds, when they become weak from illness, are easily captured by predators. Also, if birds are dying of malaria in nature it would be unlikely that they would be found by man. Except in severe epidemics, dead birds would be hidden from the sight of man and would be quickly devoured by carrion animals. In the case of the infections observed in the Red-wings examined during the past two summers at the Austin Station only one bird has been under observation while it had a heavy acute infection obtained in nature. This bird did not seem to be suffering any noticeable ill effects, and the only indication of the disease was the great number of parasites to be seen in its blood-smear. However, canaries inoculated with the Red-wings' blood demonstrated a very high mortality during the acute stages of the infection—more than half the infected canaries succumbed to the disease. Two species of *Plasmodium* were diagnosed, *P. circumflexum* and *P. cathemerium*. The former species is about twice as abundant and apparently more pathogenic. All cases observed in the blood-smears from the Red-wings were *P. circumflexum*. *Plasmodium cathemerium* was diagnosed only by injection into canaries. It may be that the Red-wings have a greater immunity to the one species, but further studies and research will be necessary to determine to what extent the disease in wild birds parallels the conditions in the human ailment.

TRANSMISSION

The Plasmodidæ are transmitted from one host to another by blood-sucking insects. The parasites develop within the insect, and the stages which are infective to the vertebrate host become concentrated in the salivary glands. During the process of sucking blood these insects inject saliva containing the parasites and thus transmit the infection into the blood-stream. Certain groups of insects have been found to be responsible for the transmission of specific parasites, and it has been demonstrated that under normal laboratory conditions the parasites will reach maturity—so as to be infective to new hosts—only in particular insects. Thus it has been found that *Hæmoproteus* is transmitted by louse-flies (Hippoboscidæ), *Leucocytozoön* is transferred from one animal to another by black flies (Simulidæ), and the vector of the genus *Plasmodium*—as is well known—is the mosquito. Curiously enough, the malaria of man is transmitted by a different group of mosquitoes from those responsible for the transference of *Plasmodium* in birds. The malaria of humans is transmitted by anopheline mosquitoes, while the culicine group have been shown to be the vectors of the bird disease. It is a simple matter for an experienced person to tell these two groups of mosquitoes apart. Most malaria studies have been done with those mosquitoes implicated in human malaria, but several investigators have determined some of the species of mosquitoes capable of transmitting bird malaria. In fact, as previously stated, mosquito transmission of malaria was discovered with birds even before it was known to be the means of contracting the disease in humans.

Different species of culicine mosquitoes transmit different species of bird malaria. The most common vector is *Culex pipiens*, which has been shown to be capable of transmitting three of the commonest species of bird plasmodia in the United States. This mosquito is often popularly referred to as the "house" mosquito, and it breeds in the temperate regions throughout the world. It can be found breeding in swamps, but becomes particularly abundant in rain-barrels or other standing water about human habitations. During the past summer it has been found to transmit readily one of the species (*P. cathemerium*) obtained from the Red-wing, as well as the same species of malaria obtained from a Cowbird (*Molothrus a. ater*). However, this species of mosquito is immune to *Plasmodium circumflexum*, the species found to be most prevalent in the adult Red-wings at the Austin Station.

The only species of mosquito which has thus far been found to be capable of transmitting the *Plasmodium circumflexum* of the Red-wing is *Theobaldia melaneura*. Very little is known of the habits of this mosquito. Matheson (1929) states that it occurs in the eastern United States from the Gulf of Mexico to Canada, and that it is rare and local. It breeds in permanent water in swamps, and on Cape Cod has been found to be most abundant in a wooded

swamp in the pools of water under the roots of the trees. Several attempts to transmit *P. cathemerium* with this mosquito have been unsuccessful, and as yet it has not been tested on any of the other species of plasmodia. One other species of *Theobaldia* (*T. morsitans*) occurs in North America, but this species has not been tested as a possible vector of bird malaria.

Another species of mosquito I have found to be capable of transmitting *Plasmodium cathemerium* from the Cowbirds and Red-wings is *Aedes sollicitans*. This is the common salt-marsh mosquito. It breeds in the salt marshes along the Atlantic and Gulf coasts. However, Huff (1927) experimented with this mosquito as a possible vector of several species of malaria obtained from English Sparrows (*Passer domesticus*) and found it immune to a strain of this species of malaria. This demonstrates that mosquitoes are specific as transmitters not only for particular species of bird malaria, but possibly also for certain strains of the same species, or perhaps that there is an immunological difference in mosquitoes collected from different localities.

Several other of the more common culicine mosquitoes have been shown experimentally to be capable of transmitting various species of bird plasmodia, but no positive reports have been published on the vectors of some of the more recently discovered species.

CONTROL MEASURES

For many years conservationists and ornithologists have been opposed to many of the mosquito-control projects, particularly those involving drainage, as being detrimental to wild life. It has been felt that these conservationists have not been aware of the prevalence of malaria in birds and therefore have not seen this side of the problem. It would be utterly impossible to control the malaria of birds by any other method but the eradication of the vectors. In the case of *Plasmodium*, this would mean mosquito-control. With the exception of certain methods of Paris green dusting, projects for the control of the mosquitoes responsible for the transmission of human malaria often serve to rid the environs of many of the culicine species as well. Several of the species responsible for the transmission of bird malaria, though not locally implicated as vectors of any human disease, are nevertheless looked upon as pests because of the discomfort they bring to the human race and are therefore controlled along with the anopheline species.

In a recent editorial in *Bird-Lore* (1935) mosquito control in isolated regions away from the vicinity of settlements is condemned as an unnecessary waste of funds as well as detrimental to the wild life of the area. Often, locally, in regions where human malaria is no longer endemic, mosquito-control projects are taken to task by conservationists as being unnecessary and serving only to upset the ecology of the wild life, especially the birds. It must be agreed, at the start, that there are not, by any means, sufficient data to prove

the value of mosquito-control to the reduction of bird malaria. However, the admirable results in the reduction of human suffering from malaria by these control measures should serve as an excellent example as to what might be done for the birds. We cannot expect to obtain funds for mosquito-control as a means of reducing the prevalence of bird malaria. However, it is indeed fortunate that the control measures for the pests of the human race often also serve to reduce the numbers of mosquitoes which feed on the birds, even species which do not feed on man.

Control of mosquito-borne avian malaria is, at present, not an urgent measure. The species of birds thus far found to be commonly infected with *Plasmodium* sp. are, for the most part, among the most abundant of the Passeriformes. However, even more devastating in its effects on our bird population than disease has been the encroachment of human civilization. One of the chief factors resulting in the reduction of the avian population of North America has been drainage. An admirable review of this subject is being distributed by the National Association of Audubon Societies (Vogt, 1937).

Where drainage is being employed as a control measure and is proving injurious to the bird population it may often be that other methods of control could be utilized. Quite frequently drainage methods are resorted to as the easiest and least expensive approach as well as the most permanent means of control. Stocking ponds with certain larvivorous fish, changing the acidity of the water, fluctuation of the water-level, and other methods have at times proved to be adequate control measures. In such cases, where other methods are feasible, funds should be diverted to methods of mosquito-control which are *not* detrimental to wild life.

The previously-mentioned editorial in *Bird-Lore* also condemns the policies which allow one group to undertake large drainage projects while another group is creating large bodies of water. However, we must not lose sight of the fact that impounding of water, performed under proper supervision and with biological foresight, can create much better habitats for wild birds than might exist in many naturally occurring marshes or swamps, and can control mosquito-breeding as well. An excellent example is the Souris River project in North Dakota, where over an extended area flood-control and maintenance of breeding and feeding areas for the birds can be regulated and maintained under all conditions of weather. It is such projects as this that may be expected to maintain our bird population. Methods of mosquito control can be incorporated in these projects and thus the prevalence of avian *Plasmodium* can be lowered.

SUMMARY AND CONCLUSIONS

Malaria is a common infection in birds. Three genera occur in the red blood cells of the avifauna. *Plasmodium*, the genus which

also causes the malaria of humans, is very widespread among the avian species, and, at least in some species of birds, its prevalence is well over fifty per cent. While *Plasmodium* infections probably do not cause a high mortality in the birds, the disease tends greatly to lower the resistance of an infected individual and thus make it vulnerable to death from other diseases or natural enemies.

As in the human disease, *Plasmodium* infections of birds are transmitted by mosquitoes. The mosquitoes which transmit avian malaria differ from those which are the vectors of the human parasites. The mosquitoes which transmit one species of avian malaria may differ from those which transmit another species. A mosquito which serves as a vector of avian malaria in one locality may elsewhere prove immune to a different strain of the same species of parasite. Some of the mosquitoes which transmit avian malaria are among the most abundant pests of mankind; others may never attack man.

While it is true that the harm done by certain anti-mosquito projects (drainage) far overbalances the advantages to be gained by reducing the *Plasmodium* infections of birds, it is advisable that methods of mosquito-control which would not interfere with wild life but which would reduce both anopheline and culicine mosquitoes should be substituted. Research to devise further suitable methods of reducing mosquito population and decreasing avian malaria as well as the disease of man, without upsetting wild-life habitats, is much needed.

BIBLIOGRAPHY

Bird-Lore
1935—Vol. 37, p. 127.

Herman, C. M.
1938—The relative incidence of blood protozoa in some birds from Cape Cod. Trans. Amer. Micr. Soc. (In press).

Huff, Clay G.
1927—Studies on the infectivity of plasmodia of birds for mosquitoes, with special reference to the problem of immunity in the mosquito. Amer. Jour. Hyg. 7: 706–734.

Manwell, R. D.
1935—How many species of avian malaria parasites are there? Amer. Jour. Trop. Med. *15*: 265–283.

Manwell, R. D. and Herman, C. M.
1935—The occurrence of the avian malaries in nature. Amer. Jour. Trop. Med. *15*:661–673.

Matheson, R.
1929—A Handbook of the Mosquitoes of North America. Thomas.

Novy, F. G. and MacNeal, W. J.
1904—Trypanosomes and bird malaria. Amer. Med. *8*: 932–934.

O'Roke, E. C.
1934—A malaria-like disease of ducks caused by *Leucocytozoon anatis*. Wickware. Univ. Mich. Sch. Forest. Publ. No. 4.

Vogt, W.
1937—Thirst on the land, a plea for water conservation for the benefit of man and wild life. Nat. Assoc. Audubon Soc. Cir. 32. 32 pp.