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EFFECT OF BEHAVIOR AND AGE OF INDIVIDUAL CICONIIFORM BIRDS ON MOSQUITO FEEDING SUCCESS[1]

H. W. KALE, J. D. EDMAN AND L. A. WEBBER

ABSTRACT. Several individuals of each of 7 species of ciconiiform birds were exposed overnight, individually in 8 x 8 x 8 foot cages with 300 *Culex nigripalpus*. Surviving mosquitoes were examined the following morning and engorgement rates (proportion of mosquitoes with blood meal) determined. Birds were tested as nestlings, fledglings, and adults. Some of the birds were observed closely to record behavioral responses to mosquito attack. Average engorgement rates on birds of the same species and age showed some variation, less for species that generally do not resist mosquito attack (great blue heron, black-crowned night heron), and more for species that do resist (white ibis, Louisiana heron, and cattle egret). In addition, nestlings of the little blue heron and snowy egret were exposed with mosquitoes and observed for defensive behavior at ages of 2–3, 5–6, 8–9, and 13–14 weeks. During the period from the 2nd to the 10th week of age in those species that resist mosquito attack as adults, an inverse relationship was found between the age of the nestling host and the proportion of mosquitoes that successfully obtain blood. This reduction in feeding rate was related to the hosts' maturation, both morphological (plumage cover) and behavioral (antimosquito activity).

INTRODUCTION

The factors affecting blood-feeding success of mosquitoes, as with most natural phenomena, are proving to be numerous and complex. Over a decade ago, Stamm (1958) observed that nestlings of the yellow-crowned night heron stood quietly and allowed scores of mosquitoes to feed on them while in nearby nests little blue heron, green heron, and Louisiana heron nestlings actively resisted mosquitoes and drove them away. Stamm suggested that individual traits of behavior may increase (or decrease) the exposure of these birds to mosquito bite and pointed out (Stamm, 1966) that the reaction of various bird species to mosquito annoyance and biting was in need of investigation.

Recently, we have shown that host behavior is important in determining the success or failure of *Culex nigripalpus* in obtaining a blood meal from ciconiiform birds (Edman and Kale, 1971). We have also studied in detail the physical activity (i.e., the various antimosquito behavior patterns) exhibited by these birds (Webber and Edman, 1972), and, more recently, we reported on the effect of mosquito density on this antimosquito behavior (Edman *et al.*, 1972). This paper reports on the effect of behavioral variation among individual ciconiiform hosts and the effect of host maturation (age) on the feeding success of *C. nigripalpus*.

METHODS

The 4-cage experimental aviary and observation cage used in these experiments and the procedures for rearing and maintaining mosquitoes have been described

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(Edman and Kale, 1971; Webber and Edman, 1972). Nestling birds were obtained from a local heronry, kept in individual cages and hand-fed raw whole fish, shrimp, and suckling mice, supplemented with a mineral-protein-vitamin mixture. Fledged young and adults were maintained in large oudoor aviaries. All birds used in the experiments were in good health and plumage, and developed characteristic breeding plumage and soft part coloration as adults. Test birds were placed in individual 8 x 8 x 8 foot cages 2–3 hours before sunset and 300 unfed female mosquitoes were introduced into each cage ½ hour after sunset. The following morning surviving mosquitoes were recovered with an aspirator and examined for blood. The proportion of mosquitoes containing blood is termed the feeding or engorgement rate. Common names of bird species mentioned follows usage established by the *Check-list of North American Birds,* 5th edition (AOU, 1957). A list of these names with scientific names appears in Appendix I.

PRELIMINARY TESTS. Preliminary tests were conducted during the summer of 1970, primarily to ascertain whether the proportions of mosquitoes feeding on young birds were similar to those previously found on adults and to determine the degree of individual variation within the same species. Two to four individuals each of several species (black-crowned night heron, Louisiana heron, cattle egret, and white ibis) were used in this study. The birds were tested as nestlings (3–5 weeks old), fledglings (7–10 weeks), and immatures (14–20 weeks). Adult birds (1–2 years old) that had been hand-reared earlier were also tested.

INDIVIDUAL VARIATION. Some of the birds used in the preliminary study were tested again in 1971 to investigate individual variation among adults. In addition to the four cattle egrets and two individuals each of the black-crowned night heron, Louisiana heron, and white ibis, two great blue herons (raised in 1970) were also used. Each bird was tested for 4 nights over a 2-week period. Subsequent to this experiment, two cattle egrets and 2 Louisiana herons were placed individually in the observation cage with 300 mosquitoes and their behavior recorded for 1 hour on 2 different nights for each bird, in an attempt to relate individual differences in antimosquito behavior to differences in blood feeding rates. Individuals which showed the greatest variation in the aviary tests were selected for these observations.

AGE VARIATION. To test in detail the effect of host age on mosquito-feeding success, four nestling little blue herons and four nestling snowy egrets were obtained from nests when approximately 10–14 days of age. The weight, size and percent feather cover of each bird were recorded at the begining of each test period. Two individuals of each species were tested and the remaining two were held in reserve. The test birds were placed in the experimental cages for 4 consecutive nights when they had attained the following ages in weeks—2–3, 5–6, 8–9 and 13–14. During the course of the study two birds acquired an intestinal infection, one injured a leg, and another broke the tip of its bill, hence each of the original test birds had to be replaced by a reserve bird by the end of the study. Since this test was designed to compare age, not individual, differences, we concluded the results would not be adversely affected by this substitution. In experiments with nestlings, a 1 x ½ inch mesh weldwire platform was used instead of the perch provided for adults to prevent the young birds from falling to the floor. A perch was placed several inches above the platform and after the first test period most nestlings were observed sitting on it.

To help clarify the results of the above test, observations of the antimosquito behavior of a little blue heron were recorded in the observation cage for 1 hour on 2 consecutive nights when the nestling attained the age of 2–3, 5–6 and 8–9 weeks.

RESULTS

PRELIMINARY TESTS. Results of the first series of experiments on age and individual variation showed that the proportion of engorged mosquitoes decreased as the age of the bird increased within the first 10 weeks after hatching in those species (white ibis, Louisiana heron, cattle egret) that have been shown (Edman and Kale, 1971; Webber and Edman, 1972) to actively resist mosquito attack as adults (Table 1). No similar relationship was observed with mosquitoes feeding on the black-crowned night heron, a species which at these mosquito densities (300) does not resist mosquito attack. In fact, feeding rates actually increased from the nestling to fledgling stages and were highest on adults. Adult night herons resist mosquito attack only when densities are very high (Edman *et al.*, 1972). Hence, additional studies are needed to confirm and understand this reverse phenomena, i.e., development of a greater tolerance to mosquito attack as the bird matures.

INDIVIDUAL VARIATION. The tests on

TABLE 1.—Comparison of mosquito (*Culex nigripalpus*) engorgement rates on ciconiiform birds of various ages.

Species	Band no.	Relative age[1]	Test nights (no.)	Mosq. engorgement[2] (%)
B.-c. night heron	1	Adult	2	67
"	2	"	2	64
"	3	Immature	2	53
"	4	Fledgling	1	53
"	5	"	1	69
"	4	Nestling	1	41
"	5	"	1	59
White ibis	1	Adult	2	28
"	2	Immature	2	31
"	3	"	2	16
"	2	Fledgling	4	50
"	3	"	4	43
"	2	Nestling	1	65
"	3	"	1	53
"	4	"	1	65
"	5	"	1	68
Louisiana heron	1	Adult	2	39
"	2	Immature	2	24
"	3	"	2	27
"	2	Fledgling	4	31
"	3	"	4	33
"	2	Nestling	1	83
"	3	"	1	85
Cattle egret	1	Adult	2	13
"	2	Immature	2	4
"	3	"	2	6
"	2	Fledgling	4	7
"	3	"	4	22
"	2	Nestling	1	48
"	3	"	1	41
"	4	"	1	49
"	5	"	1	50

[1] Nestling (3–5 weeks old); fledgling (7–10 weeks old); immature (14–20 weeks old; adult (2–3 years old).

[2] $\frac{\text{Mean no. engorged}}{300} \times 100.$

individual variation conducted in 1971 show that feeding was similar on two individuals of the black-crowned night heron (67 and 75 percent) and the great blue heron (72 and 73 percent), another species which rarely, or feebly resists mosquito attack, while in those species which exhibit intense antimosquito behavior there is a greater degree of variation (Fig. 1). Engorgement rates on the white ibis were 26 and 47 percent, on the Louisiana herons, 12 and 30 percent, and on the cattle egrets, 7, 13, 16 and 31 percent. The rate on cattle egret D was always greater than the rate on the other three egrets, and on 3 of the 4 test nights the feeding rate on egret B was the lowest of the four birds. Differences between Louisiana herons A

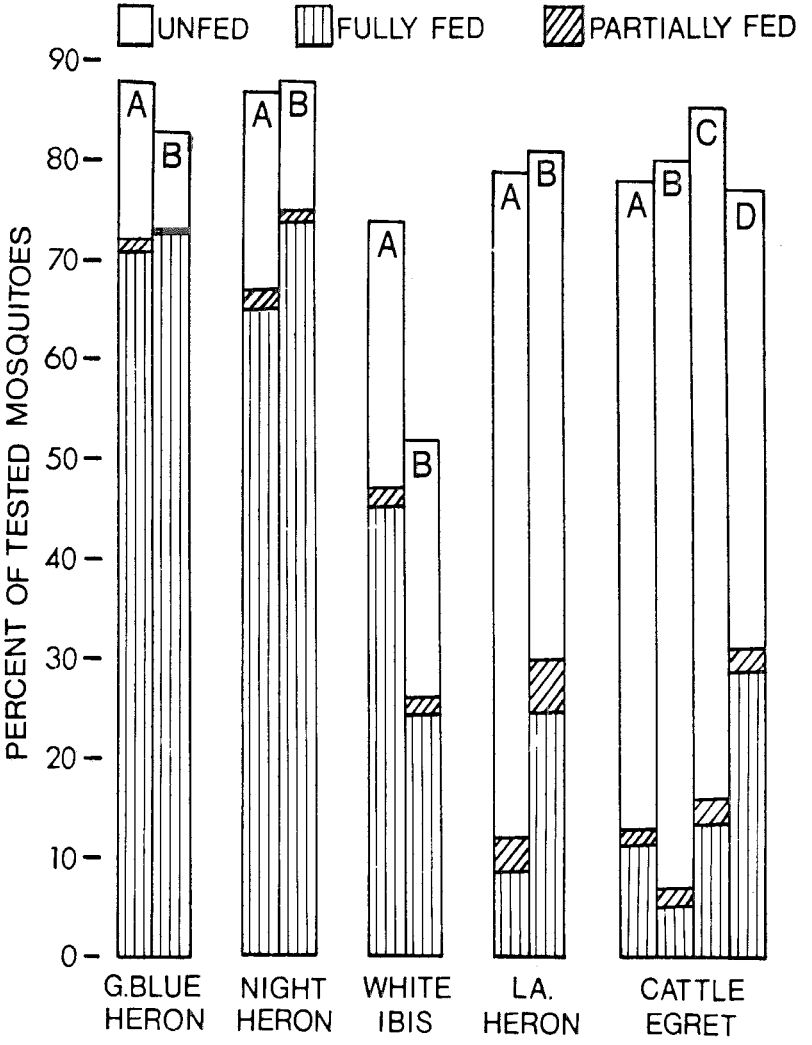

FIG. 1.—Feeding success of *Culex nigripalpus* on 2–4 different individuals of 5 ciconiiform species.

and B and white ibises A and B were also evident on all 4 test nights.

Observations of the antimosquito activities of Louisiana herons A and B and cattle egrets B and D are summarized in Table 2. Cattle egret B engaged in 1.7 x more antimosquito movements per hour (5061) than did egret D (2954), and, as a result the feeding success of mosquitoes caged with this bird was considerably lower (7 percent) than that for egret D (32 percent). Similarly, individual defensive performance differences account for the different results obtained with the 2 Louisiana herons (27 percent vs. 47 percent). Some of the disparity in the success of mosquito feeding on these birds was probably because Louisiana heron A expended a greater proportion (56 percent) of its total antimosquito activity (2999 movements/hour) protecting its feet (where most mosquitoes usually feed) whereas heron B expended considerably less (31 percent of 2213 movements/hour).

AGE VARIATION. Comparisons of mosquito feeding success with age of snowy egrets and little blue herons are illustrated in Figure 2. The feeding success on both species declined from the time they were 2–3 weeks old until they were 8–9 weeks of age. Activity of the little blue heron recorded in the observation cage indicated a corresponding age-related trend in both the type and amount of antimosquito behavior (Table 2). As this heron matured it devoted more effort in protecting the exposed legs. Total antimosquito activity increased from 2273 movements/hour at 2–3 weeks, to 2984 movements/hour at 5–6 weeks, to 3988 movements/hour at 8–9 weeks of age. The proportion of activities protecting the feet rose from 18 to 70 percent, while attention to the body region dropped from 64 percent at 2 weeks to 13 percent at 8 weeks of age.

Measurement of the physical characteristics of little blue herons and snowy egrets showed that the exposed surface area of these young birds changes rapidly and by the 6th or 7th week nestlings had nearly reached adult size and were almost as fully feathered as adults. Thus, the decline in mosquito feeding success associated with the increasing age of these birds in all probability stems from both morphological and behavioral maturation.

DISCUSSION

Individual variation in response to mosquito attack within a particular avian

TABLE 2.—Comparison of antimosquito activities of (A) individual adult herons and (B) a nestling little blue heron at three stages of development.

Body region	Head	Body	Feet	Misc.	% mosquitoes w/blood meal[1]
	Percentage of activity protecting each body region				
(A)					
Louisiana Heron					
A	30	13	56	1	27
B	50	17	31	1	47
Cattle Egret					
B	19	42	39	1	7
D	18	36	46	0	32
(B)					
Little Blue Heron					
2–3 weeks	17	64	18	1	44
5–6 weeks	24	29	47	1	21
8–9 weeks	17	13	70	1	20

[1] $\frac{\text{Mean no. engorged}}{300} \times 100.$

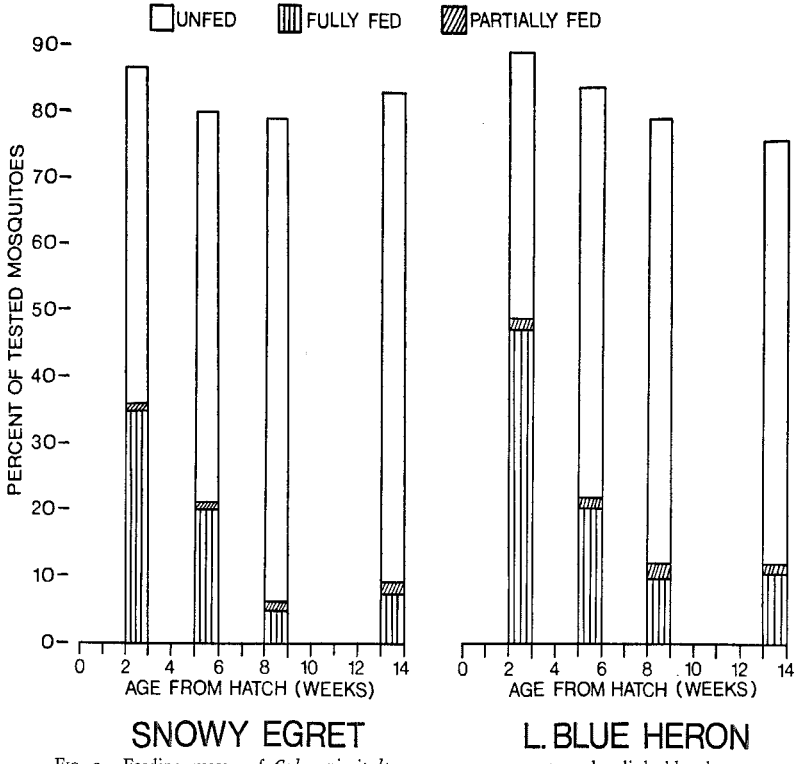

FIG. 2.—Feeding success of *Culex nigripalpus* on 2 snowy egrets and 2 little blue herons at various ages up to 14 weeks.

species has not been investigated previously, although in the course of our earlier studies we noted slight (less than 10 percent), but apparently consistent differences between individual herons (Edman and Kale, 1971). In their study of host attractancy and blood feeding, Dow *et al.* (1957) found considerable variation in engorgement rates of *Culex tarsalis* collected in traps baited with different chickens (24–84 percent), tricolored blackbirds (4–22 percent), house finches (60–98 percent), and English sparrows (4–31 percent). In another test, variation among tricolored blackbirds ranged from 17–91 percent. No behavioral observations were made in association with these comparisons, however. Dr. Albert Rudnick (1971, personal communication) and co-workers found in studies on monkeys of two species (*Macaca nemestrina* and *M. irus*) in Malaysia that the engorgement rates varied considerably with the individual host and observed that some monkeys allowed mosquitoes to feed readily, while others actively prevented them from engorging.

Variation between individuals of the same species of heron was somewhat greater than we had anticipated from earlier observations. Nevertheless, this finding does not alter our earlier conclusion that some species of adult herons, including the black-crowned night heron, great blue heron, green heron, and probably the yellow-crowned night heron (see Stamm, 1958), lack effective defensive behavior with the result that most mosquitoes attacking these species obtain a blood meal (Edman and Kale, 1971). Contrariwise, other ciconiiform species (the white ibis,

Louisiana heron, little blue heron, cattle egret, and snowy egret) all display such intense defensive behavior that even though response to mosquito attack may be more variable between individuals, the average frequency of blood engorgement by mosquitoes attempting to feed on these species is still consistently much lower.

Published information on the responses of developing young to mosquito attack is sparse. Blackmore and Dow (1958) in a study of differential feeding of *C. tarsalis* on nestlings and adults found an engorgement rate of 74 and 94 percent on two 8–11 day old pigeon squabs and 9 and 21 percent on two adult pigeons. In another test comparing young and adults, they reported engorgement rates of 96, 75, 98, and 82 percent, respectively, for nestling pigeons, English sparrows, barn swallows and domestic chickens, but only 6, 30, 33, and 51 percent, respectively, for the corresponding adult bird. These differences were attributed to the lack of plumage and quiescence of the nestlings. A study in the Central Urals of Russia (Shilova and Troitsky, 1958) indicated that nestlings of passerine and picine birds (woodpeckers and allies) were bitten by mosquitoes mainly from the 5th to the 8th day after hatching because homoiothermy was not attained before the 5th day and plumage growth protected the nestling after the 8th day, but no mention was made of the possible ontogeny of defensive behavior.

Results of the experiments reported here indicate that the age or degree of maturation of the host is an important factor affecting the feeding success of mosquitoes. A ranking of host-intrinsic factors we have so far investigated suggests that the species of host (Edman and Kale, 1971; Webber and Edman, 1972) is of foremost importance, and age of host (whether nestling or adult) second in importance, while individual behavior variation among members of the same species is third and consequently of least epidemiological significance.

Mosquito density also affects mosquito feeding success through its influence on host defensive behavior (Edman *et al.*, 1972). At times, the importance of mosquito density, which may vary greatly from night to night, may even exceed that of host age or individual variability. It is the complex interplay of all of these factors—and possibly others—that determines the success or failure of feeding by mosquitoes once they have encountered a host.

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APPENDIX I. Common and scientific names of birds referred to in this paper.

Common name	*Scientific name*
Great blue heron	*Ardea herodias*
Snowy egret	*Leucophoyx thula*
Cattle egret	*Bubulcus ibis*
Louisiana heron	*Hydranassa tricolor*
Little blue heron	*Florida caerulea*
Green heron	*Butorides virescens*
Black-crowned night heron	*Nycticorax nycticorax*
Yellow-crowned night heron	*Nyctanassa violacea*
White ibis	*Eudocimus albus*
Pigeon or rock dove	*Columbia livea*
Barn swallow	*Hirundo rustica*
English sparrow	*Passer domesticus*
Tricolored blackbird	*Agelaius tricolor*
House finch	*Carpodacus mexicanus*

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EFFECTS OF A JUVENILE HORMONE MIMIC ON *PSOROPHORA CONFINNIS* (LYNCH-ARRIBÁLZAGA) AND NON-TARGET AQUATIC INSECTS

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ABSTRACT. Monsanto 0585 (2, 6-di-*t*, butyl-4-(*a*, *a*,-dimethyl benzyl) phenol) caused high levels of larval mortality to *Psorophora confinnis* (Lynch-Arribálzaga) at 24 hr in the laboratory. In rice field tests Mon 0585 caused 100, 82, and 78 percent overall mortality (larvae and pupae) at concentrations of 2.0, 1.0 and 0.5 ppm, respectively, 5 days after treatment when applied to 1st instar larvae at time of flood. Concentrations of 2.0, 1.0 and 0.5 ppm caused 100, 96, and 84 percent overall mortality when applied to 3rd instar larvae 4 days after the rice had been flooded.

The number of Dytiscidae larvae was significantly ($P<.01$) reduced in the treated plots when compared to the untreated control population. Also, a reduction in Hydrophilidae larvae appeared possible.

Laboratory investigations have indicated that synthetic hormone chemicals show promise as mosquito control agents (Spielman and Williams, 1966; Spielman and Skaff, 1966; Jakob and Schoof, 1971). Spielman (1970) and Wheeler and Thebault (1971) conducted outdoor tests in which 100 percent control of *Culex pipiens quinquefasciatus* Say was achieved with 0.02 mg/ml of synthetic hormone. Hormonal action lasted for 72 hours with activity decreasing daily and no effect on 1st, 2nd or 3rd instar larvae was observed.

Sacher (1971) reported that a new chemical with juvenile hormone-type activity gave complete control of mosquito larvae at ca. 1.0 lb/A. He stated that this compound was practically inactive against non-target organisms which included the adult pea aphid, *Acryrthosiphon pisum* (Harris); western corn rootworm larvae, *Diabrotica virgifera* LeConte; Mexican bean beetle larvae, *Epilachna varivestis* Mulsant; house fly larvae and adults, *Musca domestica* Linnaeus; southern armyworm larvae, *Spodoptera* (=*Prodenia*) *eridania* (Cramer); and the strawberry spidermite adult, *Tetranychus atlanticus* McGregor=(*turkestani* U & N).

The present study was conducted to determine the effects of a synthetic hormone on natural populations of *Psorophora confinnis* (Lynch-Arribálzaga) and some non-target aquatic insect species in rice fields.

MATERIALS AND METHODS. Prior to conducting field tests, 1st instar *P. confinnis* larvae were collected and transported to the laboratory to determine their susceptibility to the synthetic hormone, (2,6-di-*t*, butyl-4- (*a*,*a*- dimethylbenzyl) phenol) tested under the code designation Mon

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