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SPECIES COMPOSITION, HOST FEEDING PATTERNS, AND VECTOR POTENTIAL OF MOSQUITOES (DIPTERA: CULICIDAE) FOUND ON THE MICHIGAN STATE UNIVERSITY CAMPUS

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Joan Davis

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Major professor

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Joan Davis

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ABSTRACT

SPECIES COMPOSITION, HOST FEEDING PATTERNS, AND VECTOR POTENTIAL OF MOSQUITOES (DIPTERA: CULICIDAE) FOUND ON THE MICHIGAN STATE UNIVERSITY CAMPUS

By

Joan Davis

During the summers of 1986 and 1987 a study was performed to determine the species composition, host feeding patterns, and vector potential of mosquitoes found on the Michigan State University Campus, East Lansing, Michigan and the surrounding area.

Out of 1629 mosquitoes, 477 were engorged, including Aedes vexans (Meigen), Anopheles quadrimaculatus Say, Culex salinarius Coquillett, and Coquillettedia perturbans (Walker). Blood meals were determined by the precipitin test. All mosquitoes, except Cx. salinarius, fed primarily on swine. Cq. perturbans was the only species in which major numbers fed on birds. No engorged An. punctipennis (Say), Cx. pipiens (Linnaeus), or Cx. restuans Theobald were collected. Multiple feedings occurred during 1987 at a rate of 2.29%. Mosquito feeding habits were analyzed statistically using a three way analysis of variance.

All mosquitoes collected are potential vectors of one or more animal or human diseases.

To my family

ACKNOWLEDGEMENTS

I wish to express my appreciation to my advisor, Dr. Harold D. Newson, now nearing the end of his career here at Michigan State University, for his constant encouragement, his calming reassurance when I was uncertain, for his helpful advice regarding my career, and his valuable critism on my thesis. I would also like to thank him for his willing financial assistance. It has been a valuable experience working with him.

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INTRODUCTION

Mosquitoes (Diptera: Culicidae) are worldwide pests of humans and animals, domestic and wild. They are found on the arctic tundra, and in temperate and tropical regions. Mosquitoes are a problem due to their annoying bites and their potential as disease vectors to man and animals. These insects have caused much suffering and misery, and have had an important role in shaping history, mostly due to the transmission of diseases such as malaria, filariasis, yellow fever, dengue, and viral encephalitides.

Michigan, like the rest of the world, has had its own problems with mosquitoes. Malaria was prevalent in the United States before arthropods were discovered to be vectors of disease and control measures were implemented. Epizootics of viral encephalitis are frequent in Michigan. Western equine encephalitis, eastern equine encephalitis, St. Louis encephalitis, and California serogroup encephalitis have been known to occur in this state (Michigan Mosquito Manual, 1984). Cases of these diseases have not been overly numerous, but certain varieties, such as St. Louis encephalitis in older adults and Calfornia encephalitis in childern, can be fatal. Public health agencies need to be aware of the disease potential that exists. It is the duty of public health agencies to provide the public with the most disease free environment possible.

Because mosquitoes are vectors of many diseases, public health workers need some knowledge of their biology as the first step in controlling them.

Of the three subfamilies of Culicidae, only Anophelinae and Culicinae are capable of biting, therefore are possible disease vectors. Members of Toxorhychilinae are not capable of biting animals (Service, 1986).

Most mosquitoes are anautogenous, that is, they require a blood meal for complete development of ovaries. Females have piercing-sucking mouthparts adapted for blood feeding. Mosquitoes also feed on nectar, which provides fuel for flight (Gillet, 1972).

Mosquitoes may feed at any time, but many are crepuscular or nocturnal (Service, 1986). They are attracted to hosts by body movements, visual cues, odors, carbon dioxide, heat, and moisture (Gillet 1972, Washino and Tempelis 1983). After a blood meal has been taken, some species rest on vertical surfaces near the feeding site in order to digest midgut contents. Most of the meal is broken down after 24 hours (Weitz and Buxton, 1953).

Purpose of the Study

The purpose of this study was to determine the species composition of the mosquito fauna on the Michigan State Campus and surrounding area, and secondly to discover their feeding habits

and host preferences. Many studies have been made of the feeding habits of mosquitoes (Downe 1960, Edman 1971, Edman 1974, and Hayes et al. 1973). A study of this kind, however, has not been done in the East Lansing area. Since it is neccessary to know the vector potential of mosquitoes, especially when concerned about transmission of disease, and not much is known about the species present in this area, clearly a study such as this is of importance. With this information the vector potential of the existing mosquito fauna can be evaluated.

Mosquitoes feed on a wide range of animals, but have normal host preferences (Edman and Kale, 1981). Knowledge of the vertebrate hosts of each species is an important step in evaluating the vector potential of any mosquito fauna (Edman, 1971). Host behavior can affect the success of feeding. Anti-mosquito behavior by hosts can lead to unsuccessful or interrupted feeding (Edman and Kale, 1971). When this happens, mosquitoes will sometimes complete their feeding on another host. This is termed multiple feeding. Multiple feedings are an important consideration when analyzing the vector potential of mosquito-borne diseases (Mitchell and Millian, 1981). The occurance of multiple blood meals is a good indicator of the vector potential of a mosquito fauna because multiple feedings can lead to increased disease transmission. Therefore, the occurance of multiple blood meals was searched for during this study, as well as the sources of single source blood meals.

LITERATURE REVIEW

Diseases involving man, animals and arthropods have existed for a long time. Only in recent history have these man-animal-arthropod relationships been recognized. Patrick Manson in the 1880's showed that mosquitoes were the arthropod hosts of human filarial parasites (Bates, 1949). Then in 1897 Ronald Ross in India and Giovanni Grassi in Italy found the malaria parasite developing in the bodies of an anopheline mosquitoes (Bruce-Chwatt, 1980). During the early twentieth century, with people like General William C. Gorgas working in this field, the science of malariology began to progress rapidly (Bruce-Chwatt, 1980).

Reed and coworkers in 1900 found that urban yellow fever was mosquito-borne (Aedes aegypti) (Bates, 1949). Shortly thereafter, in 1902, Reed and Carol discovered this disease was caused by a virus (Goldblum, 1964).

Much is known about the the first major outbreaks of St. Louis encephalitis which were well documented by the United States Public Health Service. Paris, Illnois in 1932, and St. Louis, Missouri in 1933 were the sites of the first recognized major outbreaks. L. L. Lumsden was the first to realize that that disease was transmitted by mosquitoes, Culex pipiens and/or Culex quinquefasciatus (Chamberlain, 1980). Reasons for this outbreak were very dry conditions and poor sanitation, excellent breeding conditions for these mosquitoes. There were 1095 reported cases

and 201 deaths during the 1933 St. Louis outbreak (Chamberlain, 1980). At that time little was known about arboviruses, and only recently had yellow fever been found to be caused by a virus. The virus causing St. Louis encephalitis was first isolated by Muckenfess et al. in 1933 (Goldblum, 1964).

Large outbreaks of western equine encephalitis occurred in 1941 in the United States and Canada. This virus was first isolated by Meyer, Haring, and Howitt in 1930 from the nervous system of a horse (Goldblum, 1964). It is possible that the natural transmission of this virus was through a bird-mosquito cycle, and that man and horses were dead end hosts (Goldblum, 1964).

Eastern equine encephalitis was first isolated by Ten Broeck and Merril in 1933, from the brains of dead horses. This disease of horses was recognized back in the 1800's in the eastern United States (Shaw, 1976). The zoophilic Culiseta melanura may be responsible for the bird to bird cycle of the virus, but other mosquitoes probably transmit the virus to mammals (Goldblum, 1964). Howitt isolated the eastern equine encephalitis virus from Mansonia perturbans in 1951 (Chamberlain et al., 1958).

The first recognized case of encephalitis caused by the California serogroup viruses occurred in 1943 in Kern County, California and the virus isolated in this case became the protype for the group (Thompson, 1983). It was not until 1964 that Thompson et al., first isolated La Crosse encephalitis virus, now recognized as a member of the California serogroup of viruses, from the brain of a child who had died of the disease (Kappus et al., 1983). La Crosse virus now is second only to St. Louis encephalitis

virus as the causitive agent of human arthropod-borne encephalitis in the United States.

Members of the California group are closely related and clinically indistinguishable from one another but antegenically distinct. These viruses are thought to be vectored primarily by Aedes species of mosquitoes (Sudia et al., 1971), and have been isolated from many members of this genus. Most of the Aedes species have been incriminated with one or more species of viruses in the California serogroup (Turell and LeDuc, 1983).

Birds, small mammals, and sometimes the mosquitoes themselves are the reservoirs of encephalitis viruses. Mosquitoes are responsible for the bird to bird transmission of St. Louis encephalitis, eastern equine encephalitis, and the western equine encephalitis viruses. When infected by these viruses, birds may have high levels of viremia but display no symptoms (Goldblum, 1964). Tree squirrels and chipmunks are involved in the horizontal amplification of California group viruses (Yuill, 1983). Mosquitoes such as Aedes triseriatus may transovarially transmit the virus to future generations. Also California group viruses may be transmitted venereally from mosquito to mosquito (Yuill, 1983).

Primary vectors of encephalitis viruses may vary geographically. For instance, in the case of St. Louis encephalitis, in the West Culex tarsalis is primarily responsible for transmission, in the East Culex pipiens is primarily responsible for transmission, and in Florida Culex nigripalpus is responsible for transmission (Mitchell et al., 1980).

With increasing incriminating evidence against mosquitoes as the vectors of many viral diseases in the United States and in several other countries (Rift Valley fever in Kenya, Murray Valley encephalitis in Australia, Japanese B encephalitis in the the Far East and Pacfic, and Venezuelan equine encephalitis in Mexico and South America), it became apparent that there was a definite need for more information concerning host-vector relationships.

The first step in determining this is to find out what species are present in a given area. Quite a number of lists of the mosquito fauna found in many different geographical areas have been made in the United States and Canada (Chapman 1959, Wiseman 1965, Smith 1969, Bickley et al. 1971, Parsons and Howell 1971, Tanimoto 1971, Parsons et al. 1972, and Cassani and Newson 1980). After host feeding patterns have been determined, vector potentials can be deduced using serological techniques. Many studies of this type have been done (Downe 1960, Edman and Downe 1964, Edman 1971, Gunstream et al. 1971, Magnarelli 1971, Taylor et al. 1971, Hayes 1973, Suyemoto et al. 1973, Edman 1974, Cupp and Strokes 1976, Nasci and Edman 1981, Richie and Rowely 1981, William and Meisch 1981, Burkot and Defoliart 1982, Kuntz et al. 1982, Nasci 1984, Anderson and Gallaway 1987, Irby and Apperson 1988, and Anderson and Gallaway 1988). A study of this type however, has never been done in Michigan. Because of the concentration of valuable livestock and Michigan State University's role in animal disease research, the Michigan State University campus and nearby areas were selected as the location for this study.

SITES AND METHODS OF COLLECTION

Mosquitoes were collected during the summers of 1986 and 1987 at the animal research centers on the southern part of the Michigan State University campus and at Van Atta's Greenhouse and Mini Zoo on M-78 in Haslett.

Most of the mosquitoes were collected with a hand held mouth-operated aspirator, which consisted of a 30 x 1 cm. length of hollow glass tubing, with netting on the end inserted into a 82.5 cm. length of rubber hose and taped together with masking tape (Service, 1986). Some were collected with a hand-held, battery-operated aspirator manufactured by Hausherr's Machine Works, Toms River, New Jersey 08753. Mosquitoes were transported in collapsible net cages, 28.75 x 15 cm. expanded. An Eveready Heavy Duty Industrial Flashlight was used to locate mosquitoes while resting on vertical surfaces or in the act of feeding. Collecting started at dusk and continued for 4 or 5 hours.

Specifically, engorged individuals resting near the host or in the act of feeding, were searched for and collected. Unengorged mosquitoes inside shelters or resting near shelters were collected, when seen.

Temperatures were taken with a pocket thermometer, Fisher Scientific, and environmental conditions were noted.

Locations

Site one was the Swine Center located near the intersection of Farm Lane and Forest Road (Figure 1). The swine center consisted of 5 buildings and one outdoor pen. Mosquitoes were collected from two buildings and the outdoor pen. These sites were chosen because mosquitoes had easy access to the pigs. The pen from which most of the mosquitoes were collected had three large windows on the north wall that were always kept open during the summer. The southern wall was screened on the lower half. Pigs were kept in large stalls. The second building where collections took place, had only one opening, a large door located on the east wall, and was not very productive. Mosquitoes were collected directly off pigs resting in the small screened outdoor pen.

Site two, the Dairy Center, is located on College Road (Figure 1). This site consisted of several buildings. Collections took place in only one of the buildings, and because bulls were kept in the other one it was and off limits. Most of the cows were kept indoors. Collecting took place in a structure which consisted of two large rooms where the cows were tethered to posts. Both rooms had windows on both outside walls, and large doors located at the ends of the rooms. There were insect zappers in one of these rooms. Usually a worker, a potential source of blood, would come in some time during the night and sweep.

Fig. 1. Topographical map of the southern part of the Michigan State University campus, location of collecting sites 1 (the Swine Center), 2 (the Dairy Center), 3 (the Sheep Center), and 4 (the Horse Research Center).

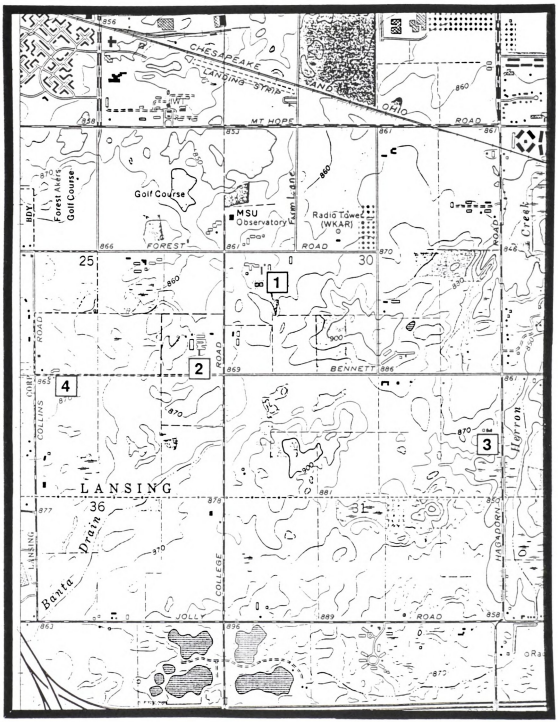
CHESAPEAKE
LANDING STRIP
OHIO
ROAD
MT HOPE
Golf Course
MSU
Observatory
Radio Tower
(WKAR)
FOREST
ROAD
Lamb Lane
Red Cedar
River
Forest Akers
Golf Course
25
30
1
2
4
3
BENNETT
ROAD
COLLINS
LANSING
36
31
Baute
Drain
COLLEGE
JOLLY
ROAD
HAGADORN
Herron
Creek
0
.5
1 Kilometer

Fig. 1.

Site three, the Sheep Research Barn, is located on Hagadorn Road (Figure 1). A large number of the sheep were allowed to graze outside near the buildings and may have served as sources of blood. Engorged mosquitoes were sometimes taken off outside walls. There were two barns, and collections were made at both. Most of the collecting was done at the larger building, to which the mosquitoes had better access. This barn opened up into outside pens on the east side. There were windows, which were kept open, on the western wall. Barn two had one pen inside the barn and an outside pen connnected to the barn on the west side. During 1987, peacocks and a goat were kept in the larger barn, and chickens were kept in the smaller barn. Occasionally one of the farm hands would drop in at night, and there were several cats on site. These could have provided additional sources of blood.

Site four, the horse barn, is located on Collins Road, (Figure 1). There were two barns; the mares were kept in one barn and the stallions in the other. Collections were done only at the mare barn. The mare barn consisted of many stalls with doors opening to the outside at the end of the stalls. There were also cats on site. Barn swallows nested here and which were possible blood meal sources. Collections were done at this site only during 1986.

Site five, Van Atta's Greenhouse and Mini Zoo, is located on M-78, about 8 miles east of East Lansing (Figure 2). Van Atta's is situated in a rural area, with many small farms nearby. This site consisted of three large pens, with various kinds of birds in them, and three small rabbit pens. Chickens, various species of pheasants, peacocks, ducks, turkeys, and Canda geese were also

Fig. 2. Map of Haslett, Michigan, location of Van Atta's Greeenhouse and Mini Zoo (site 5).

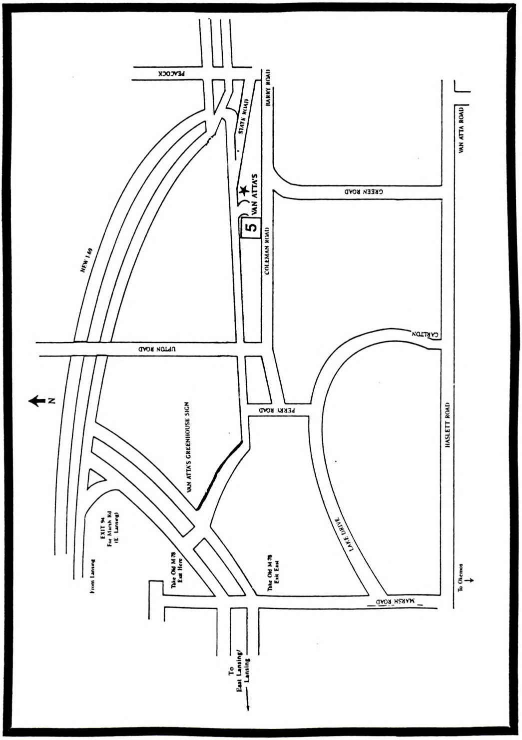
PEACOCK
STATE ROAD
BARRY ROAD
VAN ATTA ROAD
GREEN ROAD
VAN ATTA'S
5
COLEMAN ROAD
NEW I 69
CARLTON
UPTON ROAD
N
PERRY ROAD
HASLETT ROAD
VAN ATTA'S GREENHOUSE SIGN
LAKE DRIVE
EXIT 94
For Marsh Rd
(E. Lansing)
From Lansing
Take Old M-78
Exit Here
Take Old M-78
Exit East
To Okemos
MARSH ROAD
To
East Lansing/
Lansing

Fig. 2.

kept at this site. There were also many mice and rats, which were attracted to the animal feed kept near the pens, and provided more potential blood meal sources. There were several homes nearby, and the residents were often active at night and could have provided additional blood sources for mosquitoes. Collections were done at this site only during 1987.

METHODS AND MATERIALS

Collected mosquitoes were transferred to the laboratory, and placed in a freezer for 5 minutes, long enough to knock down the insects. Mosquitoes were then placed in marked vials with the collection date and location and put back in the freezer until they could be identified. After indentification the mosquitoes were sorted. Unengorged ones were discarded, engorged ones were placed in seamless cans and put back in the freezer until the precipitin tests were done.

Precipitin Test

Identification of mosquito blood meals requires a serological test. The capillary precipitin test was used to identify the source of blood meals. The precipitin test is most commonly used to determine blood sources and is undoubtly the most useful one for this purpose (Weitz, 1956). It has been found to be as accurate as some of the more advanced methods of blood meal identification and is a relatively easy and inexpensive procedure (Howenstine

personal comm., 1987). The test, based on Nutall's 1923 classic work, depends on the interaction between a saline extract of the blood meal or antigen and the suitable antisera or antibody.

Mosquitoes were prepared for testing by separating the head and throrax from the abdomen. Only the abdomen and its contents were used for the precipitin tests, because excess material was found to interfere with the test by clogging up the needles and also decreased the resolution of the reaction. Each test run consisted of 10 to 20 mosquitoes.

The precipitin test was done using methods described by Weitz (1956), Downe (1960), and Tempelis and Lofy (1963). Engorged mosquito abdomens were placed in 1.5 x 7.5 cm. test tubes and physiological saline, obtained from Fisher Scientific, was added, 0.5 ml for a well engorged abdomen and 0.25 ml for one partially engorged (Edman and Downe, 1964). Usually the blood started going into solution soon after adding saline. Tubes containing the saline and engorged abdomens were kept overnight in the refrigerator at 5 degrees C. Then they were allowed to incubate at room temperature at least an hour before testing. Abdomens were crushed with wooden applicator sticks until all of the blood had gone into solution. Tubes containing an abdomen with a partial blood meals were centrifuged in a Damon/IEC Clinical Centrifuge for 5 minutes, to clear the solution.

Each extract was then drawn up into a 1 cc tuberculin syringe fitted with 22 gauge 3.13 cm. or 3.75 cm. needles and layered about half way up a 1.5-1.8 x 33 mm. capillary tube. The capillary tubes had previously been sealed off at one end by heating. An equal

amount of antiserum, obtained from Sigma, Difco, and Serological Research Institute, was layered over the extract with a 1 cc tuberculin syringe fitted with a 27 gauge 3.75 cm. needle. A positive reaction was indicated by the presence of a white cloudy precipitate at the interface of the extract and antiserum, which was the insoluble product formed under specific conditions when antibody and antigen united. The capillary tubes were then placed in a reading block which consisted of a 40 cm. length of 2 x 4 drilled with holes 2 mm. in diameter and nailed to a 50 x 22 cm. piece of plywood covered with black cotton cloth. A light fitted with a F15T8-CW Cool White Sylvania Fluorescent bulb, was placed above the reading board.

Each engorged mosquito was first tested with an antiserum selected according to the location of its capture. If a mosquito was caught at the swine center, it was first tested against porcine antiserum. Usually mosquitoes found at a certain site had been feeding on the resident animals. If no reaction was obtained, then the extract was tested against other antisera, equine, chicken, sheep, bovine, rabbit, and human. Only when all of these possiblies had been exhausted would a blood meal be considered unidentified.

Readings were taken at 30 and 60 minutes. Most reactions took place in the first 30 minutes, and any blood meals unreacted after 60 minutes were tested further against a wider range of antisera. If a positive reaction was not obtained after the second round of testing the extract was considered unreactive.

Negative controls of saline and positive controls for each of the animal sera, obtained from the above mentioned sources, were

run before they were used in testing. In all cases the antisera was reactive with homologous blood and nonreactive with heterologous bloods.

RESULTS

A total of 1629 mosquitoes were collected over the summers of 1986 and 1987, representing 4 genera and 7 species. Eight hundred and fourteen mosquitoes were collected from July 22, 1986 to August 19, 1986, 253 of them were engorged (Figure 3). From June 3, 1987 to August 20, 1987, 815 mosquitoes were collected, 224 of them were engorged (Figure 4). Of the 477 engorged mosquitoes, 413 were tested using the capillary precipitin method. Due to the large numbers of mosquitoes found at the Swine Center, partially engorged individuals were not tested. Of the 413, tested only 3 blood meals remained unidentified. Mosquitoes containing multiple blood meals were found and collected at Van Atta's Greenhouse during the summer of 1987. Multiple blood meals occurred at a rate of 2.29% (Table 1).

Sixty two species have been identified in Michigan, and 21 species have been identified for Ingham County, Michigan (Figure 5) (Cassini and Newson, 1980). One of the seven mosquitoes collected in this study, Cx. salinarius was previously unreported in Ingham County.

Cq. perturbans was the most abundant species collected throughout the course of this investigation. During this study a total of 668 were collected, 26 during 1986 and 642 during 1987

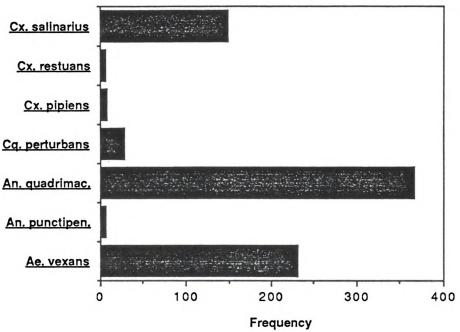

Fig. 3. Species found during 1986.

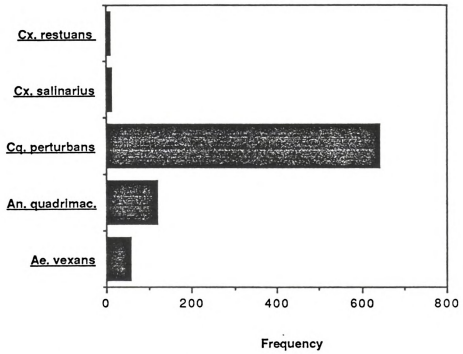

Fig. 4. Species found during 1987.

Table 1. Total percent of feeding for years 1986 and 1987.

Host	1986	1987
Porcine	65.64	49.08
Bovine	17.44	3.21
Sheep	8.21	28.90
Horse	3.20	0.00
Rabbit	0.50	12.39
Human	2.56	0.92
Multiple Feeding	0.00	2.29[1]
Unidentified	1.03	0.46

[1]All multiple blood meals contained avian-rabbit blood, andwere found at Van Atta's.

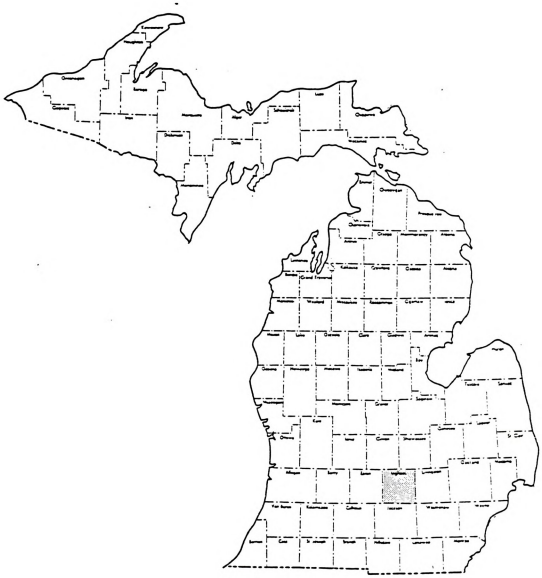

Fig. 5. Map of Michigan Counties.

(Figures 3 and 4). This difference in numbers can be explained since this is an early season mosquito, abundant in June and mid-July, and collecting in 1986 started in late July. Populations of Cq. perturbans usually drop off late in the season, about mid-August.

Forty-five percent of the Cq. perturbans collected in 1987 had fed on pigs (Table 2). Sheep were the second most attractive host, then rabbits, birds, humans, and cows. Cows proved to be relatively unattractive hosts. This may have had something to do with the location, the Dairy Center was not very accessible to mosquitoes.

Results obtained in this study were in agreement with what Tempelis (1975) stated, that Cq. perturbans is a general feeder with a preference for large domestic animals and birds. Edman (1971) and Magnarelli (1977) both found this species to feed principally on mammals and occasionally on birds.

Cq. perturbans was involved in 4 out of 5 of of the multiple blood meals identified. Magnarelli (1977) also found Cq. perturbans feeding multiply on birds and mammals. All of the multiple blood meals found contained both rabbit and bird blood, and were obtained at Van Atta's Greenhouse and Mini Zoo, which was a site containing a variety of birds and rabbits.

Anopheles quadrimaculatus was the second most abundant species collected. Three hundred and sixty were captured in 1986 and 118 during 1987 (Figures 3 and 4). Although many were captured each year, more were found during 1986 and more engorged ones were found during 1986. The greatest numbers of this species occurred in mid to late summer. Both years this species fed mostly on pigs and sheep. Bovines were blood meal sources only during

Table 2. Blood meal identifications for mosquitoes collected during June, July, and August 1987

Species	Hosts[1] Porcine	Bovine	Sheep	Avian	Rabbit	Human	Mult.[2]	NR[3]	Total
Aedes vexans	28(68.29)	6(14.63)	5(12.19).			2(4.89)			41
An. quadrimac.	4(33.33)		6(50.0)	1(8.33)	1(8.33)				12
Cq. perturbans	75(45.73)	1(0.61)	52(31.71)	5(3.05)	26(15.85)		4(2.43)	1(0.61)	164
Culex salinarius							1(100.0)		1
									218

[1] Number of blood meals identified and percent in ( ).
[2]All multiple feedings avian-rabbit, and were found at Van Atta's.
[3]Indicates no reaction by the precipitin test.

1986 (Tables 2 and 3). Other hosts included birds, rabbits, and humans. This is a predominantly mammalian feeding species (Tempelis, 1975), but avian feeding does occur. Although Williams and Meisch (1981), and Irby and Apperson (1988) found avian hosts being fed upon at a rate of less than 1.0%, others, Edman (1971) and Kuntz et al. (1982), did not find any An. quadrimaculatus feeding on birds.

Aedes vexans was the third most abundant mosquito found during of this study. This is a floodwater mosquito, and populations tend to increase rapidly after heavy rains. Many more specimens, both engorged and unengorged, of this species were found during 1986 than in 1987, which was a hotter, drier year (Figures 3 and 4). This species was found throughout the warmer months of the year.

It has been generally accepted that most Aedes spp. prefer mammalian hosts (Edman 1971, Edman and Downe 1964, Gunstream et al. 1971, Hayes et al. 1973, and Richie and Rowely 1981). Results of this study further support their observations. Pigs and cows were found to be the principal hosts of Ae. vexans (Tables 1 and 2). Of the total mosquitoes feeding on cows each year, more than 50% were Ae. vexans. Sixty-eight and 67% of Ae. vexans during 1986 and 1987 respectively fed on pigs. A study in Japan reported 82% had fed on pigs and 15% on bovines; these mosquitoes were caught by the sweep net method (Tempelis, 1975). Most studies have stated that ruminants are the principal hosts. Of cows, sheep, humans, horses, pigs, dogs and birds as possible blood meal sources, ruminants, cows and sheep, were the primary hosts in a study done

Table 3. Blood meal identifications for mosquitoes collected during July and August 1986.

Species	Hosts[1] Porcine	Bovine	Sheep	Equine	Avian	Rabbit	Human	NR[2]	Total
Aedes vexans	87(67.44)	29(22.48)	5(3.88)	4(3.10)	1(0.78)	1(0.78)	2(1.55)		129
An. quadrimac.	40(65.57)	5(8.20)	9(14.75)	2(3.28)	2(3.28)		2(3.28)	1(1.64)	61
Cq. perturbans	1(25)		2(50)				1(25)		4
Culex salinarius								1(100)	1
									195

[1]Number of blood meals identified and percent in ( ).
[2]Indicates no reaction by the precipitin test.

by Edman and Downe (1964). In a forest habitat, Burkot and Defoliart (1982) found the majority of Ae. vexans fed on deer.

Surface area and host density may be important factors in Ae. vexans feeding. Larger hosts may better tolerate mosquito biting (Nasci, 1984). Magnarelli (1977) suggested the affinity of Ae. vexans for mammals is due to host preference and not to host availability. Aedes spp. may have no preferences for particular mammals but feed on the most readily available host. Results of this study tend to agree with the latter. Nasci (1984) found Ae. vexans to be opportunistic in its host-seeking behavior where mammals were concerned, but it did not feed extensively on birds.

No bird-blood-fed Ae. vexans were detected during 1986 and less than 1.0% had fed on birds in 1987. Edman (1971) and Nasci (1984) also found less than 1.0% feeding on birds. Birds, which may not tolerate biting as well as larger vertebrates, appear to be unattractive hosts for Aedes spp. (Downe. 1960). All warm blooded hosts were readily fed upon by this species in the study made by Murphey et al. (1967), but cold blooded hosts were not used.

The fourth most abundant species was Cx. salinarius. One hundred and forty-nine where found during 1986, but only 13 in 1987. During 1987, a few of these mosquitoes were found early in the season, then populations dropped off. More were found in late July and August. Only two engorged Cx. salinarius were collected during the entire investigation, one each year. Just one of these blood meals was identified and contained both rabbit and avian blood.

The host feeding habits of Cx. salinarius in this area are still unclear due to the low number of engorged specimens caught in this study (Tables 2 and 3). Schaefer and Steelman (1969) found over 99% feeding on mammals in Louisiana. In Texas, Tempelis (1975) and Kuntz et al. (1982) reported they exclusively fed on mammals. Minnesota Cx. salinarius fed principally on passeriform birds (Tempelis, 1975). Canines were the primary hosts in North Carolina (Irby and Apperson, 1988). Hayes (1961) did not find a significant difference in their feeding on mammals or birds. Precipitin test studies in several regions have indicated Cx. salinarius may vary from a general feeder to feeding primarily on mammals in certain habitats (Edman, 1974). Cupp and Strokes' 1976 study in Louisiana showed 45% feeding on birds, mostly later in the season, equines (17%), and canines (15%) and a large percent unidentifiable (18%). Murphy et al. (1967) thought Cx. salinarius fed more on arboreal hosts, so this mosquito may have been feeding at higher elevations above ground level which were not sampled in the course of this study. Cx. salinarius may be a general feeder, feeding opportunistically, varying by geographical areas.

No engorged individuals of the remaining species were collected.

A total of 7 Cx. pipiens, less than 1.0% of the species found, were captured during mid-August of 1986 (Figure 3). This species feeds mostly on birds as many studies have shown (Hayes 1961, Murphy et al. 1967, Magnarelli 1977, and Tempelis 1967). In Kansas Edman and Downe (1964) found all singly-fed Cx. pipiens contained

mammalian blood, multiply fed individuals all contained bird and mammalian blood.

Fourteen Cx. restuans were found during this study, 6 in late July through August 1986 and 8 in early June and July of 1987. All classes of vertebrates except amphibians were fed upon by Cx. restuans in the study reported by Hayes (1961). Tempelis (1974) found minimal evidence that Cx. restuans were feeding more frequently on birds than mammals, while Magnarelli (1977) and Ritchie and Rowely (1981) found this species feeding exclusively on birds.

Six An. punctipennis were collected in 1986. Like other reported studies of Anopheles spp., they were found to feed on mammals. Studies confirming this include Edman and Downe (1964), Murphy (1967), Hayes et al. (1973), and Irby and Apperson (1988).

During 1986 the largest number of mosquitoes was collected at the Swine Center, followed by the Horse Center, the Sheep Center, and the Dairy Center (Figure 6). In 1987 the largest number of mosquitoes was found at the Van Atta's, then the Sheep Center, the Swine Center and the Dairy Center (Figure 7). From 1986 to 1987 numbers decreased at the Swine and Dairy Centers, and increased at the Sheep Center.

More mosquitoes were caught in August of 1986 than in July. In 1987 more mosquitoes were collected in July than June or August. Since the time that collecting started differed each year, only August collections can be compared. The total number of mosquitoes caught during August 1986 far exceeded the total

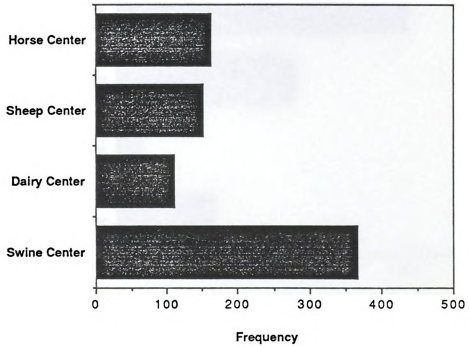

Fig. 6. Mosquitoes found at each location during 1986.

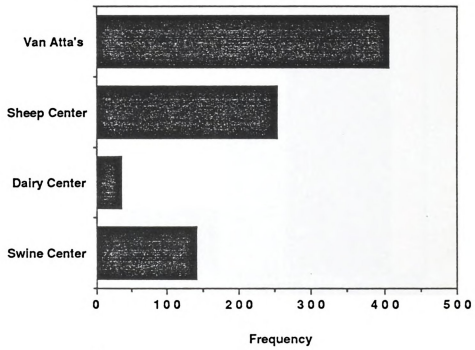

Fig. 7. Mosquitoes found at each location during 1987.

number caught during August 1987 (Figures 8 and 9). More time was spend collecting in August of 1986, and the number caught per outting was greater. Increased attempts were made to collect mosquitoes during August 1987, but few, sometimes no, mosquitoes were found during a night of collecting. Often collecting ended sooner when there was very little mosquito activity.

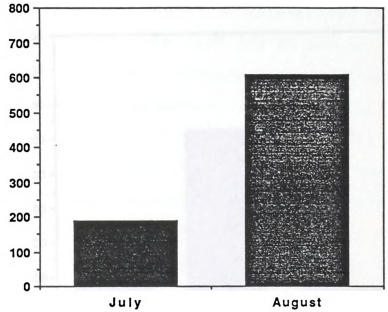

Fig. 8. Number of mosquitoes found each month during 1986.

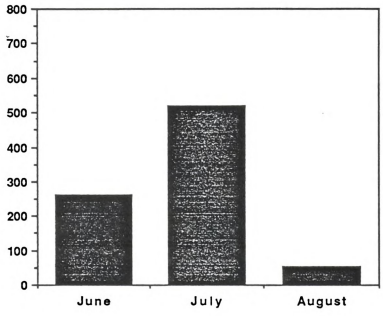

Fig. 9. Number of mosquitoes found each month during 1987.

Analysis

A three factor analysis of variance, feeding of species over locations, and months, was performed on the $\sqrt{Y}$ (arc sin) transformed data of the monthly percent of mosquitoes feeding and monthly percent of engorged mosquitoes. A general linear model was used to analyze the the data since there was no data for June 1986. Years were combined to get a complete picture of mosquito feeding. The overall analysis of variance on percent feeding was highly significant (Table 4). The main effects, species feeding and locations of feeding were both highly significant. Percent feeding per month was not significant at the 0.05 level, but was significant at the 0.1 level. Although none of the interaction terms were significant at the 0.05 level, the species-month interaction term was significant at the 0.1 level, indicating a trend in mosquitoes species feeding differently over time.

Duncan's multiple range test was performed (Table 5) and showed that Ae. vexans feeding was the same reguardless of month and location. Cq. perturbans and An. quadrimaculatus fed similarly each month at each location. The remaining species, Cx. salinarius, Cx. restuans, Cx. pipiens, and An. punctipennis, all fed similarly. None of these collected were engorged except the two Cx. salinarius. The mean number of the percent feeding at the Pig Research Center and Van Atta's was similar to the Sheep Center and the Horse Research Center, and Dairy Center was similar to the Sheep Center but different from the first two locations. The mean

Table 4. Three way analysis of variance on the monthly percent of mosquito species feeding, over months and locations.

Source of Variation	DF[1]	SS[2]	MS[3]	F	PR>F
Total	115	65579.04			
Feeding	85	58593.34	689.33	2.96***	0.0007
Species	6	27,684.26	4,614.04	19.81***	0.0001
Location	4	5,124.09	1,281.02	5.50***	0.0019
Month	2	425.79	212.9	0.91	0.4117
Species*Location	22	8317.67	378.08	1.62	0.1077
Species*Month	10	4,762.38	476.24	2.05*	0.0636
Location*Month	7	2,900.42	414.35	1.78	0.1284
Species*Month*Location	34	9,378.73	275.85	1.18	0.3206
Error	30	6,985.70	232.86		

*** significant at the 0.01 level
* significant at the 0.1 level

[1]Degrees of freedom.
[2]Sums of squares.
[3]Mean square.

Table 5. Duncans multiple range test on percent feeding.

48.18	9.91	9.69	0.49
a	bbb		cccc

Species and Means

Ae. vexans 48.18-a
Cq. perturbans 9.91-b
An. quadrimaculatus 9.69-b
Cx. salinarius 0.49-c
An. punctipennis 0.00-c
Cx. restuans 0.00-c
Cx. pipiens 0.00-c

15.89	10.36	1.65	0.28
aa	7.78	cc	
	b		

Locations and Means

Swine Center 15.89-a
Van Atta's 10.36-a
Sheep Center 7.78-b
Dairy Center 1.65-c
Horse Center 0.28-c

	6.15	4.21
21.58	bb	
a		

Months and Means

June 21.58-a
July 6.15-b
August 4.21-b

* All means with the same letter are not significantly different from each other.

number of the percent feeding during June was different from August, but similar to July (Table 5).

Analysis of the percent engorged showed that there were no significant differences in engorgment rates of the mosquitoes found engorged, Ae. vexans, An. quadrimaculatus, Cq. perturbans, or Cx. salinarius (Table 6).

Table 6. Three way analysis of variance on the monthly percent engorged of mosquitoes species, over months an locations.

Source of Variation	DF[1]	SS[2]	MS[3]	F	PR>F
Total	39	18849.58			
Engorged	29	15943.94	549.79	1.89	0.144
Error	10	2905.64	290.56		

[1]Degees of Freedom
[2]Sum of Squares
[3]Mean Square

DISCUSSION

Species Overview

Culex pipiens

Culex pipiens (Linnaeus) may be the primary vector of St. Louis encephalitis (SLE) virus to birds in Michigan. SLE is the most important epidemic arboviral disease in the United States (Chamberlain, 1980). There was one major outbreak of this disease in Michigan during 1975, and a few minor outbreaks have occurred in subsequent years. Cx. pipiens populations are most dense in urban areas, which corresponds to locations where major outbreaks of SLE have occurred. This is a cosmopolitan species that readily enters houses, thus the common name of the "northern house mosquito" (Carpenter and LaCasse, 1955). These mosquitoes may be capable of transmitting California serogroup (CE) viruses (Turell and LeDuc, 1983). CE infections in humans are incidental in the normal cycles of the virus, and usually occur when men intrude into natural woodland habitats of the small mammal hosts and mosquito vectors (Sudia et al., 1971). Western equine encephalitis virus has also been isolated from this species. WEE is enzootic in wild bird populations, and is passed from bird to bird by mosquitoes. Although infections in horses and man are incidental, infections in

horses have occurred in Michigan, but no human cases have been reported (Michigan Mosquito Manual, 1984).

Cx. pipiens feeds primarily on birds. Pigeons, blue jays, house sparrows and robins may serve as reserviors of SLE virus and can play an important role in disease transmission. Migratory birds may play an important role in Culex spp. feeding and bird virus maintance, since they are present during certain seasons, and they may be virus sources for mosquitoes. Cx. pipiens also transmits the causal agents of bird malaria, such as Plasmodium relictum and Plasmodium cathemerium.

Breeding takes place in artifical containers such as cans, tires, bottles, and bird baths. They also breed in water sources with high organic, content such as cesspools, septic tanks, and gutters (Carpenter and LaCasse, 1955). Females lay their eggs in rafts on water. There are several broods per year from eggs which are laid during the warmer months of the year.

Their effective flight range is approximately 1 mile, and peak activity of Cx. pipiens occurs at dusk and dawn. They overwinter as adult females, often in caves, cellars, and basements. Adults often rest on vertical surfaces near breeding sites during the day.

Culex restuans

Culex restuans Theobald is found in the United States and Mexico. SLE virus has been isolated from this species during the spring and fall months when populations are high. This species may be important in the overwintering and early amplification of the

SLE virus, with Cx. pipiens as the major vector during the warmer months (Mitchell et al., 1980). Dog heartworm, EEE, and CE have also been isolated from this species.

These mosquitoes feed primarily on birds, rarely on mammals. Infections in man and horses are incidental in the normal cycles of SLE virus (Bates, 1949).

Cx. restuans produces several broods per year and lays its eggs in rafts. Females oviposit their eggs in ditches, woodland pools, and containers. They overwinter as adult females and have an effective flight range of 1 mile (Michigan Mosquito Manual, 1984). Cx. restuans is abundant in the northeastern United States (Darsie and Ward, 1981), and can be quite annoying.

Culex salinarius

Culex salinarius Coquillett is found in the eastern United States. SLE virus has been isolated from this species. The role of Cx. salinarius in the transmission cycle of this virus is unclear. Birds and mammals are the usual hosts of Cx. salinarius, and this species may be important in enzootic transmission of viral diseases (Carpenter and LaCasse, 1955). This species may also transmit bird malaria.

Breeding occurs in ditches, pools, and marshy areas. There are several generations per year, and eggs are laid in rafts on the water. They overwinter as adult females.

Coquillettidia perturbans

Coquillettidia perturbans (Walker) is a Nearctic species and is a pest common to Michigan. Eastern equine encephalitis virus has been isolated from this species in Michigan. The role of Cq. perturbans in the transmission of this disease is not fully understood, but it is thought to be the major amplifying vector in this area. EEE occurs sporadically in Michigan horses, and farther east in the United States it also is a serious disease of penned pheasants, due to pecking, which may transfer the virus from bird to bird. Cq. perturbans may also transmit CE virus.

Breeding takes place in permanent bodies of water with emergent vegetation (Carpenter and LaCasse, 1955). These mosquitoes are univoltine, and eggs are laid in boat-shaped rafts along the edge of the water. This species overwinters as larvae attached to plant roots. Peak feeding of adults occurs at dawn and dusk, and they are strong fliers with an effective flight range of 1 to 5 miles. Adults of this species are found in the late spring and summer, and females readily feed on both birds and mammals.

Aedes vexans

Aedes vexans (Meigen) is a Holoarctic and Oriental species, and is a severe pest of man and domestic animals. This is one of the most widely distributed species (Darsie and Ward, 1981). They may be involved in the transmission of EEE, WEE, CE, and dog heartworm.

This mosquito feeds primarily on large domestic animals (Shemanchuk, 1969). They are fierce and abundant day biters who will also feed readily on man (Carpenter and LaCasse, 1955). Ae. vexans has an extensive flight range, 5 to 20 miles. They will fly away from their normal habitat, shady places, for a blood meal (Carpenter and LaCasse, 1955).

Breeding takes place in temporary pools and flood plains. These mosquitoes are multivoltine, and eggs are laid singly on the water surface or along the edges of receding pools. They overwinter as eggs.

Anopheles quadrimaculatus

Anopheles quadrimaculatus Say is found in the eastern United States. This species has not been associated with the transmission of viral encephalitis, but has been associated with dog heartworm and malaria, but malaria is no longer a problem in the United States.

There are several broods per year, and eggs are laid singly on permanent fresh water sources with vegetation such as canals and ponds. Adult females are the overwintering stage, and they have an effective flight range of 1 mile. These mosquitoes rest during the day beneath houses, in dark corners of buildings, or in hollows of trees, and are active at night.

This species has been found to feed primarily on mammals. The feeding patterns of Anopheles throughout the world are dependent on availability of certain mammals (Tempelis, 1975). These mosquitoes are closely associated with man and domestic animals.

Anopheles punctipennis

Anopheles punctipennis (Say) is a Nearctic species and the most widespread species of Anopheles in North America. This species is thought to be a potential vector of CE. An. punctipennis is also a vector of malaria and dog heartworm. And like other Anopheles species, feeding preference is for mammals.

Breeding takes place in a wide variety of ground water accumulations, and eggs are laid singly on the surface of water (Carpenter and LaCasse, 1955). These mosquitoes are multivoltine, and have an effective flight range of 1 or 2 miles. Adult females usually find a well protected place to overwinter.

Discussion

Overall, mosquitoes found on the Michigan State University Campus differed in their feeding habits ($P<0.01$), but engorgment rates did not differ significantly ($P>0.05$). Blood fed specimens of Cq. perturbans, An. quadrimaculatus, Ae. vexans, and Cx. salinarius were found both years of the study. No engorged specimens of An. punctipennis, Cx. pipiens, or Cx. restuans were found throughout the entire study.

Only three blood meals remained unidentified. It is possible that the blood was from hosts not tested for or the blood meal was digested beyond recognition by the precipitin method.

Only one habitat, animal shelters, was surveyed. It is possible that some of these species were feeding in habitats not sampled, or at a time of day or year when sampling did not take place, like earlier in the day or year. Statistical analysis indicated a trend in mosquitoes feeding differently over time, months.

In this study species density was low for An. punctipennis, Cx. pipiens and Cx. restuans. Their densities may have been insufficent during 1986 and 1987 to provide a true indication of their feeding preferences. Species density of Ae. vexans, An. quadrimaculatus, Cq. perturbans, and Cx. salinarius, was greater than that of An. punctipennis, Cx. pipiens and Cx. restuans, and engorged specimens of were found for each of them.

Locations

More mosquitoes were found at the Swine Center than at any other location during 1986 (Figure 6). During 1987 the greatest number of mosquitoes was collected at Van Atta's (Figure 7). The Dairy Center rated last both years.

The Swine Center yielded the most engorged mosquitoes of any location either year (Tables 2 and 3). An important factor

affecting the number of engorged mosquitoes found there was most likely host density and location accessibility. Host abundance was greatest at the Swine Center, and was less at Van Atta's, the Sheep Center, less at Dairy Center, and the Horse Center respectively. The animal shelters at Van Atta's were completely open to the elements. Mosquitoes had good access to the pig and sheep barns. The Horse and Dairy Centers were not as accessible as some of the other structures.

Even though the Dairy Center housed many cows, they were not placed closely together and were dispersed over the location. This may have had an effect on mosquito host finding activity. The Dairy Center is less than a mile from the Swine Center so distance was probably not an important factor responsible for the difference in numbers found at these two locations. There are many woodlots near these animal shelters which yield many potential resting and breeding sites for many species (Figure 1), so location of breeding sites was probably not a significant factor affecting the number engorged found at the Dairy Center.

Light was a factor that may have been important at some sites. Many times during the summer of 1987 the lights were left on at the Dairy Center late into the night. Mosquito species that prefer woodland habitats to open areas are also species that avoid light (Bidlingmayer, 1967). Bright lights may have acted as a deterrent, and could account for the decreased numbers found during 1987 at the Dairy Center.

In the case of the Horse Center, distance may have been a minor factor affecting the number of engorged mosquitoes found

there. This location is over a mile from the some of the breeding sites where many mosquito species may breed and rest (Figure 1). There were not many openings allowing mosquitoes into the barn where the horses were kept. Many more mosquitoes were collected outside this structure than inside, consequently very few engorged specimens were found at the horse barn. Less than 20 horses were kept inside the barn and they were placed far apart in separate stalls. Therefore, a lack of accessibility and decreased host density were probably reasons why low numbers of engorged mosquitoes were found at the Horse and Dairy Centers.

Structural characteristics of the animal shelters, the amount of light at the shelter during the night, and location of the shelter on campus relative to mosquito resting and breeding places may have had an effect on the number of mosquitoes found within them. A significant difference ($P<0.01$) in the percent of mosquitoes feeding at each location was found (Table 4).

Host Selection

Many factors are involved in the host selection process, such as the host's density, age, sex, size, shape and contrast, as well as their airborne emanations, diel and spatial activities, and health. Other factors related to mosquito host-seeking include: their innate selectivity patterns, diel activity, spatial activity, and physiological status (Edman et al., 1985). These factors interplay,

so when host and mosquito meet, there are several possible outcomes.

It could be that since no suitable hosts were available, no feeding took place. Not all vertebrates within a given habitat are available and suitable to all of the mosquitoes foraging in that habitat. Many of the above species that were not found engorged are known to feed primarily on birds, mainly passiform and columbiform. Only anseriform and galliform birds were available for feeding at the location that housed birds, Van Atta's.

Another possiblity that could account for the differences found in species feeding at different locations is the relative feeding habits of the mosquitoes involved. Some species may have more fixed feeding patterns while others are more opportunistic in their feeding habits. Ae. vexans has a more fixed pattern of feeding on mammals than a species such as Cq. perturbans, and will feed opportunistically on mammals found within their habitat. Fixed behavior may be described as occurring when host selection is not attuned with host availability (Washino and Tempelis, 1983). In this study Ae. vexans fed very little on birds and primarily on mammals while Cq. perturbans fed well on both mammals and birds. More Ae. vexans fed on cows and horses than any other species collected in this study. Other studies indicate this species feeds readily on large mammals (Downe, 1960). Since the Horse and Dairy Centers were somewhat inaccessible to mosquitoes, cows and horses must have been attractive enough for Ae. vexans to actively search out and feed on these animals while other species perhaps

would not do so. Cq. perturbans, being a more opportunistic feeder, fed only on hosts that were readily available.

Some mosquitoes will not fly far out into pastures, away from resting places, for a blood meal (Edman and Bidlingmayer, 1969), while some mosquitoes, like Ae. vexans and Cq. perturbans, have extensive flight ranges and will go far out into open pastures for a blood meal.

Host Defense

Feeding on small vertebrate hosts, such as rabbits and birds, throughout this study was minimal (Table 1). Smaller vertebrates may be more sensitive to mosquito biting than larger vertebrate hosts. Possibly feeding on larger less defensive hosts may be advantagous for some mosquitoes that occur in large numbers like Cq. perturbans and Ae. vexans (Nasci, 1985). Anti-mosquito behavior of some vertebrates can successfully prevent mosquitoes from feeding (Edman and Kale 1971, Edman et al. 1984).

During the summer of 1987, when populations of Cq. perturbans were high, young turkeys were observed one night piled on top of each other trying to avoid mosquito biting. They displayed many anti-mosquito motions such as head shakes, head rubs, and body fluffing. Nestlings are often bitten more than adult birds, since they have fewer feathers and are quiescent (Blackmore and

Dow, 1958). Adult birds have thick feathers, which can cause the mosquito some difficulty in probing, and they also can be quite defensive hosts.

More Cq. perturbans fed on rabbits at Van Atta's, probably due to unsuccessful feeding on birds. Edman et al. (1972) observed an increase in defensive activity displayed by birds when exposed to increases in mosquito density. Nelson et al. (1976) found Cx. tarsalis feeding more on rabbits when birds could not be fed upon due to denfensive actions. In addition there was an increase in partially engorged mosquitoes found at Van Atta's when populations of Cq. perturbans were high, probably due to unsuccessful feeding. Partial blood meals are an important factor in disease transmission because a partially engorged mosquito is likely to feed again soon. If it had first fed on an infected animal then fed on another animal it could transmit disease.

Species Found Over Time

No difference was found in the total numbers of mosquitoes collected during 1986 and 1987. Even though sampling started later in the year during 1986, and more time was spent sampling in 1987, almost equal numbers were found each year. Eight hundred and fourteen were caught in 1986 and 815 in 1987.

A difference was found in the number of engorged mosquitoes found each year. Only 224 engorged specimens were found in 1987, compared to the 253 found in 1986. Also species diversity was greater in 1986 than in 1987. Seven species were found in 1986 compared to 1987, when only 5 species were found.

Greater numbers of Cq. perturbans were found during 1987 than 1986. This is an early season mosquito, so the reduced numbers of Cq. perturbans during 1986 could be accounted for by the later start of collecting in 1986 (Tables 2 and 3). More Ae. vexans and Cx. salinarius were found during 1986 than 1987. Almost equal numbers of Cx. restuans were found each year. No Cx. pipiens or An. punctipennis were found in 1987.

Reasons for this difference in numbers may have been due to the amount of precipitation that fell each year. Adequate moisture early in the season is important for development of many species of mosquitoes. Many mosquitoes such as Culex overwinter as adults and oviposit their eggs in early spring. Precipitation during the early spring of 1987 was unusually low so many vernal ponds that normally produce large numbers of Aedes were absent that year. Cq. perturbans would probably be less affected by rainfall since they breed deep in permanant bodies of water with vegetation. The rainfall during June 1986 was much greater than that of 1987. Although the rainfall both years was above average, 1986 was higher than 1987 (Table 7).

Temperature may have been another factor affecting the number of species found each year. During June and July of 1987 temperatures were above norms for both months (Table 8). Not

Table 7. Monthly precipitation (inches) in Lansing, Michigan.[1]

Year	June	July	August	Total
1986	10.2	1.69	2.88	14.77
1987	3.30	3.35	5.64	12.29
Average[2]	3.50	2.87	3.04	9.41

[1]Local Climatological Data Lansing, MI. NOAA Publications.
[2]A 30 year average from 1951 through 1981.

Table 8. Monthly temperature (F) in Lansing, Michigan.[1]

Year	June	July	August
Ave. High	76	83	77
1986			
Ave. Low	53	62	53
Ave. High	83	86	79
1987			
Ave. Low	59	63	60
Ave. High	78	83	81
Average[2]			
Ave. Low	55	59	57

[1]Local Climatological Data Lansing, MI NOAA Publications.
[2]A 30 year average from 1951 through 1981.

many studies have been made of the optimum temperature for survival of larvae and adults of species found in Michigan, but constant exposures to extreme temperatures may be fatal to both (Bates, 1949). Night temperature, towards the middle of August 1987, dropped off somewhat. Often temperatures were below 65 degrees F. When temperatures were low mosquito activity decreased. Numbers of mosquitoes found during August 1987 were substantially less than 1986 (Figures 8 and 9).

Host Preference

Ae. vexans fed predominantly on pigs, cows, and horses. Even though the Dairy and Horse Centers were relatively inaccessible to mosquitoes, this species still fed at these locations, outnumbering the other species. Cows and horses appeared to be particularly attractive hosts for this species.

Likewise pigs were the principal hosts for An. quadrimaculatus Birds were fed upon both years by this species (<3.0%). Other mammalian hosts, sheep, humans, and rabbits, were utilized at low rates, 10.0% or less.

As with An. quadrimaculatus, pigs were the primary source of blood for Cq. perturbans. They also fed very well on sheep, and to a lesser extent on rabbits, when compared to others species in this

study. Birds were also utilized by this mosquito, more so than by other species.

The overall host preference of An. quadrimaculatus and Ae. vexans seems to be for pigs, and large mammals in general. The host preference of Cq. perturbans appeared to be less specific than that of An. quadrimaculatus and Ae. vexans, and it seemed to feed on whatever host was readily available.

Neither the host preference of Cx. salinarius, since only two engorged ones were collected, nor the host preferences of the other Culex spp. or An. punctipennis, all of which were unengorged when collected, could be determined from this study.

Vector Potential

All of the mosquitoes found during this study are potential vectors of one or more diseases. Some have greater vector potential than others. Many of these species are important in the transmission of zoonoses and in the transmission of diseases important to man.

Ae. vexans is primarily a large mammal feeder in this area and may be important in the transmission cycle of eastern equine encephalitis virus, but few were found feeding on birds. Many of the California serogroup viruses such as: CE, Jamestown Canyon (JC) virus, Keystone (KEY) virus, La Crosse (LAC) virus, South River

(SR) virus, Snowshoe Hare (SSH) virus, and Trivittatus (TVT) virus have been isolated from this species (Turell and LeDuc, 1983). Outbreaks of La Crosse encephalitis have occurred in Michigan (Calisher, 1983). Ae. vexans has been proven to be a very important in the transmission cycle of dog heartworm (Lewandowski et al., 1980). They do appear in substantial numbers in this area, and readily feed on many mammals.

Anopheles spp. are vectors of human malaria, which has been eradicated in the United States. Many of the Michigan State foreign students are from countries where malaria is still prevelent. If an infected student were fed upon by one of these species, a new outbreak of this disease may be possible.

Both An. quadrimaculatus and An. punctipennis are vectors of dog heartworm in this area, and An. quadrimaculatus occurs in large numbers each year (Lewandowski et al., 1980). An. quadrimaculatus was been found to be one of the primary vectors of dog heartworm in central Michigan. Humans can get this disease, but the filarial worm that causes dog heartworm, Dirofilaria immitis, cannot reproduce in humans (Harwood and James, 1979). However it may form lesions on the lung and heart, which may be mistaken for cancer.

Cx. salinarius, Cx. restuans, and Cx. pipiens may be vectors of viral encephalitides in Michigan. All of these Culex spp. have shown high rates of transmission of St. Louis encephalitis virus in the laboratory (Mitchell et al., 1980). These three species are capable of transmitting bird malaria, which is a widespread disease of wild birds (Hewitt, 1940). Cx. restuans and Cx. pipiens were not found in

great numbers, so their vector potential can not be determined at this time.

While more abundant than the other Culex species, Cx. salinarius' role in the transmission cycle of St. Louis encephalitis in this area is questionable. South River (SR) virus has been isolated from this species, but not much is known about the natural history of this virus (Turell and LeDuc, 1983). Cx. salinarius may be vector of dog heartworm, and Cx. pipiens is a potential vector also (Lewandoski et al. 1980, Irby and Apperson 1988).

Outbreaks of St. Louis encephalitis virus and western equine encephalitis virus can occur under certain conditions, such as when populations of Cx. pipiens or Cx. tarsalis are high and environmental conditions are favorable. High temperatures favor the reproduction of viruses. With increased temperatures there is a decrease in the extrinsic incubation periods for arboviruses such as St. Louis encephalitis and western equine encephalitis (Mitchell et al., 1980). The summer of 1987 was particularly hot, and showed conditions favorable for increased viral reproduction.

Other factors like rainfall are important to the mosquito vectors. Decreased rainfall favors higher populations of Cx. pipiens. Dry conditions cause pooling and concentration of water, ideal conditions for the reproduction of this mosquito, while increased rainfall, more flooding and run off, favor high populations of Cx. tarsalis (Mitchell et al., 1980).

The threat posed by Cq. perturbans is greater still due to the considerable numbers which occur in Michigan and their feeding on both birds and mammals. Four of the Cq. perturbans collected

contained both bird and rabbit blood. This species appears to be opportunistic in its feeding habits, and opportunistic feeders are thought to have greater potential as vectors of viral disease (Washino and Tempelis, 1983). Also Cq. perturbans fed on rabbits, when available, and small mammals may be important in the maintenance of some California serogroup viruses. Eastern equine encephalitis and Trivittatus viruses have been isolated from this species, and EEE has occurred more than once in Michigan horses (Shaw, 1976).

Both Ae. vexans and Cq. perturbans are major pest mosquitoes in Michigan and can cause much annoyance and blood loss to both man and animals. Annoyance by mosquitoes can lead to loss of productivity in domestic animals. These mosquitoes can cause much misery, particularly for younger more defenseless animals like the turkey chicks described earlier. Sick animals, too, are a likely targets for these mosquitoes. Mosquitoes feeding on sick animals increase the possibility of disease transmission.

From an epidemiological viewpoint Cq. perturbans, Ae. vexans, and An. quadrimaculatus are of particular concern, since these mosquitoes were found engorged, they fed on a variety of animals, and occurred in relatively large numbers during this investigation.

Importance of Mosquito Monitoring

It is always important to maintain a surveillance on the existing mosquito fauna. Mosquito control workers should be alert for the possibility of the presence of an unusual species and be prepared to take the appropriate control measures. Some species of mosquitoes are excellent vectors of certain viral diseases. It is possible for new species of mosquitoes to establish themselves in different geographical areas. Two species, Cx. tarsalis and Ae. albopictus, which have been found in Ohio are of particular interest to those monitoring for mosquitoes in Michigan.

Cx. tarsalis (Coquillett) is a known vector of western equine encephalitis and St. Louis encephalitis viruses and a suspected vector of California encephalitis virus. It is a common species in the western United States and feeds often on birds (Tempelis, 1975), but this can vary owing to the geography of an area and time of year. These mosquitoes are also common in Ohio (Parsons, personal comm., 1988) and have been found in a few locations in northern Michigan (Darsie and Ward, 1981).

Cx. tarsalis is a fierce biter, attacking at dusk and dawn and has been found to readily enter houses in search of blood meals (Carpenter and LaCasse, 1955). Passeriform and columbiform birds serve as primary hosts of Cx. tarsalis. They will readily feed on mammals if given a chance, but cows, man and horses are incidental hosts. There is a seasonal shift in feeding from birds to mammals, which occurs in mid-July and coincides with outbreaks of western

equine encephalitis and St. Louis encephalitis in mammals. This seasonal change in feeding is a significant factor that makes Cx. tarsalis an important vector of viral diseases (Tempelis et al., 1967).

Mosquito control workers need to be on the lookout for the asian tiger mosquito Ae. albopictus (Skuse). This species is indigenous to Oriental and Australian regions of the world, but has been found in the United States on several occasions, mostly due to importation of items such as tires that contain water and mosquito larvae. Ae. albopictus has been found in tire shipments in Los Angeles, California (Eads, 1972), in a refuse dump in Memphis, Tennesse (Reiter and Darsie, 1984), in Harris County, Texas (Sprenger and Wuithiranyagool, 1986), and in three counties in Ohio (Parsons personnal comm., 1988). It is believed that the mosquitoes traveled to Ohio via a shipment of tire casings from Texas where they have become established (Parsons personnal comm., 1988).

The presence of Ae. albopictus is a cause for concern because this mosquito is a vector of dengue viruses and has shown laboratory transmission of Janpanese B encephalitis, western equine encephalitis (Bates, 1949), La Crosse encephalitis (Parsons personnal comm., 1988), and San Angelo encephalitis virus (Tesh, 1981).

Ae. albopictus is a woodland species that has successfully adapted to urban habitats (Reiter and Darsie, 1984). These mosquitoes are agressive biters and will readily leave their woodland resting places for a blood meal.

SUMMARY AND CONCLUSIONS

A study was done on the Michigan State University campus and a nearby area to determine the host feeding patterns, species composition, and vector potential of the indigenous mosquitoes.

Over two years five locations containing domestic animals, including the Swine, Dairy, Sheep, and Horse Centers on the Michigan State campus, and Van Atta's Greenhouse and Mini Zoo in Haslett Township, were surveyed. One thousand six hundred and twenty-nine mosquitoes were collected, 814 in 1986, and 815 in 1987. A total of 477 engorged specimens were collected, 253 and 224 in 1986 and 1987 respectively. Multiple feedings occurred at only one location, Atta's Greenhouse and Mini Zoo. All multiple blood meals consisted of both avian and rabbit blood.

Mosquitoes were more abundant during 1986 than 1987, even though sampling started in late July in 1986, and sampling began in early June in 1987. Species diversity was greater in 1986 when 7 species were found, than in 1987 when only 5 species were found.

Cq. perturbans was the most abundant mosquito found during this study, An. quadrimaculatus was second in abundance, Ae. vexans next, then Cx. salinarius, Cx. restuans, Cx. pipiens, and An. punctipennis. Engorged specimens of Cq. perturbans, Ae. vexans, An quadrimaculatus, and Cx. salinarius, were found. No engorged Cx. restuans, Cx. pipiens, or An. punctipennis were found. Reasons for

this could have been due to insufficient numbers to observe any feeding.

In general mosquitoes found during this study fed preferentially on large mammals. Pigs were the primary hosts of Cq. perturbans, Ae. vexans, and An. quadrimaculatus.

Cq. perturbans was the only mosquito that often fed on birds. This species seems to be an opportunistic feeder, feeding generally on all animals found within the locations surveyed during this study.

Ae. vexans fed preferentially on large mammals, including pigs, horses, and cows. This species actively sought out preferred hosts more so than the other species. Other hosts included humans, rabbits, and birds.

An. quadrimaculatus, like most anopheline mosquitoes, fed primarily on mammals. Although this species did feed on birds either year, other hosts included humans and rabbits.

Host preferences could not be determined for Cx. salinarius because only two engorged specimens were found. One contained rabbit-avian blood, and the midgut contents of the other one could not be identified.

Factors that affected feeding included host density, host availibility, and host defense. Structure of the animal shelters had an effect on the numbers of engorged mosquitoes found at each location. It was found that the greater access to a location, the greater the number of engorged mosquitoes that were found within the structure. Also the amount of light at a location during the hours of outside darkness may have deterred some species from

entering. Temperature and rainfall also may have had an effect on the species diversity found each year.

A significant difference was found when a three way analysis of variance of species feeding over locations and time was done on transformed data of the percent feeding per month. The analysis was significant, and the main effects of species feeding and locations were both significant.

All species found during this study are potential vectors of diseases such as St. Louis encephalitis, western equine encephalitis, eastern equine encephalitis, malaria, several members of the California serogroup viruses, dog heartworm, and bird malaria. Cq. perturbans, Ae. vexans, and An. quadrimaculatus are of particular concern due to their opportunistic feeding habits and their abundance in this area. Both Ae. vexans and Cq. perturbans are nuisance mosquitoes and can be quite annoying to man and domestic animals.

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APPENDIX

APPENDIX 1

Record of Deposition of Voucher Specimens*

The specimens listed on the following sheet(s) have been deposited in the named museum(s) as samples of those species or other taxa which were used in this research. Voucher recognition labels bearing the Voucher No. have been attached or included in fluid-preserved specimens.

Voucher No.: 1988-01

Title of thesis or dissertation (or other research projects):

Species Composition, Host Feeding Patterns, and Vector Potential of Mosquitoes (Diptera: Culicidae) Found on the Michigan State University Campus

Museum(s) where deposited and abbreviations for table on following sheets:

Entomology Museum, Michigan State University (MSU)

Other Museums:

Investigator's Name (s) (typed)
Joan Davis

Date 14 July 1988

*Reference: Yoshimoto, C. M. 1978. Voucher Specimens for Entomology in North America. Bull. Entomol. Soc. Amer. 24:141-42.

Deposit as follows:

Original: Include as Appendix 1 in ribbon copy of thesis or dissertation.
Copies: Included as Appendix 1 in copies of thesis or dissertation.
Museum(s) files.
Research project files.

This form is available from and the Voucher No. is assigned by the Curator, Michigan State University Entomology Museum.

APPENDIX 1.1

Voucher Specimen Data

Page 1 of 1 Pages

Species or other taxon	Label data for specimens collected or used and deposited	Number of: Culicidae								
		Eggs	Larvae	Nymphs	Pupae	Adults ♂	Adults ♀	Other	Museum where deposited
Aedes vexans (Meigen)	East Lansing, MI 24 June 1986					2			MSU
	8 July 1987					1			MSU
Anopheles punctipennis (Say)	East Lansing, MI 24 July 1986					1			MSU
Anopheles quadrimaculatus Say	East Lansing, MI 24 July 1986					3			MSU
	18 August 1987					1			MSU
Coquillettedia perturbans (Walker)	East Lansing, MI 24 July 1986					4			MSU
	14-24 July 1987					6			MSU
Culex pipiens (Linnaeus)	East Lansing, MI 14-18 August 1986					2			MSU
Culex restuans Theobald	East Lansing, MI 24 July 1986					1			MSU
	16 June-6 August 1987					4			MSU
Culex salinarius Coquillet	East Lansing, MI 22-31 July 1986					3			MSU
	6 August 1987					1			MSU

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

Joan Davis

Date 14 July 1988

Voucher No. 1988-01

Received the above listed specimens for deposit in the Michigan State University Entomology Museum.

Richard L. Fencher 15 July 1988

Curator Date