POPULATION SURVEYS AND CONTROL OF MOSQUITOES IN THE GREATER WINNIPEG AREA

A Thesis

Presented to

The Department of Entomology

Faculty of Agriculture and Home Economics

The University of Manitoba

Winnipeg

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

David Lorne Smith

May 1959

ACKNOWLEDGMENTS

The writer wishes to express sincere appreciation to the late Mr. E. J. Stansfield for his continual interest and valued guidance during these investigations.

Grateful acknowledgment is extended to Dr. A. J. Thorsteinson, Head, Department of Entomology, University of Manitoba, and Professor A. G. Robinson, Associate Professor of Entomology, University of Manitoba, for their guidance and helpful criticisms in the preparation of this thesis.

Thanks are due to the Veterinary and Medical Entomology Unit, Guelph, Ontario, for supplies of *Aedes aegypti* eggs, and to the Desplaines Valley Mosquito Abatement District, Chicago, Illinois, for the shipment of *Gambusia affinis*.

These investigations were made possible by a grant from the Greater Winnipeg Mosquito Abatement District to the Department of Entomology, University of Manitoba.

ABSTRACT

by

David Lorne Smith

POPULATION SURVEYS AND CONTROL OF MOSQUITOES IN THE GREATER WINNIPEG AREA

A survey was made on the control methods used by the Greater Winnipeg Mosquito Abatement District. It was found that a pre-season application of DDT gave much better results than spraying during the mosquito breeding season.

Light trap catches over the past two years have shown that mosquito controls eliminated up to 90 percent of infestations in the area.

Tests have indicated that the top minnow, *Gambusia affinis*, cannot overwinter in this climate.

Tests have shown that no resistance to DDT has developed in the mosquitoes of the Winnipeg area.

Mosquitoes were successfully tagged with rhodamine-B. Attempts were made to study flight range and habits.

Attempts to establish a colony of prairie *Aedes* mosquitoes were unsuccessful. The limiting factor was the refusal of the mosquitoes to mate in captivity.

TABLE OF CONTENTS

CHAPTER		PAGE
I.	INTRODUCTION	1
	The Problem	3
	Importance of Problem	4
II.	THE SURVEY AREA: PRECIPITATION AND TEMPERATURE. 1957 AND 1958	6
	Description of Survey Area	6
	Precipitation, 1957 and 1958	6
	Temperatures, 1957 and 1958	8
III.	PRE-SEASON APPLICATION OF DDT	11
	History of Pre-season Control in Winnipeg	11
	Survey and Results	12
	Comparison with Other Methods	14
	Discussion	16
IV.	SURVEY OF ADULT MOSQUITO POPULATIONS BY LIGHT TRAP	17
	Methods and Equipment	17
	Results	21
	Discussion	23
V.	LARVAL CONTROL BY PREDACEOUS MINNOWS .	27
	Review of Literature	27
	Top Minnows, Gambusia affinis	29

CHAPTER		PAGE
	Rearing of *Gambusia affinis* in the Laboratory. .	29
	Reproduction under Natural Conditions	30
	Cold Hardiness of Top Minnows	31
	Larval Control by Top Minnows	32
	Effect of Insecticide on Top Minnows	32
	Discussion	33
	A Predaceous Minnow Native to Manitoba	34
VI.	RESISTANCE OF MOSQUITOES TO INSECTICIDES	36
	Review of Literature	36
	Tests for Resistance	36
	Methods	37
	Results	38
	Discussion	38
VII.	DETERGENT AS A LARVICIDE	43
	Methods and Results	43
	Discussion	45
VIII.	RELEASE AND RECOVERY OF MOSQUITOES TAGGED WITH RHODAMINE-B	49
	Review of Literature	49
	Methods and Results	50
	Discussion	52

CHAPTER		PAGE
IX.	REARING OF PRAIRIE *AEDES* MOSQUITOES	53
	Methods and Results	53
	Discussion	55
X.	SUMMARY AND CONCLUSIONS	56
	Summary	56
	Conclusions	59
	LITERATURE CITED	61
	APPENDIX	63

LIST OF FIGURES

FIGURE		PAGE
1.	Precipitation and Temperature, Winnipeg, 1957	7
2.	Precipitation and Temperature, Winnipeg, 1958	9
3.	Acres Pre-season Control vs Days Fogging, Winnipeg, 1955-1958	15
4.	New Jersey Mosquito Light Trap	18
5.	Locations of New Jersey Mosquito Light Traps, Winnipeg, 1957-1958	20
6.	Average Mosquito Light Trap Collections inside Winnipeg, 1957	22
7.	Average Mosquito Light Trap Collections inside and outside Winnipeg, 1958	24

LIST OF TABLES

TABLE PAGE

1. Effect of DDT at Concentrations of 0.004 - 2.50 p.p.m. on *Aedes vexans* Larvae Collected at Oak Bluff, Manitoba, 1958 39

2. Effect of DDT at Concentrations of 0.004 - 2.50 p.p.m. on *Aedes intrudens* and *Aedes dorsalis* Larvae Collected in Greater Winnipeg (Tuxedo), 1958 40

3. Effect of DDT at Concentrations of 0.004 - 2.50 p.p.m. on *Aedes vexans* Larvae Collected in Greater Winnipeg (Windsor Park), 1958 41

4. Effect of DDT at Concentrations of 0.004 - 2.50 p.p.m. on *Aedes vexans* Larvae Collected in Greater Winnipeg (Assiniboine Park), 1958 42

5. Susceptibility of Fourth Instar Mosquito Larvae to Tide Detergent at Concentrations of 1 - 1000 p.p.m., June 20, 1958 44

6. Susceptibility of Fourth Instar Mosquito Larvae to Tide Detergent at Concentrations of 25 - 100 p.p.m., June 25, 1958 46

7. Susceptibility of Fourth Instar Mosquito Larvae to Tide Detergent at Concentrations of 25 - 100 p.p.m., June 26, 1958 47

TABLE | PAGE

8. Susceptibility of Fourth Instar Mosquito Larvae to Tide Detergent at Concentrations of 25 - 100 p.p.m., July 5, 1958 48

CHAPTER I

INTRODUCTION

It is estimated that there are about 2,000 species of mosquitoes distributed throughout the world (Horsfall, 1955). They can be found thriving in mines several thousand feet below the surface of the earth, and at altitudes of more than 10,000 feet (Horsfall, 1955). There are few other groups among the biting insects which can match the adaptability of mosquitoes, their habitats ranging from the tropics well into Arctic regions. They breed in almost any type of water, in salt marshes, sloughs, temporary pools, rain barrels, tin cans, bottles, and numerous other places where water stands for several days or more (Herms, 1953).

The economic importance of mosquitoes is well known. Agriculture may be retarded, real estate values suffer, and losses from lowered industrial efficiency may be high from mosquito annoyance alone (Headlee, 1945). Yet these losses are small when compared to the damage done by the diseases transmitted by mosquitoes. In the tropics such diseases as malaria, dengue, yellow fever, filariasis, and encephalitis kill many millions of people each year (Chandler, 1956). The occurrence of these diseases diminishes and finally disappears, as one moves from the tropics into the colder climates until the annoyance factor alone is most important.

Mosquito populations reach a much higher density in colder climates than they do in the tropics (Chandler, 1956). Tropical species have no resting stage in the life cycle, and breeding is continuous throughout the year, giving a constant level of infestation. Mosquitoes in colder climates have a resistant stage, usually in the egg, which can survive the winter. Hatching occurs with the return of unfrozen surface water and warm weather. Development to the adult stage is rapid. Resistant eggs are laid and the whole life cycle is completed in a fairly short time. Instead of being spread throughout the year the entire population is concentrated into a short period during the summer. This is what happens in the case of the prairie mosquitoes around Winnipeg. Large populations infest the area several times during the summer, the density being quite low the rest of the time.

Many different methods have been devised to control mosquitoes throughout the world. The methods used in one area are not necessarily successful in another and they must be tested to see if they can meet the problems presented by climatic conditions, environment, and species present in an area.

Twenty-two species of mosquitoes have been described from the Greater Winnipeg area (McLintock, 1944). The most important species from the standpoint of annoyance is *Aedes vexans* Meigen. McLintock (1944) found that 30 percent of his collections consisted of

A. vexans. Light trap collections in 1957 and 1958 have shown that it makes up about 85 percent of mosquito populations in the area.

Mosquito control in Greater Winnipeg was first begun in 1927 when an organization called the Greater Winnipeg Anti-Mosquito Campaign was formed. Control operations by this group were financed by voluntary public contributions until 1953 when the Greater Winnipeg Mosquito Abatement District was formed. The G.W.M.A.D. today represents the only incorporated mosquito control group in Canada. It is comprised of 15 member municipalities which finance operations by a 20 cent per person levy. The control area covers 225 square miles with a population of some 450,000 people.

The Problem

This study was conducted during 1957 and 1958 in the Greater Winnipeg area. The main investigation was concerned with the following:

A. Surveys of mosquito populations

1. Survey of adult mosquito populations by New Jersey light traps.

11. Survey of larval populations by dipper counts.

B. Control methods

1. A comparison of pre-season treatments of DDT with conventional control methods.

11. The use of fish for larval control.

C. Some preliminary studies on resistance of local species of mosquitoes to DDT, flight behaviour of mosquitoes, the use of detergent as a larvicide, and the rearing of prairie *Aedes* mosquitoes.

Importance of Problem

Experiments in the U.S.A. have shown that pre-season application of DDT spray and granules is a very effective method of controlling mosquitoes (Geis, 1953; Vannote, 1953; Nowell and Parish, 1956). Preliminary work in 1956 by the G.W.M.A.D. with granular application of DDT during the winter on a limited acreage indicated this to be an effective method of control in the Winnipeg area. However, before the main effort could be concentrated along this line, it was decided that a scientific survey should be undertaken to verify its effectiveness. With such a large scale expenditure of public funds there must be definite proof of the value of such a program. This proof could only be obtained by continuous surveys of larval populations in both treated and untreated areas beginning as soon as melting snow created suitable conditions for hatching and development. This assessment was conducted in 1957 and 1958 by the writer on a grant from the G.W.M.A.D.

In addition to investigations on the value of pre-season granular treatments, other studies were conducted on the use of both imported and native minnows as a predator control in permanent ponds, the use of household detergent to control mosquito larvae in rain barrels, the resistance of local mosquitoes to DDT, flight behaviour of mosquitoes, and the rearing of prairie *Aedes* mosquitoes.

CHAPTER II

THE SURVEY AREA: PRECIPITATION AND TEMPERATURE, 1957 and 1958

Description of Survey Area

The survey work was conducted throughout an area covering some 225 square miles in and around Greater Winnipeg. Because of the flat terrain and heavy clay soil, drainage from low lying areas is poor. Numerous poplar bluffs grow around sloughs and depressions, providing shade which holds the water well into early summer. The factors of heavy soil and poor drainage combine to provide many transient and semi-permanent pools which are ideal for the breeding of mosquitoes.

Precipitation, 1957 and 1958

Precipitation was abnormal in both 1957 and 1958. In 1957 rainfall was far below normal in May but heavy rains in the third week of June filled all the mosquito breeding areas with water. This rainfall was the main factor in producing the hatch of mosquito eggs which resulted in a large flight of adults in July. Precipitation during July, August and September was close to normal for those months. (Figure 1.)

In 1958 there was little snowfall from January until the spring thaw. This resulted in a very dry spring with little water remaining in breeding spots after the middle of April. Below

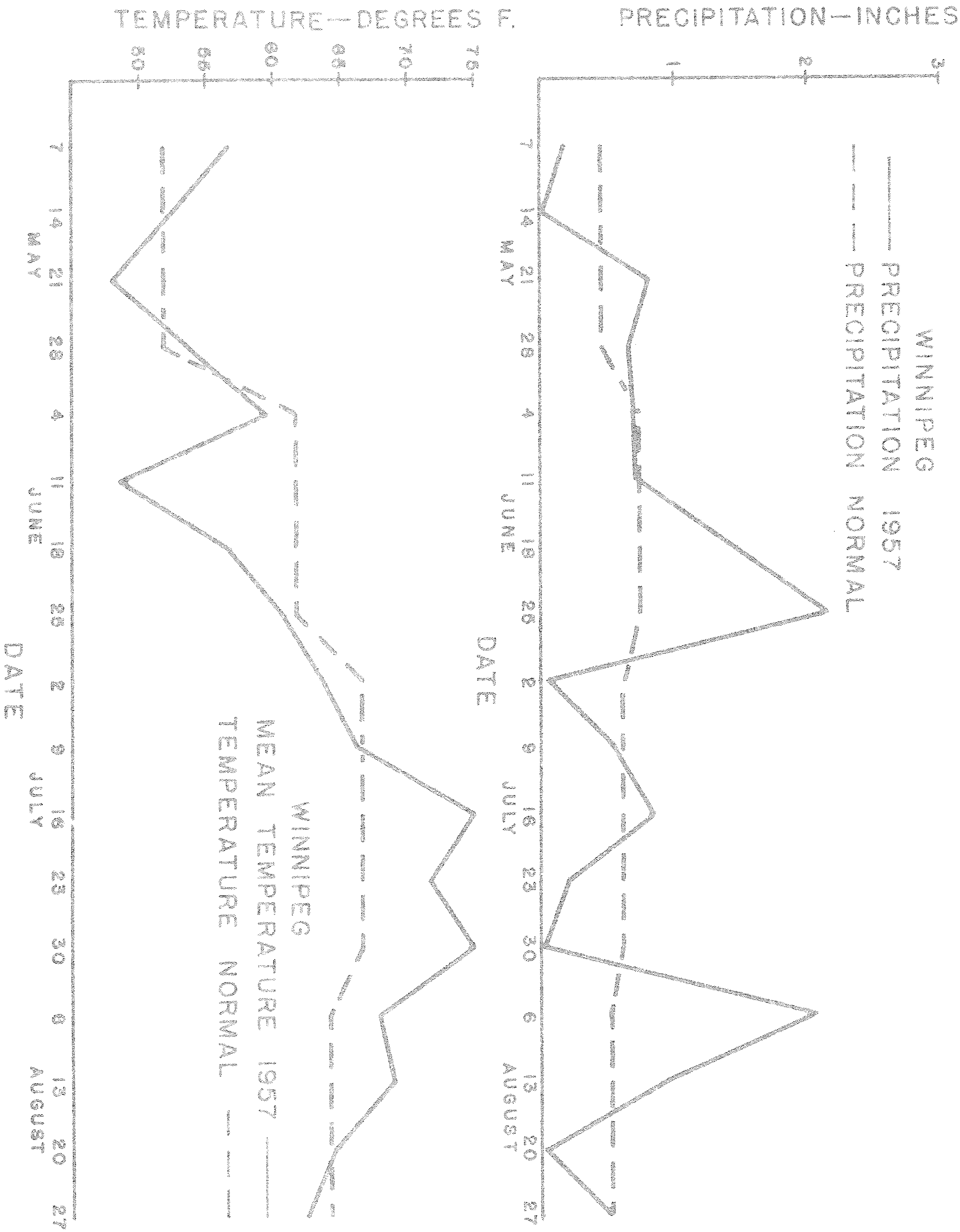

FIGURE 1. Precipitation and Temperature, Winnipeg 1957.

normal precipitation continued through May and June. July, however, was at the opposite extreme when 5.65 inches of rain fell, mostly during the early part of the month. (Figure 2.) This heavy rainfall caused much the same situation as happened in 1957. All the low-lying areas were filled with water resulting in a large hatch of mosquito eggs. Precipitation during August and September was far below normal.

Temperatures, 1957 and 1958

Seasonal temperatures play an important part in mosquito breeding and development. Low temperatures decrease the percentage of eggs hatching and slow down the development of larvae considerably while higher temperatures increase hatching and development (Bates, 1949). This is the reason that large flights of adult mosquitoes rarely appear early in the summer. They always occur later on when average temperatures are higher.

In 1957 the mean temperature for May was two degrees above normal, for June it was five degrees below normal, and in July it was five degrees above normal. (Figure 1.) The high temperatures in July coincided with heavy rainfall and this resulted in a heavy hatch of eggs and rapid development of the larvae. In 1957 the time which elapsed between hatching until the adults invaded the city was about eight days.

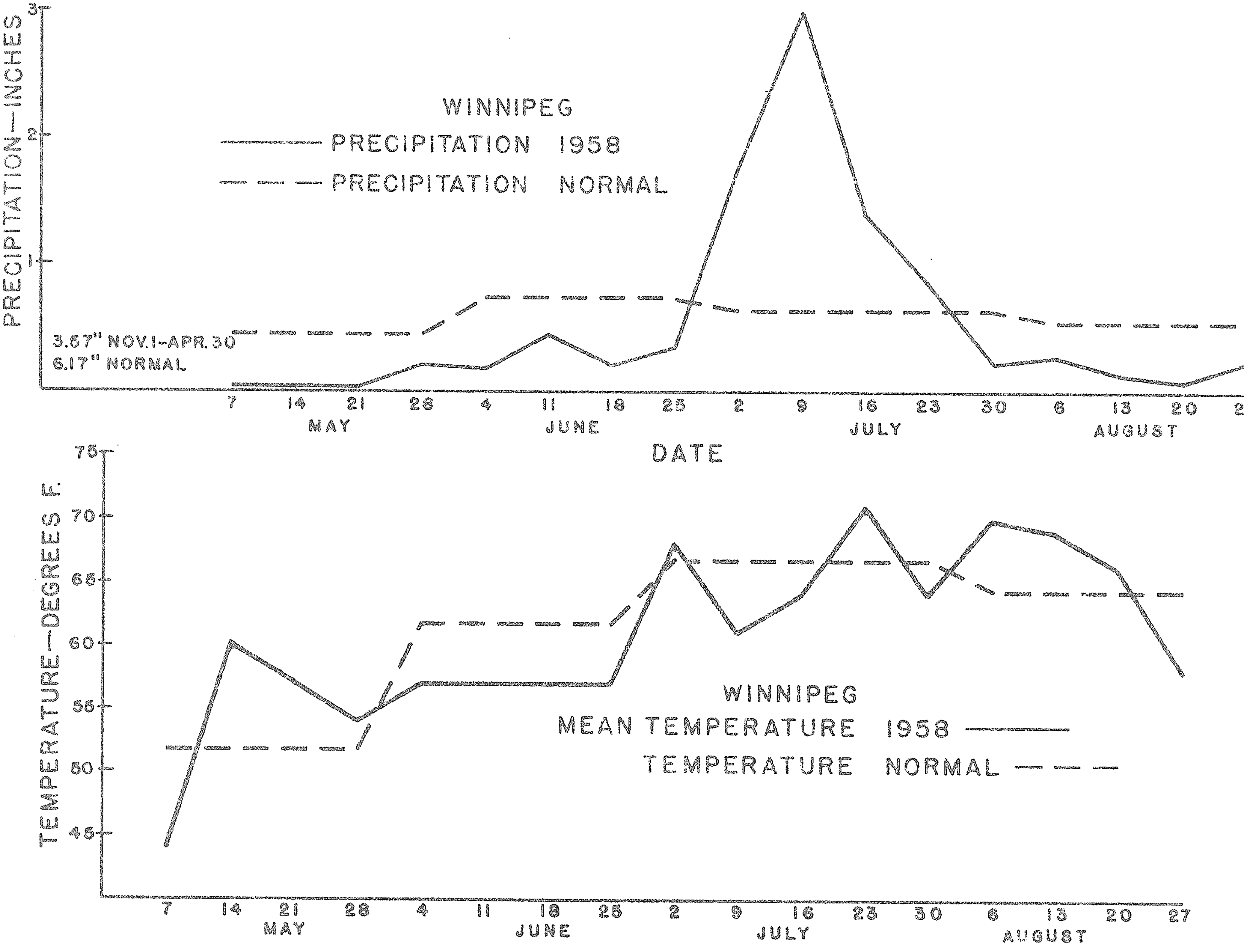

FIGURE 2. Precipitation and Temperature, Winnipeg 1958

In 1958, July temperatures were below normal and although a good hatch of eggs resulted from the heavy rains, larval development was slower, the time between egg hatching and invasion of the city being eighteen days. May had slightly above normal temperatures, but June, July, August and September were all below normal. (Figure 2.)

CHAPTER III

PRE-SEASON APPLICATION OF DDT

History of Pre-season Control in Winnipeg

The method of applying insecticide to a breeding area before mosquito development begins was first tried in Winnipeg in the fall of 1947 when two and one-half acres of low land were sprayed by truck with DDT at the rate of two pounds per acre. This treatment prevented mosquito development in the area until June 30, 1948.

In September, 1948, the experiments were continued. Six acres were sprayed at the rate of four pounds of DDT per acre, and 34 acres at the rate of one and one-half pounds of DDT per acre. The rate of four pounds of DDT per acre was effective in inhibiting development for the entire summer of 1949. The lighter application prevented development until late August. Larvae were present in a check plot as early as April 25.

In September, 1949, 57 acres were sprayed with DDT at the rate of 3.7 pounds per acre. No larvae were found here during the summer of 1950.

These experiments were carried on in succeeding years with further success, and in 1954 pre-season application of DDT was used on a large scale. One hundred and fifty acres were treated in the fall of 1954 with two pounds of DDT per acre. Since then pre-season spraying by truck has expanded yearly. Nearly 7,700 acres were treated for the 1959 season.

Although the ground application of DDT spray as a pre-season treatment proved to be extremely effective in controlling mosquitoes, its use is limited to open areas where trucks carrying the spray equipment can travel. In order to treat wooded areas and swamps, the spreading of DDT granules by aircraft was adopted in 1956.

During the winter of 1955 - 56, approximately 560 acres of bushland were treated with DDT impregnated tobacco stem granules. The granules proved to be equally as effective as the pre-season sprays. Almost 14,000 acres of bush and inaccessible swamp land were treated with granules by aircraft during the winter of 1957-58. The total acreage of pre-season work done for the 1959 season was 18,555 acres.

Survey and Results

In 1957 and 1958, a survey of the Greater Winnipeg area was carried out with the object of evaluating the effectiveness of the pre-season treatment work done by the Greater Winnipeg Mosquito Abatement District. The evaluation was based on a comparison of larval counts made in the pre-season treatment areas with areas that received either in-season treatments or none.

1957 was an especially good year for such an evaluation because of the excessive rainfall in June, followed by above normal temperatures.

During the winter of 1955-56, approximately 560 acres of bushland were treated with granules by aircraft at the rate of one pound of DDT per acre. No larvae were found by G.W.M.A.D. workers in the summer of 1956. To determine the effectiveness of this type of treatment over a period of two years, 177 acres of the 560 were left untreated for observation in 1957. The area was checked periodically throughout the summer. No development was found until July 8, and this was very light.

In the winter of 1956-57, 6,117 acres of low-lying bushland received aerial applications of DDT granules at one and one-half pounds per acre. Surveys were made in these areas throughout the 1957 season but no mosquito larvae were found despite above-normal rainfall in June. In contrast to this, large populations were found in surrounding areas not treated with granules.

During the winter of 1957-58, nearly 14,000 acres of low land were treated with DDT granules. The summer of 1958 was unusual in that, of the five months from May to September, only July had appreciable rainfall. (Figure 2.) Rainfall in this month was 5.65 inches or almost double the normal. Precipitation for the other four months was far below normal. Once again, no breeding was observed in any of the pre-season treatment areas despite the excessive rainfall in July. In one location, many first instar larvae were found dead. They had apparently been killed by the insecticide as soon as they hatched from the egg.

Many areas which had not been treated during the previous fall and winter were heavily infested in June.

Comparison with Other Control Methods

Areas not controlled by pre-season treatments were also checked during the survey. Breeding was always found in these areas early in the season and continued as long as water was present. Spraying with DDT destroys larvae effectively, but it was found that the effects lasted for only a short time and further treatments were necessary throughout the season. One such breeding area was sprayed on May 13, 1957, resulting in complete control of larvae and pupae. However, by June 24, mosquitoes were present once again.

Fogging for adult control is only a temporary control. Adults present in an area at the time of fogging are destroyed but since there is no residual effect, new infestations can move in almost immediately. Information from the past four years has shown that as pre-season acreage has risen, the number of days fogging required to control adults in Winnipeg has decreased. (Figure 3.)

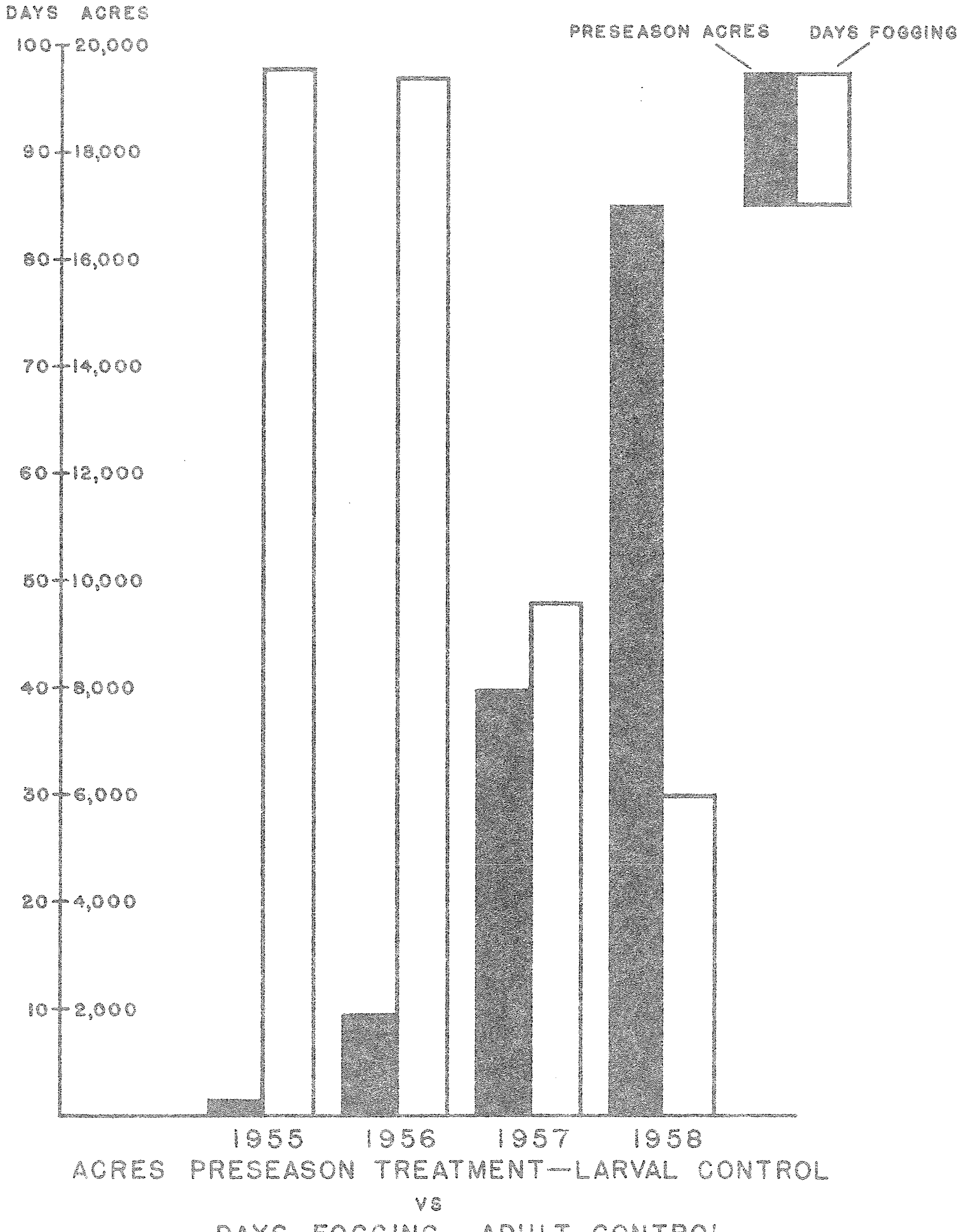
DAYS ACRES
100 20,000
90 18,000
80 16,000
70 14,000
60 12,000
50 10,000
40 8,000
30 6,000
20 4,000
10 2,000
PRESEASON ACRES
DAYS FOGGING
1955
1956
1957
1958
ACRES PRESEASON TREATMENT—LARVAL CONTROL
vs
DAYS FOGGING—ADULT CONTROL

FIGURE 3.

Discussion

Observations over the past two years have demonstrated that a pre-season application of DDT by truck and plane is the most effective method of controlling mosquitoes. This method requires only one treatment per year in comparison to the several ground spray treatments required to give the same degree of control, making it more economical over the long run.

CHAPTER IV

SURVEY OF ADULT MOSQUITO POPULATIONS BY LIGHT TRAPS

To obtain a true picture of the mosquito population in an area it is necessary to have some means of measuring a cross section of the population. Such a measurement can be made by counting mosquito "landing rates" or "biting rates" during a certain period of time (Rings and Richmond, 1953). Collections with a net can also be used, but all these methods can produce variable results even when made by one person. The use of a standardized light trap eliminates these human variables and gives a more accurate estimate of the relative numbers of mosquitoes in an area. For this reason mosquito light traps were used to measure adult populations in the Greater Winnipeg area.

Methods and Equipment

The type of trap used in this survey was the standard New Jersey Mosquito Light Trap. (Figure 4.) They were supported on tripods so that they hung approximately four feet from the ground. The traps were operated twice each week throughout the season and were connected to electric timers which automatically turned the power on at 7 p.m., and off at 7 a.m. the next morning. A cyanide killing jar was placed in each trap before operation and brought back to the laboratory the next morning. The catches were then sorted as to sex and counted.

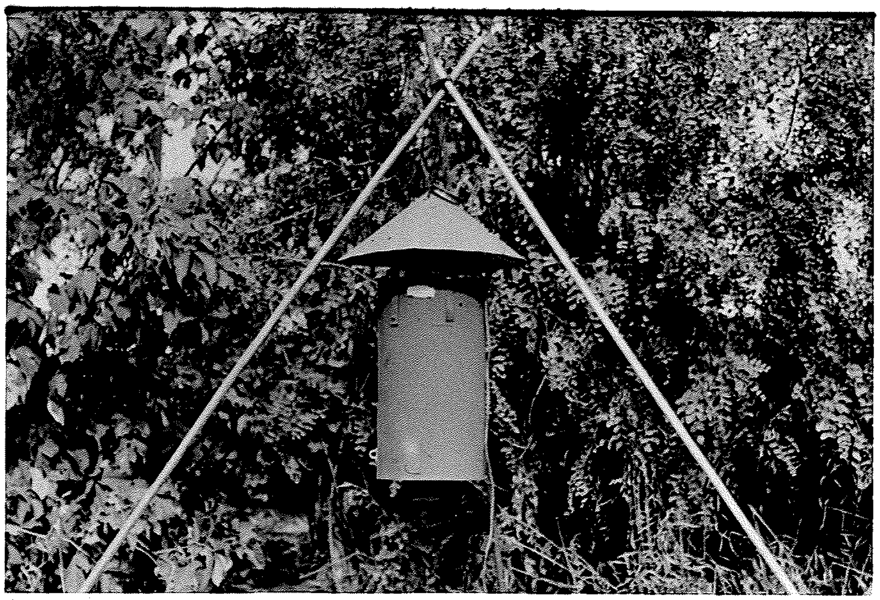

FIGURE 4.

NEW JERSEY MOSQUITO LIGHT TRAP

In 1957 four light traps were operated inside the Greater Winnipeg Mosquito Abatement District boundaries. They were located at Kildonan Golf Course, Windsor Golf Course, Assiniboine Park and the University of Manitoba. One trap was operated at Boissevain, Manitoba for two weeks in September, 1957 to compare the catches in an area where no mosquito control is practiced with an area with extensive control measures.

In addition to the four traps operated inside Greater Winnipeg, four new light traps were operated outside the control area in 1958. These were located at Oak Bluff south of No. 3 highway, Oak Bluff north of No. 3 highway, Lilyfield, north-west of the city, and at Navin School, east of the city. (Figure 5.)

The light traps were operated from June 14 to October 4 in 1957, and from May 20 to September 26 in 1958.

The locations of the traps were selected to provide similar conditions of environment and to give the best possible coverage of the Greater Winnipeg area with the traps available. Seven were surrounded partially by bush and shrubs but with some open areas so that the light would be visible for some distance. The eighth, at Navin School, was in the open with no bush or shrubs nearby. The light trap operated at Boissevain in 1957 was located in a well sheltered yard on the edge of town.

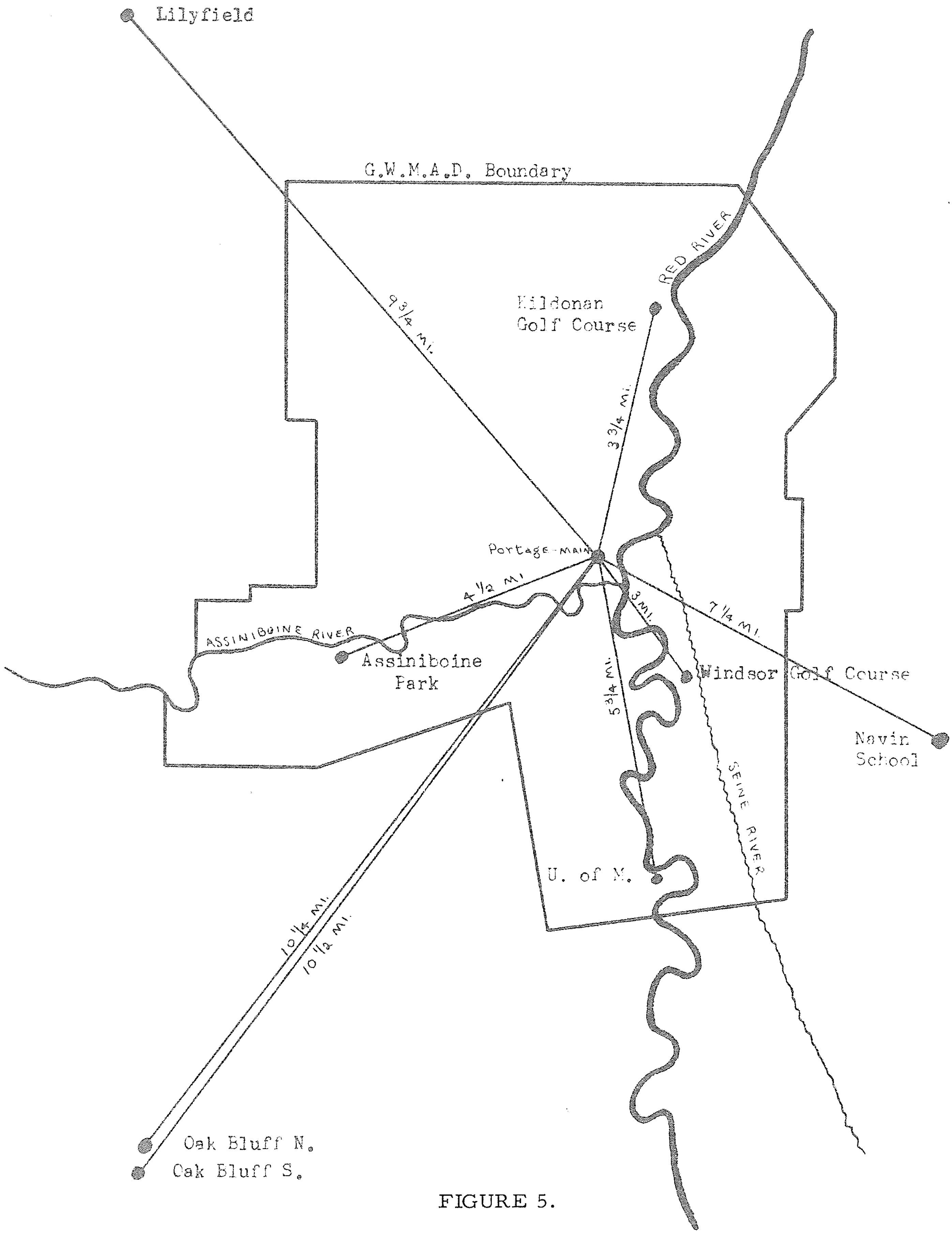

FIGURE 5.

Locations of New Jersey Mosquito Light Traps, Winnipeg, 1957 - 1958

Results

Operation of the four light traps used inside the city in 1957 did not begin until June 14. Catches at that time were quite low and remained that way until the end of the month. An increase was noted between July 2 and July 9. The peak catch came on July 12. (Figure 6.) On this date the highest catch was 436 females at the University of Manitoba; at Kildonan Golf Course, 143 females; at Windsor Golf Course, 238; and at Assiniboine Park, 384. (Appendix 1.) This peak occurred after heavy rains flooded breeding areas in the early part of July. The heavy rains were followed by high temperatures which stimulated hatching and rapid larval development. Light trap collections remained at a fairly high level until the end of July and then began to taper off. Adult flight activity was negligible during August and September. The last mosquitoes were trapped on October 4.

Three smaller flights occurred during the summer on July 2, July 30 and August 20, but none of these caused annoyance in Greater Winnipeg. All four peaks diminished within one week.

Appendix 1 shows the similarity of the total catches for each of the four traps during the season.

Despite differences in environmental conditions the mosquito collections at Boissevain gave some comparison of populations inside and outside a control area. The peak catch was lower than that

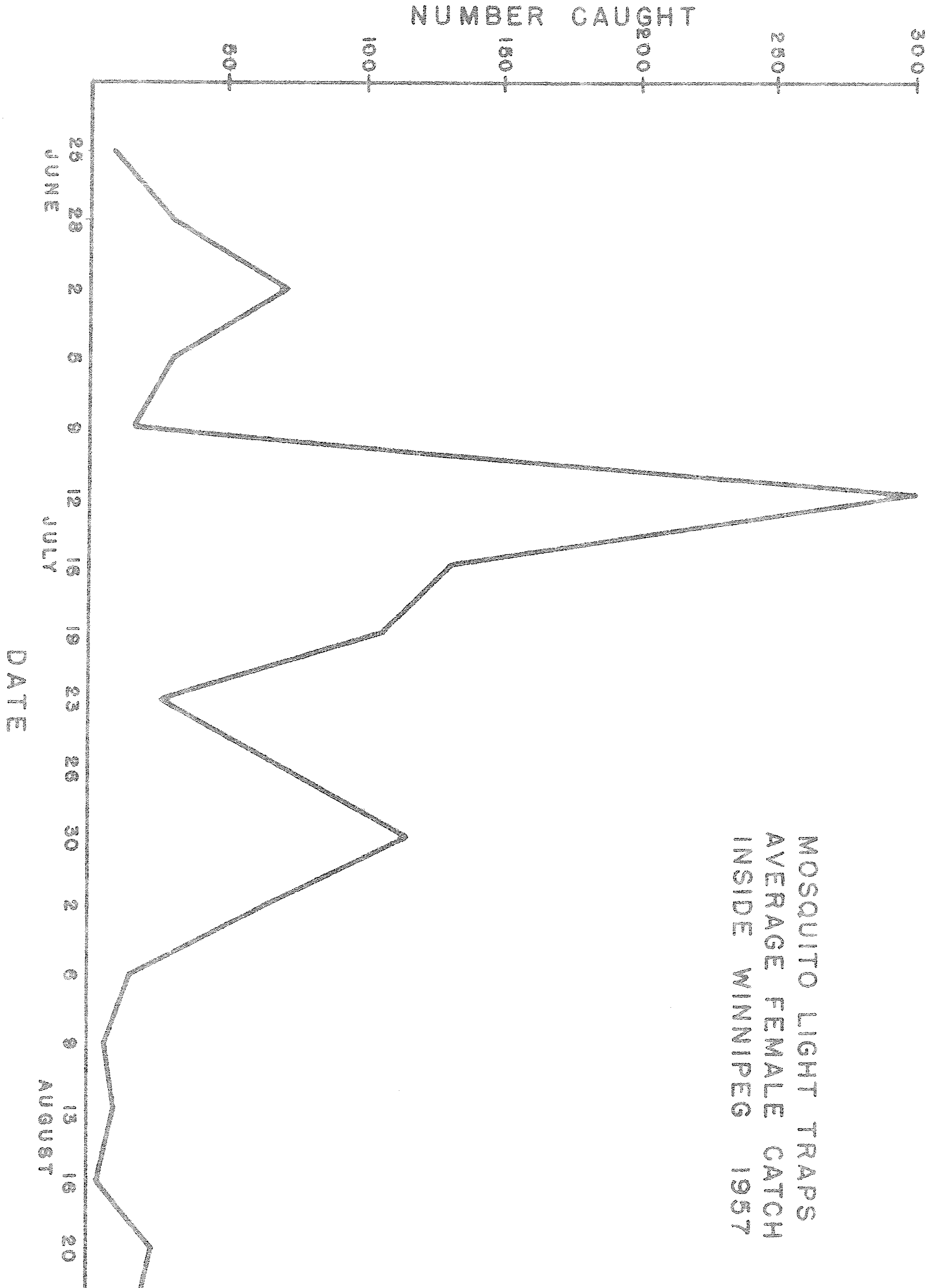

FIGURE 6.

Average Mosquito Light Trap Collections
inside Winnipeg, 1957.

recorded in Winnipeg but the average nightly catches were much higher. The highest catch recorded was 355 females and 513 males on September 10. The total catch of female mosquitoes for fourteen trap nights was 1,296 for an average nightly catch of 90.2. This was much higher than the 40.0 per night average recorded in Winnipeg. (Appendix 2.)

Operation of the eight light traps in 1958 began on May 20. Catches both inside and outside the city were very low, averaging about three females per night from May 20 to July 18. On this date the outside catches began to rise rapidly while the inside traps showed only a slight increase. The peak flight activity occurred on July 22 when the inside traps averaged about 400 females per trap and the outside traps averaged well over 4,000 females per trap. (Figure 7.) The highest catch recorded was 8,288 females at Lilyfield. (Appendix 4.)

As in 1957, only one major flight occurred in 1958. Three other peaks of minor importance occurred on August 1, 12 and 19. All four peaks diminished within one week.

Discussion

The 1957 and 1958 seasons were quite different to each other with regard to weather conditions and these differences showed up in the general trends of light trap catches during the two years.

In 1957, four flights of mosquitoes occurred. The first, on

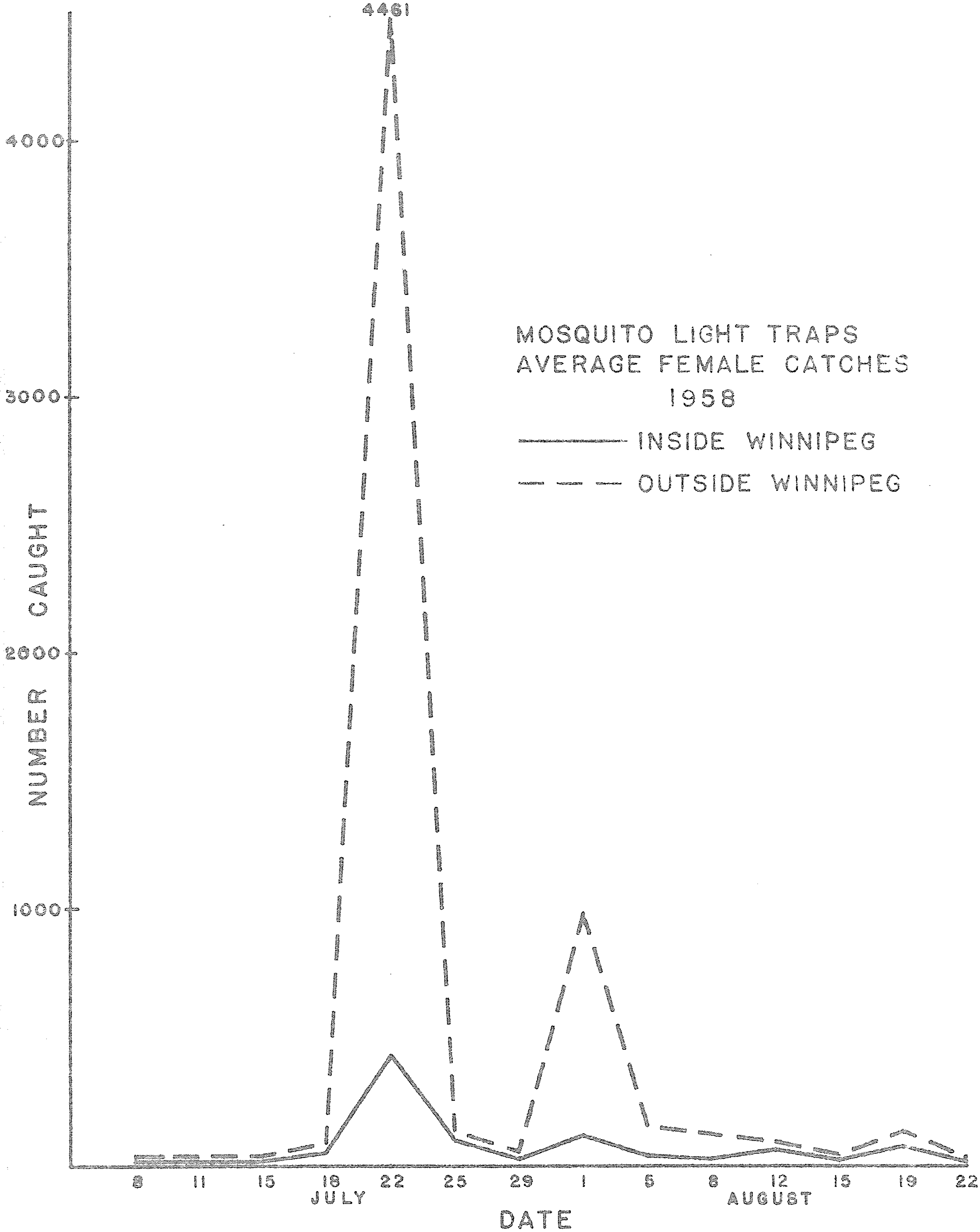

FIGURE 7. Average Mosquito Light Trap Collections, Winnipeg, 1958

June 2, came from breeding areas still flooded by the spring run-off when rising temperatures stimulated mosquito development. The second peak, on July 12, was the largest and was the result of heavy rains which reflooded breeding areas. With above normal temperatures prevailing, mosquito development was rapid. During this peak an average of 300 female mosquitoes per trap was caught. In contrast to this the catches of the inside traps averaged 428 females during the peak infestation of 1958. A normal amount of snow fell during the winter of 1956-57 and the spring run-off flooded breeding sites. Some of the eggs hatched early in the spring. When reflooding occurred in June, a fairly large flight of mosquitoes was produced but not as large as that occurring in 1958. In 1957 egg hatching was spread over a period of about two months, while egg hatching in 1958 was restricted to a period of about two weeks.

Light trap catches in 1958 were always higher outside the district than inside. The total catch outside was almost ten times greater than the inside total. In spite of the fact that the peak catch inside Winnipeg in 1958 was appreciably higher than the peak catch in 1957, the average number of female mosquitoes per trap through the season was lower. In 1957, the average collection per night was 39 females per trap, while in 1958 it was 26.3 per trap.

Infestations of mosquitoes can be detected by the outside traps several days before they show up in the inside traps (Figure 7.), and this proved to be useful in predicting when infestations would reach the city. If the same collection trends occur in succeeding years fogging operations in the city can be started as soon as outside catches begin to rise. In this way there would be no delay in controlling infestations moving into the city.

Although no definite flight patterns of mosquitoes invading the city have been worked out it is fairly clear that most of the adult mosquitoes infesting the city originate from surrounding untreated areas mainly to the west. This is supported in part by the fact that the light trap catches at Navin School east of the city remained quite low during 1958, while the traps west of the city recorded fairly high catches throughout the season.

This might indicate that the pre-season and other treatments inside the district almost completely eliminate breeding and that most, or at least a significant part, of the adult mosquito activity inside the district results from mosquitoes that have migrated into the district from outlying breeding areas beyond the reach of pre-season treatments.

CHAPTER V

LARVAL CONTROL BY PREDACEOUS MINNOWS

Review of Literature

It is widely acknowledged that one of the most effective and economical methods of controlling an insect pest is to introduce and encourage natural predators. Although there are many animals which prey on mosquitoes, probably none is as effective as fish. Many fish species feed on insects, the insects sometimes being important for this reason in commercial fish production. There are some which feed almost exclusively on the larvae of mosquitoes and other biting flies and they are valuable in reducing the numbers of these pests.

Horsfall (1955) lists some 34 species of fish which are predaceous on mosquito larvae, most of them being native to tropical and subtropical regions. Probably the most effective member of this group is the top minnow, *Gambusia affinis* (Baird and Girard). Axelrod (1955) states that this small fish is capable of eating its own weight in mosquito larvae per day. Some other highly predaceous fish are the prolific guppy and the killifish which are both native to Southern U.S.A.

The effectiveness of fish in anti-mosquito work depends on fecundity, abundance, and the length of life cycle of the fish; size of the adult fish; feeding habits and food preferences; ability to penetrate plant cover which offers protection to mosquito larvae; and hardiness of the fish. Few other fish fulfill these requirements so well as the top minnow (Sweetman, 1936).

Sweetman (1936) states that mosquito control with fishes, if carried out properly, has always been found cheaper, more effective, and more permanent than artificial methods such as oiling or spraying with insecticides. Failure in control is usually attributed to poor management or unsuitability of the habitat for the fish.

Predaceous fish are most effective in permanent water where their populations can build up to and remain at a high level. In temporary bodies of water, the build-up is too slow to affect mosquitoes breeding in this type of habitat.

Only one record was found of Gambusia affinis being introduced into Canada for mosquito control (Mail, 1954). These fish were released at Banff, Alberta in 1924, into warm springs there. As late as 1953, observations showed that there were still Gambusia minnows present. This is the furthest north that these fish have been successfully established. There are no records of G. affinis being established in a climate as severe as that which prevails in Manitoba.

There are many species of minnows native to Manitoba (Hinks, 1943). One of the best known is the spot tail minnow, Notropis hudsonius (Clinton), which is sold in quantity for fish bait. It is common in all the larger lakes and rivers. The diet of this fish consists mainly of algae, insect larvae, and small crustacea (Hinks, 1943).

Top Minnows, Gambusia affinis

Because of the many reports of successful introductions of top minnows into some of the more northern states of the U.S.A., it was thought that these minnows might be able to survive the cold winters of Manitoba. In September, 1957, Mr. E. J. Stansfield, the field manager of the G.W.M.A.D. arranged to have approximately 150 Gambusia affinis shipped to Winnipeg from the Desplaines Valley Mosquito Abatement District in Chicago where they are used extensively for mosquito control. Trials have been conducted to test their cold hardiness, their reproductive potential under laboratory and natural conditions, and their suitability as predators of mosquito larvae in this area.

Rearing of Gambusia in the Laboratory

For the breeding trials a number of top minnows were kept in an aquarium at room temperature and subjected to a light period of 16 hours per day. They were fed on a standard fish food obtained from a pet shop. These fish are viviparous and as the young develop the abdomen of the female distends. When the females began to reproduce they were placed in breeding traps in another aquarium. The breeding traps were constructed in such a way that the young fish could escape, while the larger fish remained confined. The top minnow, Gambusia is noted for a voracious appetite and traps are recommended to prevent the females from eating their own young.

Each female produced about ten young but although they were confined in the breeding traps most of the newly born fish were eaten. The females were attracted by even the slightest movement, and only one out of every four or five young fish born was able to escape.

The survivors were fed on a variety of foods such as Daphnia and other small aquatic organisms but the most successful rearing medium proved to be a commercial food called Liquifry. With this food they could be reared to a size large enough to feed on Daphnia. On this medium growth was very slow and mortality was high, and only a few survived.

Reproduction under Natural Conditions

In May, 1958 fifty top minnows were placed in a large pond (about 40' by 80' by 6' deep) in King's Park just south of the University of Manitoba to test their ability to survive and reproduce under natural conditions. These fish had been maintained during the winter in the laboratory and were released as soon as outside temperatures were suitable. Within a month after their release a rapid increase in population was noted. Reproduction continued throughout the summer and by September there were several thousand minnows in the pond.

There is no previous record of G. affinis reproducing in outdoor ponds in regions where average summer temperatures are as low as those in Winnipeg (George, K. G., in litt.). The fairly heavy growth of water plants and the ample food supply in the form of small aquatic organisms made this an ideal breeding site for the fish.

Twenty-five minnows were placed in a large shallow slough in St. Vital in May, 1958. The pond was examined often during the summer but none of the fish was observed. Because of the size, and amount of heavy vegetation around the edges of the slough, it was difficult to make an effective search for the minnows.

Cold Hardiness of Top Minnows

To test the hardiness of top minnows in our climate a number of these fish were placed in suitable ponds of permanent water. In September, 1957 twenty minnows were released in an isolated dugout three miles west of the University. Later observations showed that they were still alive at the time of freeze-up. Checks were made on this pond throughout the summer of 1958 but none of the minnows could be found and it was assumed that they had died during the winter.

In October, 1958 about one thousand top minnows were removed from the pond in King's Park and transferred to the trout hatchery at Caddy Lake to insure a good supply of minnows for the summer of 1959. A large number were left to overwinter in the pond, but whether they are able to survive the winter will not be known until the spring of 1959.

Larval Control by Top Minnows

In the summer of 1958 several fish ponds which were heavily infested with mosquito larvae were found. These sites were ideal for mosquito breeding since they were no longer being stocked with fish and the water contained dead leaves and other organic matter. A close examination of one pool revealed the presence of many Culex egg rafts as well as larvae in all stages of development. Fifteen top minnows were released in the pond and within a few days the majority of the larvae had been destroyed.

No other releases of minnows were made to test their ability to prey on mosquito larvae. However, in the King's Park pond where the population of top minnows was fairly high, no mosquito larvae were seen throughout the summer.

Effect of Insecticide on Top Minnows

In one fish pond the pupation and emergence of adult mosquitoes occurred before top minnows could destroy them. The surface area of about ten square feet was treated with one-third pint of New Jersey Larvicide containing ten percent pyrethrum. This application destroyed the larvae and pupae but had no harmful effect on the minnows.

Discussion

If top minnows could survive in this region during the winter they would be very useful in the control of mosquito larvae in permanent water. These minnows could probably be reared in large numbers in the laboratory for releasing but the equipment and space required for such rearings would make it impractical. The ideal method for large scale rearing would be to use natural ponds from which the fish could be taken and transferred to mosquito breeding waters.

Our observations have shown that top minnows can reproduce during the summer in Manitoba. As mentioned earlier the fifty minnows placed in the King's Park pond produced a population of several thousand by freeze-up. The population increase was quite slow, however, and it was not until the end of July that large numbers of fish were present in the pond. For best advantage in mosquito control a large population would have to be available by June at least.

This might be accomplished if a greater number of minnows were present to begin with in the spring. If a permanent population of top minnows could be established in a pond, sufficient numbers could be left to provide a good supply of minnows by June.

There is as yet no definite proof as to whether or not top minnows are able to survive our winters. Those released in September, 1957, apparently did not. However, these fish were released immediately after being brought from Chicago and the rapid change in temperature and environment may have weakened them. The minnows left in the pond in King's Park for the winter of 1958-59 entered the winter properly conditioned and may be better able to withstand the cold.

The top minnow proved to be an excellent predator on mosquito larvae. In the laboratory a few G. affinis would easily devour several dozen mosquito larvae in a short time and they were also effective in the field.

A Predaceous Minnow Native to Manitoba

Since the success of top minnows depends largely on their ability to overwinter in this climate it was thought that some native species of minnow might be more useful in mosquito control. During the course of investigations, large concentrations of minnows were seen in some of the ditches and dugouts around Winnipeg and also in some of the larger and deeper sloughs of Western Manitoba. Some of these minnows were brought to the laboratory and tentatively identified as the spot tail minnow, Notropis hudsonius. In the laboratory they have proved to be almost equal to G. affinis as predators on mosquito larvae and observations in their natural habitat have shown that larvae are rare when these fish are present in numbers.

The suitability of the spot tail minnow will depend largely on its reaction to being moved from its natural habitat, although it seems to be able to withstand a wide variety of conditions. It has been seen in shallow patches of water in unshaded ditches where daytime water temperatures were high. They have also been taken in good condition through thick ice in midwinter.

The fact that N. hudsonius is oviparous would not seem to detract from its value as a predator on mosquito larvae. Investigations in the U.S.A. have shown that Fundulus spp. which are oviparous are very useful in mosquito control (Headlee, 1945). The main disadvantage of oviparous minnows is that for a short time after hatching, the young fry are too small to prey on larvae. The newly born young of viviparous minnows are much larger, and they begin to prey on mosquito larvae immediately (Headlee, 1945).

Large concentrations of N. hudsonius have been seen in ponds early in the spring. It is probable that once this minnow was permanently established in a pond, sufficient numbers would be present each spring to control early larval infestations. The progeny of the overwintering minnows would control later larval populations.

From the information available it would appear that Notropis hudsonius is suitable for release into mosquito breeding areas.

CHAPTER VI

RESISTANCE OF MOSQUITOES TO INSECTICIDES

Review of Literature

The end of World War II marked the beginning of a new era in mosquito control. At that time DDT and benzene hexachloride were made available to the public and their effectiveness seemed to indicate that the problem of controlling insect pests was over. Within a very short time, however, it became apparent that some insects had developed a tolerance to the new insecticides.

The first case of mosquito resistance to insecticides was reported from the Pontine marshes in 1947 in Italy (King, 1952). DDT had been used there during the latter stages of the war to control anophelene mosquitoes. Laboratory tests proved that they were resistant and that they retained this resistance even after eight generations of freedom from DDT. In 1949 it was reported that salt marsh mosquitoes in Florida were not being controlled by DDT (Donier et al, 1949).

Since that time the incidence of mosquito resistance to insecticides has been rising steadily. Testing for resistance has become a standard procedure for most mosquito abatement districts.

Tests for Resistance

Several tests were conducted on mosquito larvae collected in the Greater Winnipeg area to determine whether any resistance to insecticides has developed. The tests were made for resistance to DDT since it has been used almost exclusively for mosquito control in this area for the past thirteen years. A test kit provided by the World Health Organization was used and it consisted of five concentrations of DDT ranging from 0.004 p.p.m. to 2.50 p.p.m.

Methods

The larvae used in each test were collected in the field. Sufficient larvae were collected so that 300 third or early fourth instar individuals of the same species could be selected. These larvae were placed in groups of 25 in twelve containers. Test concentrations of 0.004, 0.02, 0.10, 0.50, and 2.50 parts per million were prepared from the kit. Two replicates of each concentration were used, with two containers with tap water used as checks. The larvae were added to the test containers and after a period of 24 hours the numbers of dead, living and moribund individuals were recorded. Moribund larvae are here defined as those incapable of rising to the surface or of showing the characteristic diving reaction when the water is disturbed. They may also show discoloration, unnatural positions, tremors, or lack of co-ordination. Larvae which pupated during the tests were eliminated. Species determination was made from the check larvae.

Results

Instructions provided with the W.H.O. test kit state that tests with control mortality in excess of 20 percent should be discarded. Of the several tests for resistance conducted on our local species of mosquitoes only three were satisfactory. (Tables 1, 2 and 3.) The control mortalities in the rest of the tests were above 20 percent and were unsatisfactory. One such test is shown in Table 4. Larval mortality in the valid tests was complete even at the lowest concentration of DDT. The only case of larvae surviving was in test No. 2, where two larvae survived in the 0.004 p.p.m. concentration for 24 hours. In all other cases the larvae were dead or moribund in less than the 24 hour test period.

Discussion

The results of the resistance tests (Tables 1, 2, 3 and 4.) show that no resistance to DDT has yet developed in the mosquitoes in the Greater Winnipeg area even though this insecticide has been used extensively for the past thirteen years. The susceptibility of these species to DDT is shown by their inability to live for more than a few hours when subjected to the various concentrations. The high control mortality in some of the tests may have been due to traces of insecticide absorbed by the glass containers in previous tests. All the containers were carefully washed with detergent after each test but apparently enough insecticide remained to kill the larvae.

TABLE 1.

EFFECT OF DDT AT CONCENTRATIONS OF 0.004 - 2.50 P.P.M. ON *Aedes vexans* LARVAE COLLECTED AT OAK BLUFF, MANITOBA -- 1958

Concentration of insecticide	Replicate number	Final condition of larvae at 24 hrs.				
		L	M	D	Total	% M + D
0.004	1			25	25	100
	2			25	25	100
0.02	1			25	25	100
	2			25	25	100
0.10	1			25	25	100
	2			25	25	100
0.50	1			25	25	100
	2			25	25	100
2.50	1			25	25	100
	2			25	25	100
Control	1	25			25	0
	2	25			25	0

* L - living, M - moribund, D - dead.

TABLE 2.

EFFECT OF DDT AT CONCENTRATIONS OF 0.004 - 2.50 P.P.M. ON *Aedes intrudens* and *Aedes dorsalis* LARVAE COLLECTED IN GREATER WINNIPEG (TUXEDO) 1958

Concentration of insecticide	Replicate number	Final condition of larvae at 24 hrs.				
		L	M	D	Total	% M + D
0.004	1			25	25	100
	2	2		23	25	92
0.02	1			25	25	100
	2			25	25	100
0.10	1			25	25	100
	2			25	25	100
0.50	1			25	25	100
	2			25	25	100
2.50	1			25	25	100
	2			25	25	100
Control	1	25			25	0
	2	25			25	0

* L - living, M - moribund, D - dead.

TABLE 3.

EFFECT OF DDT AT CONCENTRATIONS OF 0.004 - 2.50 P.P.M. ON *Aedes vexans* LARVAE COLLECTED IN GREATER WINNIPEG (WINDSOR PARK) 1958

Concentration of insecticide	Replicate number	Final condition of larvae at 24 hrs. L	M	D	Total	% M + D
0.004	1			25	25	100
	2			25	25	100
0.02	1			25	25	100
	2			25	25	100
0.10	1			25	25	100
	2			25	25	100
0.50	1			25	25	100
	2			25	25	100
2.50	1			25	25	100
	2			25	25	100
Control	1	23	2		25	8
	2	24	1		25	4

* L - living, M - moribund, D - dead.

TABLE 4.

EFFECT OF DDT AT CONCENTRATIONS OF 0.004 - 2.50 P.P.M. ON *Aedes vexans* LARVAE COLLECTED IN GREATER WINNIPEG (ASSINIBOINE PARK) 1958

Concentration of insecticide	Replicate number	Final condition of larvae at 24 hrs.				
		L	M	D	Total	% M + D
0.004	1			25	25	100
	2			25	25	100
0.02	1			25	25	100
	2			25	25	100
0.10	1			25	25	100
	2			25	25	100
0.50	1			25	25	100
	2			25	25	100
2.50	1			25	25	100
	2			25	25	100
Control	1	6		19	25	76
	2	4		21	25	84

* L - living, M - moribund, D - dead.

CHAPTER VII

DETERGENT AS A LARVICIDE

Tin cans, bottles, rain barrels, and other artificial containers provide excellent breeding sites for some mosquitoes, especially certain Culex species. The use of larvicides in small containers is impractical, and in cases where rain water is saved for washing purposes insecticidal contamination is undesirable.

Tests were conducted in 1958 to determine whether Tide detergent, a common household commodity, could be substituted for insecticides to control mosquito larvae in rain barrels.

Methods and Results

Concentrations of 1000 p.p.m., 100 p.p.m., 10 p.p.m., and 1 p.p.m. of Tide detergent were prepared to find the lowest range at which it was toxic to mosquito larvae. Larvae used in the tests were taken from their natural breeding sites. Ten fourth instar larvae were used in each test and after 24 hours the living, dead or moribund individuals were counted.

After 24 hours, 100 percent mortality was observed in the 1000 p.p.m. and 100 p.p.m. concentrations. The 10 p.p.m. concentration gave 80 percent mortality and the 1 p.p.m. concentration gave no mortality. (Table 5.)

Since 100 p.p.m. of detergent resulted in 100 percent mortality,

TABLE 5.

SUSCEPTIBILITY OF FOURTH INSTAR MOSQUITO LARVAE TO TIDE DETERGENT AT CONCENTRATIONS OF 1 - 1000 P.P.M., JUNE 20, 1958

Concentration of detergent	Final condition of larvae at 24 hours			
	Living	Dead or moribund	Total	% mortality
1000 p.p.m.	0	10	10	100
100 p.p.m.	0	10	10	100
10 p.p.m.	2	8	10	80
1 p.p.m.	10	0	10	0
Check	10	0	10	0

the next range of concentrations chosen was 100 p.p.m., 75 p.p.m., 50 p.p.m., and 25 p.p.m., the same test procedure being used. In one test, 75 p.p.m. gave only 50 percent mortality but all the other concentrations in the range 50 - 100 p.p.m. in three tests gave 100 percent mortality. At 25 p.p.m., mortality ranged from 50 to 100 percent. (Tables 6, 7 and 8.)

By calculation it was found that the 50 p.p.m. concentration could be duplicated by adding one teaspoon of detergent to eight gallons of water.

Discussion

These tests show that low concentrations of detergent can be successfully substituted for insecticides for the control of mosquito larvae in artificial containers. The presence of detergent at even 100 p.p.m. is hardly noticeable and would not be objectionable. Since tap water was used in all the tests the concentration required to inhibit breeding in rainwater would be lower because it is softer. In rainwater the addition of 50 p.p.m. of detergent would probably give satisfactory control, this being the equivalent of one teaspoon of detergent for eight gallons of water.

TABLE 6.

SUSCEPTIBILITY OF FOURTH INSTAR MOSQUITO LARVAE TO TIDE DETERGENT AT CONCENTRATIONS OF 25 - 100 P.P.M., JUNE 25, 1958

Concentration of detergent	Final condition of larvae at 24 hours			
	Living	Dead or moribund	Total	% mortality
100 p.p.m.	0	10	10	100
75 p.p.m.	5	5	10	50
50 p.p.m.	0	10	10	100
25 p.p.m.	5	5	10	50
Check	7	3	10	30

TABLE 7.

SUSCEPTIBILITY OF FOURTH INSTAR MOSQUITO LARVAE TO TIDE DETERGENT AT CONCENTRATIONS OF 25 - 100 P.P.M., JUNE 26, 1958

Concentration of detergent	Final condition of larvae at 24 hours			
	Living	Dead or moribund	Total	% mortality
100 p.p.m.	0	10	10	100
75 p.p.m.	0	10	10	100
50 p.p.m.	0	10	10	100
25 p.p.m.	1 pupated	9	10	90
Check	10	0	10	0

TABLE 8.

SUSCEPTIBILITY OF FOURTH INSTAR MOSQUITO LARVAE TO TIDE DETERGENT AT CONCENTRATIONS OF 25 - 100 P.P.M., JULY 5, 1958

Concentration of detergent	Final condition of larvae at 24 hours			
	Living	Dead or moribund	Total	% mortality
100 p.p.m.	0	10	10	100
75 p.p.m.	0	10	10	100
50 p.p.m.	0	10	10	100
25 p.p.m.	2	8	10	80
Check	7	3	10	30

CHAPTER VIII

RELEASE AND RECOVERY OF MOSQUITOES TAGGED WITH RHODAMINE-B

Review of Literature

Many different methods of tagging insects for flight studies have been described. Among the many materials used for marking are inks, dyes, lacquers, paints, stains, fluorescent pigments, radioisotopes and genetic markers. Most of the methods utilizing paints and lacquers are unsuitable for marking insects as fragile as mosquitoes. Dusts do not usually adhere well to the insect. The use of radioactive materials requires expensive equipment. The use of fluorescent dyes has been described by the following workers.

Reeves *et al* (1949) fed rhodamine-B in sugar solutions to mosquitoes. They found that after feeding, the abdomens of the mosquitoes became red in natural light and bright red under ultraviolet light.

Zukel (1945) tagged *Anopheles quadrimaculatus* with rhodamine-B, anthracene, and fluorescene. Anthracene was applied as an aerosol, while rhodamine-B and fluorescene were applied as dusts after mixing with gum arabic. When the dusts were used the mosquitoes were placed in an atmosphere of saturated humidity for fifteen minutes to make the particles adhere.

Smith _et al_ (1956) sprayed a 0.25 percent aqueous solution of rhodamine-B over emerging swarms of mosquitoes in the field with large power sprayers. Counts made immediately after spraying showed that 70 percent of the emerging mosquitoes were marked. Recovery was made primarily by manual collections as the insects attempted to bite.

Preliminary experiments on the use of fluorescent dyes for tagging mosquitoes were carried out in 1958 with the purpose of studying flight range and habits of our local species.

Methods and Results

The marking material used in these experiments was a fluorescent dye, rhodamine-B. The first attempt at tagging was made by spraying an aqueous solution of the dye on caged mosquitoes. This method proved to be unsuitable since the amount needed to show up well under the ultraviolet light affected the flight of the insects.

The dye was then offered in a ten percent sugar solution. With this method it was found that the mosquitoes fed readily until their abdomens were fully distended. When examined under the ultraviolet light the tagged individuals could be easily distinguished from the untagged ones.

Once the tagging procedure had been perfected releases were made for flight studies. Mosquitoes collected in the field were brought to the laboratory and allowed to feed on the dye. Releases were made near a New Jersey light trap two hours before the trap was turned on.

On August 21, 1958 about 300 tagged mosquitoes were released 3 feet from the light trap. Wind was from the northwest at 8 m.p.h. Temperature at time of release was 66° F. and dropped to a low of 46° F. during the night. The light trap was operated for the next four nights. No tagged mosquitoes were recovered on the first night. Two tagged mosquitoes were trapped on the second night when temperatures dropped to 48° F. On the third night the low temperature was 53° F. and five marked mosquitoes were recovered. No mosquitoes were trapped on the fourth night when the minimum temperature was 37° F.

On August 25, fifty tagged mosquitoes were released three feet from the trap. At the time of release the wind was from the northwest at 9.5 m.p.h. The trap was run on the next three nights but no tagged mosquitoes were recovered. Minimum temperatures for these nights were 43, 51 and 46° F., respectively.

On August 28, about 200 tagged mosquitoes were released 100 yards southeast of the trap. Wind was from the southeast at 6 to 8 miles per hour, and temperature was 64° F. The trap was operated for three nights but no tagged mosquitoes were recovered. Minimum temperatures for the three nights were 57, 47 and 46° F., respectively.

Discussion

Successful tagging of mosquitoes was accomplished by feeding rhodamine-B in sugar solution. This method of tagging was superior to spraying since, as far as we know, it in no way affected the flight of the mosquitoes. Some mortality was caused by collecting and transporting the insects to the laboratory but those which had been injured soon died and only apparently healthy individuals were released.

Little information regarding flight range and habits was obtained from the release and recovery trials. The only mosquitoes recovered had been released only a few feet from the trap and had remained in the surrounding vegetation. Those released 100 yards from the trap were not recovered.

Failure to recover any number of the tagged insects was probably due largely to the low night temperatures which inhibited mosquito flight activity in general and also the relatively small number of marked mosquitoes released. Any future releases would have to consist of very large populations to ensure recovery of sufficient numbers to yield information of any value.

CHAPTER IX

REARING OF PRAIRIE *AEDES* MOSQUITOES

Methods and Results

Attempts have been made to establish cultures of our local species of *Aedes* mosquitoes in the laboratory. Three different methods were used:

1. Larvae and pupae were collected in large numbers from their natural breeding sites, brought to the laboratory, and reared to the adult stage. The adults were kept in 18" x 18" x 24" cages and could be maintained for several weeks on sugar solution. No mating activity was noticed, however, and they would not feed on free blood or attempt to bite. The mosquitoes finally died without laying any eggs.

2. A site heavily infested with mosquitoes was visited by the investigator and females allowed to bite. As they became engorged with blood they were placed in vials or cages and brought to the laboratory. Strips of damp blotting paper were placed in the vials, and discs of filter paper were placed in the cages for oviposition. The mosquitoes were fed on a ten percent sugar solution. Many eggs were produced but they shrivelled a few days after oviposition and would not hatch.

3. Mosquitoes were collected from a heavily infested area where swarming activity was taking place. Males and a few females were

collected from the swarms and females were collected from the surrounding area. The mosquitoes were placed in a 3' x 3' x 8' cage outside and fed on ten percent sugar solution for one week at which time the cage was accidentally knocked over. No mating activity was noticed during this time even though the mosquitoes were subjected to natural temperatures, humidity and light.

A colony of *Aedes aegypti* was established in the laboratory so that rearing techniques could be studied. It was hoped that similar methods could be used to rear local *Aedes* species. The techniques described by Trembley (1955) for rearing *A. aegypti* were used.

In early attempts to rear *A. aegypti*, a larval medium consisting of a willow leaf infusion was used. A high mortality among larvae and pupae resulted, and the few adults which were produced were very weak and died soon after emergence. A microscopic examination of larvae and pupae revealed the presence of a fungus similar to that described by Steinhaus (1949). He states that fungi of the family Coelomomycetaceae develop in the body cavities of larvae and pupae, resulting in mortality as high as 95 percent.

In later rearing attempts, the willow leaf infusion was boiled and this produced healthy larvae, pupae and adults.

The same techniques were used successfully in rearing both *A. aegypti* and local *Aedes* species from larval to adult stage. However, the native species could not be made to mate, bite, or lay viable eggs in captivity.

Discussion

The factor limiting the rearing of prairie Aedes mosquitoes through more than one generation seems to be provision of conditions required for mating. Aedes adults have been seen swarming in sheltered sites in low lying areas. The swarms begin almost at ground level and rise to a height of ten to fifteen feet. No swarms were formed in an eight foot cage located outdoors in a similar environment.

In the laboratory the adults were subjected to varying light intensities in an attempt to stimulate mating. Although flight activity increased as light intensity was lowered, no mating occurred. Colored lights were also tried but with no success.

Eggs were obtained from females allowed to engorge on blood in the field but none hatched. It has been found (Bates, 1949) that in some cases females will feed on blood and lay eggs without being mated. It is possible that the field collected females were unmated and laid sterile eggs.

CHAPTER X

SUMMARY AND CONCLUSIONS

Summary

Twenty-three species of mosquitoes have been described from the Greater Winnipeg area. The most important, in terms of numbers and annoyance, is *Aedes vexans*, and the control efforts of the Greater Winnipeg Mosquito Abatement District are concerned mainly with this mosquito.

Spraying and fogging with DDT were the main methods used for controlling mosquitoes until the introduction of pre-season treatments with DDT spray and granules. Since its large scale introduction in 1954, pre-season acreage has increased from 150 acres to 18,555 acres for the 1959 season. During 1957 and 1958 a survey of larval populations was conducted to compare the relative effectiveness of pre-season treatments with spraying during the breeding season. Observations have shown that pre-season treatments eliminate mosquito breeding for the entire season while spraying eliminates breeding for only several weeks. During the past three years the number of days fogging required to stop mosquito annoyance in the city dropped from 98 days to 30 days as pre-season acreage was increased from 1,891 acres to 18,555 acres.

A survey of adult mosquito populations was conducted with the purpose of comparing the numbers of mosquitoes inside and outside a control area. In 1957 four New Jersey light traps were operated inside Greater Winnipeg. One trap was operated at Boissevain, Manitoba, for two weeks in September. In 1958 four traps were operated inside, and four traps outside the city. In both years light trap catches outside the control district were higher than those inside. During the peak of flight activity in 1958 the average catch of the outside traps was about ten times greater than the average of the inside traps.

An investigation into the possibility of using predaceous minnows for larval control was begun in 1957 when some top minnows, *Gambusia affinis*, were imported from Chicago. Trials were conducted to test their ability to overwinter and reproduce during the summer under natural conditions in this climate. Indications so far are that *Gambusia affinis* cannot overwinter in this climate. They can, however, multiply rapidly during the summer under natural conditions. A native minnow tentatively identified as *Notropis hudsonius* has been found near Winnipeg in ditches and ponds. No mosquito larvae were found in the same habitat as this fish. In the laboratory *N. hudsonius* proved to be almost equal to *G. affinis* as a predator of mosquito larvae and it is hoped that this fish can be used in the future for mosquito control.

Because of reports of resistance of mosquitoes to insecticides in many areas, experiments were carried out to determine whether mosquitoes in the Greater Winnipeg area have developed any resistance to DDT. A kit supplied by the World Health Organization was used in the tests. Concentrations ranging from 0.004 p.p.m. to 2.50 p.p.m. of DDT were found to be fatal to mosquito larvae collected inside the control district.

Tests were made to determine what concentration of a common household detergent (Tide) would be required to kill mosquito larvae in rain barrels and similar containers. The tests showed that field collected larvae were susceptible to concentrations as low as 25 p.p.m. or one teaspoon of detergent in 16 gallons of water. More reliable control is given by 50 to 100 p.p.m. of this detergent.

Small amounts of rhodamine-B mixed with sugar solution were used to tag mosquitoes to be released for flight studies. When viewed under an ultraviolet light, tagged individuals could be easily separated from untagged ones. Mosquitoes were collected in the field, brought to the laboratory, allowed to feed on the tagging material until their abdomens were fully distended, and then released. Recovery was made by light trap. Seven marked mosquitoes from a group released beside the light trap were recovered during the three nights after release. Releases were made on two other occasions, one beside the trap, and the other 100 yards away but none of these was recovered.

Attempts were made to establish a permanent colony of local species of _Aedes_ mosquitoes. Three methods of rearing were used:

1. Larvae and pupae were collected in the field and reared to the adult stage in the laboratory. The adults were confined in cages for mating and oviposition.

2. Female mosquitoes which had been allowed to bite and engorge with blood were collected and brought to the laboratory for oviposition. Eggs were laid on wet blotting paper but they soon shrivelled, indicating sterility.

3. Male and female mosquitoes were collected from heavily infested sites and placed in a 3' x 3' x 8' cage erected in a location similar to their natural habitat in an attempt to simulate conditions required for mating, biting and oviposition.

None of these methods was successful in establishing a permanent culture. Larvae and pupae could be reared to the adult stage and the adults could be maintained for several weeks on sugar solution but they could not be stimulated to mate or feed on blood.

Conclusions

1. Observations made over the past two years have shown that pre-season treatments are far superior to spraying during the breeding season to eliminate mosquito annoyance. Only one treatment per year is required in contrast to the several spray applications needed to give the same degree of control.

2. Light trap catches outside the city were higher than catches inside during 1957 and 1958. In 1958, control operations reduced mosquito populations inside the city to about one-tenth the populations present in surrounding areas during the peak infestation in July.

3. Indications are that the top minnow, Gambusia affinis, is not able to overwinter this far north. It can, however, survive and multiply in outdoor pools during the summer. A native minnow, Notropis hudsonius, has proven under laboratory conditions to be a good predator on mosquito larvae.

4. It has been proven that no resistance to DDT has yet developed in the mosquitoes in the Winnipeg area. Concentrations of DDT as low as 0.004 p.p.m. were fatal to larvae collected in the field.

5. Rhodamine-B was used successfully to tag mosquitoes. No information regarding flight range and habits was obtained due to cold weather prevailing when releases were made.

6. Attempts to establish a permanent colony of local Aedes mosquitoes were unsuccessful. Larvae and pupae could be reared to the adult stage, and adults could be kept alive for several weeks but they could not be stimulated to mate, bite or oviposit in captivity.

LITERATURE CITED

Axelrod, H. R., and L. P. Schultz. 1955. Handbook of Tropical Aquarium Fishes. McGraw - Hill Book Company, New York.

Chandler, A. C. 1956. Introduction to Parasitology. John Wiley and Sons Inc., New York.

Donier, C. C., T. L. Cain, and W. C. McDuffie. 1950. Aerial Spray Tests on Adult Salt Marsh Mosquitoes Resistant to DDT. Jour. Econ. Ent. 43:506-510.

Geis, R. W. 1953. Aerial Application of Granular Insecticides in S.E. Pennsylvania. Mosq. News. 13:1, p. 55.

Greater Winnipeg Anti-Mosquito Campaign. Reports 1947-1952.

Greater Winnipeg Mosquito Abatement District. Reports 1953-1957.

Headlee, T. J. 1945. The Mosquitoes of New Jersey and Their Control. Rutgers University Press, New Brunswick.

Herms, W. B. 1953. Medical Entomology. The Macmillan Company, New York.

Hinks, David. 1943. Fishes of Manitoba. Department of Mines and Resources, Province of Manitoba.

Horsfall, W. R. 1955. Mosquitoes. Their Bionomics and Relation to Disease. The Ronald Press Company, New York.

King, W. V. 1952. Mosquitoes and DDT. U.S.D.A. Yearbook. pp. 327-330.

Mail, G. A. 1954. Mosquito fish *Gambusia affinis* (Baird and Girard), in Alberta. Mosq. News. 14:2, pp. 282-283.

McLintock, J. 1944. The Mosquitoes of The Greater Winnipeg Area. Canadian Ent. 76:89-104.

Nowell, W. R., and D. W. Parish. 1956. Effectiveness of a Pre-hatching Treatment for the Control of Salt Marsh Mosquitoes in Florida. Mosq. News. 16:3, pp. 212-219.

Reeves, W. C., and B. Bookman. 1948. Studies on the Flight Range of Certain Culex Mosquitoes, Using a Fluorescent Dye Marker, With Notes on Culiseta and Anopheles. Mosq. News. 8:61-69.

Rings, R. W., and E. V. Richmond. 1953. Mosquito Survey of Horn Island, Mississippi. Mosq. News. 13:4, p. 252.

Smith, G. F., A. F. Geib, and L. W. Isaac. 1956. Investigations of a Recurrent Flight Pattern of Flood Water Aedes Mosquitoes in Kern County, California. Mosq. News. 16:4, pp. 251-256.

Steinhaus, E. A. 1949. Principles of Insect Pathology. McGraw - Hill Book Company, New York.

Sweetman, H. L. 1936. The Biological Control of Insects. Comstock Publishing Company, Ithica, New York.

Tremblay, H. L. 1955. Mosquito Culture Techniques and Experimental Procedures. American Mosquito Control Association Bulletin, No. 3.

Vannote, R. L. 1953. Further Observations of the Use of Granular Dusts. Mosq. News. 13:3, p. 183.

Zukel, J. W. 1945. Marking Anopheles Mosquitoes With Fluorescent Compounds. Science. 106:102-157.

APPENDIX 1.

LIGHT TRAP COLLECTIONS, JUNE 14 - OCTOBER 4, 1957

Date	Kildonan Golf Course ♂	Kildonan Golf Course ♀	Windsor Golf Course ♂	Windsor Golf Course ♀	Assiniboine Park ♂	Assiniboine Park ♀	University of Manitoba ♂	University of Manitoba ♀
June 14	0	5	0	0	0	3	0	15
18	2	5	5	6	not run		0	6
21	1	8	1	2	0	1	0	4
25	0	24	not run		2	3	0	1
28	0	36	0	21	0	28	0	36
July 2	9	90	0	22	0	60	0	111
5	2	24	9	61	5	22	1	15
9	10	20	2	32	2	7	2	7
12	99	143	28	238	34	384	25	436
16	22	130	41	211	13	90	9	103
19	14	105	16	62	70	123	11	138
23	4	34	1	28	4	29	0	14
26	39	156	12	65	16	39	5	29
30	23	141	93	109	43	111	24	102
Aug. 2	9	71	1	3	7	94	16	87
6	1	46	1	4	1	30	2	21
9	not run		1	1	1	6	5	15
13	2	14	2	7	0	6	1	13
16	8	6	1	1	1	6	1	4
20	2	11	61	51	9	30	8	4
23	33	27	5	14	17	14	0	8
27	6	13	13	15	5	9	3	0
30	9	11	3	5	1	9	0	3
Sept. 3	5	4	0	2	0	3	0	0
6	1	9	0	2	not run		not run	
10	2	7	0	7	5	25	0	0
13	0	3	2	1	0	1	0	1
16	0	0	1	8	0	0	0	1
20			not run	cold weather				
24			not run	cold weather				
28			not run	cold weather				
Oct. 1	6	7	not run		0	0	0	0
4	1	4	not run		not run		0	5
Total	390	1162	300	959	234	1102	113	1145
	for 29 trap nights		for 27 trap nights		for 27 trap nights		for 29 trap nights	
Average per trap night	13.4	40.0	11.1	35.5	8.6	40.8	3.8	38.7

Average catch per trap night	♂	♀
	9.1	40.0

APPENDIX 2.

LIGHT TRAP COLLECTIONS, SEPTEMBER 5 - SEPTEMBER 18, 1957 AT BOISSEVAIN, MANITOBA

Date	Numbers ♂	Numbers ♀	
Sept. 5	290	286	
6	131	102	
7	68	48	
8	55	100	
9	14	14	Trap didn't go until 11 p.m.
10	513	355	
11	336	232	
12	62	46	
13	16	18	
14	52	30	
15	18	17	
16	6	13	
17	47	22	
18	24	13	
Total	1632	1296	

APPENDIX 3.

LIGHT TRAP COLLECTIONS, MAY 20 - SEPTEMBER 23, 1958

Date	Kildonan Golf Course		Windsor Golf Course		Assiniboine Park		University of Manitoba	
	♂	♀	♂	♀	♂	♀	♂	♀
May 20	0	0	not run		0	0	0	0
23	0	0	0	0	0	2	0	0
27	0	0	0	0	0	0	0	0
30	0	3	0	2	1	1	0	0
June 3	2	11	0	2	0	1	0	0
6	0	4	0	1	1	4	1	0
10	0	4	0	1	2	5	2	0
13	1	0	2	0	1	2	0	1
17	6	3	6	5	0	3	2	5
20	3	1	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
27	0	2	0	1	0	0	0	0
July 1	6	15	0	4	1	4	0	7
4	1	1	0	2	0	0	2	3
8	0	3	0	2	0	0	0	2
11	1	8	3	3	0	1	4	1
15	0	4	1	3	1	0	3	1
18	8	21	12	4	61	17	14	7
22	131	247	221	407	133	431	303	629
25	41	73	83	208	131	93	20	33
29	8	11	3	13	6	29	2	3
Aug. 1	12	26	102	181	86	157	96	123
5	16	35	14	32	29	23	not run	
8	11	55	1	6	7	18	14	25
12	29	48	126	129	38	43	56	57
15	5	8	10	13	1	8	8	23
19	7	23	66	107	28	64	42	108
22	0	4	3	1	3	1	0	2
26	1	0	0	1	0	0	0	0
29	1	6	2	2	1	3	1	5
Sept. 2	0	1	4	21	0	16	2	26
5	0	2	not run		5	4	not run	
9	1	0	1	2	3	11	5	2
12	0	0	0	3	2	2	1	2
16	0	0	0	0	0	0	0	0
19	0	0	2	2	0	0	1	1
23	not run		6	6	3	17	3	4
Total	291	576	663	1145	541	960	582	1061
	36 trap nights		35 trap nights		37 trap nights		35 trap nights	
Average per trap night	8.0	16.0	18.6	33.2	14.6	25.9	16.6	30.3
Average catch per trap night		♂ ~~14.5~~	♀ ~~26.3~~					

APPENDIX 4.

LIGHT TRAP COLLECTIONS, MAY 20 - SEPTEMBER 23, 1958

Date	Oak Bluff S. ♂	Oak Bluff S. ♀	Oak Bluff N. ♂	Oak Bluff N. ♀	Lilyfield ♂	Lilyfield ♀	Navin School ♂	Navin School ♀
May 20								
23								
27	0	0						
30	6	10						
June 3	0	26						
6	22	22	2	5				
10	3	10	0	2	0	1		
13	0	2	5	4	0	2		
17	17	22	8	12	24	19		
20	0	0	0	0	0	0		
24	0	0	0	0	0	0		
27	1	2	1	3	2	14		
July 1	not run		3	13	1	4	0	5
4	1	0	0	0	1	8	0	0
8	1	3	0	8	0	2	4	2
11	1	2	1	17	2	7	12	0
15	3	0	8	17	1	2	3	5
18	417	143	1	27	381	156	4	4
22	1408	6391	791	1543	834	8288	308	2545
25	1026	171	82	146	822	137	70	30
29	68	53	83	83	77	66	18	18
Aug. 1	710	753	643	730	507	2409	58	80
5	111	298	51	186	114	180	25	16
8	139	164	12	117	30	159	49	62
12	62	170	32	32	140	115	70	41
15	8	19	0	0	20	31	4	7
19	298	347	21	29	325	151	30	36
22	3	9	2	7	5	5	1	1
26	2	1	0	0	2	3	0	2
29	2	40	0	1	5	23	not run	
Sept. 2	71	445	11	90	25	197	1	4
5	12	74	not run		7	28	9	5
9	7	17	not run		8	1	8	2
12	15	26	0	0	8	0	1	2
16	4	2	0	0	1	1	0	0
19	6	4	2	0	5	2	5	1
23	10	20	3	7	3	5	0	7
Total	4434	9246	1762	3079	3350	10016	680	2875
	34 trap nights		30 trap nights		31 trap nights		24 trap nights	
Average per trap night	131.2	271.9	58.7	102.6	108.0	323.1	28.3	119.8

Average catch per trap night	♂	♀
	85.7	211.9