MOSQUITO CONTROL ON SMITH MOUNTAIN RESERVOIR BY PUMPED STORAGE WATER LEVEL MANAGEMENT

by

William Jess Gladney, B.S., M.S.

Dissertation submitted to the Graduate Faculty of

the Virginia Polytechnic Institute

in candidacy for the degree of

DOCTOR OF PHILOSOPHY

in

Entomology

APPROVED: _____

Chairman, Dr. E. Craig Turner, Jr.

_____ _____

Dr. James McD. Grayson Dr. Stuart E. Neff

_____ _____

Dr. Michael Kosztarab Dr. Robert L. Pienkowski

_____

Dr. William A. Parsons

March, 1967

Blacksburg, Virginia

TABLE OF CONTENTS

LIST OF FIGURES

Figure Page

Figure Page

LIST OF TABLES

Table Page

ACKNOWLEDGEMENTS

The writer wishes to express his sincere appreciation to Dr. E. Craig Turner, Jr., for his guidance and aid during the research here reported; to Dr. Stuart E. Neff, Dr. Robert L. Pienkowski, Dr. Michael Kosztarab, Dr. William A. Parsons, and Dr. James McD. Grayson for their advice, suggestions, and service on the graduate committee; and to the Appalachian Power Company for the grant which made this work possible.

Special thanks are also due Mr. Joe C. Plunk, Mr. Cecil Kessinger, Mr. V. Dean Warren, Mr. George Newton, Miss Joy Fisher, and Dr. Jakie A. Hair for their assistance in the field and laboratory and Dr. Alan Stone for confirmation of certain identifications.

Gratitude is extended to the author's wife, Bonita, for encouragement throughout the period of this study and for typing the manuscript.

I. INTRODUCTION

Disease and annoyance due to mosquitoes have long been associated with impounded waters. The Federal Security Agency (1947) reports that long before the discovery of the transmission of malaria by mosquitoes, there are records of dams being destroyed by irate citizenry who attributed the local occurrence of malaria to the presence of impounded water. Although malaria has been almost completely suppressed in this country, other diseases transmitted by mosquitoes such as encephalitis may appear sporadically any time there is sufficiently high virus activity associated with a vector population. Even with the total absence of a disease threat, the annoyance caused by mosquitoes in many situations is enough to limit human inhabitance and depress real estate values around recreational areas.

Since the early part of this century, it has been known that mosquito control over the vast majority of impounded waters may be effectively accomplished by frequent water level fluctuation. Christopher and Bowden (1957) state that water level management, properly employed, is the most potent single measure that can be applied toward controlling mosquito production in a manmade impoundment. Water management for mosquito control means the manipulation of water levels in such a manner that the microhabitat normally favorable for mosquito propagation is either destroyed or the mosquitoes are prevented from developing beyond their larval stage.

The pumped storage plan of water level management employed on the Smith Mountain system is unique in that a portion of the water moved

from the upper lake, through the upper dam's turbines, is retained in the lower lake for temporary storage. Then, when demand for power is low, usually on weekends but also at night, the turbines at the upper dam are reversed and, operating as pumps, move a portion of the retained water back into the upper lake to be used again. The result of this situation is a constant rise and fall of the water line which, due to a number of factors, probably reduces the mosquito populations. It was, therefore, suspected that the pumped storage process to be put into effect on Smith Mountain Lake in Virginia during July, 1965, would create a variation in the water level that would reduce mosquito breeding to some extent within the impoundment.

The concept of pumped storage is unique and relatively new to the United States. The first plant to utilize pumped storage was the Brunnenmühle plant built in Germany in 1908 (Harza, 1961). Other western European countries quickly followed Germany's cue by building their own pumped storage systems, usually with slight modification to suit their own particular needs. The United States lagged behind Europe in its acceptance of the pumped storage principle. It was not until 1955 that the first major pump-turbine was installed at Hiwassee dam on the T.V.A. system.

Jaski (1954) provides a comprehensive discussion of the general process and economic feasibility of pumped storage. The reversible pump-turbine employed in pumped storage is similar to the older conventional turbines with the major exception of having the additional capacity of pumping or recycling water from a lower reservoir back up

into an upper reservoir. When water is passed through the turbine at the upper dam, hydroelectric power is generated. However, during off-peak periods when demand for electricity is low, the turbine may be reversed and consequently, a portion of the water from the lower reservoir is moved back into the upper reservoir. The power for this recycling process may be derived from coal-burning steam plants which, for economical reasons, should be kept in operation although there is little demand for power they produce during the off-peak period. Thus, the power from steam plants that would ordinarily be available in surplus quantities may be employed for pumping water back into the upper reservoir where it may be used again to generate hydroelectric power. No reference was found in the literature in regard to mosquito problems associated with reservoirs that employ the pumped storage process.

Smith Mountain Reservoir, which was formed by impounding the Roanoke and Blackwater Rivers in southwestern Virginia, is a project of the Appalachian Power Company. A smaller lake below the Smith Mountain dam was created by the construction of Leesville dam. The project was completed in 1965 with the primary purpose of generation of hydroelectric power, but it also serves as a major recreation facility for the area.

Probably an increase in the mosquito population occurred after the construction of Smith Mountain dam. However, this fact cannot be documented since no pre-impoundment mosquito survey was conducted. Such a survey would have been useful for the purpose of defining the mosquito species present and their respective population densities prior

to reservoir construction. Had this information been available, a more precise analysis could have been made upon the effect of the impoundment on the local mosquito population.

The primary objectives of this study were to survey the seasonal abundance of mosquito species present within the proximity of the impoundment and to investigate the effect of the pumped storage water level schedule upon mosquitoes breeding within the lake proper. In addition to information concerning seasonal abundance, attempts were also made to secure data on the times of flight activity of the various mosquito species present within the study area.

II. LITERATURE REVIEW

A. Water Level Management Considerations

Carter (1914) was one of the first individuals to have noted the deleterious effects of water level variation to mosquito breeding. He observed that, "These changes of elevation within a shorter time than the cycle of development of the mosquito should tend to prevent breeding. As the water falls it should leave some larvae stranded in the grass and behind drift, while the rise would expose them to some extent to fish, from which the shallow water and other conditions at the edges had protected them. Accidental changes should work to their disadvantage, because it would be a change from protective conditions which they themselves had sought out." Although Carter's observations were of a casual nature without supporting data, later research has proven that his assumptions were correct. Carter (1915) and Carter, LePrince, and Griffitts (1916) carried out more detailed, scientific investigations on impounded ponds that helped substantiate Carter's original statements. On the basis of their study they also recommended the maintenance of reservoirs at high elevation during the non-breeding season in order to kill brush and vegetation and to strand flotage. They also advised the storage of summer freshets in order to give as much variation of level as possible during the mosquito breeding season. This varying level strands flotage and exposes larvae to attack by fish and other predators. Hinman (1938) found that as the water level receded in an experimental pool, concentrations of larvae occurred in

small depressions and subsequent death occurred. However, he felt that more important than this was the drawing of the larvae out of the vegetated margin into the open water where minnows and other predators could attack them.

Darrow (1949) conducted experiments to determine the fate of Anopheles quadrimaculatus Say as affected through water level fluctuation in impoundments. Her work was carried out in an experimental fluctuation pool constructed above an inlet of Wilson Reservoir of the Tennessee Valley Authority. It was ascertained from these studies that from 75 to 100 percent of the larvae migrated with the receding waters and that the numbers stranded appeared to be inversely proportioned to the rate of water level recession and all larval instars were equally susceptible to stranding. She also found that the combined effects of exposure to both predators and climate for 8-hour periods on clear summer days resulted in the death of about 92 percent of the larvae and 75 percent of the pupae left stranded and exposed on the dewatered shore; however, 100 percent larval mortality resulted after 48 hours of exposure.

Van Dine (1922) conducted studies near Mound, Louisiana, upon the effect of impounding the waters of a bayou on mosquito breeding. He observed the favorable influence of variation in the water level due to leakage at the dam. When the water line receded, a very clean margin around the impounded water resulted and this dewatered area had its aquatic and semi-aquatic vegetation destroyed. Therefore, when the water was returned to its original level, the margins were clear of the

vegetation that normally provided protection to mosquito larvae. Van Dine thus concluded that growth of marginal vegetation was discouraged by a varying water level.

Hinman (1938), in discussing the biological effects of water level fluctuation on anopheline breeding, quotes from the Regulations Governing the Impounding of Waters (Alabama State Board of Health, Montgomery, Alabama, 1927) that "During the mosquito breeding season, pronounced fluctuations of the water level may be, or may be made to be, a controlling factor in breeding. When the water level is varied at ten-day intervals, a 24-inch fluctuation on steep slopes and a 48-inch fluctuation on flat slopes will make prolific breeding impossible. Changes in water level tend to prevent rank growth of aquatic plants and aid fish enemies (Gambusia) in reaching the mosquito larvae or flush the larvae within reach of the fish."

Smillie (1927) reported on the necessity for proper shoreline maintenance through clearing heavy brush and timber in areas that were to be submerged by impounded waters. This was clearly demonstrated in 1924 when the Gantt impoundment in Covington County, Alabama, inundated a section of land that had not been properly cleared in the design of the project. The result of this situation led to heavy anopheline production and a consequent malaria epidemic that produced 238 confirmed cases from a total population of 742 in the town of Gantt, Alabama.

The most extensive work on mosquito control by water level fluctuation came with the creation of the Tennessee Valley Authority in the mid-1930's and their efforts in controlling malaria along the tandem of

impoundments created on the Tennessee River.

Stromquist (1935), in discussing malaria control on the Tennessee Valley system, pointed out the value of water level management on the Wilson and Norris Reservoirs. On Lake Wilson in 1934 effective control was maintained with a fluctuation of one foot at ten-day intervals. When the fluctuation was reduced to only six inches, an increased production was observed and following the raising of the pool to the maximum level, still greater production resulted in spite of the use of more than double the quantity of larvicides. On this same lake in 1935, the water level was held constant with the result that effective control was not established until vegetation was removed from 30 miles of shoreline to make possible effective application of larvicides. Here the lack of water level variation more than doubled the cost of malaria control during the season, due to additional larvicidal work and marginal clearing.

Hinman (1941)* states that the most important factor in the management of water for malaria control on manmade impoundments is the incorporation in the design of the project a provision for effective variation of water level. He further contends that proper reservoir preparation, supplemented by shoreline maintenance, are also fundamental features. In the preparation of most reservoirs, it is necessary that the entire area to be flooded be cleared of all trees and that all

---

*Hinman is quoted extensively throughout this section. When the source is not specified, the reference will be understood to be Hinman (1938, 1941).

timber be removed. Not only is this an important anti-larval measure, but it may be a requisite for removal of hazards to navigation and sources of drift which may be objectionable at the dam.

An important consideration with new impounded water projects is the initial wintertime filling of the reservoir. Dr. E. L. Bishop (1936), the first Director of Health of the Tennessee Valley Authority, stated as a precondition that no reservoirs would be filled on the T.V.A. system during the mosquito breeding season. It has been demonstrated repeatedly that if the impoundage is allowed to fill during the mosquito breeding season in the southeastern states, a situation conducive to the propagation of Anopheles quadrimaculatus, as well as several other mosquito species, will follow. When water rises slowly into terrestrial vegetation, it picks up debris which makes a rich medium for larvae. Thus, a new reservoir should be filled sometime after the close of one mosquito breeding season and before the beginning of the following one. Preferably each project should have provision for a so-called "malaria surcharge." This process entails filling the reservoir above the normal summertime operating level and then rapidly drawing the water level down to this point just at the beginning of the breeding season. This results in the stranding of drift and flotage which would otherwise provide potential protection to mosquito larvae.

Following adequate reservoir preparation, the next and most important step in mosquito control on impounded waters is the proper management of the water level, if such can be provided. Pool level fluctuation for mosquito control may be employed along two distinct

lines. A slow, continuous drawdown throughout the entire breeding season may be effective if it is of a sufficient magnitude. Such a procedure is termed seasonal recession. On storage reservoirs where a wide drawdown follows the requirements for power production, navigation, or flood control, this simple process usually provides adequate mosquito control. On the other hand, there are numerous projects on which only a limited amount of water level fluctuation is allowable. If stream flow or upstream reservoirs allow a regular pool level variation between constant limits, a cyclical fluctuation may be provided. This consists of a drawdown of a certain amount and then refilling to the previous elevation within a regular interval. Therefore, the elevation of the lake may be lowered one foot over a period of 3.5 days and refilled a foot over the same period. This would constitute a weekly cyclical variation in level of one foot. The time interval in which this cycle is accomplished might be of any length but probably should not exceed ten days (it should be less than the length of life of the larval stage of the mosquito). This type of fluctuation is usually experienced where reservoirs are located in tandem and the drawing down process in one lake may coincide with the filling of the one immediately below it. It should be pointed out, however, that any project utilized as a hydro-electric development will invariably undergo a certain variation in water level. If this variation can be scheduled to be periodic, it will be advantageous in preventing the development of mosquito larvae. Hess and Kiker (1944) found that the use of cyclical fluctuations of 1½ to 2 feet in amplitude, without seasonal recession, gave satisfactory control

on Wilson Reservoir during the 1943 season.

On the T.V.A. lakes a combination of seasonal recession and cyclical fluctuation has been found to be a most effective measure against mosquito breeding. With this process the reservoir is lowered a definite amount during the first half of the cycle but the refilling process does not take it back to the original level, e.g., lowered 1.0 ft. but refilled only 0.9 ft. This results in a "staircase" type of schedule which has been found quite effective. Each individual periodic drawdown, whether it is part of the cyclical variation or of the seasonal recession, accomplishes several things, including strandage of debris which may have entered the lake recently and strandage of larvae, pupae, or eggs at the margin. In addition, a certain percentage of the larvae (75-100% as determined by Darrow, 1949) are flushed out of the marginal breeding areas into open water where they are destroyed, presumably by fish and other predators. Finally, the drawdown reduces the total area of potential breeding surface.

Fluctuation of pool level has a profound effect upon vegetation within the fluctuation zone. According to Hinman (1941), many aquatics (Potamogeton, Chara, etc.) cannot withstand even temporary dewatering, and it appears that certain semi-aquatic plants are unable to thrive under conditions which alternately dewater and inundate them. The great majority of terrestrial plants are killed with only a few days of flooding and, thus, if a cyclic variation schedule is employed, the entire fluctuation zone would tend to be clear of vegetation.

Another variation on the theme of water level fluctuation remains

to be considered. This may be employed as a modification of the cycles represented by either gradual seasonal drawdown or by cyclic fluctuation in combination with seasonal drawdown. Since both of these processes result in a constantly receding shoreline, it is obvious that marginal vegetation will tend to invade down to the waterline. To aid in preventing this, it may be advisable to refill to maximum elevation or approximate this at intervals throughout the mosquito breeding season. Or, advantage could be taken of heavy rainfall to refill the reservoir at irregular intervals. These irregular fillings should tend to retard the invasion of terrestrial and semi-aquatic plants into the fluctuation zone. Hinman (1941) summarizes his thoughts regarding water management by stating that "regardless of the exact mechanism by which fluctuation of water level exerts its beneficial effect, it should be considered as prophylactic rather than palliative. Through the control of water level, the objective becomes one of making the environment unsuitable to the development of mosquitoes rather than attempting merely to destroy developing larvae."

The Federal Security Agency (1947) and Hess and Kiker (1944) presented outlines of the various phases of water level management and their application. These phases consisted of initial filling, surcharge, fluctuation, seasonal recession, and constant level. All of these aspects have been discussed previously with the exception of constant level. Constant level pool entails bringing the water to or above the basic clearing line by the beginning of the vegetative growing season, where it should be maintained with a minimum of fluctuation until the

beginning of significant mosquito production. This phase is employed to delay the development of marginal vegetation. The success of later water level manipulation for mosquito control depends to a large degree upon the use of constant level phase. If water is removed from the shoreline within the fluctuation zone even for a few days during the spring growth period, many plants will sprout and produce growth which will survive for a while even though reflooded. Further, this downward invasion of growth into the zone of cyclic fluctuation may later interfere with the effectiveness of the water level variation. Where the constant level pool phase is applicable, it may be sufficiently valuable as a growth control measure to extend it into the beginning of the mosquito breeding season, even though some mosquito production will be the result. This is justified since a cleaner shoreline will be the result later in the season when more effective mosquito control is necessary. Fig. 1 illustrates diagrammatically the beneficial phases of water level management including surcharge, cyclical fluctuation, and cyclical fluctuation combined with seasonal recession.

With the present day dissension from some quarters over pesticides in our ecosystem, it is gratifying that such complaints, whether justified or not, can be answered with a measure of management mosquito control. Hall (1951) points out that in order to obtain the objective of mosquito control over the T.V.A. system, three major elements are employed: naturalistic measures, chemical measures, and mechanical measures. Of these, water level management, a naturalistic measure, is the most important element and is used as a control procedure on 24

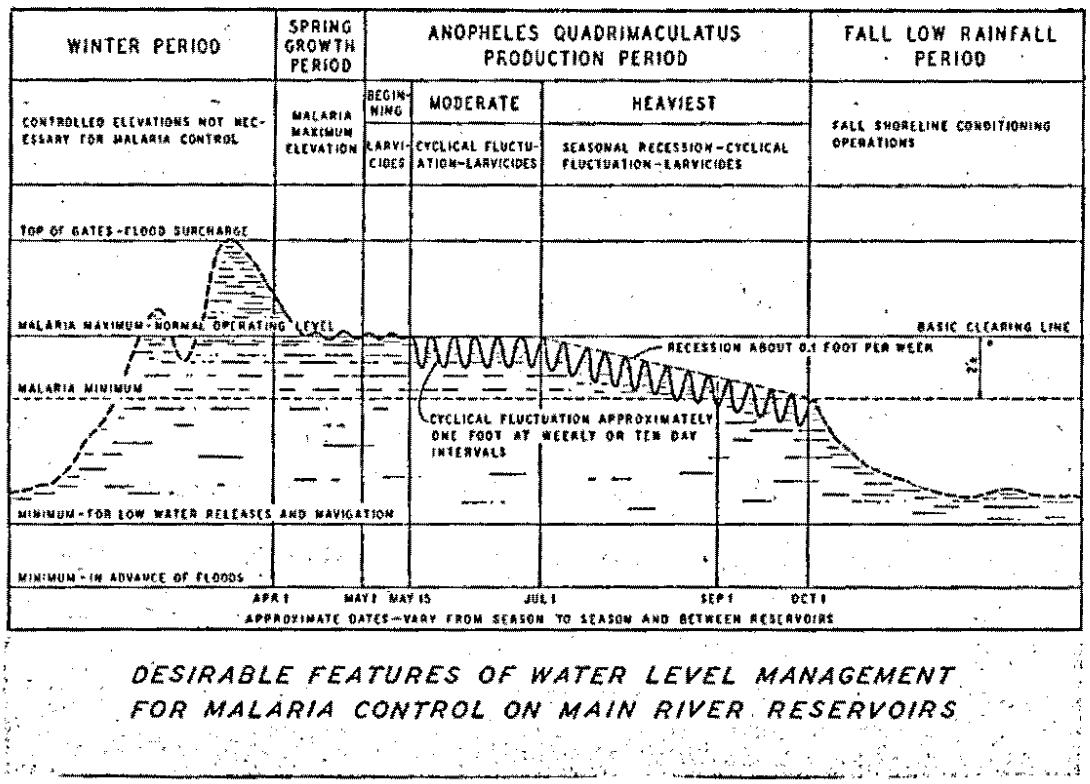


Fig. 1. Diagrammatic illustration of the beneficial phases of water level management. From Hess and Kiker (1944).

reservoirs which have in aggregate more than 10,000 miles of shoreline. The long-term objective of the program has been to place progressively increasing reliance upon water level management with decreasing emphasis on the more costly and repetitive measures of chemical control. The effectiveness of water level management is borne out by the fact that of the 24 impoundments involved, water level management is now being relied upon entirely on 16 reservoirs, with minor supplementary larviciding being required on two reservoirs and considerable supplementary larviciding and other measures on only 6 reservoirs.

The most recent work concerning mosquito control by water level management was carried out by Edman (1964). He found that a high surcharge with subsequent withdrawal from the reservoir at the rate of 0.1 foot per week was adequate in controlling Culex tarsalis Coquillett and Aedes vexans (Meigen) on Gavins Point Reservoir in Nebraska. On the other hand, an unscheduled three-foot rise in the water level during August created a situation that greatly favored the production of Aedes vexans.

Christopher and Bowden (1957) reported on the various primary purposes of reservoirs and the water management problems associated with each. Dams are constructed and reservoirs impounded for a number of reasons. Such reasons generally include domestic or industrial water supplies, flood control, irrigation, hydroelectric power, recreation and navigation. Some reservoirs are termed multi-purpose in that they are constructed and operated to serve two or more of the above functions. Water supply, irrigation, and recreational reservoirs are constructed

to store water during periods of high streamflow to assure an ample supply for use throughout the year as it is needed. The operation of these types of reservoirs is usually aimed toward maintaining the reservoir water level at or as near full pool elevation as possible consistent with supplying the demand for water. On the other hand, a flood control reservoir requires the opposite type of operation. In these reservoirs there must be enough storage space available when needed to collect and hold, at least temporarily, flood waters in excess of that which can be safely passed downstream. Operation of a reservoir primarily designed to serve navigation requires that a certain channel depth be maintained at all times. In addition, sufficient water must also be available to operate the navigation locks.

Reservoir water management for hydroelectric power generation may at times be more complicated than those operations mentioned above. The most efficient operation demands that all available water be passed through the turbines and not over the spillway. In considering the several different types of reservoirs, it should be apparent that each individual reservoir presents specific problems with respect to the application of water management for mosquito control. The degree of effective mosquito control which can be achieved on a particular reservoir will depend chiefly on how closely the requirements of control can be incorporated into an overall water management schedule without materially interfering with operations necessary in carrying out the primary purpose of the reservoir.

Since Anopheles punctipennis (Say) and Culex salinarius Coquillett

were the two dominant species which comprised over 70 percent of the total mosquito population in the Smith Mountain area, some consideration is given the biologies of these two species in the following discussion.

B. The Biology of Anopheles punctipennis (Say)

According to Matheson (1966), Anopheles punctipennis is the most widely distributed nearctic anopheline. It occurs in southern Canada and throughout the eastern, central, and southern states to New Mexico, and from the Pacific states into western Canada.

The eggs of Anopheles punctipennis are boat-shaped, pointed on both ends, and are laid singly on the surface of water where there is emergent or floating vegetation and debris of various kinds. The eggs, which possess floats that keep them at the surface of the water, hatch in from two to three days under favorable conditions into larvae according to King, et al. (1960). Horsfall (1955) found that eggs are resistant to a certain amount of drying. Eggs that had been stranded by receding water in a forest pool in central Illinois hatched nine days later when they were floated.

Horsfall (1955) states that larvae require 12-14 days for development in the presence of abundant food and in the face of an inadequate food supply, the interval may be lengthened to over a month. The pupal stage lasts from 2-4 days.

Bradley and King (1941) point out that A. punctipennis may utilize both permanent and temporary waters for breeding; however, the most general characteristic of their breeding waters is that they are clean.

Foul or contaminated waters are seldom inhabited. Unlike other species of Anopheles, A. punctipennis is frequently found in moving as well as still water. The margins of streams often provide adequate protection for this species.

Boyd (1929) analyzed temperatures of anopheline breeding waters and concluded that A. quadrimaculatus breeds in the warmer waters which have a rather limited diurnal range. Anopheles punctipennis prefers waters that either are distinctly cooler or have a wide variation in diurnal range. These differences were particularly evident in the fall when breeding of A. quadrimaculatus was definitely limited and this species was replaced by A. punctipennis in many locations. Boyd also states that the range of A. punctipennis extends much farther north.

The preference of A. punctipennis for neutral to alkaline breeding waters is quite well established. Boyd (1929) observed that larvae of A. punctipennis in both Georgia and North Carolina have but rarely been found in waters having a pH lower than 6.1 and never in those below pH 5.1. The mean pH values for the breeding waters of A. punctipennis were found to be approximately 7.10 in North Carolina and 7.32 in Georgia.

Boyd (1929) observed a considerable variation in the amount of dissolved oxygen in various anopheline-breeding waters in North Carolina, the range being from 0.1 to 14.0 ppm. However, no larvae were found in waters devoid of oxygen.

Bradley and King (1941) reported that A. punctipennis breeds in a great variety of places. Margins of flowing streams, pools in

intermittent stream beds, springs, ponds and pools, artesian wells, artificial water receptacles, and new borrow pits and other excavations are noted as breeding places of this species. It is often found in association with A. quadrimaculatus in the more permanent water situations. It has also been noted by Bradley and King (1941) that it is the first anopheline to occur in certain rain or flood pools when microorganisms are scarce, and to be replaced by A. quadrimaculatus as a richer flora and fauna develop. Cool, clean water free from the products of organic decay is, in the opinion of most authors, most suited to the species. However, Carpenter (1941) thought that they tolerate more filth in their breeding places than other anophelines in Arkansas.

Frequencies of association of A. punctipennis with larvae of other mosquito species were determined in Virginia by Dorsey (1944). An analysis of 969 collections showed that A. punctipennis larvae were taken from the same breeding waters: (1) 342 times with Culex territans Walker; (2) 191 times with C. restuans Theobald; (3) 139 times alone or in "pure culture"; (4) 72 times with C. salinarius; (5) 69 times with Aedes vexans; (6) 54 times with C. erraticus (Dyar and Knab); (7) 50 times with Anopheles quadrimaculatus; and with other species very rarely.

Bradley and King (1941) point out that anopheline adults seek shelter for daytime resting places and such shelter includes corners in stables, porches of all sorts, chicken houses and out-buildings, especially privies, culverts, beneath overhanging vegetation on stream banks and in hollow trees. These authors also state that A. punctipennis tolerates more illumination in its daytime shelters than does A.

quadrimaculatus and that A. punctipennis is rarely found inside houses.

Horsfall (1955) reported that in domestic situations A. punctipennis has been found to feed naturally on man, horse, cow, pig, sheep, dog, cat, and fowl.

No information could be found on the flight range of A. punctipennis; however, Bradley and King (1941) consider all nearctic anophelines to be comparatively weak fliers. In the case of A. quadrimaculatus, it is a common practice to limit control measures to a radius of from 1/2 to 1 mile from habitations, depending on intensity of breeding, since many authors believe that few migrate farther than a mile from their breeding grounds.

C. The Biology of Culex salinarius Coquillett

This mosquito is commonly distributed from Utah eastward throughout the remainder of the continental United States. Eggs are deposited in rafts on the surface of fairly clean freshwater sites, and Horsfall (1955) quotes from Mitchell (1907) that each raft contains 50-55 eggs. Dyar (1922) states that larvae live in permanent pools in marshes containing grass and Lemna, and that they are frequently very abundant near the seashore, and hence named. However, they also occur inland, even in water barrels on occasion.

In Oklahoma, Rozeboom (1942) found C. salinarius breeding in artificial containers, pools in streams, springs, and seeps. Owen (1937) reports that this species occupies the margins of semi-permanent ponds, marshes, and temporary rain pools in Minnesota. Dorsey (1944), while

conducting a mosquito survey near Williamsburg, Virginia, collected C. salinarius larvae in every type of breeding location encountered, including treeholes and brackish water, but they were most numerous in quiet, freshwater pools in streams and channels. Dorsey also analyzed the frequencies of association of C. salinarius with larvae of other mosquito species and from a total of 346 collections he found C. salinarius associated with: (1) C. restuans 88 times; (2) C. territans 74 times; (3) A. punctipennis 72 times; (4) C. salinarius alone in "pure culture" 55 times; and with other species very rarely.

Wallis and Spielman (1953) successfully colonized C. salinarius and found that the eggs of this species hatched within two days after oviposition and that the larval stage lasted eight days in the laboratory at a temperature of 27 ± 3°C. No mention was made of the length of the pupal period.

According to Carpenter and LaCasse (1955), larval development of this species under natural conditions begins early in the season and continues at a rather uniform rate during the summer and early fall throughout most of its range. Larvae and adults may be found any time during the year in the extreme South, but inseminated females overwinter in hibernation farther north.

The adults are often found resting during the daylight hours in outbuildings and other similar shelters. Carpenter and LaCasse (1955) report that males and females are often captured in large numbers in New Jersey light traps in the Atlantic and Gulf coastal regions where the species probably reaches its greatest abundance. Huffaker and Back

(1943) found that C. salinarius constituted more than half of the total mosquitoes taken in several types of collections, and many were taken while biting during the first three-hour period after dark. King, et al. (1960) state that adults may disperse quite widely from their breeding places. Some indication of their flight range was elucidated by MacCreary and Stearns (1937) when they collected C. salinarius in two light traps in Delaware Bay about eight miles from the nearest shore.

The females bite readily outdoors and according to Matheson (1966), they occasionally enter houses to feed on man. Rozeboom (1942) collected this mosquito from human bait more often than any other Culex in Oklahoma.

III. METHODS AND MATERIALS

A. Methods Employed in Sampling Adult Mosquito Populations.

1. The New Jersey light trap.

Numerous workers throughout the world are charged with the responsibility of obtaining accurate measures of adult mosquito populations for the purpose of determining the effectiveness of various control procedures. Voluminous accounts have been published of the various types and modifications of devices employed by such workers. In the past quarter-century, the New Jersey mosquito light trap as described by Mulhern (1942) has emerged as the most universally accepted method for sampling populations of adult mosquitoes.

These traps are based on the attraction of mosquitoes to light sources during the dark evening hours. However, Huffaker and Back (1943) point out that different species may be attracted to different degrees, depending upon the prevailing conditions and the species; such factors as time of day, lightness of the environment, and meteorological conditions are known to complicate the analysis. These workers conducted experiments to compare the effectiveness of several methods of sampling mosquito populations including light traps operated in the usual manner, light traps baited with CO_2 as an additional attractant, CO_2 baited traps without light, light traps with no attractant (only the fan was used), landing rate counts, sweeping, and collections from resting shelters. Their results revealed that none of these methods could be depended upon for an adequate, non-selective analysis of a

heterogeneous mosquito population. They reported that a trap with no attractant seemed to give the best qualitative results, but this method caught too few mosquitoes to be of practical use in itself.

In defense of the New Jersey light trap, however, it may be noted that its more favorable points have been the ease with which records may be obtained and the degree to which such a record is devoid of the usual errors associated with the use of any non-mechanical device. Also, workers concerned with discrepancies in sampling procedures may feel justified in their efforts if they assume the attitude of Bates (1949) who states that "Any datum on mosquito abundance is bound to be an index, since there is no way of making a census of the actual number of individuals found in a particular area. For the most part the index serves only as a guide to population fluctuations in a given place, or to variations from place to place: the rise and fall of the index is assumed to correspond directly to fluctuations in the absolute populations, but we have no idea of the real size of the population at anytime or place." (p. 41)

During the summers of 1965 and 1966 modified New Jersey light traps (Fig. 2) were operated at six permanent and several temporary or "spot-check" locations within the proximity of selected mosquito breeding grounds at Smith Mountain and Leesville Reservoirs. These sites were initially located from the air in the spring of 1965. The use of a helicopter provided by Appalachian Power Company proved to be an invaluable tool in spotting potential mosquito breeding areas. Undoubtedly, the aerial survey provided the most practical and rapid means

Fig. 2. Modified New Jersey light trap in operation.

Fig. 3. Light traps and batteries ready for transport.

for accurate location of mosquito source production.

The light traps were operated at the six permanent locations an average of two rain-free nights each week during the mosquito breeding season and "spot-checks" were made at irregular intervals whenever heavy mosquito breeding was suspected in any given area. Each trap was powered by direct current from a 12-volt automobile battery. Traps and batteries were transported to and from the various collecting sites in a frame built and mounted on a pick-up truck (Fig. 3).

Care was exercised in the selection of the exact spot where each trap was to be situated. In all cases tree limbs that were approximately six feet from the ground were used for supporting the light traps, and the traps faced at least 180° of cleared area but dense forest always provided a background. This forest background afforded some degree of protection from strong winds that are known to deter mosquito flight towards a source of attraction. All traps were placed in areas devoid of artificial illumination that may have acted as a competing light source.

The traps used in these studies were modified for collecting at pre-set time intervals. Mr. U. F. Earp of the Agricultural Engineering Department, Virginia Polytechnic Institute, designed the timing apparatus and Dr. J. A. Hair, now a research entomologist at the Communicable Disease Center, Atlanta, Georgia, assisted in the necessary wiring of these devices. A time switch that operated on alternating current was installed on each trap. The direct current from the 12-volt automobile battery was converted to the alternating current necessary to operate

the timer by a Powercon® vibrator inverter (Cornell-Dubilier Electronics; Fuquay Springs, N. C.).

In preliminary trappings the timers were set to turn the trap on at 8 p.m. E.D.T. and to turn the trap off at 12 midnight E.D.T. It was hoped that by operating the light traps only four hours during the evening hours that enough power would be conserved in the batteries to allow two consecutive nights of trapping without having to replace or recharge the batteries used on the first night. However, it was soon learned that the power drain placed on the batteries during the first evening created a situation that often led to the vibrator inverter burning out on the second evening if the same battery was used. Apparently, there is a critical high level of direct current above which the battery must be maintained in order for the inverter to function properly. Therefore, after these preliminary trials, the timers were not used and the trap was set to operate throughout the night on direct current for the purpose of obtaining data on seasonal abundance. However, the automatic timers were very useful in obtaining information on peaks-of-adult flight activity to be described in another section. For these experiments, a freshly charged battery was provided for each night of trapping.

2. The Malaise trap.

Malaise (1937) has described the use and construction of a novel insect trap, and Townes (1962), who also published an account of its construction plans, states that this type of trap merits more development and use than it has had. The original trap was a tent-like

structure made of fine, weatherproof netting supported by a wooden frame. A collecting assembly at the top of the trap consisted of a funnel made of aluminum screening that opened into a killing jar. This trap catches all kinds of actively flying insects, particularly Diptera, Hymenoptera, and Lepidoptera. Insects are trapped by flying into one of the four baffles in the lower half of the device, and their natural tendency to work upwards leads them to the killing jar at the top of the structure. The upper half of the trap is covered with a roof made of weatherproof netting that also aids in preventing the insect's escape while it is working its way toward the collecting assembly.

Breeland and Pickard (1965a, 1965b) used a Malaise trap in conducting a survey of tabanids, muscoids, and stinging wasps on the T.V.A.'s land between the Lakes national recreation area in western Kentucky and Tennessee. These workers noted that the trap was also effective in capturing a surprising number of adult mosquitoes. They further stated that to their knowledge the device had never been employed previously for the purpose of sampling mosquito populations.

Breeland and Pickard (1965a) outlined the advantages that the Malaise trap would provide mosquito workers: (1) The trap will gather species such as Toxorhychites septentrionalis (Dyar and Knab) that normally elude other collecting methods in common use. (2) The trap can operate almost anywhere, including places not easily accessible, or where the briefness of favorable weather or the paucity of the fauna would discourage the ordinary collector. (3) It collects efficiently both day and night under variable weather conditions. Only conditions

that inhibit mosquito flight would reduce its effectiveness. (4) The operator need not be present except at collecting time, and there is no fear of mechanical failure. (5) With proper care the specimens taken are in "museum condition." (6) Since the trap does not attract, it gives a completely unbiased sample of mosquito activity.

This last opinion of Breeland and Pickard may be open to question since Brown (1951) showed that dark-shaded patterns are clearly attractive to Aedes mosquitoes, and it is likely that bright shades are actively repellent since even in very dim light in the field a black dummy was more attractive to Aedes than a white one. However, employing green netting in the construction of Malaise traps probably reduces their attractiveness since Brown (1954) discovered an unexpectedly low attractiveness of green dummies in the field due to their lack of contrast against the foliage.

Two Malaise traps were constructed and operated during the 1966 season at two of the established permanent study sites. These traps were modeled after the design of Marston (1965), and the primary difference between them and the devices described by Malaise (1937), Townes (1962), and Breeland and Pickard (1965a) was that the traps built for these studies employed a tubular aluminum frame for an 11' X 11' tent (Sears, Roebuck and Company, Catalog No. 6H7894N) instead of a wooden one for a supporting structure.

The completed trap is shown in operating position in Fig. 4. Interior baffles were made of 18 X 14 mesh, green Lumite® saran, and the top panels which formed the roof were cut from 20 X 20 mesh, natural

Fig. 4. The Malaise trap in operating position.

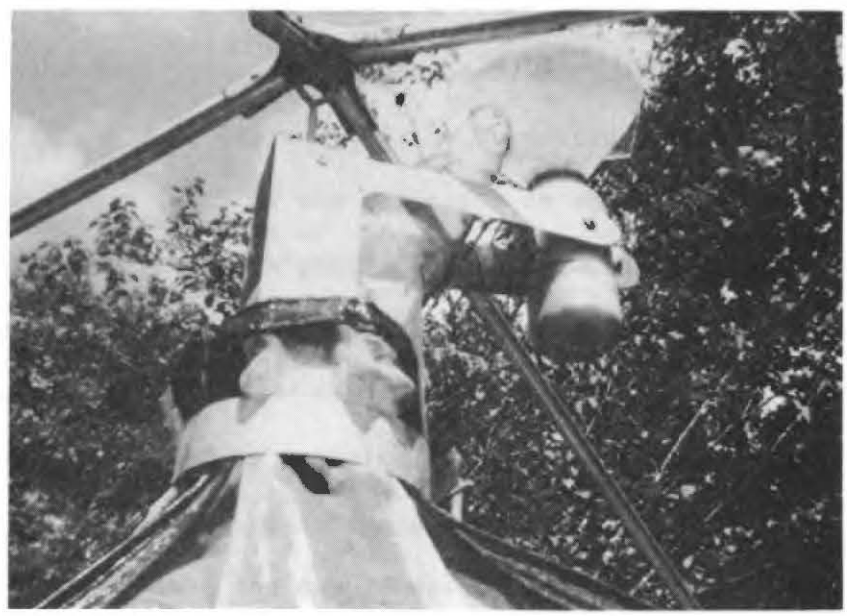


Fig. 5. Malaise trap collecting assembly.

or "clear" Lumite® saran (Chicopee Manufacturing Company; Cornelia, Georgia). This material was too heavy and bulky to sew with a conventional sewing machine, and the models used in these studies were sewn by a local upholstering company.

The collecting assembly at the top of the trap (Fig. 5) consisted of sheet metal strips obtained from a local sheet metal works, an aluminum screen funnel that opened into a two-inch in diameter hole cut in the side of a large polyethylene plastic funnel, and a cyanide killing jar. The top of the polyethylene funnel was closed by cementing a piece of stiff Plexiglass® plastic over the upper end with epoxy glue. The lower tapered portion of the plastic funnel was cut away to provide a two-inch bottom which opened into the cyanide killing jar. The trap was stabilized by driving wooden stakes into the ground about six feet from the trap between the legs in each direction, and plastic clothesline was alternately wrapped around a stake and passed through a hook at each of the four upper angles of the frame. Samples were taken by collapsing two legs on one side of the supporting frame to bring the killing jar within reach of the collector as shown in Fig. 6. The samples were then placed in pint-sized food containers, marked as to locality and date, and transported back to the laboratory for sorting and identification.

Traps were placed in relatively open areas in the field. At first the traps were set up in the afternoon, allowed to operate throughout the night, and then the sample was collected and the trap taken down the next morning. However, this soon proved to be a time-consuming

Fig. 6. Trap shown with two legs collapsed to bring collecting assembly within reach of collector.

procedure and after a few weeks, the traps were permanently established and left to operate 24 hours a day throughout the remainder of the season. Samples were taken of a single evening's catch an average of twice a week by placing an empty killing jar on a trap in the late afternoon prior to dusk and removing it the next morning shortly after dawn. The traps also operated during the irregular periods when the single night collections were not being taken (e.g., approximately 59 consecutive hours between the completion of one single night's collection and the beginning of another single evening collection period). By allowing the trap to collect during this time interval, mosquito species such as Psorophora ferox (Humboldt) and Toxorhynchites septentrionalis (Dyar and Knab) that are normally active during the daylight hours were taken.

3. Diurnal resting shelters.

Adults of several mosquito species that are inactive during the day normally congregate in dark, cool diurnal resting places. Inspection of such shelters often provides a useful index to population densities. This method is particularly valuable when used for mosquitoes that are not readily attracted to light traps such as Anopheles quadrimaculatus.

Carpenter (1946) and Pratt, et al. (1960) have described the various objects that may be employed for daytime resting shelters. They are usually divided into two general types: natural and artificial. Natural shelters include places normally present in an area such as

houses, stables, chicken houses, privies, culverts, caves, hollow trees, and overhanging banks along streams.

Artificial shelters are devices placed in the field specifically for the purpose of evaluating mosquito populations. A great many different types of artificial resting stations have been used, including boxes, barrels, and nail kegs.

Suitable natural resting stations were not available in sufficient numbers near the six permanent study areas at Smith Mountain Impoundment. Therefore, heavy duty cardboard barrels that measured 14-1/4 inches in diameter and 31 inches in height were used for these studies. Since all barrels used were of identical size and shape, a high degree of standardization was provided which would have not been possible had natural shelters been employed. The cardboard barrels gave good service and normally retained their shape for about 40 days during the season. However, the effects of weathering usually necessitated their replacement after a 40-day period.

These stations were examined twice a week during the 1965 and 1966 seasons and adults, if present, were collected with an aspirator, killed in a cyanide collecting jar, and placed in metal tins marked as to locality and date.

4. Biting collections.

Information regarding mosquito species feeding or attempting to feed upon man is of great practical value in that it provides an estimate of the nuisance level of the population as well as records of

the exact species present in a particular area.

Biting collections were made at irregular intervals at the two study sites at Smith Mountain that exhibited the heaviest mosquito production. These collections were made by exposing both arms to the bites of female mosquitoes for a one-hour period. All mosquitoes that landed were collected with an aspirator, killed with cyanide, and placed in metal tins marked as to locality and date.

B. Larval Surveys.

Potential breeding sites were sampled for mosquito production at all six of the permanent study areas and at several other points over the two reservoirs. Any breeding source (e.g., water-filled hoofprints, temporary rain pools) which was not directly associated with the lake proper but near enough to contribute to the mosquito population of the area was also sampled. An ordinary white enamel dipper about four inches in diameter was employed for collecting mosquito larvae, and the following index as described by Edman (1964) was used: heavy production, more than an average of 10 larvae per dip; moderate production, an average of from 1 to 10 larvae per dip; and light production, an average of less than 1 per dip.

Larvae were poured from the dipper into a white enamel photographic pan until an accumulation of 10 dips had been obtained. The larvae were then transferred from this pan to a small vial by a wide-mouth pipette and preserved in 70% ethanol. Collected larvae were cleared for 24 hours in a saturated phenol-absolute ethanol solution,

mounted in Canada balsam on slides, and identified to species. Pupae taken from breeding sites were placed in pint-sized, cardboard food containers covered with 40 mesh saran screening, reared to the adult stage, and then identified to species.

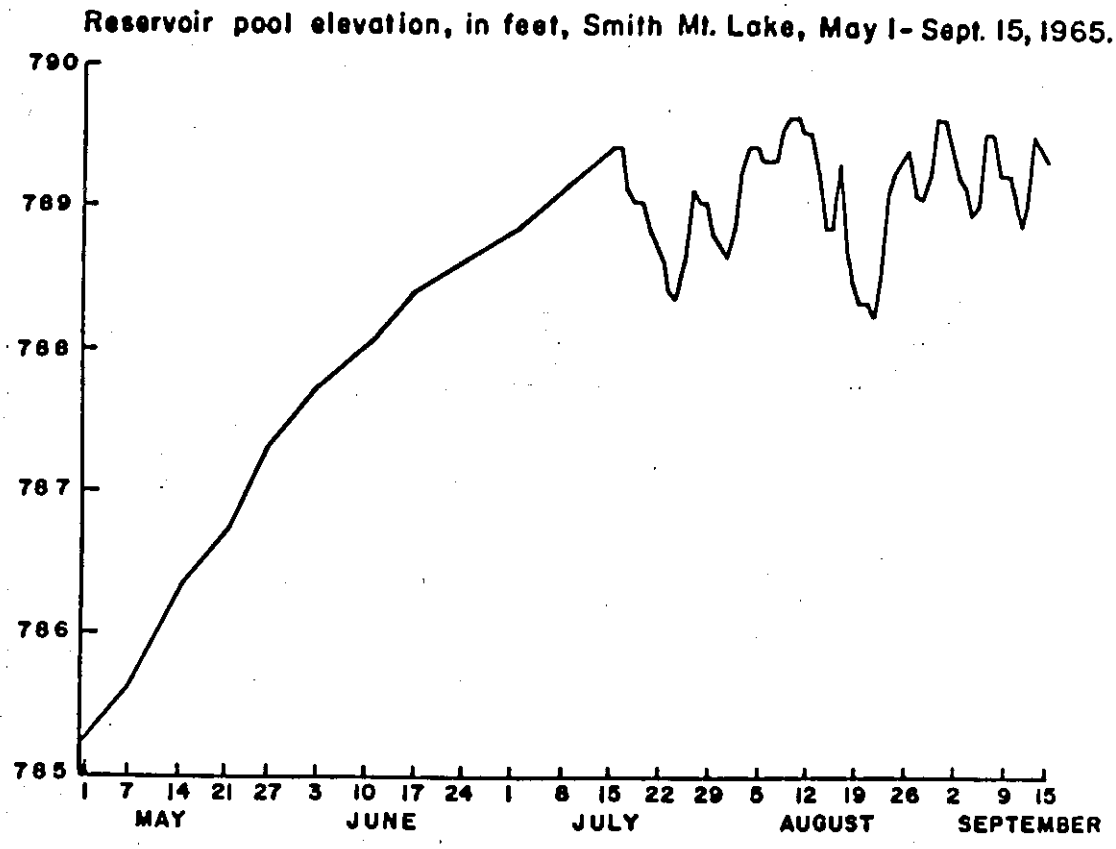
IV. RESULTS

A. Reservoir Operation.

Reservoir pool elevations for the period May 1 to September 15, 1965, are graphically illustrated in Fig. 7. It may be noted from the graph that the reservoir was in the process of filling from May 1 until July 15. Bishop (1936) points out that if a new impoundment is allowed to fill during the mosquito breeding season, a situation conducive to the propagation of several mosquito species will follow. Directly in accordance with Bishop's statements, the highest mosquito populations of the 1965-1966 study were encountered during and immediately after this rising pool phase.

After July 15 the pumped storage water level schedule was put into effect to continue throughout the season. This process resulted in a cyclical variation with no seasonal recession. Hinman (1938) has given an excellent account of the several ways that fluctuation may be employed in mosquito control on impounded waters. He points out that in the past, cyclical fluctuation has been utilized most frequently. Usually, this was on a weekly basis by drawing the water level down one or more feet and subsequently refilling to near top elevation within the seven-day period. The speed of the drawdown and refilling has varied; either one or both may be rapid. Likewise, the period at which maximum and minimum elevation was maintained has been varied. Essentially, cyclical fluctuation was the type schedule employed on Smith Mountain Reservoir from July 15, 1965, until the end of the mosquito

Fig. 7


Reservoir pool elevation, in feet, Smith Mt. Lake, May 1- Sept. 15, 1965.
790
789
788
787
786
785
1 7 14 21 27 3 10 17 24 1 8 15 22 29 5 12 19 26 2 9 15
MAY
JUNE
JULY
AUGUST
SEPTEMBER

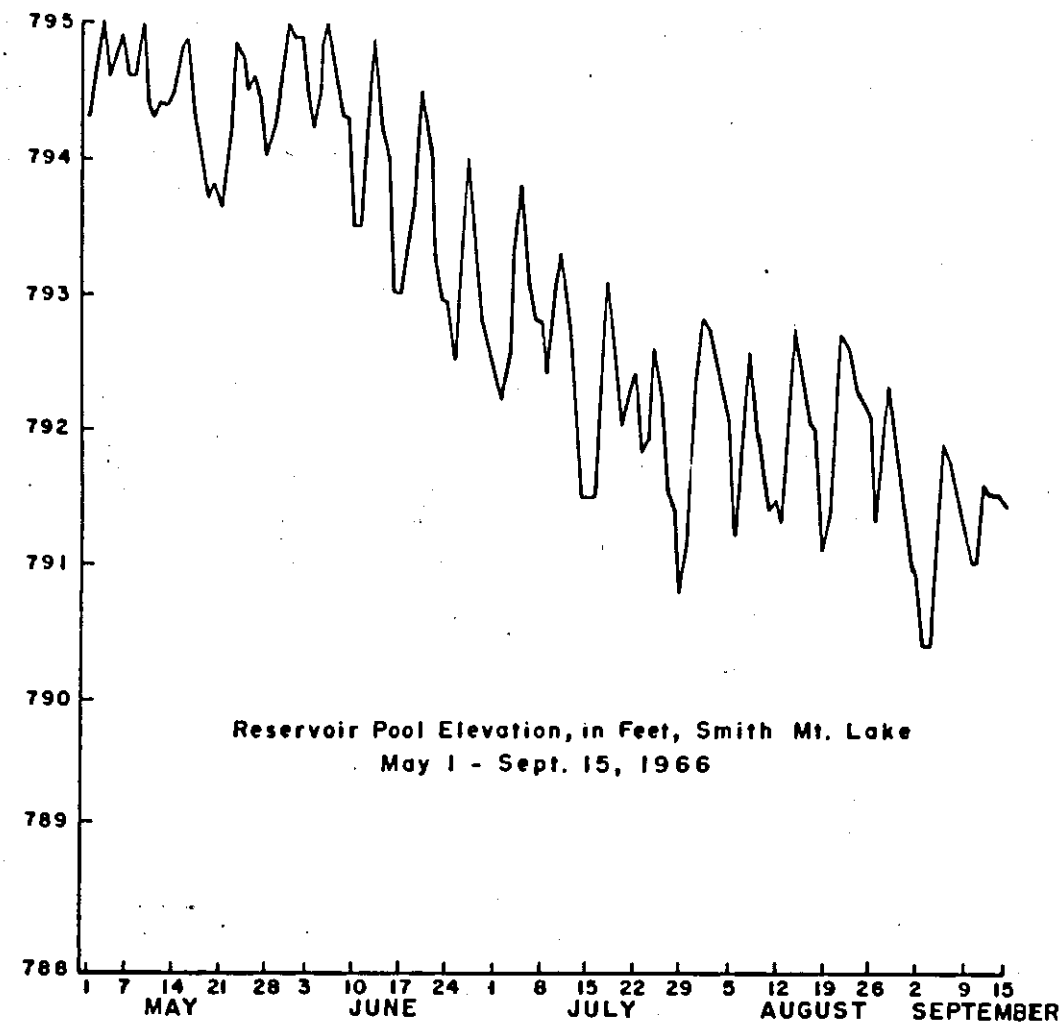
breeding season as shown in Fig. 7. The reservoir was in the rising pool stage up until July 15 with no cyclical variation.

The sudden one-foot drop after July 15 may be considered a surcharge; however, unlike the "malaria surcharge" recommended by Hinman (1938), the pool level at Smith Mountain was returned to its original elevation on August 3 and a large percentage of the stranded drift was refloated.

Hinman (1938) further suggests that in contrast to a cyclical or periodic fluctuation, a slow seasonal drawdown might be desirable on large reservoirs where an insufficient water supply exists to refill it on a weekly basis. During the winter and spring, the reservoir would be maintained intermittently at top elevation. Then just before the beginning of the mosquito breeding season, a regular weekly drawdown would start. Therefore, a progressively lower water line would result as the season advanced. For this type of schedule to be effective, the drawdown must be great enough to keep the shoreline receding before the constantly advancing mat of vegetation.

If a combination of the two above types of fluctuation were put into effect, it would combine the benefits of cyclical fluctuation and slow gradual (seasonal) drawdown. This is the basic type schedule employed on Smith Mountain Impoundment during the season of 1966, as illustrated in Fig. 8. The scheme put into effect at Smith Mountain also had the additional benefits of a rapid drawdown and refilling and a wide variation in the cyclical fluctuation (0.3 - 1.1 ft./week in 1965 and 0.4 - 2.0 ft./week in 1966). It should be pointed out that the

Fig. 8


795
794
793
792
791
790
789
788
Reservoir Pool Elevation, in Feet, Smith Mt. Lake
May 1 - Sept. 15, 1966
1 7 14 21 28 3 10 17 24 1 8 15 22 29 5 12 19 26 2 9 15
MAY
JUNE
JULY
AUGUST
SEPTEMBER

severe drought conditions that occurred over most of the summer of 1966 contributed greatly to the overall seasonal recession experienced on Smith Mountain Reservoir and in future seasons of normal rainfall, this additional mosquito breeding deterrent may not prevail.

Another very important factor in the control or prevention of mosquitoes on impounded waters is that of proper reservoir preparation. Inspection of the clearing line in the fall of 1964 indicated that an adequate job had been done over the vast majority of the impoundment from the standpoint of elimination of brush and timber that would have created potential mosquito breeding sites.

B. Results of the 1965-1966 Study.

1. Adult mosquito survey.

Table 1 contains a list of the 20 mosquito species collected by light trap during the 1965-1966 study and their respective percentages of the total population. Culex salinarius comprised 50.2 percent of the total population and Anopheles punctipennis 20.6 percent, the two totaling over 70 percent of the total population. Next ranked Aedes vexans, Anopheles quadrimaculatus, Culex erraticus, Mansonia perturbans (Walker), and Psorophora confinnis (Lynch Arribálzaga), respectively.

These studies also produced a new mosquito record for Virginia. Aedes cinereus Meigen was taken on several occasions from both light and Malaise traps. This species is not listed for Virginia in literature by Dyar (1922), Dorer, et al. (1944), Dorsey (1944), Carpenter and LaCasse (1955), and Bickley (1957). Dr. Alan Stone, U.S. National

Museum, Washington, D. C., verified the identifications of Aedes cinereus and also confirmed the fact that it was a new state record.

It is interesting to note that Malaise trap collections provided three additional mosquito species that were never encountered in the two years of light trap collections. One specimen of Aedes grossbecki Dyar and Knab, one of Psorophora cyanescens (Coquillett), and two of Toxorhynchites septentrionalis (Dyar and Knab) were collected in Malaise traps in 1966; therefore, these three may be added to the species list of Table 1, bringing the total number of species to 23 taken from the Smith Mountain area. In addition Aedes atlanticus Dyar and Knab and Psorophora ferox (Humboldt) were collected from light traps in 1966, but, neither of these two species were taken in 1965.

Tables 2 and 3 are lists of the total number of mosquitoes taken by light traps in the six study areas during 1965 and 1966. The average number of females per catch, the percentage of the total females composed of A. punctipennis, C. salinarius, and other species are also included in these tables. It may be seen from Table 2 that C. salinarius was the dominant species at each of the study sites in 1965 with the exception of 11a-Rt. 605. Table 2 reveals that C. salinarius was also the dominant species in 1966 at three of the permanent study locations.

The map (Fig. 9) illustrates the approximate locations of the six permanent sites utilized in this study. These sites are referred to on the map as: 1a-Hardy Ford, 2a-Rt. 668, 3a-Pelican Point, 4a-Pelican Point, 9a-B-Bar-B area, and 11a-Rt. 605.

Site 1a. Hardy Ford. This site was a cove which contained an

Table 1. Species of mosquitoes collected by light trap at Smith Mt. and Leesville Lakes during 1965 and 1966.

Species	Total Number	Percent of Total Population
Aedes atlanticus Dyar and Knab	1	—[a]
Ae. canadensis (Theobald)	7	—[a]
Ae. cinereus Meigen[b]	25	—[a]
Ae. triseriatus (Say)	11	—[a]
Ae. trivittatus (Coquillett)	12	—[a]
Ae. vexans (Meigen)	401	6.0
Anopheles crucians Wiedemann	29	—[a]
A. punctipennis (Say)	1,382	20.6
A. quadrimaculatus Say	371	5.5
Culex erraticus (Dyar and Knab)	293	4.4
C. peccator Dyar and Knab	2	—[a]
C. restuans Theobald	190	2.8
C. salinarius Coquillett	3,367	50.2
C. territans Walker	60	0.9
Culiseta inornata (Williston)	3	—[a]
Mansonia perturbans (Walker)	217	3.2
Psorophora ciliata (Fabricius)	10	—[a]
P. confinnis (Lynch Arribálzaga)	214	3.2
P. ferox (Humboldt)	5	—[a]
Uranotaenia sapphirina (Osten Sacken)	108	1.6
	6,708	100

[a]/ Less than 0.5% of total.

[b]/ New state record for Virginia.

Table 2. A. punctipennis and C. salinarius collected by light trap at each of the six permanent study areas, May 15-September 21, 1965.

Species	1a Hardy Ford		2a Rt. 668		3a Pelican Pt.	
	♀	♂	♀	♂	♀	♂
Anopheles punctipennis	90	22	53	50	44	13
Culex salinarius	677	416	111	47	46	12
Other species	127	9	22	3	24	1
Total mosquitoes	894	447	186	100	114	26
Total collections	27		28		22	
Average females/catch	33.1		6.6		5.2	
Percent A. punctipennis (♀)	10.0%		28.5%		38.6%	
Percent C. salinarius (♀)	75.7%		59.7%		40.4%	
Percent other species	14.3%		11.8%		21.0%	

Species	4a Pelican Pt.		9a B-Bar-B		11a Rt. 605	
	♀	♂	♀	♂	♀	♂
Anopheles punctipennis	103	35	482	67	81	23
Culex salinarius	171	57	791	280	36	7
Other species	71	3	244	41	262	69
Total mosquitoes	345	95	1,517	388	379	99
Total collections	22		26		12	
Average females/catch	15.7		58.3		31.6	
Percent A. punctipennis (♀)	29.9%		31.8%		21.4%	
Percent C. salinarius (♀)	49.5%		52.1%		9.5%	
Percent other species	20.6%		16.1%		69.1%	

Table 3. A. punctipennis and C. salinarius collected by light trap at each of the six permanent study areas, May 7-September 15, 1966.

Species	1a Hardy Ford		2a Rt. 668		3a Pelican Pt.	
	♀	♂	♀	♂	♀	♂
Anopheles punctipennis	66	8	5	1	5	0
Culex salinarius	293	56	15	6	4	1
Other species	126	20	11	0	4	1
Total mosquitoes	485	84	31	7	13	2
Total collections	29		30		21	
Average females/catch	16.7		1.0		0.6	
Percent A. punctipennis (♀)	13.6%		16.1%		38.4%	
Percent C. salinarius (♀)	60.4%		48.3%		30.7%	
Percent other species	25.9%		35.4%		30.7%	

Species	4a Pelican Pt.		9a B-Bar-B		11a Rt. 605	
	♀	♂	♀	♂	♀	♂
Anopheles punctipennis	5	1	31	2	121	6
Culex salinarius	11	2	80	28	72	14
Other species	14	2	83	8	708	48
Total mosquitoes	30	5	194	38	901	68
Total collections	21		32		32	
Average females/catch	1.4		6.1		28.2	
Percent A. punctipennis (♀)	16.6%		15.9%		13.4%	
Percent C. salinarius (♀)	36.6%		41.2%		7.9%	
Percent other species	46.6%		42.7%		78.5%	

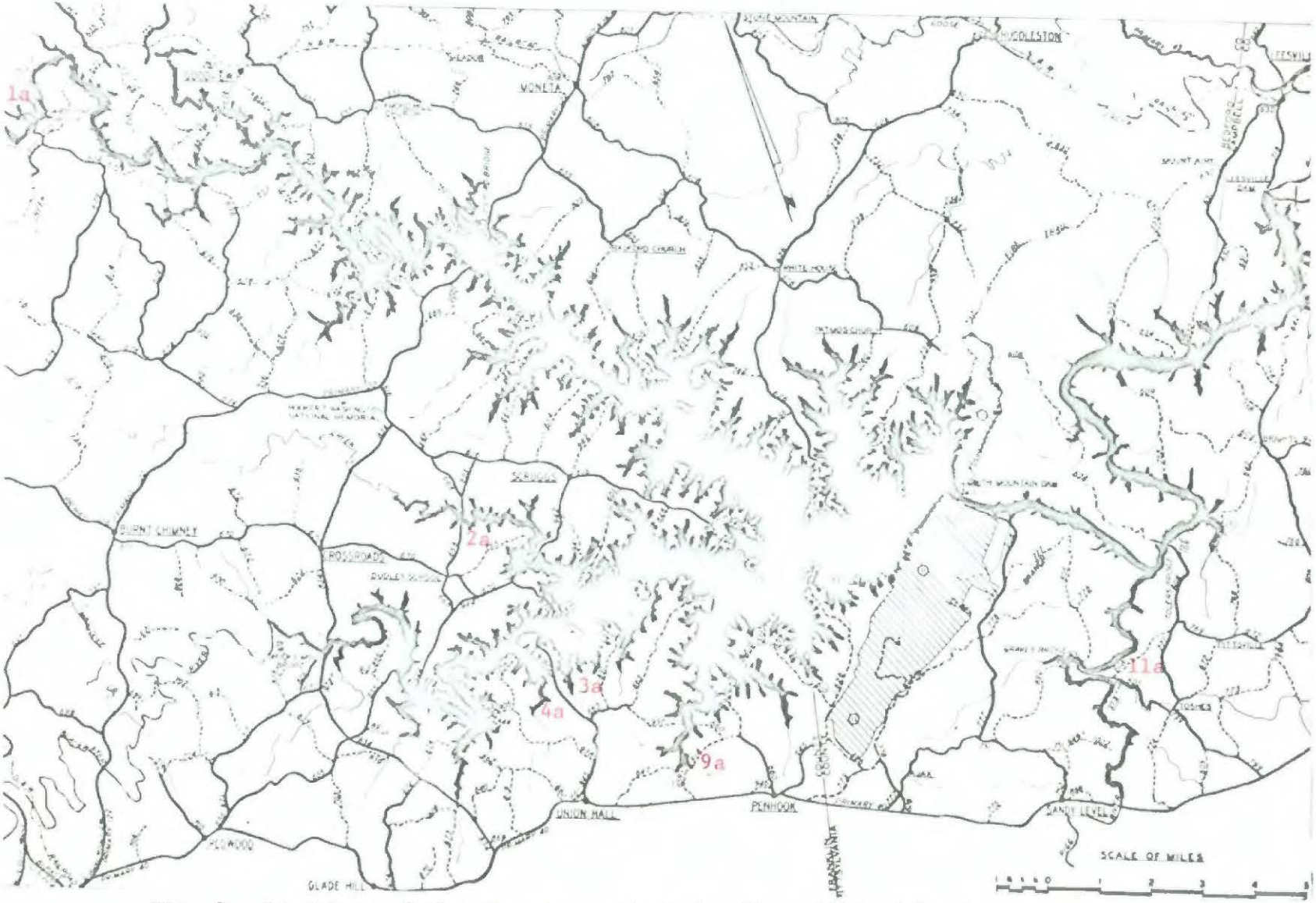


Fig. 9. Locations of the six permanent study sites utilized in the 1965-66 study. Stations are marked in red.

abundance of aquatic and terrestrial vegetation during the rising pool phase in 1965 (Fig. 10) and offered favorable breeding conditions for the larvae of Anopheles punctipennis and Culex salinarius. The situation that best typified the majority of mosquito breeding grounds at Smith Mountain Lake was that of small coves containing calm water and abundant aquatic and terrestrial growth.

Fig. 11 graphically depicts the seasonal abundance of C. salinarius and A. punctipennis at Hardy Ford for the 1965 season. It may be noted from this graph that populations of these two species were at their peaks of abundance between June 24, and July 22. After July 22 the populations declined drastically and never again reached their former high numbers. By referring to the graph of the reservoir pool elevation of Smith Mountain Reservoir (Fig. 7), it may be observed that the water level began fluctuating markedly after July 15.

Fig. 12 reveals that mosquito populations at the Hardy Ford area were held in check reasonably well throughout the summer of 1966. It is of particular significance that the average females per catch declined from 33.1 in 1965 (Table 2) to 16.7 in 1966 (Table 3). Undoubtedly, an even more substantial reduction would have been the result had it not been for an adjacent pasture which often contained standing water in numerous depressions and hoofprints (Fig. 13) that did not ebb and flow with the weekly cycle of water level fluctuation. Larval collections made in the quiet, shaded water in the pasture often revealed high counts of Aedes vexans, Psorophora confinnis, Culex salinarius, and Anopheles punctipennis, particularly after heavy rains. This source

Fig. 10. A portion of Hardy Ford Cove which supported large numbers of A. punctipennis and C. salinarius larvae during the rising pool phase of 1965.

Fig. 11

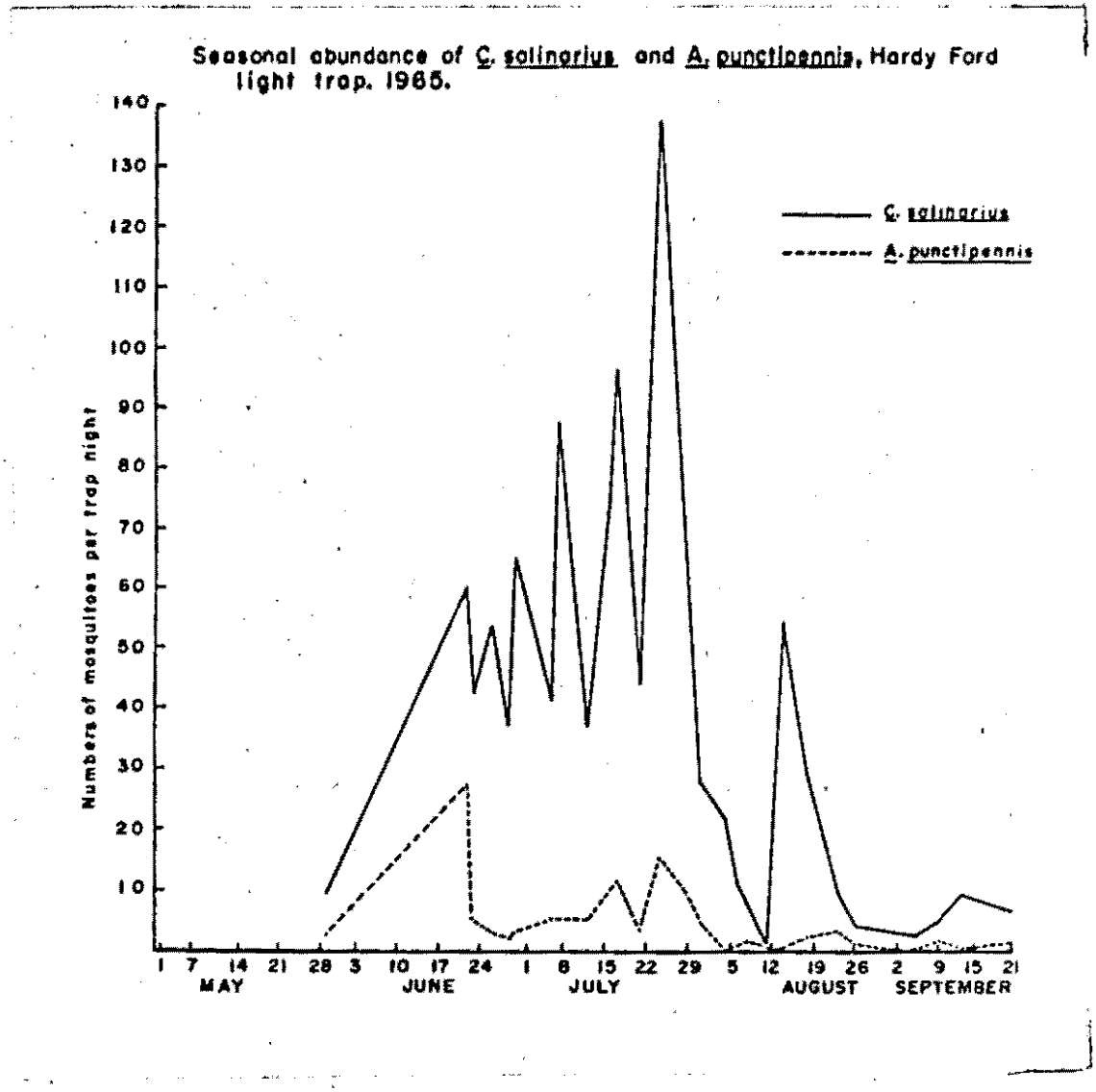

Seasonal abundance of C. salinarius and A. punctipennis, Hardy Ford light trap. 1965.
Numbers of mosquitoes per trap night
140
130
120
110
100
90
80
70
60
50
40
30
20
10
C. salinarius
A. punctipennis
1 7 14 21 28 5 10 17 24 1 8 15 22 29 5 12 19 26 2 9 15 21
MAY
JUNE
JULY
AUGUST
SEPTEMBER

Fig. 12

Seasonal abundance of *C. salinarius* and *A. punctipennis*, Hardy Ford Light Trap, 1966.

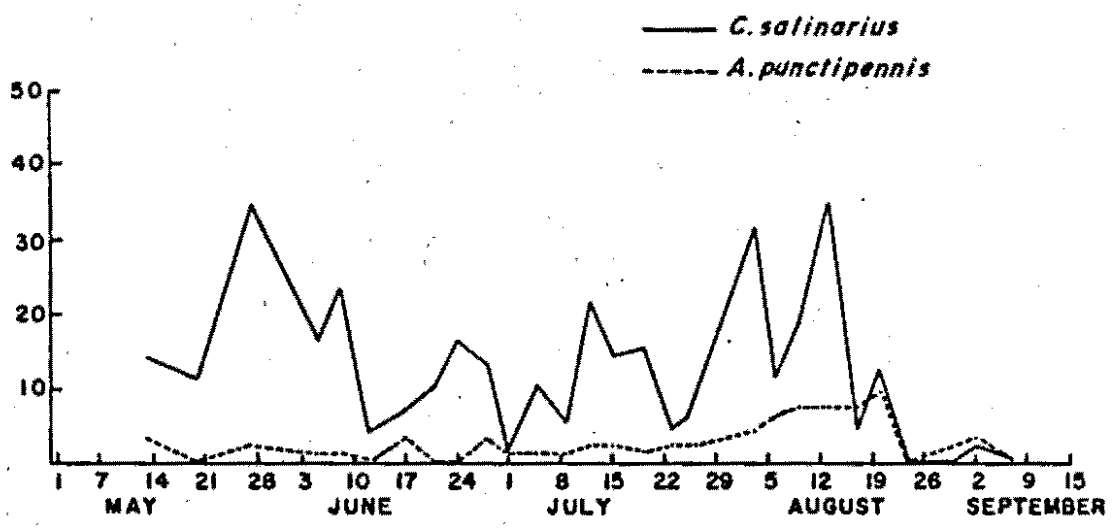


Fig. 13. Portion of a pasture adjacent to Hardy Ford that provided a breeding site for larvae of Ae. vexans, P. confinnis, C. salinarius, and A. punctipennis.

contributed substantially to the numbers of adults taken at the Hardy Ford light trap in 1966.

The resting shelters provided only meager data for the two-year study as shown in Tables 4 and 5. However, it may be noted from these two tables that the two dominant mosquito species declined in number from 1965 to 1966 and that A. quadrimaculatus was not present in this area in significant numbers either year.

The typical effects of a weekly fluctuation cycle at Hardy Ford are shown in Figs. 14 and 15. Note the stranded debris in Fig. 15.

Site 2a. Rt. 668. A small embayment (Fig. 17) west of Scruggs, Virginia, served as the second study site; however, it was never as productive as Hardy Ford from the standpoint of mosquito source production. The first larvae of these investigations were taken at this location in mid-May, 1965. It may be seen from the lower graph of Fig. 16 that numbers of adults taken in light trap collections began to decline before July 15, 1965. In this cove the rising pool level during the first half of June (Fig. 7) inundated much of the aquatic growth which had afforded mosquito larvae protection from wind and wave action. The submergence of a great portion of this vegetation coupled with the water level fluctuation reduced mosquito abundance to near minimal numbers.

Seasonal abundance records are graphically illustrated for the two dominant mosquito species for 1965 in the lower half of Fig. 16. However, collections were so low in 1966 that it was necessary to plot the total mosquito population, including all species collected, for this

Table 4. Mosquito species taken at resting stations at each of the six permanent study areas, May 15-September 21, 1965.

Species	Site 1a	Site 2a	Site 3a	Site 4a	Site 9a	Site 11a
A. quadrimaculatus	—[a]	—[a]	—[a]	—[a]	27	18
A. punctipennis	31	6	4	9	11	5
C. salinarius	7	—[a]	—[a]	—[a]	6	—[a]
C. erraticus	—[a]	—[a]	—[a]	—[a]	—[a]	8
Total times station inspected	27	28	22	22	26	12

Table 5. Mosquito species taken at resting stations at each of the six permanent study areas, May 7-September 15, 1966.

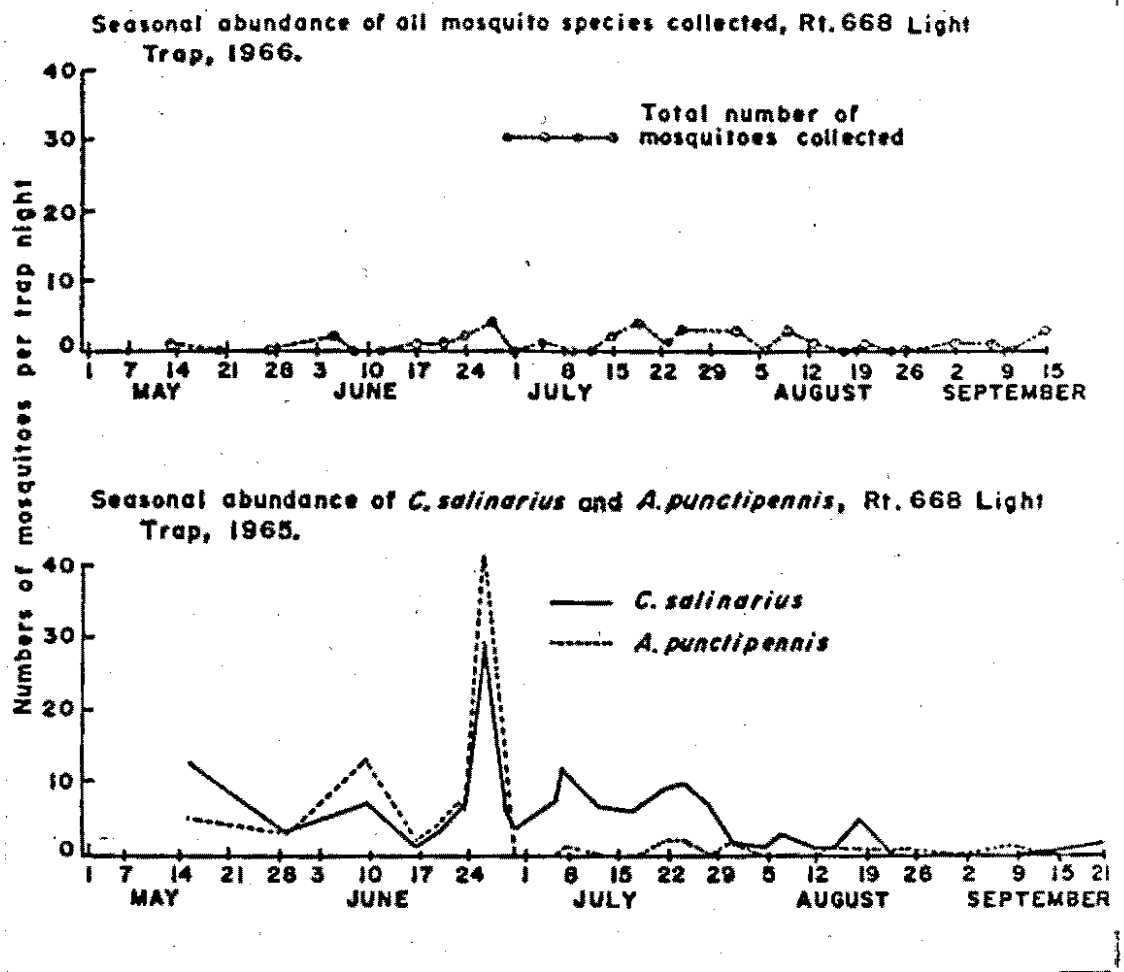
Species	Site 1a	Site 2a	Site 3a	Site 4a	Site 9a	Site 11a
A. quadrimaculatus	—[a]	—[a]	—[a]	—[a]	—[a]	24
A. punctipennis	8	—[a]	—[a]	—[a]	8	7
C. salinarius	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]
C. erraticus	—[a]	—[a]	—[a]	—[a]	—[a]	6
U. sapphirina	—[a]	—[a]	—[a]	—[a]	—[a]	4
Total times station inspected	29	30	21	21	32	32

[a]/ Less than 3 specimens taken at site for entire season.

Fig. 14. Hardy Ford Cove at high point of weekly fluctuation cycle (middle of season, 1966). Elevation 792.6 ft.

Fig. 15. Close-up view of same area as in Fig. 14 at low point of weekly fluctuation cycle (middle of season, 1966). Elevation 790.8 ft.

Fig. 16


Seasonal abundance of all mosquito species collected, Rt. 668 Light Trap, 1966.
Total number of mosquitoes collected
Numbers of mosquitoes per trap night
40
30
20
10
0
1 7 14 21 28 3 10 17 24 1 8 15 22 29 5 12 19 26 2 9 15
MAY
JUNE
JULY
AUGUST
SEPTEMBER
Seasonal abundance of C. salinarius and A. punctipennis, Rt. 668 Light Trap, 1965.
C. salinarius
A. punctipennis
Numbers of mosquitoes per trap night
40
30
20
10
0
1 7 14 21 28 3 10 17 24 1 8 15 22 29 5 12 19 26 2 9 15 21
MAY
JUNE
JULY
AUGUST
SEPTEMBER

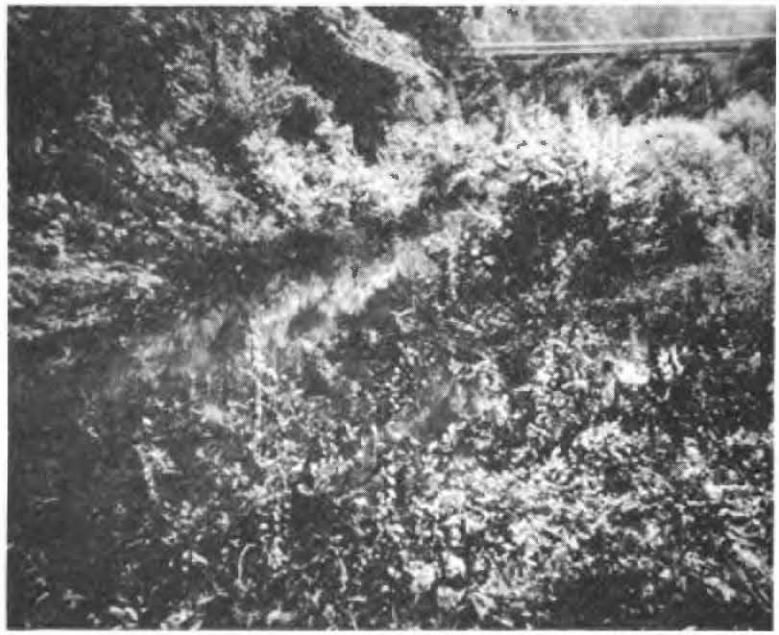


Fig. 17. Embayment at Rt. 668 during rising pool phase (1965 season). Elevation 789 ft.

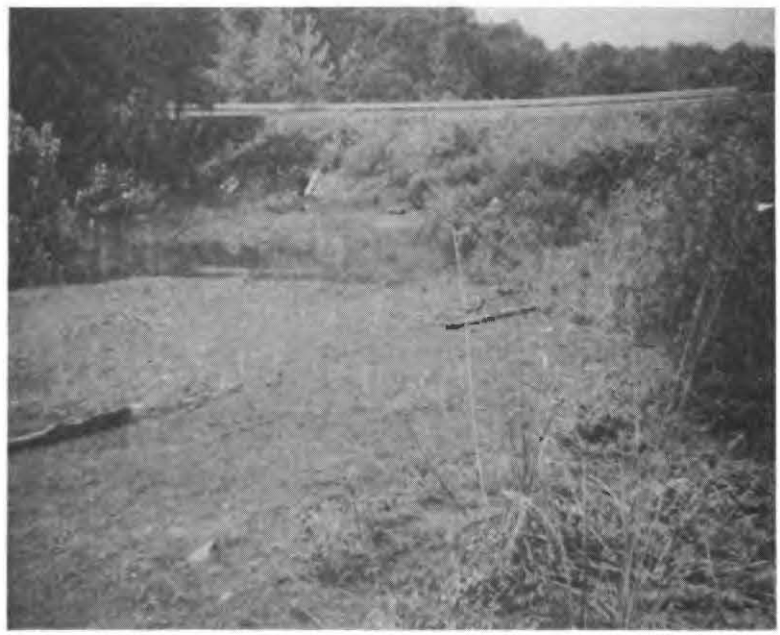


Fig. 18. Same view as Fig. 17 except several yards more distant during low point in weekly fluctuation cycle (1966 season). Elevation 790.8 ft.

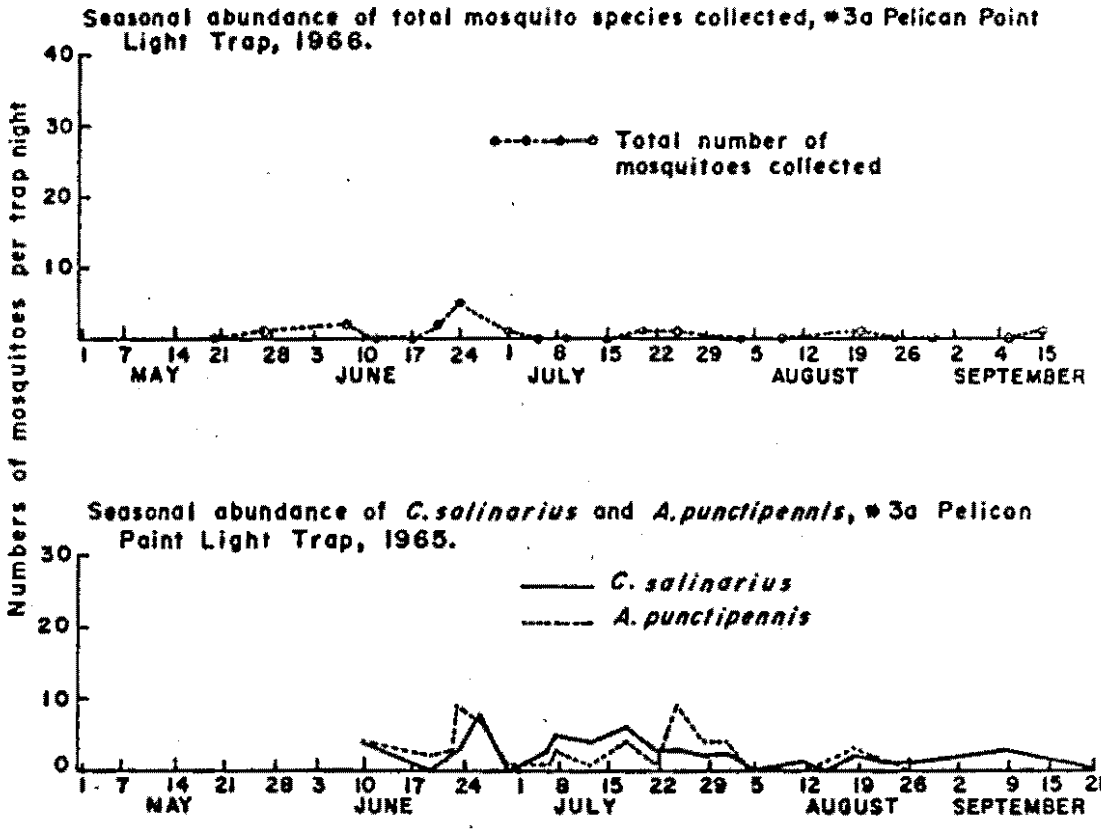
year as illustrated in the upper half of Fig. 16. Nevertheless, it is apparent from the comparison of the two that a substantial reduction occurred from one year to the next.

With an average of 6.6 females per catch in 1965 (Table 2) and an average of 1.0 females per catch in 1966 (Table 3), this breeding site never produced mosquitoes in exceptionally high numbers except during the latter part of June, 1965 (Fig. 16). The lack of mosquitoes present in resting stations as shown in Tables 4 and 5 prevented any meaningful data from being taken from these sources at Site 2a.

Fig. 17 shows this breeding site in the rising pool phase during 1965 at an elevation of 789 feet. Fig. 18 is a photograph of this same area at the low point in the weekly fluctuation cycle during 1966 (elevation 790.8 ft.). Fig. 18 was photographed several yards farther back to show the dewatered and denuded shore.

Site 3a. Pelican Point. This area was a small inlet north of Union Hall, Virginia, and near Pelican Point, a family campground and picnic area. Due to isolation from roadways, access to this location was attained by motor driven boat. Mosquito abundance here was comparable to that of Site 2a. With an average number of 5.2 females per catch in 1965 (Table 2) and 0.6 females per catch in 1966 (Table 3), it was the least productive of all breeding areas sampled. Again, A. punctipennis and C. salinarius populations are plotted for 1965 and the total mosquito population plotted for 1966 in Fig. 19. The paucity of adults found in resting stations at Pelican Point is apparent from Tables 4 and 5.

Fig. 19


Seasonal abundance of total mosquito species collected, #3a Pelican Point Light Trap, 1966.
Numbers of mosquitoes per trap night
40
30
20
10
Total number of mosquitoes collected
1 7 14 21 28 3 10 17 24 1 8 15 22 29 5 12 19 26 2 4 15
MAY
JUNE
JULY
AUGUST
SEPTEMBER
Seasonal abundance of C. salinarius and A. punctipennis, #3a Pelican Point Light Trap, 1965.
30
20
10
0
C. salinarius
A. punctipennis
1 7 14 21 28 3 10 17 24 1 8 15 22 29 5 12 19 26 2 9 15 21
MAY
JUNE
JULY
AUGUST
SEPTEMBER

Site 4a. Pelican Point. A cove near Site 3a and also reached by motor driven boat served as our fourth study area. Mosquito abundance ranged somewhat higher here than at Site 3a due to the larger expanse of more favorable mosquito breeding grounds (Fig. 20). The sudden decline in the mosquito population after July 22, 1965, may be noted from the lower graph and the continued reduction throughout 1966 may be seen in the upper graph of Fig. 21. Average females per catch declined from 15.7 in 1965 (Table 2) to 1.4 in 1966 (Table 3). A. punctipennis was the only species encountered in any significant numbers in resting stations at this site (Table 4).

Both Sites 3a and 4a at Pelican Point were selected for study because of their similarity to the many small coves and embayments that are typical of Smith Mountain Lake. Neither place produced mosquitoes in outstandingly high numbers in 1965, but it is evident from Figs. 19 and 21 that total mosquito production in 1966 decreased to near minimal levels.

Site 9a. B-Bar-B property. The fifth permanent study site was located on property owned by Appalachian Power Company, which has plans for its future development as a recreational area. This site offered the widest expanse of aquatic and semi-aquatic growth of any area sampled on the upper reservoir. Carex was the most abundant plant associated with the littoral zone of the reservoir at this site. Larval collections made in pure stands of Carex often produced high numbers of C. salinarius and A. punctipennis. As shown in Fig. 22, light trap catches here were extremely high in 1965 until the cyclical water level

Fig. 20. A portion of Site 4a-Pelican Point that supported high larval populations of A. punctipennis and C. salinarius during the 1965 season.

Fig. 21

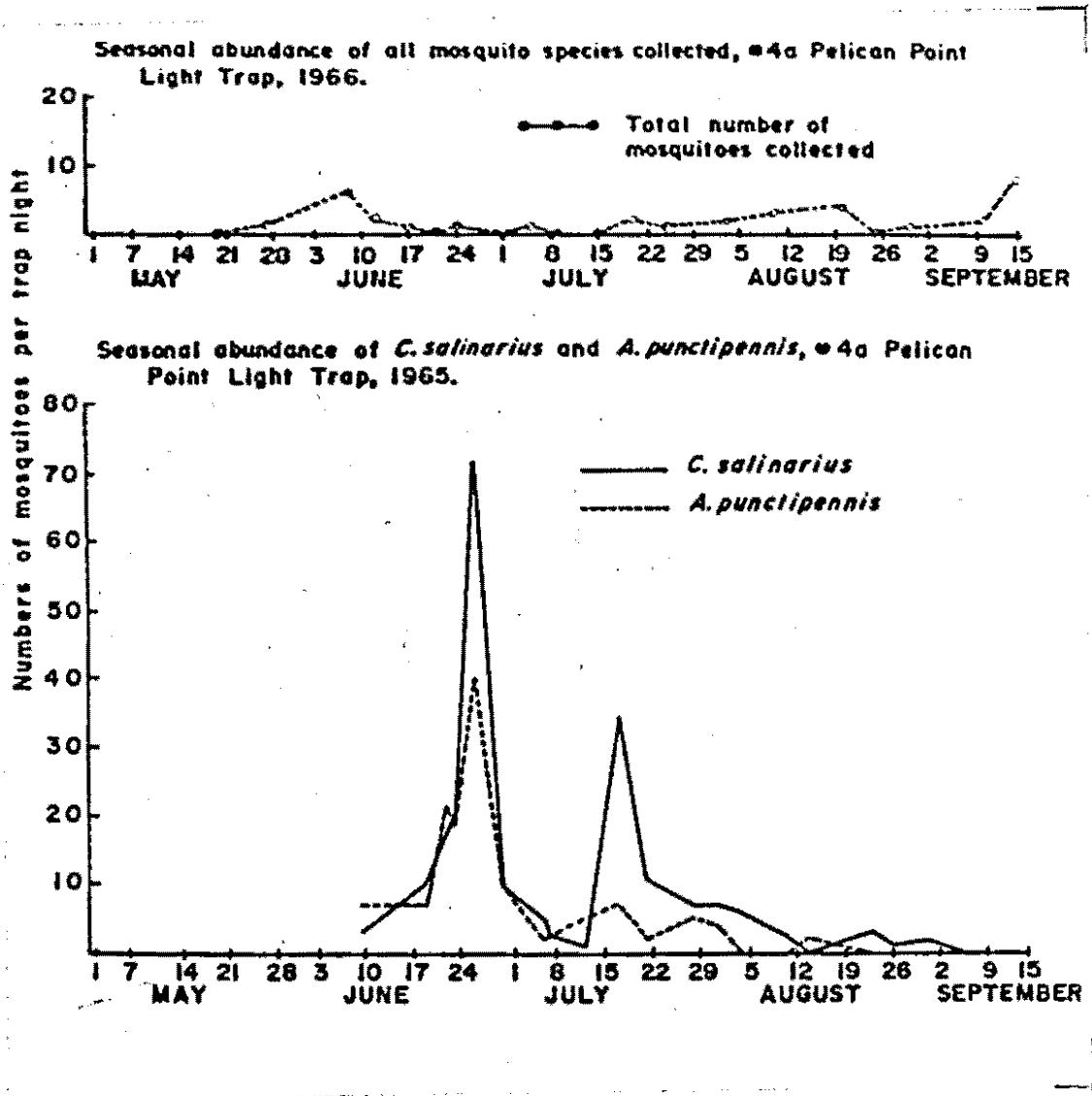
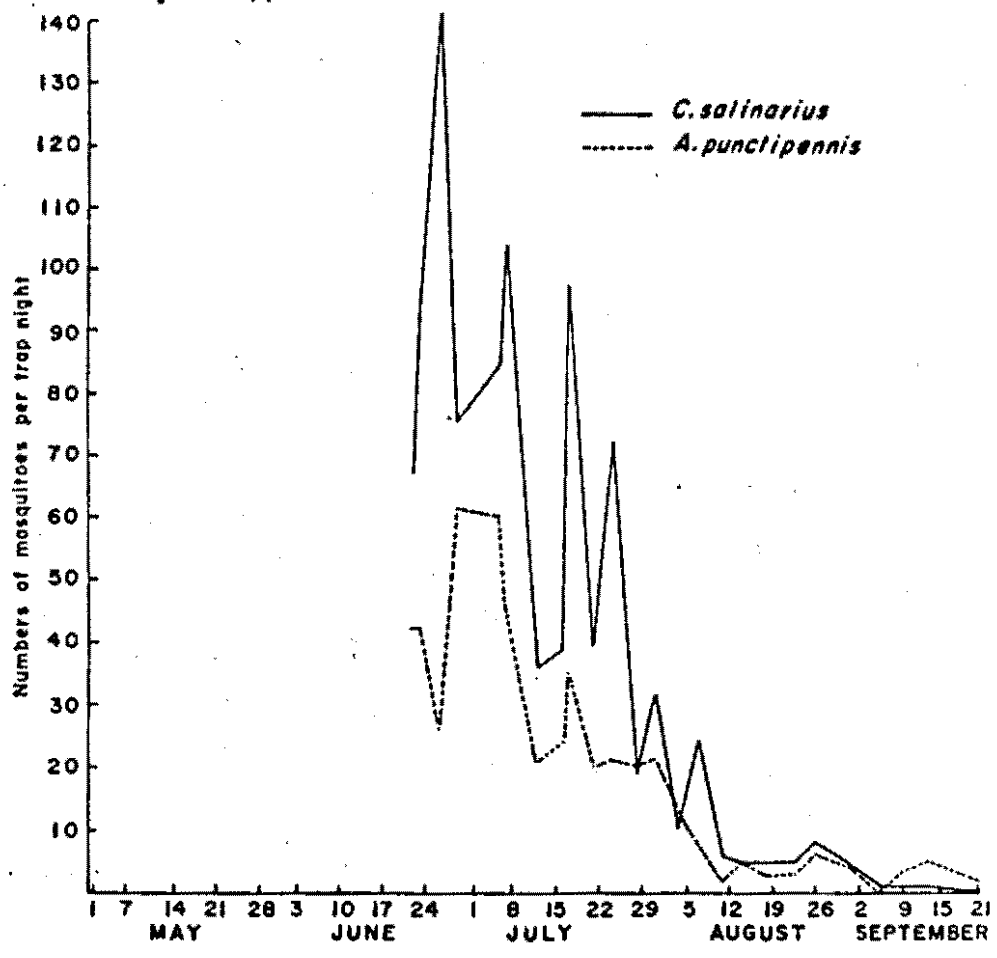

Seasonal abundance of all mosquito species collected, #4a Pelican Point Light Trap, 1966.
Total number of mosquitoes collected
Numbers of mosquitoes per trap night
20
10
1 7 14 21 28 3 10 17 24 1 8 15 22 29 5 12 19 26 2 9 15
MAY JUNE JULY AUGUST SEPTEMBER
Seasonal abundance of C. salinarius and A. punctipennis, #4a Pelican Point Light Trap, 1965.
C. salinarius
A. punctipennis
Numbers of mosquitoes per trap night
80
70
60
50
40
30
20
10
1 7 14 21 28 3 10 17 24 1 8 15 22 29 5 12 19 26 2 9 15
MAY JUNE JULY AUGUST SEPTEMBER

Fig. 22


Seasonal abundance of C. salinarius and A. punctipennis, B-Bar-B Light Trap, 1965.
C. salinarius
A. punctipennis
Numbers of mosquitoes per trap night
140
130
120
110
100
90
80
70
60
50
40
30
20
10
1 7 14 21 28 3 10 17 24 1 8 15 22 29 5 12 19 26 2 9 15 21
MAY
JUNE
JULY
AUGUST
SEPTEMBER

management plan was put into effect. The rapid decline in the mosquito population was most pronounced at this site, particularly in the latter half of July, 1965, and continuing through the summer of 1966 (Fig. 23). During this year, neither of the two dominant species was ever collected in numbers greater than 10 per trap night. In contrast to this, collections made before mid-July, 1965, for C. salinarius alone often totaled over 90 specimens per trap night. On a seasonal basis, this region produced the highest number (58.3 from Table 2) of females per catch during 1965; on the other hand, average females per catch declined to 6.1 in 1966 (Table 3).

Malaise trap collections at the B-Bar-B property provided little significant data for the 1966 season. Apparently, since this type trap offers no strong source of attraction to mosquitoes, it must be operated in areas of dense mosquito populations to provide useful quantitative data. Table 6 reveals that from a total of 30 nights of trapping, the Malaise trap produced only a total of 74 specimens. However, it should be noted that light traps which did offer an attracting source also produced low collections during the 1966 season at this site (Table 3). Had Malaise traps been employed during the summer of 1965, a more complete analysis could have been made of the change in population densities from one year to the next.

Table 4 indicates that A. quadrimaculatus was more prevalent in this region than at any other area sampled during 1965. Resting stations provided an average of over one A. quadrimaculatus per inspection for this year; however, this species was not taken at any time during the

Fig. 23

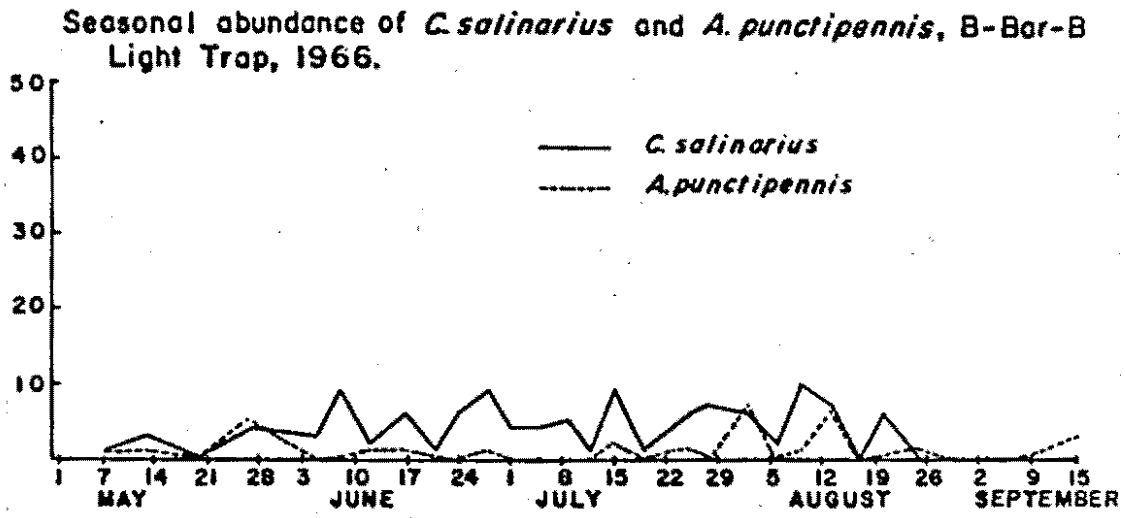

Seasonal abundance of C. salinarius and A. punctipennis, B-Bar-B Light Trap, 1966.
50
40
30
20
10
C. salinarius
A. punctipennis
1 7 14 21 28 3 10 17 24 1 8 15 22 29 5 12 19 26 2 9 15
MAY
JUNE
JULY
AUGUST
SEPTEMBER

Table 6. Total number and species of mosquitoes taken by single evening Malaise trap collections at Site 9a-B-Bar-B, 1966 season.

Species	Total Number	% of Total Collected
Anopheles punctipennis	2	2.7
Culex salinarius	11	14.9
C. territans	28	37.8
C. restuans	2	2.7
C. erraticus	1	1.4
Aedes canadensis	1	1.4
Ae. vexans	25	33.8
Psorophora confinnis	3	4.1
Toxorhynchites septentrionalis[a]	1	1.4
Total	74	100
Total collections: 30	Average mosquitoes/collection: 2.5	

[a]/ Species taken by Malaise trap only.

Table 7. Number of mosquitoes taken from human bait in one hour at B-Bar-B property.

Species	1965 (July 17)	1966 (July 17)
Anopheles punctipennis	1	1
Culex salinarius	51	3
Aedes vexans	2	2
Mansonia perturbans	0	4
Total	54	10

1966 season at diurnal resting shelters.

An indication of the reduction in biting annoyance from 1965 to 1966 is presented in Table 7 with a total of 54 females feeding within a one-hour period in 1965 compared with 10 females taken from human bait on the same date in 1966. Both collections were taken at dusk under basically ideal conditions for mosquito feeding activity. Lack of daylight feeding activity prevented the taking of mosquitoes in large numbers for biting counts during the day. However, when such collections were made, Aedes vexans, Psorophora ferox and Aedes trivittatus were the mosquitoes involved.

A number of mosquito breeding sources not directly associated with the reservoir waters were present at the B-Bar-B property and contributed to the mosquito population of this area. The primary extra-reservoir sources were large depressions that retained water for a considerable time after a rain as shown in Fig. 24. Such places often supported heavy larval concentrations of Aedes vexans, Ae. canadensis, Psorophora confinnis, and at times, Anopheles punctipennis. Also, a small oxbow basin, which was formed by a meandering stream that entered the reservoir at the B-Bar-B area, supported high numbers of C. territans and occasionally, A. punctipennis larvae. It is obvious that the water level fluctuation schedule would have no effect upon mosquitoes breeding in such situations.

Numerous spot-check collections made at various points on the lower Leesville Reservoir usually revealed low mosquito production. Situations such as the one shown in Figs. 25 and 26 which appeared to offer

Fig. 24. Temporary rain pool breeding habitat of Aedes vexans, Aedes canadensis, Psorophora confinnis, and Anopheles punctipennis on the B-Bar-B property.

Fig. 25. Aerial view of a small flood plain on the lower Leesville Reservoir.

Fig. 26. A close-up view of same area as in Fig. 25 that appeared to offer excellent mosquito breeding grounds.

excellent breeding potentialities were quickly dewatered and, subsequently, inundated again. Water level variations on the smaller Leesville impoundment were of a much greater magnitude than on Smith Mountain, often being on the order of a five-foot rise or fall from one day to the next.

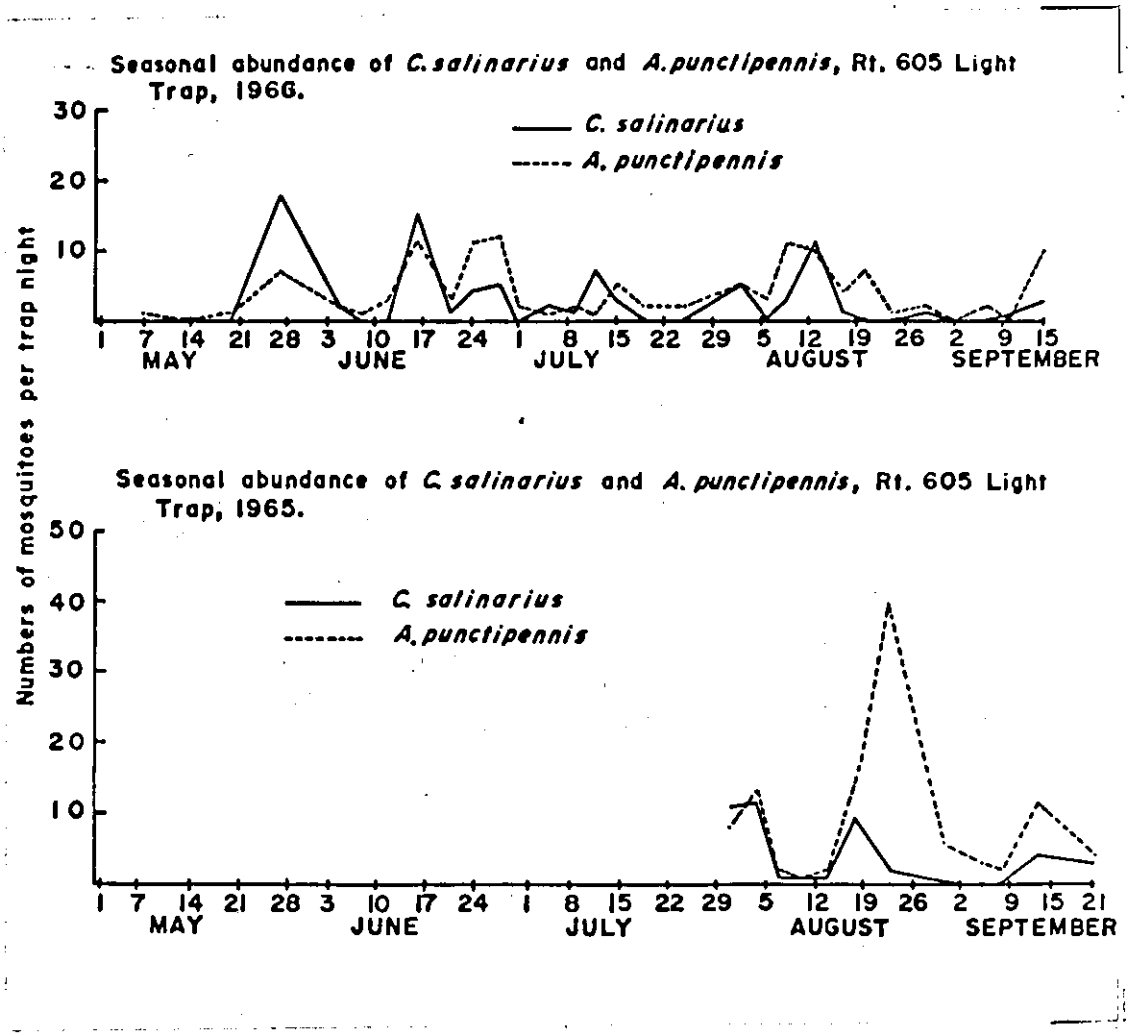
Site 11a. Rt. 605. Our sixth and final permanent study area (Figs. 27 and 28) was a body of water adjacent to Leesville Lake but was in no way under the influence of the water level fluctuation schedule. It was created by the construction of a spillway on Frying Pan Creek that would have normally entered Leesville Lake had it not been for this obstruction. Anopheles quadrimaculatus production as determined by light trap was much greater here than at any other area sampled, and it was the only location where Culex salinarius and Anopheles punctipennis were not the two dominant species collected (Tables 2 and 3). Resting station counts (Tables 4 and 5) further attest to the presence of A. quadrimaculatus for both years in this area. Since this site was not affected by the pumped storage water level variation, it served as a check or control for the other areas sampled. Only a total of 12 light trap collections were made at this site in 1965 because it was not discovered until the latter part of July. However, it may be seen from the lower graph in Fig. 29 that of the collections made from July 31 through September 21, the higher catches occurred during the latter half of August--a time when collections at Smith Mountain were at extremely low levels.

It may be noted from Fig. 29 and from Tables 2 and 3 that a

Fig. 27. Aerial photograph of 11a-Rt. 605 study site that produced high numbers of A. quadrimaculatus.

Fig. 28. Ground level view of same area as in Fig. 27.

Fig. 29


Seasonal abundance of C. salinarius and A. punctipennis, Rt. 605 Light Trap, 1966.
C. salinarius
A. punctipennis
Numbers of mosquitoes per trap night
30
20
10
1 7 14 21 28 3 10 17 24 1 8 15 22 29 5 12 19 26 2 9 15
MAY
JUNE
JULY
AUGUST
SEPTEMBER
Seasonal abundance of C. salinarius and A. punctipennis, Rt. 605 Light Trap, 1965.
C. salinarius
A. punctipennis
50
40
30
20
10
1 7 14 21 28 3 10 17 24 1 8 15 22 29 5 12 19 26 2 9 15 21
MAY
JUNE
JULY
AUGUST
SEPTEMBER

substantial reduction in the mosquito population did not occur at this location from the 1965 to the 1966 season. An average of 31.6 females per catch was taken in 1965, compared to an average number of 28.2 collected for 1966 at this site.

Table 8 is a composite of eight 1-hour biting collections taken at Site 11a. Mansonia perturbans and Culex erraticus were the two mosquito species taken most often by this method. The level of mosquito annoyance is indicated by the fact that an average of 29.8 females per hour were taken from human bait.

Comparisons of Malaise trap collections from Site 9a (Table 6) with those from Site 11a (Table 9) reveal the quantitative and qualitative richness of the mosquito fauna at the non-reservoir area (Site 11a). A total of 9 more species was taken at the non-reservoir site than at the study area associated with the reservoir in 1966. In addition, an average of 45.4 mosquitoes per collection were taken from the Site 11a Malaise trap in comparison to an average of 2.5 per collection at Site 9a.

It should be noted that C. territans was the dominant species taken in Malaise traps at both sites (37.8% of total catch at Site 9a from Table 6 and 67.8% of total catch at Site 11a from Table 9.) This species was also taken in high numbers in larval studies as shown in Tables 10 and 11 of the following section dealing with the larval survey. However, C. territans was never taken in biting counts, and it was collected only in scant numbers from light traps (Table 1). Its absence from biting collections is understandable since King, et al. (1960)

Table 8. Number of mosquitoes from human bait in eight 1-hour dusk-biting collections at Site 11a-Rt. 605, 1966 season.

Species	Total Number	% of Total Collected
Aedes atlanticus	1	—[a]
Aedes canadensis	2	0.8
Aedes cinereus	8	3.4
Aedes triseriatus	4	1.7
Aedes trivittatus	2	0.8
Aedes vexans	8	3.4
Anopheles crucians	1	—[a]
Anopheles punctipennis	6	2.5
Anopheles quadrimaculatus	4	1.7
Culex erraticus	54	22.7
Culex salinarius	3	1.3
Mansonia perturbans	143	60.1
Psorophora ciliata	1	—[a]
Psorophora ferox	1	—[a]
Total	238	100

Total collections: 8 Average biting/hour: 29.8

[a]/ Less than 0.5% of total.

Table 9. Total number and species of mosquitoes taken by single evening Malaise trap collections at Site 11a-Rt. 605, 1966 season.

Species	Total Number	% of Total Collected
Aedes atlanticus	1	—[a]
Aedes canadensis	21	1.4
Aedes cinereus	9	0.6
Aedes grossbecki[b]	1	—[a]
Aedes triseriatus	1	—[a]
Aedes trivittatus	3	—[a]
Aedes vexans	100	6.9
Anopheles crucians	1	—[a]
Anopheles punctipennis	18	1.2
Anopheles quadrimaculatus	3	—[a]
Culex erraticus	31	2.1
Culex restuans	96	6.6
Culex salinarius	101	7.0
Culex territans	985	67.8
Mansonia perturbans	52	3.6
Psorophora ferox	12	0.8
Psorophora cyanescens[b]	1	—[a]
Uranotaenia sapphirina	16	1.1
Total	1,452	100

Total collections: 32 Average mosquitoes/collection: 45.4

[a]/ Less than 0.5% of total.

[b]/ Species taken by Malaise trap only.

report that C. territans is fairly common, but the adults are seldom seen and evidently do not attack man. They have been observed feeding on frogs and are believed to live on cold-blooded animals. Their relative scarceness at light traps is not completely understood, but peak-of-activity studies, which are discussed in a following section, reveal that this species is primarily a crepuscular and diurnal flier and, hence, light traps would not be effective in their capture.

2. Larval survey.

Summaries of the 1965 and 1966 larval surveys are presented in Tables 10 and 11. The general locations of the larval collecting sites are marked on the map in Fig. 30. A total of 14 species representing 6 genera were taken in larval collections during the two-year study. Although highly satisfactory techniques for quantitatively measuring larval populations have never been developed by mosquito workers, the dipper method does provide information relative to specific source production of a given mosquito species. In other words, it reveals the exact breeding place of a particular species, but, due to variations in size between habitats, the ability of some species to elude the collector more readily than others, and the lack of standardization inherent in the technique, this method does not produce reliable quantitative data. Therefore, strict consideration of the numerical data in Tables 10 and 11 should be de-emphasized in favor of the general trends of light, moderate, and heavy production also shown in these tables.

Table 10. Larval survey, Smith Mountain Reservoir area, 1965 season.

Station No. on Map	Site Description and Location	Species	Total No. (Larvae and Pupae)
a.***	Hardy Ford Cove breeding site as shown in Fig. 10 directly associated with reservoir waters.	A. punctipennis	57
		A. quadrimaculatus	2
		C. salinarius	89
		C. territans	25
		C. restuans	1
c.*	Small embayment at Site 2a (Fig. 17) directly associated with reservoir containing partially submerged terrestrial growth during rising pool phase.	A. punctipennis	22
		A. quadrimaculatus	4
		C. salinarius	14
		C. territans	14
		Ae. canadensis	4
d.**	Stream inlet (Fig. 20) on reservoir at Site 4a containing small willow growth and Carex.	A. punctipennis	39
		C. salinarius	5
e.*	Larval breeding grounds of Site 3a-Pelican Point.	A. punctipennis	11
f.***	Main body of reservoir margins at Site 9a containing dense stands of Carex.	A. punctipennis	18
		C. salinarius	97
		C. territans	4
		Ae. canadensis	1
		C. restuans	13
g.*	Standing water in depressions left by tractor tires and heavy construction equipment.	C. pipiens complex	5
		C. restuans	13
		Ae. vexans	3
		P. confinnis	1
j.*	Flood plain (Fig. 25) below dam on Leesville Reservoir.	Culex spp. (2nd instar)	6

Table 10.--(continued)

Station No. on Map	Site Description and Location	Species	Total No. (Larvae and Pupae)
1.**	Marsh area (Fig. 27) at Site 11a created by spillway on Frying Pan Creek.	A. punctipennis	8
		A. quadrimaculatus	22
		C. restuans	4
		C. territans	11
		U. sapphirina	4

*Light production: less than 1 per dip.

**Moderate production: 1-10 per dip.

***Heavy production: over 10 per dip.

Table 11. Larval survey, Smith Mountain Reservoir area, 1966 season.

Station No. on Map	Site Description and Location	Species	Total No. (Larvae and Pupae)
a.*	Hardy Ford Cove breeding site as shown in Fig. 14 directly associated with reservoir waters.	A. punctipennis	6
		Anopheles spp. (2nd instar)	17
		Culex spp. (2nd instar)	6
		Culex territans	19
		Aedes spp. (3rd instar)	4
b.***	Pasture adjacent to Hardy Ford Cove with abundant willow growth and numerous hoofprint depressions (Fig. 13).	A. punctipennis	21
		A. quadrimaculatus	1
		Culex spp. (2nd instar)	84
		Ae. vexans	31
c.*	Small embayment at Site 2a directly associated with reservoir which had the majority of its vegetation destroyed during the 1966 study (Fig. 18).	Anopheles spp. (2nd instar)	13
		Culex spp. (2nd instar)	2
m.**	Ground pool depressions adjacent to Site 2a.	A. punctipennis	2
		C. territans	1
		C. restuans	65
d.*	Stream inlet on reservoir at Site 4a. Majority of Carex and willow growth present during 1965 was inundated or destroyed during 1966 study.	Anopheles spp. (3rd instar)	13
e.*	Larval breeding grounds of Site 3a-Pelican Point.		0

Table 11.--(continued)

Station No. on Map	Site Description and Location	Species	Total No. (Larvae and Pupae)
f.*	Main body of reservoir margins at Site 9a containing dense stands of Carex.	A. punctipennis	4
		C. salinarius	1
		Mansonia spp. (2nd instar)	1
		Culex spp. (2nd instar)	6
h.***	Series of large rain pools (Fig. 24) at Site 9a associated with Carex and various kinds of terrestrial growth.	A. punctipennis	19
		Ae. vexans	186
		Ae. canadensis	58
		Ae. trivittatus	2
		Ae. cinereus	1
		P. confinnis	61
i.***	Stagnant water present in small oxbow basin near Site 9a.	A. punctipennis	4
		C. territans	433
j.*	Flood plain (Fig. 25) below dam on Leesville Reservoir.	Anopheles spp. (3rd instar)	8
k.**	Small, low lying area inundated at high tide but retaining standing water in depressions after water level receded from high water line.	A. punctipennis	2
		Ae. vexans	34
l.**	Marsh area (Fig. 27) at Site 11a created by spillway on Frying Pan Creek.	A. punctipennis	22
		A. quadrimaculatus	14
		C. restuans	52
		C. territans	55
		Ae. vexans	1
		Ae. crucians	1

*Light production: less than 1 per dip.

**Moderate production: 1-10 per dip.

***Heavy production: over 10 per dip.

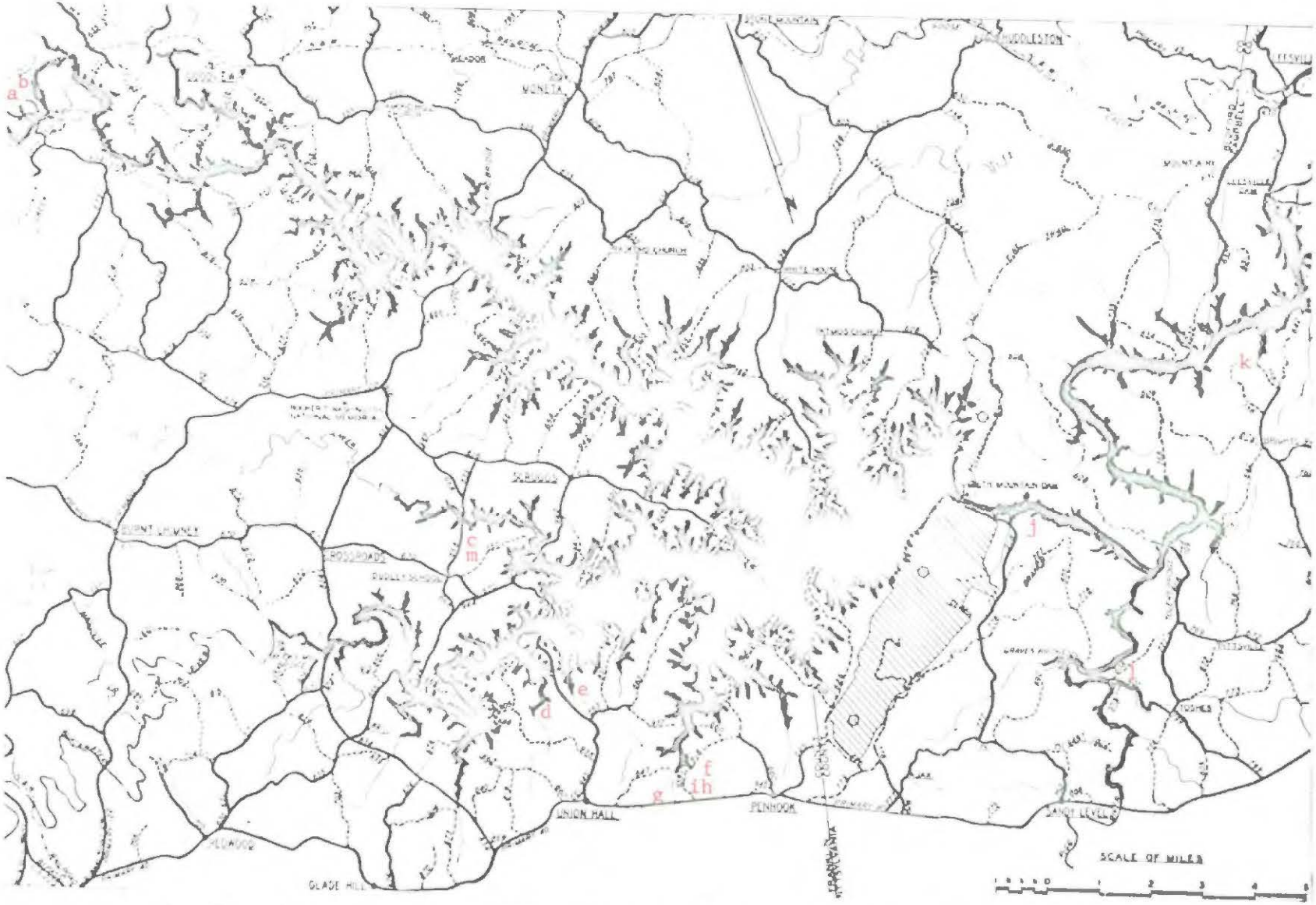


Fig. 30. Approximate locations of larval stations, 1965-1966 study. Stations are marked in red.

Larval abundance of A. punctipennis and C. salinarius corresponded closely to adult samples of the same species, particularly in the 1965 study. The overall reduction in numbers of larvae from 1965 to 1966 at all sites associated with the reservoir proper is apparent from Tables 10 and 11. It is evident from Table 11 that the ratio of larvae in the second or third instar of development to those in the fourth or final (and identifiable) stage is quite high. This strongly indicates that larval development often proceeded no further than the third instar in waters directly associated with the impoundment.

C. Peak-of-Adult Activity Studies.

Standfast (1965) states that in a study of mosquito biology it is essential to know the period of the day or night when the mosquito is active. Although the studies discussed in this section have no direct relation to mosquito control by water level management, they were undertaken with the objective of providing more information on the flight rhythms of Virginia culicids.

It is necessary to have an understanding of the elements responsible for initiating or suppressing mosquito flight. Wright and Knight (1966) point out that although periodic in nature, the activity pattern of adult mosquitoes can be shortened, delayed, or even postponed altogether by the unfavorable forces of temperature, relative humidity, air movement, and barometric pressure. Abnormalities in light intensity produced by extra heavy cloud cover during the day or the appearance of a bright moon at night are capable of further modifying this pattern.

Wright and Knight (1966) studied the effects of the exogenous factors of light intensity, temperature, relative humidity, air movement, and barometric pressure on the flight activity of Aedes vexans and Aedes trivittatus in Iowa. In their work, light intensity appeared to be the most critical factor in controlling activity of these two crepuscular species when other exogenous factors were not at extremes of their range (e.g., when temperature and humidity values were not extremely low). However, these workers' samples were taken at 15-minute intervals within the time span of 45 minutes pre-sunset to 2 hours post-sunset

for Ae. vexans and Ae. trivittatus with a limited 5½ hour diurnal study for Ae. trivittatus. Maximum flight activity was initiated in the first 15-minute post-sunset period and subsided to a rather constant low level about 60 minutes after darkness, but these experiments were terminated 2 hours after sunset.

Strict adherence to the proposition that the onset and cessation of activity is controlled entirely by exogenous factors, such as light intensity, must be avoided since, as Clements (1963) points out, endogenous circadian rhythms play an important part in the control of mosquito activity. Harker (1961) states that circadian rhythms are maintained by a physiological clock within the organism that must first be "set" by an external stimulus, such as a change from light to dark, but thereafter maintains the rhythm independent of further stimuli. Bates (1941) in laboratory studies showed that the activity of A. superpictus can be independent of the light intensity variation stimulus once the rhythm is established.

Other factors further complicate attempts in defining definite periods of activity and quiescence. Many species have been shown to exhibit two peaks of activity during a 24-hour period, and Lumsden (1952) suggests that the two peaks are produced by mosquitoes of different ages. Separate circadian rhythms within different individuals of the same species may produce at least slightly different times in initiation and cessation of flight.

It is apparent that the complex interactions of climatic factors and endogenous rhythms would make difficult the determination of precise

activity times of adult mosquitoes. Therefore, in our studies sampling periods were divided into intervals corresponding to dusk (7:52* D.S.T.)-11 p.m., 11 p.m.-1 a.m., 1 a.m.-3 a.m., and 3 a.m.-dawn (6:13* D.S.T.) for one series of experiments. And in another set of investigations, 24-hour cycles were divided in half by taking 2-hourly interval samples for the nocturnal and crepuscular periods from 7 p.m. to 7 a.m. and a single 12-hour diurnal sample from 7 a.m. to 7 p.m. In this manner sharp delineations in activity times were not determined; however, certain trends in flight activity were established.

The areas used in these investigations were three of the permanent study sites mentioned in previous sections: 1a-Hardy Ford, 9a-B-Bar-B property, and 11a-Rt. 605. Mosquito flight activity was measured by timer-equipped light traps and Malaise traps previously discussed under Methods and Materials.

Several workers, including Standfast (1965), Harcourt and Cass (1958), Horsfall (1962), Williams (1935), and Hutchins (1940), have used variously modified light traps which partition the catch into desired time intervals. These traps could be classified into two general groups--falling disc types and turntable types.

In our studies, four timer-equipped light traps placed in close proximity to one another (Fig. 31) were operated at a given site on each night of sampling. Individual traps were pre-set to collect at one of

---

*Average times of sunset and sunrise, respectively, obtained from the 1966 Nautical Almanac for the period of the peak-of-activity studies.

Fig. 31. Timer-equipped light traps in operating position for sampling peaks-of-flight activity. (Trap on extreme left has utility box open to show timer apparatus.)

four time intervals during the dark evening hours. The four time intervals represented were dusk-11 p.m., 11 p.m.-1 a.m., 1 a.m.-3 a.m., and 3 a.m.-dawn (D.S.T.). Nights which presented conditions unfavorable for mosquito flight (e.g., rainfall, low temperatures, etc.) were avoided.

A total of 30 peak-of-activity study collections were taken by this method during the summer of 1966 and Table 12 presents the data obtained from these experiments.

According to Williams (1935), the numbers of insects taken by light traps are influenced by the factors of activity, density, and phototactic response. Clements (1963) cites several examples of short term changes in phototaxis. Corbet (1961) presents evidence that swarming, oviposition, and the acquisition of a blood meal effect mosquito response to light and expresses the opinion that a large proportion of the mosquitoes collected in light traps are engaged in non-specific locomotor activity. Evidence has also been presented by Standfast (1965) that indicates that host-seeking activity and the acquisition of a blood meal depress the phototactic response.

Therefore, it would appear that a sampling device which offered little or no attracting force to mosquitoes would be devoid of the limitations inherent in light traps and would provide a much more accurate measure of overall mosquito flight activity. With this thought in mind, we conducted a series of peak-of-activity investigations using the Malaise trap as a sampling apparatus. In addition to its freedom from reliance upon the variable phototactic responses of mosquitoes

Table 12. Composite of 30 peak-of-activity study collections by light trap. Summer, 1966.

Mosquito Species	dusk–11 pm		11 pm–1 am		1 am–3 am		3 am–dawn	
	♂	♀	♂	♀	♂	♀	♂	♀
Aedes vexans	1	16	1	7	4	20	0	2
Ae. cinereus	0	4	0	5	0	4	0	3
Ae. canadensis	0	1	0	0	0	0	0	0
Ae. atlanticus	0	1	0	1	0	0	0	0
Anopheles punctipennis	3	48	0	20	0	17	2	4
A. crucians	0	10	0	10	0	5	0	1
A. quadrimaculatus	2	41	0	21	0	7	0	5
Culex salinarius	15	66	1	32	8	30	2	13
C. restuans	1	29	1	24	0	21	0	11
C. territans	1	10	0	2	1	4	1	2
C. erraticus	4	37	0	9	7	17	1	5
Mansonia perturbans	3	56	0	11	1	7	0	4
Psorophora confinnis	3	0	0	6	0	9	0	2
P. ciliata	0	0	0	0	0	2	0	0
P. ferox	0	2	0	0	0	1	0	0
Uranotaenia sapphirina	15	25	5	8	2	12	0	1

during the night, this trap also permitted the collection of samples with equal efficiency during crepuscular and diurnal periods as well as at night.

The Malaise trap provided a means for 24-hour activity studies. Each 24-hour period of sampling was begun by placing an empty cyanide jar on the trap at 7 p.m. (D.S.T.). The trap catch was removed from the jar at 2-hour intervals at 9 p.m., 11 p.m., 1 a.m., 3 a.m., 5 a.m., and 7 a.m. respectively. After the 7 a.m. collection, the trap was allowed to operate for a continuous 12-hour period throughout the day, and this final sample was removed at 7 p.m. to complete the 24-hour cycle.

Immediately before the killing jar was removed from the trap to collect each 2-hour sample, the interior baffles were inspected for mosquitoes which had not completed their migration to the collecting assembly at the top. The few mosquitoes found in the process of migration to the top were aspirated from the interior of the trap, killed, and placed in with the major sample already present in the cyanide killing jar. The entire process of aspirating the lingering mosquitoes from the interior, collapsing the trap to remove the sample from the killing jar, and re-establishing the trap required less than 5 minutes. Two possible sources of error were the presence of the investigator at the trap during collecting time and a small, dim head lamp worn by the collector when nocturnal samples were being removed. Table 13 presents the data taken from 7 peak-of-activity study collections by Malaise trap during the summer of 1966 at Site 11a-Rt. 605.

Table 13. Composite of 7 peak-of-activity study collections by Malaise trap. Summer, 1966--11a-Rt. 605.

Mosquito Species	7-9 pm		9-11 pm		11 pm-1 am		1-3 am		3-5 am		5-7 am		7 am-7 pm	
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
Aedes vexans	0	30	0	4	0	2	0	1	0	2	0	6	0	1
Ae. cinereus	0	4	0	0	0	0	0	0	0	0	0	1	0	0
Anopheles punctipennis	0	2	0	2	0	2	0	0	0	0	0	0	0	2
A. quadrimaculatus	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Culex salinarius	1	12	0	5	0	13	0	5	0	0	0	13	0	3
C. restuans	0	7	0	7	0	15	0	17	0	5	0	18	0	6
C. territans	3	50	0	8	0	6	0	2	0	0	0	59	1	81
C. erraticus	0	2	0	3	0	0	0	1	0	1	1	1	0	3
Mansonia perturbans	0	4	0	9	0	9	0	6	0	4	0	6	0	0
Psorophora confinnis	0	0	0	0	0	0	0	0	0	0	0	0	1	5
P. ferox	0	3	0	0	0	2	0	0	0	0	0	1	0	10
Uranotaenia sapphirina	0	0	2	1	2	0	1	1	0	0	0	3	0	1

Inspection of Tables 12 and 13 reveals that generally low numbers of most species were taken by both methods. However, certain trends in activity are evident for some species, and a few interesting comparisons of the data taken by both methods can be made.

Activity of Ae. vexans as indicated by light trap (Table 12) revealed two peaks during the night--one at the dusk-11 p.m. period and a slightly larger one during the 1 a.m.-3 a.m. period. However, in contrast to the behavior measured by light traps, Ae. vexans showed no peak of activity in the early morning hours in Malaise traps (Table 13), but a burst of activity was apparent in the late diurnal and crepuscular periods.

Both A. punctipennis and A. quadrimaculatus exhibited similar activity patterns at light traps. Maximum flight activities were initiated in the dusk-11 p.m. period, but subsided to gradually decreasing levels throughout the remainder of the night. The Malaise trap did not provide sufficient numbers of any of the anophelines to permit determinations of their activity patterns by this method.

Table 12 indicates that C. salinarius flight activity was at its peak during the first period of light trap operation from dusk-11 p.m., but subsided to approximately one-half this intensity during the following two sampling periods, and to the lowest level during the final 3 a.m.-dawn period. Malaise trap samples for this species (Table 13) yielded small numbers but did show three apparent peaks: one during the late diurnal and crepuscular period, another at the 11 p.m.-1 a.m. period, and a third during the dawn period.

The light trap study for C. restuans indicates that this species' time of flight is remarkably evenly distributed throughout the night. On the other hand, Malaise trap collections point to a greater activity during the middle of the night from 11 p.m.-3 a.m. and during the dawn crepuscular period from 5-7 a.m. with at least limited activity during the day.

Table 13 offers the apparent solution to the problem of why light trap collections of C. territans were extremely low in spite of the high larval and Malaise trap collections discussed in the previous section. Table 13 shows that C. territans exhibited two distinct periods of flight activity. One took place during the dusk crepuscular period from 7 p.m.-9 p.m. while the other was evident during the dawn crepuscular period from 5-7 a.m. Large numbers were also taken in the diurnal sample from 7 a.m.-7 p.m. It is obvious that light traps cannot attract efficiently during such periods of full and partial light; hence, they were evidently functioning during the time of flight minima for this species and, consequently, relatively few adults were collected by this device.

Table 12 indicates that C. erraticus was most active from dusk-11 p.m. and declined thereafter to a constant low level. Malaise trap activity studies for this species (Table 13) yielded low numbers and erratic results.

Collections of Mansonia perturbans by light trap (Table 12) revealed that this mosquito is most active during the early evening hours from dusk until 11 p.m., after which time flight subsides to generally

low levels. At least limited activity prevails during the 7-9 p.m. period as shown in Table 13; however, no flight activity was detected for this species during the full daylight hours.

No activity trend for Psorophora confinnis or P. ferox could be established by either sampling method; however, Tables 13 and 14 indicate that there is a diurnal and a nocturnal cycle of activity for both of these species.

The results obtained for Uranotaenia sapphirina by both methods (Tables 12 and 13) express an exclusive limitation of activity to the nocturnal hours for this mosquito.

V. DISCUSSION AND CONCLUSIONS

Although 23 mosquito species representing 8 genera were found to occur in the Smith Mountain area, Culex salinarius and Anopheles punctipennis represented over 70 percent of the specimens taken in light traps.

The pumped storage process of hydroelectric power generation produced two of the classic beneficial water level management phases for mosquito control during the 1965 and 1966 seasons on Smith Mountain Impoundment. The 1965 reservoir fluctuation schedule (Fig. 7) represented the constant cyclical variation phase after July 15, 1965. On the other hand, the 1966 water level fluctuation schedule (Fig. 8) combined the benefits of cyclical variation and slow seasonal drawdown due to drought conditions. The effectiveness of these two phases in controlling the two dominant mosquito species breeding in association with Smith Mountain Reservoir is evident from the seasonal abundance records obtained for the two-year study.

Seasonal abundance graphs for 1965 also indicated that a slowly rising pool which invaded marginal vegetation produced a situation highly favorable for the propagation of C. salinarius and A. punctipennis. The advantageous effect of cyclical variation was demonstrated when the situation immediately shifted from the slow rise on July 15, 1965, to a constant cyclic fall and rise that continued throughout the remainder of the season.

Mosquito populations at each of the five permanent study areas on the upper reservoir were at minimal levels during the cyclic fluctuation-

slow recession phase of 1966. These studies closely parallel the results obtained for several of the reservoirs on the T.V.A. system which employed similar phases of cyclical variation and seasonal recession in combination with cyclical fluctuation.

The availability and consequent study of an adjacent area which was not under the influence of the pumped storage water level schedule provided a check or control site. Since there was no substantial reduction in the mosquito population from one year to the next at this site, it is apparent that the water level variation on the impoundment was the major factor responsible for the mosquito suppression on Smith Mountain Reservoir during the 1966 season.

The larval survey produced little useful quantitative data. However, this study did reveal the exact habitats involved in mosquito production and indicated that sites not directly associated with reservoir waters often constituted an important larval breeding source that contributed to the overall adult mosquito population of the reservoir area.

The collection of Aedes cinereus is considered a significant find since it represents a new mosquito record for Virginia. This is somewhat surprising in view of the extensive and numerous mosquito surveys that have been conducted in the state. However, the majority of these surveys (Dorsey, 1944; Dorer, et al., 1944; and Bickley, 1957) have been carried out in the coastal areas, and the collection of Ae. cinereus in southwestern Virginia by this survey indicates that this species is either absent or scantily distributed in coastal areas.

In addition to providing information relating to the basic biology

of mosquitoes, the determination of peak flight activity times has an important control implication. Wright and Knight (1966) point out that insecticidal fogs are widely used in adult mosquito control and because of the fineness of fog droplets, the bulk of them will not impinge upon stationary objects but will do so if the target has an additive velocity of its own. Therefore, in the application of fogs, it is highly advantageous to conduct fogging operations when the mosquitoes to be controlled are most active.

Peak-of-activity investigations also provided the answer to the problem of why Culex territans population densities as measured by light traps were extremely low in contrast to the high numbers of this species taken in larval samples and Malaise trap collections. Activity studies conducted by Malaise trap revealed that this species exhibits definite bursts of flight during the crepuscular periods of dusk and dawn and that it is somewhat active during periods of full daylight. It is, therefore, impossible for light traps to sample adequately a mosquito species that is predominantly active at such times.

VI. SUMMARY

Smith Mountain Impoundment in southwestern Virginia was created by the construction of a dam on the Roanoke River. It is a project of the Appalachian Power Company, and its primary function is generation of hydroelectric power. Appalachian Power Company provided a grant-in-aid to the Virginia Agricultural Experiment Station for the purpose of studying mosquito populations associated with the impounded waters.

That effective mosquito control may be attained on reservoirs by proper water level management practices is a fact well documented by such agencies as the T.V.A. The water level management schedule put into effect at Smith Mountain Impoundment on July 15, 1965, and that continued throughout the summer of 1966 was found to reduce mosquito breeding significantly within the impoundment. The means by which the water level fluctuation schedule was accomplished is a unique process, termed pumped storage. This process basically involves the passing of water through the turbines at the upper dam, the retention of this water in the lower reservoir, and recycling the water back into the upper reservoir by reversible pumps at times of off-peak demand for electricity. This operation resulted in a constant rise and fall of the water level which greatly reduced the extent of aquatic habitats favorable for mosquito propagation.

Mosquito populations were sampled by light traps, Malaise traps, larval dip collections, resting stations, and biting collections. Culex salinarius and Anopheles punctipennis were found to be the two dominant mosquito species breeding in association with the impoundment.

Seasonal abundance records indicated that significant reductions in populations of these two species occurred immediately after the cyclic water level schedule was initiated.

In addition to investigations relating to mosquito control by water level management, peak-of-mosquito activity studies were conducted. Basically, these studies revealed a pattern of high level activity for the majority of species during the late crepuscular and early nocturnal periods with activity gradually subsiding as the night progressed. This pattern was evident for most species of Culex collected with the exception of C. territans. In contrast to the generalization of Bates (1949) that time of flight is a group character with related species tending to show similar behavior, C. territans exhibited two distinct peaks--one at the dusk crepuscular period and the other at the dawn crepuscular period with flight minima occurring during the nocturnal hours.

VII. LITERATURE CITED

Bates, M. 1941. Laboratory observations on the sexual behavior of anopheline mosquitoes. J. Exp. Zool. 86(1): 153-73.

Bates, M. 1949. The natural history of mosquitoes. The Macmillan Co.; New York, xv+379 p., 9 figs., 14 tables.

Bickley, W. E. 1957. Notes on the distribution of mosquitoes in Maryland and Virginia. Mosq. News 17(1): 22-25.

Bishop, E. L. 1936. Malaria control activities of the Tennessee Valley Authority. Pub. Health Serv. Report 51: 970-75.

Boyd, M. F. 1929. Studies on the bionomics of North American anophelines: physical and chemical factors in their relation to the distribution of larvae in northeastern North Carolina. Amer. J. Hyg. 9(2): 346.

Bradley, G. H., and W. V. King. 1941. Bionomics and ecology of nearctic Anopheles. Amer. Assoc. Adv. Sci. Publ. No. 15, p. 79-87.

Breeland, S. G., and E. Pickard. 1965a. The Malaise trap--an efficient and unbiased mosquito collecting device. Mosq. News 25(1): 19-21.

Breeland, S. G., and E. Pickard. 1965b. The Malaise trap--a survey tool in medical entomology. Mosq. News 25(4): 398-400.

Brown, A. W. A. 1951. Studies of the responses of the female Aedes mosquito. Part IV. Field experiments on Canadian species. Bull. Entomol. Res. 42: 575-582.

Brown, A. W. A. 1954. Studies on the responses of the female Aedes mosquito. Part VI. The attractiveness of coloured cloths to Canadian species. Bull. Entomol. Res. 45: 67-78.

Carpenter, S. J. 1941. The mosquitoes of Arkansas. 2nd ed. Ark. State Board of Health; Little Rock, Ark. 87 p., 15 plates, 1 table.

Carpenter, S. J. 1946. Artificial shelters for measuring densities of Anopheles quadrimaculatus. J. Econ. Entomol. 38(6): 721.

Carpenter, S. J., and W. J. LaCasse. 1955. Mosquitoes of North America (north of Mexico). University of California Press; Berkeley and Los Angeles, vi+360 p., illus.

Carter, H. R. 1914. Impounded waters--some general considerations of its effect on the prevalence of malaria. Pub. Health Serv. Report 29: 3458-3486.

Carter, H. R. 1915. Impounded waters--their effect on the prevalence of malaria survey at Blewetts Falls. Pub. Health Serv. Report 30: 15-33.

Carter, H. R., J. A. LePrince, and T. H. D. Griffitts. 1916. Impounded water--surveys in Alabama and South Carolina during 1915 to determine its effect on prevalence of malaria. Pub. Health Bull. No. 79, 34 p.

Christopher, G. S., and N. W. Bowden. 1957. Mosquito control in reservoirs by water level management. Mosq. News 17(4): 273-7.

Clements, A. N. 1963. The physiology of mosquitoes. The Macmillan Co.; New York. ix+393 p., 90 figs., 21 tables.

Corbet, P. S. 1961. Entomological studies from a high tower in Mpanga Forest, Uganda. VI. Nocturnal flight activity of Culicidae and Tabanidae as indicated by light-traps. Trans. Royal Entomol. Soc. London 113(3): 301-14.

Darrow, E. M. 1949. Factors in the elimination of the immature stages of Anopheles quadrimaculatus Say in a water level fluctuation cycle. Amer. J. Hyg. 50(2): 207-35.

Dorer, R. E., W. E. Bickley, and H. P. Nicholson. 1944. An annotated list of the mosquitoes of Virginia. Mosq. News 4(1): 48-50.

Dorsey, C. K. 1944. Mosquito survey activities at Camp Peary, Virginia. Ann. Entomol. Soc. Amer. 37(3): 376-87.

Dyar, H. G. 1922. The mosquitoes of the United States. Proc. U. S. Nat. Mus. 62: 1-119.

Edman, J. D. 1964. Control of Culex tarsalis (Coquillett) and Aedes vexans (Meigen) on Lewis and Clark Lake (Gavins Point Reservoir) by water level management. Mosq. News 24(2): 173-85.

Federal Security Agency. 1947. Malaria control on impounded water. U. S. Government Printing Office; Washington, D. C. xiii+422 p., 215 figs., 42 tables.

Hall, T. F. 1951. Water level management for the control of Anopheles quadrimaculatus in the Tennessee Valley. Proc. of the 38th Annu. Meeting N. J. Mosq. Exterm. Assoc., p. 84-89.

Harcourt, D. G., and L. M. Cass. 1958. A controlled interval light trap for microlepidoptera. Can. Entomol. 90: 617-622.

Harker, J. E. 1961. Diurnal rhythms. Annu. Rev. Entomol. 6: 131-44.

Harza, R. D. 1961. Review of existing foreign pumped storage projects. Harza Engineering Co., Chicago, Ill. 42 p. (mimeographed).

Hess, A. D., and C. C. Kiker. 1944. Water level management for malaria control on impounded waters. J. Nat. Mal. Soc. 3(3): 181-96.

Hinman, E. H. 1938. Biological effects of fluctuation of water level on anopheline breeding. Amer. J. of Trop. Med. and Hyg. 18(5): 483-95.

Hinman, E. H. 1941. The management of water for malaria control. Amer. Assoc. Adv. Sci. Publ. No. 15, p. 324-32.

Horsfall, W. R. 1955. Mosquitoes--their bionomics and relation to disease. The Ronald Press Co., New York. viii+723 p., 206 tables.

Horsfall, W. R. 1962. Trap for separating collections of insects by interval. J. Econ. Entomol. 55(5): 808-11.

Huffaker, C. B., and R. C. Back. 1943. A study of methods of sampling mosquito populations. J. Econ. Entomol. 36(4): 561-69.

Hutchins, R. E. 1940. Insect activity at a light trap during various periods of the night. J. Econ. Entomol. 33(4): 654-57.

Jaski, F. E. 1954. Pump-turbines--1954 progress report. Allis-Chalmers Electrical Rev., 4th quarter, p. 2-7.

King, W. V., G. H. Bradley, C. N. Smith, and W. C. McDuffie. 1960. A handbook of the mosquitoes of the southeastern United States. U. S. Dept. of Agric. handbook No. 173, U. S. Govt. Printing Office; Washington, D. C. 188 p., 25 figs., 10 plates.

Lumsden, W. H. R. 1952. The crepuscular biting activity of insects in the forest canopy in Bwamba, Uganda. A study in relation to the sylvan epidemiology of yellow fever. Bull. Entomol. Res. 42: 721-60.

MacCreary, D., and L. A. Stearns. 1937. Mosquito migration across Delaware Bay. Proc. of the 24th Annu.Meeting N. J. Mosq. Extermin. Assoc., p. 188-97.

Malaise, R. 1937. A new insect trap. Entomologisk Tidskrift 58: 148-160.

Marston, N. 1965. Recent modifications in the design of Malaise insect traps with a summary of insects represented in collections. J. Kansas Entomol. Soc. 38 (2): 154-62.

Matheson, R. 1966. Handbook of the mosquitoes of North America. 2nd ed. Hafner Publishing Co. New York and London. viii+314 p., 41 figs., 33 plates.

Mulhern, T. D. 1942. New Jersey mechanical trap for mosquito surveys. N. J. Agric. Expt. Sta. Circular No. 421. 8 p.

Owen, W. B. 1937. The mosquitoes of Minnesota, with special reference to their biologies. Minn. Agric. Expt. Sta. Tech. Bull. No. 126. 75 p.

Pratt, H. D., K. S. Littig, and R. C. Barnes. 1960. Survey and control of mosquitoes of public health importance. U. S. Pub. Health Serv., C.D.C.; Atlanta, Ga., 51 p., illus.

Rozeboom, L. E. 1942. The mosquitoes of Oklahoma. Okla. Agric. Expt. Sta. Tech. Bull. No. 16. 56 p.

Smillie, W. G. 1927. Studies on an epidemic of malaria at the Gantt impounded area, Covington County, Alabama. Amer. J. Hyg. 7(1): 40-72.

Standfast, H. A. 1965. A miniature light trap which automatically segregates the catch into hourly samples. Mosq. News 25(1): 48-53.

Stromquist, W. G. 1935. Malaria control in the Tennessee Valley. Civ. Engr. 5(12): 771-74.

The Nautical Almanac. 1966. U. S. Government Printing Office; Washington, D. C. viii+519 p.

Townes, H. 1962. Design for a Malaise trap. Proc. Entomol. Soc. Wash. 64(4): 253-62.

Van Dine, D. L. 1922. Impounding water in a bayou to control breeding of malaria mosquitoes. U. S. Dept. of Agric. Bull. No. 1098, 22 p.

Wallis, R. C., and A. Spielman. 1953. Laboratory rearing of Culex salinarius. Proc. Entomol. Soc. of Wash. 55(3): 140-42.

Williams, C. B. 1935. The times of activity of certain nocturnal insects, chiefly Lepidoptera, as indicated by a light trap. Trans. Royal Entomol. Soc. London 83(4): 523-55.

Wright, R. E., and K. L. Knight. 1966. Effect of environmental factors on biting activity of Aedes vexans (Meigen) and Aedes trivittatus (Coquillett). Mosq. News 26(4): 565-78.

Appendix Table I. Sample laboratory data sheet.

Malaise and Mosquito Light Trap Records
Smith Mountain and Leesville Lakes
Virginia

County_____ Year 196__ Week_____

Trap No._____ Location_____ Identifier_____

Species	Light Trap									Malaise Trap								
	M	F	M	F	M	F	Total M	Total F	Ave. F	M	F	M	F	M	F	Total M	Total F	Ave. F
Aedes canadensis																		
Aedes cinereus																		
Aedes stimulans group																		
Aedes triseriatus																		
Aedes trivittatus																		
Aedes vexans																		
Anopheles crucians group																		
Anopheles punctipennis																		
Anopheles quadrimaculatus																		
Culex erraticus																		
Culex peccator																		
Culex restuans																		
Culex salinarius																		
Culex territans																		
Culiseta inornata																		
Culiseta melanura																		
Mansonia perturbans																		
Orthopodomyia signifera complex																		
Toxorhynchites spp.																		
Psorophora ciliata																		
Psorophora confinnis																		
Psorophora ferox																		
Uranotaenia sapphirina																		
TOTAL																		

Attention Patron:

The one-page vita has been removed

from the scanned document

MOSQUITO CONTROL ON SMITH MOUNTAIN RESERVOIR BY PUMPED STORAGE WATER LEVEL MANAGEMENT

by

William Jess Gladney

Abstract

Six study areas were established at various points on Smith Mountain Lake in southwestern Virginia for the purpose of assessing the effect of the pumped storage water level schedule upon mosquito populations associated with the impounded lake waters. Pumped storage, a process relatively new in the hydroelectric field in the United States, basically involves the passing of water through turbines at the upper dam, the retention of this water in the lower reservoir, and recycling the water back into the upper reservoir by reversible pumps at times of off-peak demand for electricity.

The data obtained in these investigations indicate that the pool level variation as affected by the pumped storage process of hydroelectric power generation produced a deleterious effect upon mosquito larval development and survival.

Mosquito populations were sampled by light traps, larval dip collections, resting stations, and biting collections. Malaise traps, which are tent-like devices made of fine weatherproof netting, were also employed in these studies. Culex salinarius Coquillett and Anopheles punctipennis (Say) together comprised over 70 percent of the total population of the reservoir area as indicated by light traps. Next ranked are Aedes vexans (Meigen), Anopheles quadrimaculatus Say, Culex

erraticus (Dyar and Knab), Mansonia perturbans (Walker), and Psorophora confinnis (Lynch Arribálzaga), respectively. Malaise trap collections provided three mosquito species, including Psorophora cyanescens (Coquillett), Toxorhynchites septentrionalis (Dyar and Knab), and Aedes grossbecki Dyar and Knab, that were never encountered by the other sampling methods.

Seasonal abundance records obtained during the mosquito breeding seasons of 1965 and 1966 revealed that after the initiation of the pumped storage process mosquito populations were significantly reduced and never again approached their former levels. However, larval surveys revealed that several larval habitats (e.g., temporary rain pools, partially flooded pastures) not directly associated with the reservoir proper and not under the influence of the water level fluctuation cycle, often constituted important sources that contributed to the overall mosquito population of the area.

Investigations were also conducted to determine the times of peak flight activity of the mosquito species present within the lake region. Timer-equipped light traps and Malaise traps were employed as sampling devices for this work. The light traps provided data only for the dark evening hours, whereas Malaise traps yielded data for a complete 24-hour activity sample. Precise delineations of flight activity periods were not ascertained by the methods used; however, activity trends for some mosquito species were established.

In general, these studies revealed a pattern of high level activity for the majority of species during the dusk crepuscular and early

nocturnal periods with activity gradually subsiding as the evening progressed. This pattern was particularly evident for most species of Culex with the exception of C. territans. Malaise trap collections indicated that C. territans is least active during the periods of full darkness, but that it exhibits definite peaks-of-flight activity during the dusk and dawn crepuscular periods.