MOSQUITO CONTROL ON SMITH MOUNTAIN RESERVOIR BY PUMPED STORAGE WATER LEVEL MANAGEMENT[1]

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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.

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.

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 hydro-

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electric power, but it also serves as a major recreation facility for the area.

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 turbines of the upper dam is retained in the lower lake for temporary storage. Then when demand for power is low, 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 during July, 1965, would create a variation in the water level that would reduce mosquito breeding to some extent within the impoundment.

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 population densities prior to reservoir construction.

The primary objectives of this study were to survey the seasonal abundance of mosquito species present within the proximity of the newly created impoundment and to investigate the effect of the pumped storage water level schedule upon mosquitoes breeding within the lake proper.

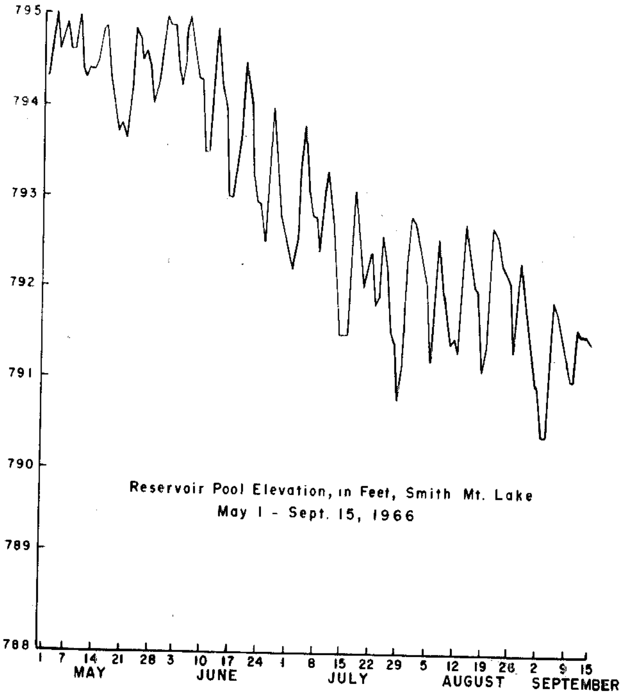
Methods. Standard New Jersey light traps, Malaise traps, larval dip collections, resting stations, and biting collections were employed in our 2-year mosquito survey at Smith Mountain Lake. However, light trap collections provided the most useful quantitative data for comparisons of relative mosquito abundance from one site to another and from one year to the next.

During the summers of 1965 and 1966 light traps 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 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.

Two Malaise traps, which are tent-like devices made of fine weatherproof netting, 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 Malaise traps described by Malaise (1937), Townes (1962), and Breeland and Pickard (1965) was that our traps 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.

Results. Reservoir Pool Fluctuation. Reservoir pool elevations for the period May 1 to September 15, 1965, are illustrated in the lower graph of Fig. 1. It may be noted from this 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


Reservoir Pool Elevation, in Feet, Smith Mt. Lake
May 1 - Sept. 15, 1966
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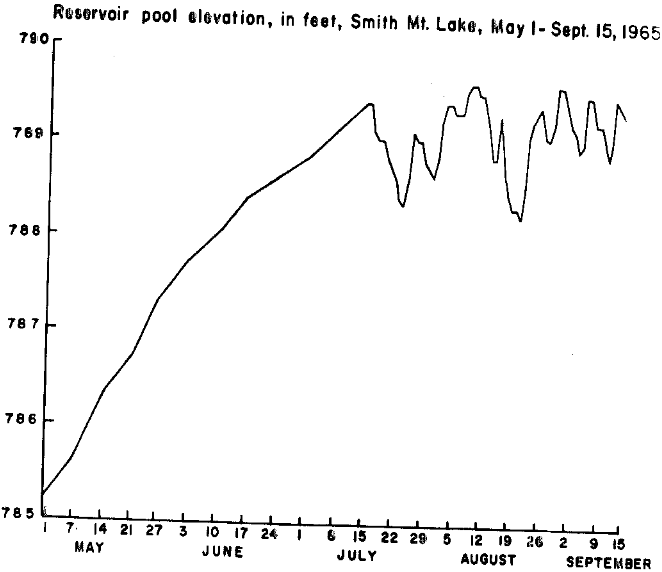
Reservoir pool elevation, in feet, Smith Mt. Lake, May 1- Sept. 15, 1965
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Figure 1.

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 of the pool level. Hinman (1938) has given an 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 performed on a weekly basis by drawing the water level down one or more feet and subsequently refilling to near top elevation within the 7-day period. The speed of the drawdown and refilling has varied and either one or both may be rapid. Essentially, cyclical fluctuation was the type schedule employed on Smith Mountain Reservoir from July 15, 1965, until the end of the breeding season as shown in Fig. 1. The reservoir was in the rising pool stage up until July 15 with no cyclical variation.

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. Therefore, a progressively lower waterline would result as the season advanced.

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 the upper half of Fig. 1. 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 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.

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.

ADULT MOSQUITO SURVEY. Table 1 contains a compilation of the 20 mosquito species collected by light trap during the 1965–1966 study and their respective percentages of the total population. *Culex salinarius* constituted 50.2 percent and *Anopheles punctipennis* 20.6 percent of the total light trap catch. The next most prevalent species were *Aedes vexans, Anopheles quadrimaculatus, Culex erraticus, Mansonia perturbans,* and *Psorophora confinnis,* respectively.

These studies also produced a new mosquito record for Virginia. *Aedes cinereus* was taken on several occasions from both light and Malaise traps in Franklin and Pittsylvania Counties. This species is not listed for Virginia in the 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 identification 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*, one of *Psorophora cyanescens*, and two of *Toxorhynchites septentrionalis* 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.

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 data are tabulated in accordance with the method of Edman (1964). 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 11 a-Rt. 605. Table 3 reveals that *C. salinarius* was also the dominant species in 1966 at three of the permanent study locations.

DESCRIPTION OF STUDY SITES AND COLLECTION RESULTS.

Site 1a. Hardy Ford. This site was a cove which contained an abundance of aquatic and terrestrial vegetation during

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 ♀	1a Hardy Ford ♂	2a Rt. 668 ♀	2a Rt. 668 ♂	3a Pelican Pt. ♀	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. ♀	4a Pelican Pt. ♂	9a B-Bar-B ♀	9a B-Bar-B ♂	11a Rt. 605 ♀	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.

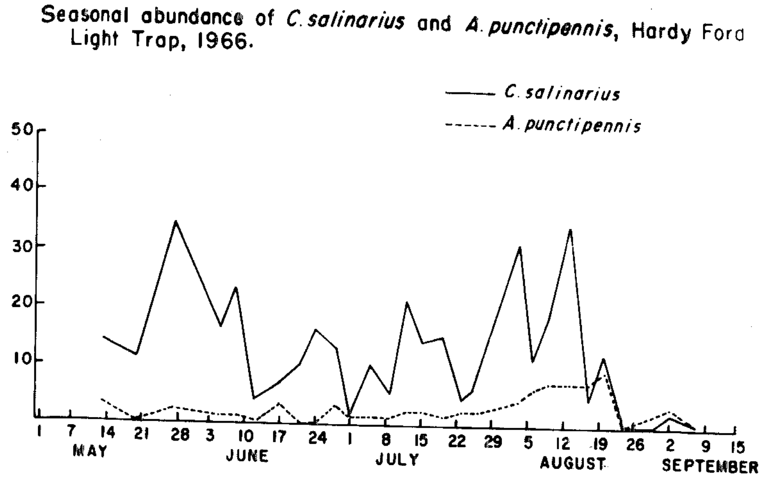
Species	1a Hardy Ford ♀	1a Hardy Ford ♂	2a Rt. 668 ♀	2a Rt. 668 ♂	3a Pelican Pt. ♀	3a Pelican Pt. ♂
Anopheles punctipennis	66	8	5	1	5	0
Culex-salinarius	293	56	15	6	4	1
Other species	126	20	11	0	4	1
Total mosquitoes	485	84	31	7	13	2
Total collections	29		30		21	
Average females/catch	16.7		1.0		0.6	
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. ♀	4a Pelican Pt. ♂	9a B-Bar-B ♀	9a B-Bar-B ♂	11a Rt. 605 ♀	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%	

the rising pool phase in 1965 and offered favorable breeding conditions for the larvae of *A. punctipennis* and *C. 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.

The lower graph of Fig. 2 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 1965 reservoir pool elevation (Fig. 1), it may be observed that the water level began fluctuating markedly after July 15.

The upper graph of Fig. 2 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 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 *A. vexans, P. confinnis, C. salinarius,* and *A. punctipennis,* particularly after heavy rains. This source contributed substantially to the numbers of adults taken at the Hardy Ford light trap in 1966.


Seasonal abundance of C. salinarius and A. punctipennis, Hardy Ford Light Trap, 1966.
C. salinarius
A. punctipennis
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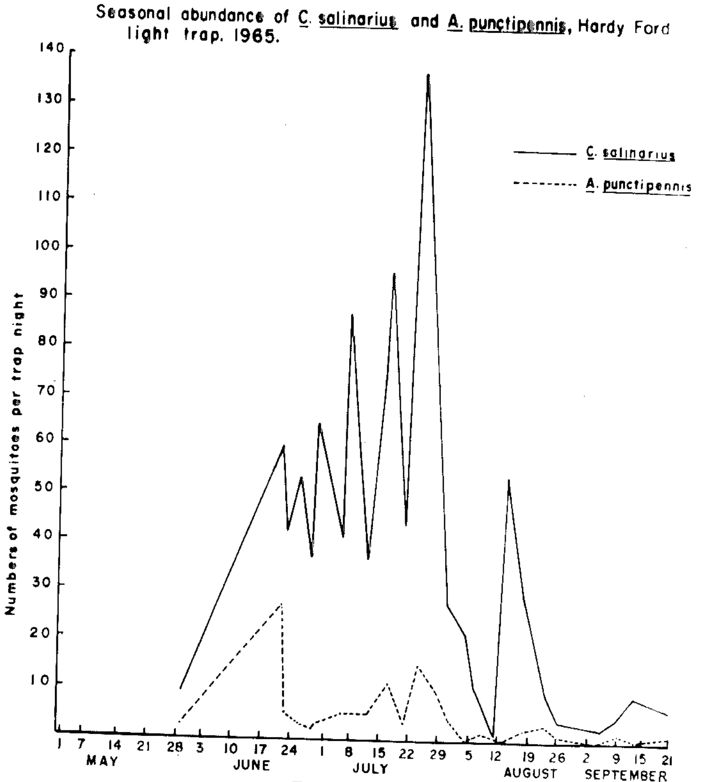
Seasonal abundance of C. salinarius and A. punctipennis, Hardy Ford light trap, 1965.
C. salinarius
A. punctipennis
Numbers of mosquitoes per trap night
140
130
120
110
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FIGURE 2.

Site 2a. Rt. 668. A small embayment 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.

Seasonal abundance records are illustrated for the two dominant mosquito species for 1965 in the bottom graph of Fig. 3. However, collections were so low at this site in 1966 that it was necessary to plot the total mosquito population, including all species collected for this year (Top graph, Fig. 3). Nevertheless, it is apparent from the comparison of the two graphs 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. 3).

Site 3a. Pelican Point. Mosquito abundance at this area was comparable to that of Site 2a. With an average number of 5.2 females per catch in 1965 (Table 2) and 0.6 female per catch in 1966 (Table 3), it was the least productive of all breeding areas sampled. Again, *A. punctipennis* and *C. salinarius* population samples are plotted for 1965 and the total mosquito population samples plotted for 1966 in Fig. 4.

Site 4a. Pelican Point. A cove near Site 3a 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. The sudden decline in the mosquito population after July 22, 1965, may be noted from the

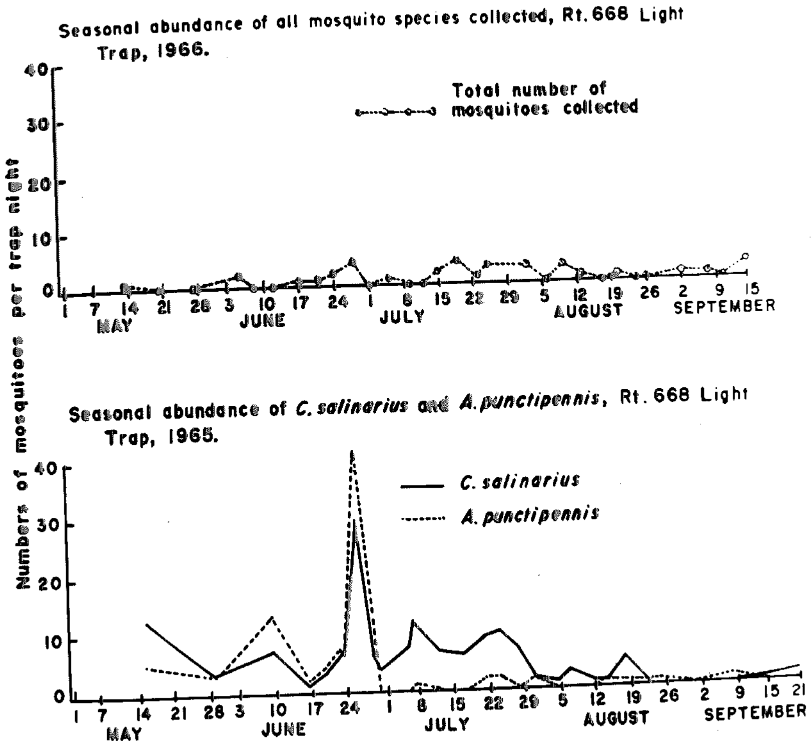


Figure 3.

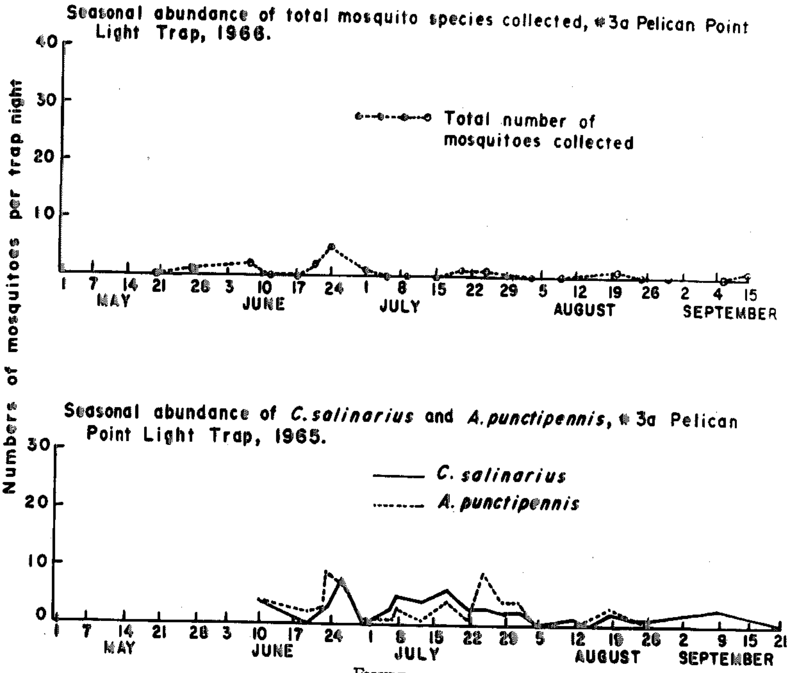


FIGURE 4.

lower graph and the continued reduction throughout 1966 may be seen in the upper graph of Fig. 5. Average females per catch declined from 15.7 in 1965 (Table 2) to 1.4 in 1966 (Table 3).

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. 4 and 5 that total mosquito production in 1966 decreased to near minimal levels.

Site 9a. B-Bar-B property. 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. 6, light trap catches were extremely high in 1965 until the cyclical water level 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. 6). 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. From a total of 30 nights of trapping, the Malaise trap produced only a total of 74 mosquito specimens. However, it should be noted that light traps which did offer an attracting source also produced low

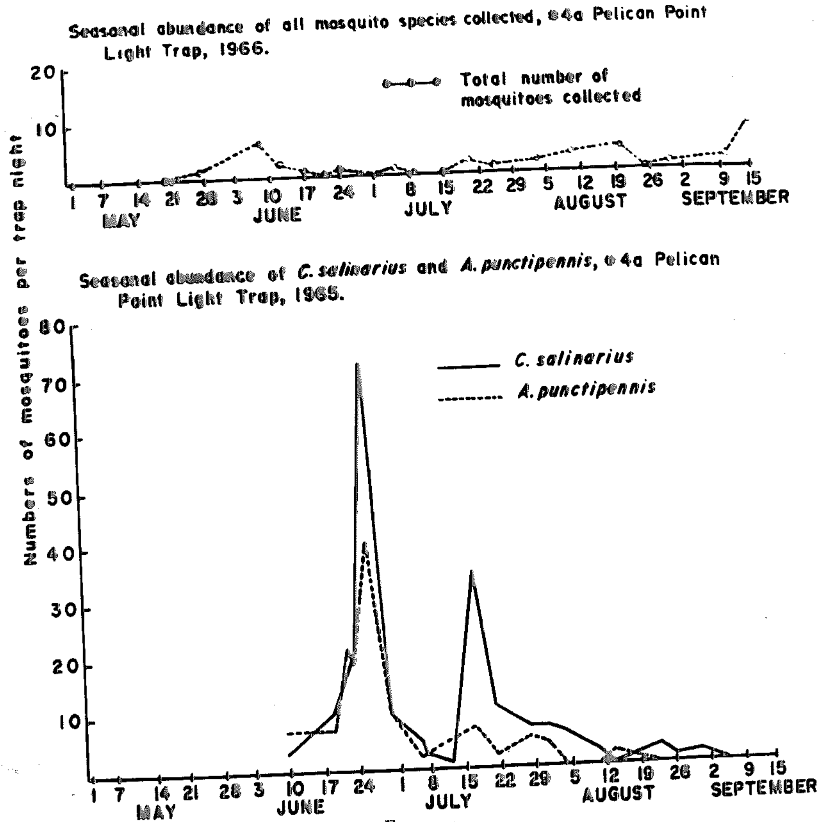


FIGURE 5.

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.

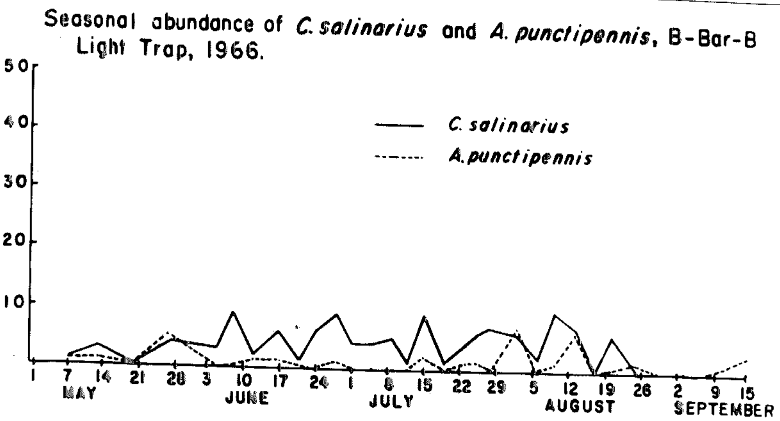
An indication of the reduction in biting annoyance from 1965 to 1966 is presented in Table 4 with a total of 54 females feeding within a 1-hour period in 1965 compared with 10 females taken from human bait on the same date in 1966.

Numerous spot-check collections made at various points on the lower Leesville Reservoir usually revealed low mosquito production. Situations which appeared to offer 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 5-foot rise or fall from one day to the next.

Site 11a. Rt. 605. Our sixth and final

TABLE 4.—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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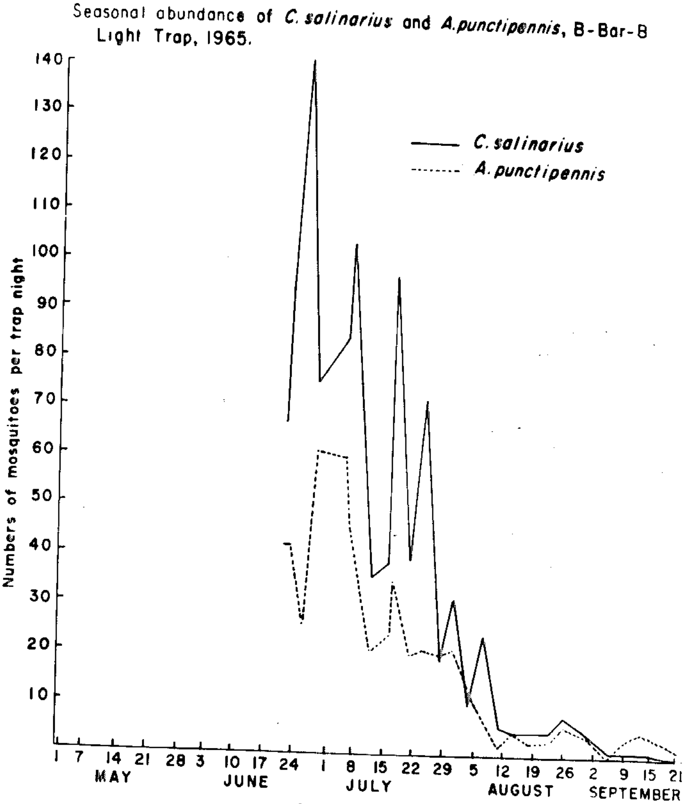
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C. salinarius
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FIGURE 6.

permanent study area 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).

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. 7 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. 7 and from Tables 2 and 3 that a 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.

SUMMARY 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.

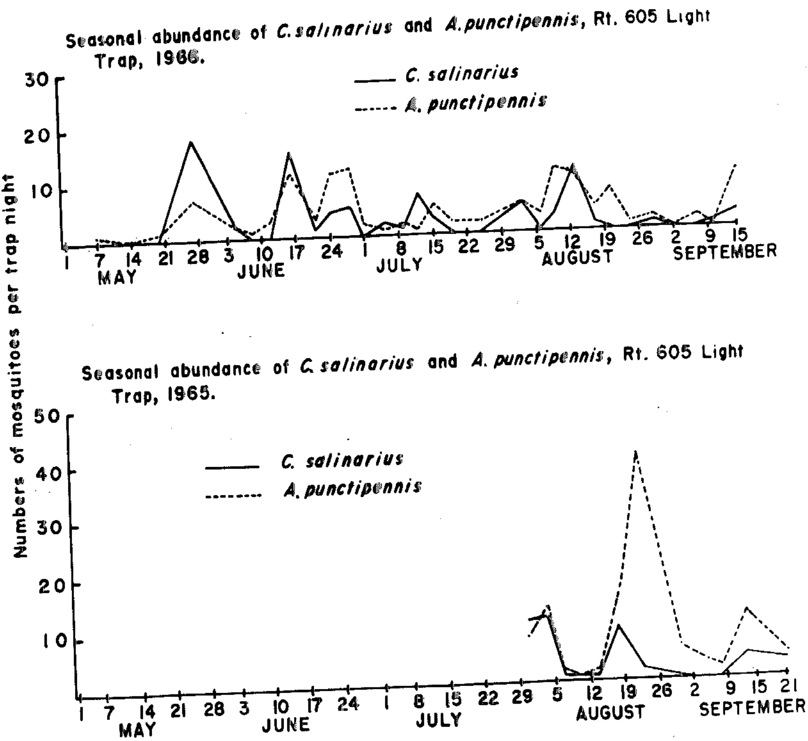

FIGURE 7.

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 (lower graph, Fig. 1) represented the constant cyclical variation phase after July 15, 1965. On the other hand, the 1966 water level fluctuation schedule (upper graph, Fig. 1) combined the benefits of cyclical variation and slow seasonal drawdown. 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 significant 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.

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