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THREE-YEAR INVESTIGATION OF MOSQUITO BREEDING IN NATURAL AND IMPOUNDED TIDAL MARSHES IN DELAWARE

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Summary

An investigation of mosquito breeding in natural and impounded tidal marshes in Delaware was conducted from 1953 to 1955. Study areas included two natural marshes and two fresh-water impoundments, one completed in 1939 and the other after the first summer of study. The impoundments were designed to improve waterfowl habitat, and consisted largely of open expanses of water several feet in depth containing submerged plants with marginal stands of emergent vegetation.

In the tidal marsh, the mosquitoes dipped in greatest numbers were *Aedes sollicitans* and *Aedes cantator,* the two most important pests in the area. They were followed in abundance by *Culex salinarius* and *Anopheles bradleyi.* However, numbers varied considerably each year. *C. salinarius* was the species taken most commonly in 1953, *A. cantator* in 1954, and *A. sollicitans* in 1955. Breeding in the tidal marsh was not uniform, but occurred mainly in the upper edges near the mean high tide level, in sites characterized by growth of saltgrass, saltmeadow cordgrass, and mixtures of the two alone or with saltmarsh cordgrass.

Permanent impoundment of fresh water in the mosquito-breeding zone along the mainland reduced salinity and prevented frequently fluctuating water levels. As a result, the two important salt-marsh *Aedes* pests were almost entirely eliminated due to lack of suitable oviposition sites. *An. bradleyi* also was makedly reduced; however, *C. salinarius,* a broadly adapted species, continued to thrive. Impoundage favored breeding of certain fresh-water mosquitoes, including the permanent-water species, *Anopheles quadrimaculatus, Uranotaenia sapphirina,* and *Culex restuans,* and a flood-water species, *Aedes vexans,* which occurred only after rises in the pond level resulting from heavy rains. By reason of their daytime resting habits, generally limited flights, non-biting of humans, or the smaller numbers produced, these species, compared to the salt-marsh *Aedes,* were of less or no importance as pests. Most breeding occurred in woods edge, phragmites, cattail, switchgrass and, during the first year after flooding, swampdock.

In the impoundments, maintenance of a high, fairly stable water level, which flooded emergent vegetation, resulted in the production of large numbers of permanent-water mosquitoes *(Culex, Anopheles,* and *Uranotaenia),* but few *A. vexans.* High water also favored submerged pondweeds, which are heavily utilized by waterfowl. Recession of the water from the vegetated margin during the summer caused the growth of moist-soil annual and perennial plants attractive to waterfowl and muskrats. Under a draw-down condition, fewer permanent-water mosquitoes were produced, but subsequent reflooding before late fall resulted in larger numbers of *Aedes.* Lowering of the water level below the roots of host plants each summer for several weeks or more effectively prevented the successful breeding of *Mansonia perturbans.*

The principal mosquitoes taken in the light trap were *A. sollicitans, C. salinarius,* and *An. crucians* complex (probably mostly *bradleyi).* No one species was clearly dominant, *C. salinarius* being the most common in 1953, *An. bradleyi* in 1954, and *A. sollicitans* in 1955. However, *A. sollictans* accounted for almost all of the daytime biting. In the *Mansonia* traps in

Shearness Pond during 1955, the average emergence was 2.6 adults per square foot of cattail marsh, or 0.5 adult per cattail stalk.

Prior to impoundment, the principal wildlife utilization of the tidal marshes was by several species of surface-feeding ducks, shorebirds, rails, muskrats, fish, diamond-backed terrapins and blue crabs. Following fresh-water flooding, much larger numbers of waterfowl and certain other water birds utilized the ponds. Only a few birds showed considerable declines. Muskrat populations were restricted by the high water level in the impoundments, but many species of fish continued to thrive and several new species were noted. Fresh-water flooding eliminated diamond-backed terrapins and blue crabs, but bullfrogs and snapping turtles appeared.

Because of the small acreage of the impoundments in relation to the surrounding tidal marsh, the declines in certain wildlife were of little importance. The net effect of fresh-water flooding was a significant reduction of nuisance mosquitoes in an important breeding zone and greatly enhanced conditions for waterfowl and certain other marsh birds.

To minimize most effectively the mosquito nuisance and to provide conditions favorable for waterfowl in impoundments, it is recommended that, where possible, a combination of the flooding and draw-down management be practiced.

THREE-YEAR INVESTIGATION OF MOSQUITO BREEDING IN NATURAL AND IMPOUNDED TIDAL MARSHES IN DELAWARE[1]

Richard F. Darsie, Jr. and Paul F. Springer [2] [3]

The practice of impounding water to produce new or better habitat for wildlife has increased greatly during the past two decades. Because of growing needs and demands for areas suitable for wildlife conservation and for hunting and fishing, undoubtedly many more impoundments will be built in the future. In some localities this poses the problem of how to carry on such a program without causing a mosquito nuisance. Experience with large reservoirs has indicated that satisfactory naturalistic means of mosquito control can be developed (Bishop and Hollis, 1947). However, this requires study and to date there has been little investigation of either the extent of mosquito breeding or its control in impoundments for wildlife.

From 1953 to 1955 the U. S. Fish and Wildlife Service and the University of Delaware Agricultural Experiment Station conducted a cooperative investigation of mosquito breeding in natural and impounded tidal marshes in Delaware. The purpose of the study was threefold: (1) to determine, over a three-year period, the mosquito breeding potential of waterfowl impoundments in comparison to that of natural tidal marshes, (2) to measure the utilization of these areas by wildlife and (3) to ascertain methods of managing water and vegetation in the impoundments that would lessen numbers of troublesome mosquitoes and, at the same time, maintain their wildlife values.

This study was a companion to one carried on during the same years in New Jersey by the New Jersey Division of Fish and Game, the U. S. Department of Agriculture, and the New Jersey Agricultural Experiment Station. Previously, an agreement had been reached by all of the aforementioned agencies plus the Delaware Board of Game and Fish Commissioners for coordinated, cooperative studies in the two states. Broad entomological aspects of the work were directed by the U. S. Department of Agriculture.

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[3]The following personnel assisted in the dipping studies: Messrs. D. MacCreary, C. A. Triplehorn and L. Miller, Delaware Agricultural Experiment Station, and Mr. H. C. Boyer, U. S. Fish and Wildlife Service. The authors are indebted to them and to Mr. H. C. Chapman, Dr. A. W. Lindquist, Mr. W. C. McDuffie, Dr. C. N. Smith and Dr. H. H. Stage, U. S. Department of Agriculture; Mr. A. L. Nelson, Dr. A. C. Martin, Mr. J. H. Steenis, Mr. N. Hotchkiss and other staff members, Patuxent Research Refuge; Messrs. D. M. Hickok and E. H. Chandler, former and present manager, respectively, Bombay Hook National Wildlife Refuge; Dr. L. A. Stearns, Delaware Agricultural Experiment Station; Mr. R. E. Griffith, U. S. Fish and Wildlife Service; Mr. N. G. Wilder, Delaware Board of Game and Fish Commissioners; Dr. F. Drouet, Chicago Natural History Museum; Mr. D. A. Cutler and associates, Delaware Valley Ornithological Club; and Dr. H. H. Engelbrecht, U. S. Weather Bureau, and the Division of Tides and Currents, U. S. Coast and Geodetic Survey, for assistance and cooperation during the study.

During each of the first two years of study, findings in both states were reported briefly in joint papers (Chapman *et al.*, 1954, 1955). Results in Delaware during 1955 were presented by Springer and Darsie (1956) while a summary of the three years of study in New Jersey was prepared by Chapman and Ferrigno (1956).

Description of Study Areas

Studies were conducted at Bombay Hook National Wildlife Refuge, located along Delaware Bay in Kent County two miles east of Leipsic, Delaware. Nearby larger towns include Smyrna to the northwest and Dover to the southwest, both at distances of about seven miles.

Four areas adjacent to the mainland were selected for study. Two of these consisted primarily of regularly flooded salt marsh with smaller amounts of salt meadow.[4] They were retained in their natural state during the study. One of the salt-marsh areas, Bear Swamp Marsh, is to be flooded in the future while the second area will remain unimpounded and, hence, was designated as the check area. The other two sites, Raymond Pond and Shearness Pond, were portions of the tidal marsh which had been flooded to form fresh-water impoundments for waterfowl. This was accomplished by the erection of dikes between adjacent headlands to retain precipitation, surface run-off and the flow from seeps and upland streams. Dikes were constructed of peat, obtained by dragline from borrow pits on each side, with a topping of clay. The completed structures were 10 feet above the surface of the marsh, 120 feet wide at the base, and 12 feet at the top with a slope of approximately 5:1 on the sides. Shearness Pond was not completed until after the end of the first year of study. The primary water management plan for the impoundments has been to maintain open expanses of water several feet in depth to encourage growths of pondweeds (Najadaceae) and other choice duck foods. Because the fertility and clarity of the water were favorable for the growth of submerged plants, a planned drawdown to foster emergent growth was not undertaken. A description of the individual areas follows.

Bear Swamp Marsh, the most northerly of the study areas, see Fig. 1, is scheduled to be impounded in 1959 and will be about 200 acres in extent. The dominant vegetation types, from the mainland toward the bay, were: (1) phragmites *(Phragmites communis)*; (2) a mixed growth on fairly well drained sites, called type II, of sprangletop *(Leptochloa fascicularis)*, saltgrass *(Distichlis spicata)*, saltmeadow cordgrass *(Spartina patens)*, fall panicum *(Panicum dichotomiflorum)*, and dwarf spikerush *(Eleocharis parvula)*; (3) saltmeadow cordgrass and (4) saltmarsh cordgrass *(Spartina alterniflora)*.[5] By 1955 saltgrass had increased to such an extent in the saltmeadow-cordgrass type that it was reclassified as mixed type I, on poorly drained sites. Salinity of the water ranged from 7.5 to 54 per cent of the mean salinity of ocean water with the low readings occurring in the spring.[6]

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[4]Classification of wetland types based on Martin *et al.* (1953)

[5]Common names of plants generally after Hotchkiss (1950) and Hotchkiss and Stewart (1947) and scientific names after Fernald (1950) and Gleason (1952).

[6]Mean salinity of the Atlantic Ocean is 32,210 p.p.m.

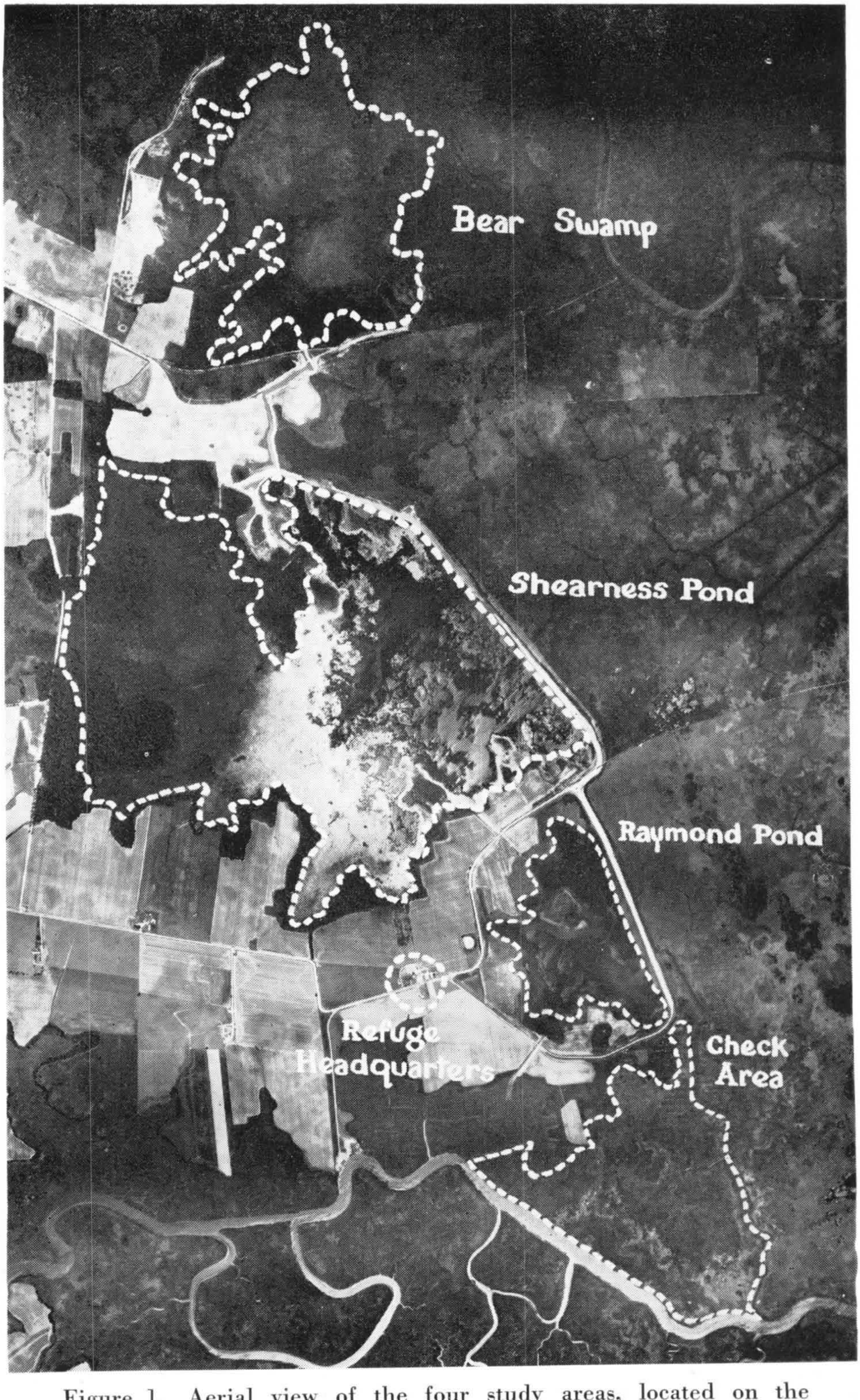


Figure 1. Aerial view of the four study areas, located on the Bombay Hook National Wildlife Refuge, and used in the three-year impoundment study.

The pH varied from 6.3 to 8.3. This area differed from the other tidal marshes studied in having few well-defined tidal streams.

The check area, situated between the Leipsic River and Raymond Pond, included 263 acres. Its main vegetation types, from the mainland toward the bay, were: (1) a mixed growth on poorly drained sites, called type I, of Olney's three-square *(Scirpus olneyi),* saltmeadow cordgrass, saltmarsh cordgrass, saltmarsh cyperus *(Cyperus filicinus),* and aster *(Aster sublatus)*; (2) saltmeadow cordgrass; (3) saltgrass and (4) saltmarsh cordgrass. Water salinity varied from 5.4 to 69 percent of ocean water and pH from 3.3 to 7.9. The mean tidal range in the Leipsic River at the west end of the check area (Whitehall Landing) was 4.0 feet.

Raymond Pond, a 100-acre impoundment completed in 1939, consists largely of an open expanse of water with a narrow marshy border. At the south end of the pond, a ditch containing a sluice box equipped with splash boards connects the pond with the check area. On the north end, there is another sluice box and a ditch leading to Shearness Pond. Because of its small watershed, the level of the pond receded 15 to 20 or more inches during the summer unless water was diverted into it from Shearness Pond. The principal vegetation types, from the mainland to open water, were: (1) switchgrass *(Panicum virgatum)*; (2) phragmites; (3) blue, broadleaf and narrowleaf cattail *(Typha glauca, latifolia and angustifolia);* (4) rose-mallow *(Hibiscus moscheutos)*; (5) algae (primarily *Rhizoclonium hieroglyphicum,* but including *Nostoc piscinale, Oscillatoria tenuis* and *Spirogyra* sp.) and (6) pondweeds *(Potamogeton berchtoldi, Ruppia maritima, Potamogeton pectinatus* and *Zannichellia palustris).* Recession of the water level and exposure of mud flats during the early summer of 1954 resulted in a heavy germination and growth of (7) wild millet *(Echinochloa walteri)* plus fragrant and red-root cyperuses *(Cyperus odoratus* and *erythrorhizos)* and fall panicum. In the latter part of the summer of 1955, another type (8) three-square *(Scirpus americanus),* which had germinated during low-water periods of the previous years, became common in parts of the pond. Salinity of the water ranged from 1.5 to 7.7 per cent of ocean water (with one record of 14 per cent) and pH from 4.9 to 9.4.

Shearness Pond lies between Raymond Pond and Bear Swamp Marsh and encompasses about 560 acres. The dike for this area was partially constructed at the beginning of the study in June, 1953, and was completed on October 2 of that year. Until that time, the main tidal stream into the marsh continued to function so that the vegetation of the area during the summer of 1953 was probably similar to that existing before dike construction started. However, diking across the other tidal streams prior to this study impeded drainage at low tide. Before impoundment the area consisted of a tidal marsh, behind which was a shrub swamp. In the tidal marsh, the main vegetation types, from the shrub swamp toward the bay, were: (1) a mixed growth on well-drained sites, called type III, of saltmarsh cordgrass, tidemarsh waterhemp *(Acnida cannabina).* beaked spikerush *(Eleocharis rostellata),* dwarf spikerush, and saltmarsh fleabane *(Pluchea purpurascens);* (2) narrowleaf cattail; (3) saltmeadow cordgrass and (4) saltmarsh cordgrass. In the tidal marsh, water salinity varied from 33 to 50 per cent of ocean water and pH from 6.3 to 7.4. The main plants in shrub swamp were: alder *(Alnus serrulata)*, red maple *(Acer rubrum)*, swamp rose *(Rosa palustris)*, black willow *(Salix nigra)*, buttonbush *(Cephalanthus occidentalis)*, waterwillow *(Decodon verticillatus)*, swampdock *(Rumex verticillatus)*, and arrow-arum *(Peltandra virginica)*.

Appreciable flooding of the impoundment with fresh water did not occur until October 29, 1953. By the next May, full pond stage was reached. A rapid decline in salinity occurred as flooding progressed. On September 25, a week before blocking the main tidal stream, the average salinity of the water was 48 per cent of ocean water. Subsequently, the following readings were obtained: October 9—40 per cent; October 30—25 per cent, November 18—14 per cent, May 2—2.4 per cent.

In order to kill the salt-marsh vegetation, the water in Shearness Pond was held at a level of about one and one-half to two feet over the general marsh surface during the spring and early summer of 1954. Thereafter, the lack of rainfall and sinking of a section of dike prevented maintenance of a level as high as desired, but flooding was sufficient to kill the saltmarsh cordgrass and most of the saltmeadow cordgrass and mixed vegetation. However, stands of the latter two types survived where higher elevations were exposed by recession of the water or where portions of the marsh formed a number of semi-floating islands. Narrowleaf cattail was little affected by the initial flooding but stands were thinned somewhat in 1955. New vegetation types present after impoundment, from the upland to open water, were: (5) woods edge, (6) switchgrass, and (7) phragmites. In protected parts of these newly flooded types, duckweed *(Lemna minor)* appeared. Although most of the shrub swamp was flooded, the only accessible type was (8) swamp dock. During 1955, considerable growth of wild millet, fragrant and red-root cyperuses, fall panicum, saltmarsh fleabane and fireweed *(Erechtites hieracifolia)* appeared in the woods-edge type. Salinity after diking ranged from 0.2 to 7.0 per cent of ocean water and pH from 5.8 to 8.0.

Study Procedures

A dual approach was used to determine the effects of fresh-water flooding on mosquito production. The first involved a comparison of breeding in the impoundments with that in the nearby tidal marshes. The second consisted of a comparison of mosquito breeding in Shearness Marsh before and after impoundment.

Within the principal vegetation types of each area, five dipping stations were established at intervals of 50 to over 500 feet and sampled at weekly intervals. Individual samples consisted of ten dips, or as near that number as possible, within a 25-foot radius of a station. For this purpose, a long-handled, white-enamelled dipper was used. Where a muskrat house was located near a station in 1954 and 1955, generally five dips were taken next to the house and five away from it. Also, at stations in woods edge, five samples were taken in marginal, woodland pools containing decaying leaves and five in the pond proper. At each station a field record was made of the number of larvae and pupae of the genera collected. Larvae were further classified as small (first and second instar) and large (third and fourth instar). Portions of each collection were preserved for laboratory identification. A record was made also of the number of dips, distribution and depth of water, kinds of aquatic predators and occurrence of mosquito egg rafts.

In the three years of investigation, dipping collections were made during the following periods: June 30 to October 27, 1953; April 12 to October 8, 1954; and May 4 to September 22, 1955. During 1954, dipping in wild millet in Raymond Pond was not initiated until August 24, soon after this type became flooded. The next year in this pond, collections in three-square were started on August 11, when growth was sufficiently dense to warrant dipping. Following flooding of Shearness Pond during the fall, winter and spring of 1953-54, sampling stations were established in the new vegetation types, but dipping was no longer possible in the salt-marsh type that had been destroyed by impoundment. Because of the extent and variability of woods edge, ten dipping stations, in contrast to the usual five, were set up in this type in 1954. For comparative purposes in the tables, however, the number of mosquitoes dipped was reduced by one-half to correspond with other five-station figures. Dipping was carried on at only five stations in this type during 1955. Also, in that year no collections were made in phragmites in Shearness Pond or in mixed type II in Bear Swamp Marsh because of the previous low take of mosquitoes.

Special collections of *Mansonia perturbans* (Walker) larvae following the technique of McNeel (1931), as modified by Hagmann (1952), were made in the impoundments during October of 1953 and 1954 with a 16-mesh strainer and during April of 1955 and 1956 with a 50-mesh strainer.

In addition to larval and pupal collections, sampling of adult mosquito populations was carried on during the study. The principal method was the nightly operation of a New Jersey light trap at the Refuge headquarters building from May 18 to October 28, 1953; April 16 to October 10, 1954; and May 4 to September 30, 1955. It was situated 0.2 and 1.7 miles from the check area and Bear Swamp Marsh, and 0.2 and 0.3 mile from Shearness and Raymond Ponds, respectively. In addition, the emergence of adult *M. perturbans* mosquitoes in Shearness Pond during 1955 was studied by the use of five conical screen traps, covering areas of either 0.9 or 1.6 square feet.

Other information gathered during the study included: (1) daily records of precipitation at the headquarters area and (2) of tidal fluctuations in the Leipsic River at Whitehall Landing; (3) water-level readings in Raymond and Shearness Ponds several times a week; and (4) semi-monthly to monthly sampling of water from two or three stations in each vegetation type of the four study areas to determine salinity by the silver nitrate and potassium dichromate technique and by a Beckman pH meter or a Hellige pocket comparator. Determination of pH was made within a few hours after collection of stoppered samples. Temperature and additional precipitation data were obtained from the Dover weather station, which is located seven miles southwest of refuge headquarters. The long period of station operation (established 1870) made possible a comparison of data at Dover during 1953-55 with the cumulative averages.[7] Since maximum and minimum temperatures at the

[7]Weather records for Dover taken from "Climatological Data, Maryland and Delaware" published by the U. S. Department of Commerce, Weather Bureau.

refuge showed little variation from those at Dover, they were not kept after 1953. Adjusted tidal data for the first part of each year's study and for isolated missing dates were determined from the record at Philadelphia, Pennsylvania. Water-level readings in Raymond Pond from April to June, 1953, were obtained by refuge personnel.

Utilization of the study areas by water birds and certain other conspicuous birds that are associated with wetland habitats was recorded from April 1, 1954, to March 31, 1956, at weekly or biweekly intervals, except during the winter when records were taken monthly or bimonthly. Counts generally were made while dipping and were supplemented by observations from towers and other vantage points. An attempt was made to obtain a complete enumeration at each visit. However, difficulty in observing bitterns, wood ducks *(Aix sponsa),* rails and gallinules *(Gallinula chloropus)* necessitated special, more thorough traversing of the areas in order to obtain counts of these secretive species. No observations were made in the shrub swamp in Shearness Pond, all counts being restricted to the more open section of 330 acres occupied by the former tidal marsh.

Aerial censuses of muskrat houses within the study areas were made by refuge personnel during late November and early December of each year from 1952 to 1954.

Weather and Tidal Conditions

A monthly record of precipitation and temperature at Bombay Hook and Dover during the three years of study is presented in Table 1. Figs. 2 to 4 show the daily precipitation at Bombay Hook and the fluctuations both in the water levels of Raymond and Shearness Ponds and in the level of the highest daily tide in the Leipsic River.

In 1953, precipitation was higher than normal during April and May but lower than normal from June through most of October. As a result, the water level of Raymond Pond declined considerably during the latter part of the summer and receded completely from the vegetated margin. Exceptionally high tides occurred in early April, May, mid-September and late October, at the end of the mosquito breeding season. Temperatures were slightly above normal with the greatest departure occurring in May.

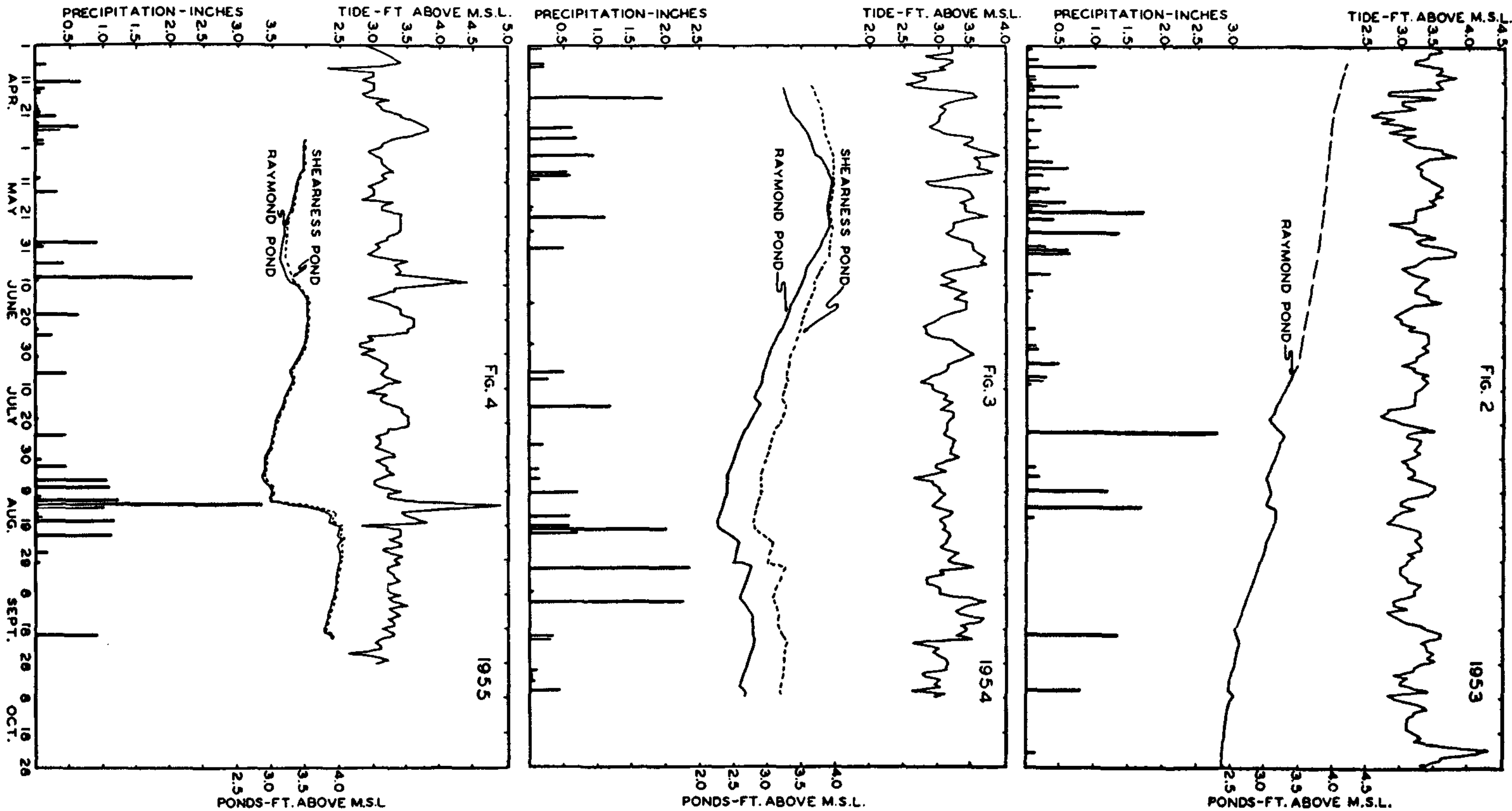
In 1954, precipitation was near normal except for the drouth in early summer. At Dover, June was the third driest and July the fourth driest on record. Only 0.18 inch of rain was recorded at Bombay Hook in June. Following a peak in May, the water levels in the ponds declined rapidly and marginal mud flats in Raymond Pond were exposed by early summer. Appreciable reflooding did not occur until the latter part of August and early September following several heavy rains, including those accompanying hurricanes "Carol" and "Edna". Although the water level in Shearness Pond underwent similar fluctuations, a higher, more-stabilized condition prevailed than in Raymond Pond. The highest tides occurred in mid-April, May, early June and early September. April and the first part of October were unseasonably warm; otherwise the temperature was only slightly above normal.

Table 1. Monthly Precipitation and Temperature Records at Bombay Hook Wildlife Refuge and Dover, Delaware, from April to October During 1953 to 1955.[1]

Month	1953					1954					1955				
	Bombay Hook	Dover				Bombay Hook	Dover				Bombay Hook	Dover			
	Precipitation	Precipitation		Temperature		Precipitation	Precipitation		Temperature		Precipitation	Precipitation		Temperature	
	Total	Total	Depart. from Normal	Average	Depart. from Normal	Total	Total	Depart. from Normal	Average	Depart. from Normal	Total	Total	Depart. from Normal	Average	Depart. from Normal
April		3.87	0.29	54.3	1.1	3.51[2]	3.31	−0.27	57.9	4.7		2.71	−0.87	57.0	3.8
May		7.33	3.52	67.5	3.8	3.97	3.75	−0.06	62.1	−1.6	1.41	2.17	−1.64	66.6	2.9
June		1.64	−2.02	73.1	0.6	0.18	1.11	−2.55	73.5	1.0	3.66	5.81	2.15	69.5	−3.0
July		3.88	−0.84	78.1	1.5	2.17	1.51	−3.21	77.4	0.8	0.97	1.55	−3.17	81.8	5.2
Aug.	3.91	4.11	−0.76	75.0	0.3	7.13	5.04	0.17	75.6	0.9	10.92	13.23	8.36	78.5	3.8
Sept.	1.35	1.36	−2.32	70.4	1.6	3.04	4.01	0.33	70.6	1.8	0.95[2]	1.82	−1.86	67.8	−1.0
Oct.	5.87	5.23	2.33	59.6	2.1	0.47[2]	2.36	−0.54	61.9	4.4		3.27	0.37	60.4	2.9
Total		27.42	0.20			20.47	21.09	−6.13				30.56	3.34		
Average				68.2	1.5				68.4	1.7				68.8	2.1

[1]Precipitation in inches and temperature in °F.

[2]Periods included are April 7-30, 1954; October 1-14, 1954; or September 1-23, 1955.



Figures 2 to 4. Level of highest daily tide, water levels in Raymond and Shearness Ponds and daily precipitation at Bombay Hook National Wildlife Refuge, Delaware, during 1953 (2), 1954 (3) and 1955 (4). M.S.L. refers to mean sea level.

In 1955, precipitation was considerably below normal during most of the months of study with July again being very dry. However, the heavy precipitation in August (third highest for August on record at Dover), resulting largely from hurricanes "Connie" and "Diane", caused the seasonal total to be above average. In Shearness and Raymond Ponds an attempt was made to keep the water level more nearly constant than in previous years. This was only partly successful since sinking of a section of the Shearness dike during the first part of the season necessitated keeping water below the desired level. Water was released from the Finis Swamp storage pool into Shearness Pond during the latter part of July but the amount was insufficient to equalize the loss from evaporation, transpiration and seepage. The rains in August rapidly refilled the ponds and a more nearly uniform level was maintained thereafter. Extremely high tides occurred in late April, June and mid-August. The period of study also was characterized by low temperatures in June, the near-record July heat and record-breaking high August temperatures.

Comparison of Mosquito Breeding in Natural and Impounded Marshes

SPECIES OCCURRENCE. The total average numbers of each species, the percentages these numbers represent and the average number of each species per dip are shown for the unimpounded and impounded study areas in Tables 2A and 2B.[8]

In all, 12 species were dipped in the natural salt marsh. They generally were dominated in numbers by the flood-water *Aedes* species, *sollicitans* (Walker) and *cantator* (Coq.). Each year of the study the percentage of these two increased until, in 1955, they comprised 96 per cent of all larvae sampled. The high incidence during 1955 was correlated with exceptionally well-defined periods of alternate drying and flooding conducive to the development of these species (see Table 1 and Figure 4). In most years, *A. sollicitans* outnumbered *A. cantator,* but, in 1954, more of the later species were taken, primarily due to a late summer brood which does not ordinarily develop to large proportions. It was triggered by two hurricanes which were accompanied by heavy rainfall. The resultant lower salinity favored *A. cantator.* This observation agrees with those of Chidester (1916) and Cory and Crosthwait (1939) on the salinity tolerance of this species.

Next in over-all prevalence in the salt marsh were *Culex salinarius* Coq. and *Anopheles bradleyi* King, semi-permanent water breeders. The numbers taken each year showed similar trends; both were most numerous in 1953 when they ranked first and third, respectively, and steadily decreased thereafter so that by 1955 they composed less than four per cent of the total. It appears that similar ecological conditions, such as lack of favorably spaced rains and tides to keep breeding sites flooded, adversely affect both these species.

[8]Number of dips was the number intended rather than the number actually taken.

Dipping of the impounded marshes yielded 16 species of mosquitoes, mostly permanent-water types. *C. salinarius* was, by far, the most numerous, and only in 1954, when *Culex restuans* Theo. and *Uranotaenia sapphirina* (Oster Sacken) increased in the newly created Shearness Pond, did it fall below 76 per cent of the total. *Anopheles quadrimaculatus* Say ranked second, ranging from 12 to 14 per cent followed by *U. sapphirina* and the flood-water *Aedes* mosquitoes, of which the principal species was *A. vexans* (Meig.). The salt-marsh *Aedes* and *Anopheles* were notably reduced in numbers compared to their populations in the tidal areas and comprised less than one per cent of the impoundment total in any year.

It should be pointed out, however, that in New Jersey, Chapman and Ferrigno (1956) reported several large broods of *A. sollicitans* produced in somewhat more saline impoundments in which the water level had been drawn down. Because of the lack of rainfall, the areas become dry. On reflooding, apparently in part from tidal sources, breeding occurred. Since no purposeful drawdown of the ponds was attempted in the Delaware study, the possibility of a similar incident was mostly eliminated. Nevertheless, during the dry weather of the late summer of 1953 and of June and July, 1954, a partial reduction in the water level of Raymond Pond exposed large portions of mud flats, without producing a brood of salt-marsh *Aedes* on reflooding.

Completion of Shearness dike near the end of the first year of study afforded a pre- and post-impoundment evaluation of mosquito breeding. Although this marsh produced relatively few mosquitoes before fresh-water flooding, the species were those which are tolerant of relatively high salinity. *C. salinarius* made up 60 per cent of the total, *An. bradleyi* 29, and salt-marsh *Aedes* 9. The following year, after impoundment and freshening, *An. bradleyi* and the salt-marsh *Aedes* both were reduced to 0.1 per cent of the total or less. Fresh-water species were quick to appear in the newly-created pond, of which only the margins were sampled regularly. The dominant *Anopheles* changed from *bradleyi* to *quadrimaculatus*, which comprised 16 per cent of the total, and *Aedes,* from *sollicitans* and *cantator* to *vexans*, 0.6 per cent. *C. salinarius* continued as the most prevalent *Culex* breeder, making up 32 per cent of the total, with *C. restuans,* a common spring species, 24 per cent. In addition, *U. sapphirina* appeared in great numbers at some stations.

The second year of impoundment was quite different. *C. salinarius* comprised 81 per cent of the total, with *An. quadrimaculatus, C. restuans* and *U. sapphirina* showing marked diminution. The number of *Culex territans* Walker increased somewhat over that of the previous season.

During the first year of the study, dipping was not initiated until June 30. In order to compare findings validly, then, with those during the latter two years, tables 3A and 3B were prepared to show immature mosquitoes dipped from June 29 to September 4. The breeding observed during this period provides an index to the adult production from the Fourth of July until Labor Day (September 7, 1953; September 6, 1954; September 5, 1955), which is the season of primary concern to mosquito abatement agencies in the middle Atlantic states.

Table 2A. Number and per cent (in parentheses) of mosquitoes dipped in unimpounded study areas during 1953 to 1955.[1]

Species	Check Area Number and Per Cent 1953	Check Area 1954	Check Area 1955	Bear Swamp Number and Per Cent 1953	Bear Swamp 1954	Bear Swamp 1955
Anopheles						
bradleyi	1079 (9.5)	762 (4.9)	103 (0.5)	1744 (35.1)	570 (19.1)	24 (1.6)
spp.	64 (0.5)	40 (0.2)		83 (1.6)	15 (0.5)	
Total	1143 (10.1)	802 (5.2)	103 (0.5)	1827 (36.8)	585 (19.7)	24 (1.6)
Aedes						
canadensis					1 (*)	
cantator	2796 (24.8)	5944 (38.9)	4272 (22.5)	56 (1.1)	465 (15.6)	291 (20.2)
sollicitans	3774 (33.5)	3938 (25.8)	14032 (73.9)	277 (5.5)	1735 (58.2)	1119 (77.7)
taeniorhynchus			3 (*)			
vexans	153 (1.3)			2 (*)	3 (0.1)	1 (*)
spp.	14 (0.1)	42 (0.2)	1 (*)		24 (0.8)	
Total	6737 (59.8)	9927 (65.1)	18308 (96.5)	335 (6.7)	2228 (74.8)	1411 (97.9)
Culex						
restuans		1 (*)				
salinarius	3369 (29.9)	4477 (29.4)	559 (2.9)	2794 (56.3)	153 (5.1)	5 (0.3)
territans		8 (*)				
spp.				1 (*)	1 (*)	
Total	3369 (29.9)	4486 (29.4)	559 (2.9)	2795 (56.3)	154 (5.1)	5 (0.3)
Minor Genera						
Culiseta inornata		35 (0.2)		1 (*)	9 (0.3)	
morsitans		1 (*)				
Psorophora ciliata	5 (*)					
Total	5 (*)	36 (0.2)		1 (*)	9 (0.3)	
Grand Total of Mosquitoes	11254	15248	18970	4958	2976	1440
Total Dips	3520	5200	4200	3520	5140	3150
Average per Dip[2]	3.19	2.93	4.51	1.40	0.57	0.45

Table 2A. (Continued)

Species	Shearness Area Number and Per Cent		Average for Unimpounded Areas Number and Per Cent						Average Per Dip[2]		
	1953		1953		1954		1955		1953	1954	1955
Anopheles											
bradleyi	245	(22.0)	1023	(17.7)	666	(7.3)	63.5	(0.6)	0.29	0.15	0.01
spp.	84	(7.5)	77	(1.3)	27	(0.2)			0.02	**	
Total	329	(29.6)	1100	(19.0)	693	(7.6)	63.5	(0.6)	0.31	0.16	0.01
Aedes											
canadensis					0.5	(*)				**	
cantator	53	(4.7)	968	(16.7)	3205	(35.1)	2281	(23.3)	0.28	0.61	0.62
sollicitans	45	(4.0)	1365	(23.6)	2837	(31.1)	7576	(74.2)	0.39	0.54	2.06
taeniorhynchus							1.5	(*)			**
vexans			52	(0.9)	1	(*)	0.5	(*)	0.01	**	**
spp.	7	(0.6)	7	(0.1)	33	(0.3)	0.5	(*)	**	**	**
Total	105	(9.4)	2392	(41.4)	6076.5	(66.6)	9859.5	(96.6)	0.69	1.17	2.68
Culex											
restuans					0.5	(*)				**	
salinarius	669	(60.3)	2277	(39.4)	2315	(25.4)	282	(2.7)	0.66	0.44	0.07
territans					4	(*)				**	
spp.	6	(0.5)	2	(*)	0.5	(*)			**	**	
Total	675	(60.8)	2279	(39.4)	2320	(25.4)	282	(2.7)	0.66	0.44	0.07
Minor Genera											
Culiseta inornata			0.3	(*)	22	(0.2)			**	**	
morsitans					0.5	(*)				**	
Psorophora ciliata			2.5	(*)					**		
Total			2.8	(*)	22.5	(0.2)				**	
Grand Total of Mosquitoes	1109		5774		9112		10205				
Total Dips	3290		3443		5170		3675				
Average per Dip[2]	0.33		1.67		1.76		2.77		1.67	1.76	2.77

[1]The length of time samples were taken are as follows: 1953—June 30 to October 27; 1954—April 12 to October 8; 1955—May 4 to September 22.

[2]Based on intended number of dips.

*Less than 0.1 per cent.

**Less than 0.01 per ~~cent.~~dip

Table 2B. Number and per cent (in parentheses) of mosquitoes dipped in impounded study areas during 1953 to 1955.

Species	Raymond Pond Number and Per Cent 1953	Raymond Pond 1954	Raymond Pond 1955	Shearness Pond[1] Number and Per Cent 1954	Shearness Pond[1] 1955
Anopheles					
bradleyi	12 (0.1)	17 (0.8)	3 (0.1)	4 (*)	
punctipennis		1 (*)	2 (*)		1 (*)
quadrimaculatus	799 (12.0)	160 (7.2)	465 (22.2)	1317 (16.1)	416 (8.9)
spp.	4 (*)	52 (2.3)	3 (0.1)	37 (0.5)	3 (*)
Total	815 (12.2)	230 (10.3)	473 (22.5)	1358 (16.6)	420 (8.9)
Aedes					
cantator	9 (0.1)	50 (2.2)	3 (0.1)	12 (0.1)	11 (0.2)
sollicitans	2 (*)	4 (0.2)	2 (*)	1 (*)	6 (0.1)
vexans	102 (1.5)	515 (23.1)	99 (4.7)	47 (0.6)	48 (1.0)
Total	113 (1.6)	569 (25.5)	104 (4.9)	60 (0.7)	65 (1.3)
Culex					
erraticus			2 (*)	2 (*)	
pipiens	13 (0.2)	1 (*)	17 (0.8)	81 (1.0)	4 (*)
restuans		8 (0.4)		1997 (24.4)	1 (*)
salinarius	5297 (79.9)	1373 (61.7)	1415 (67.6)	2637 (32.2)	3786 (80.6)
territans	69 (1.0)	14 (0.6)	25 (1.1)	28 (0.3)	222 (4.7)
spp.	1 (*)	3 (0.1)		14 (0.2)	1 (*)
Total	5380 (81.1)	1399 (62.8)	1459 (69.7)	4759 (58.1)	4014 (85.5)
Minor Genera					
Culista inornata		21 (0.9)	1 (*)	33 (0.4)	
morsitans		2 (0.1)		0.5 (*)	
spp.				0.5 (*)	
Psorophora ciliata	2 (*)				
confinnis	5 (0.1)	4 (0.2)	1 (*)		1 (*)
Uranotaenia sapphirina	314 (4.7)	1 (*)	55 (2.6)	1978 (24.2)	193 (4.1)
Total	321 (4.8)	28 (1.2)	57 (2.7)	2012 (24.6)	194 (4.1)
Grand Total of Mosquitoes	6629	2226	2093	8189	4693
Total Dips	4400	7540	5960	5660	4200
Average per Dip[3]	1.50	0.29	0.35	1.44	1.11

Table 2B. (Continued)

Species	Average for Impounded Area Number and Per Cent 1953[2]		1954		1955		Average per Dip[3] 1953[2]	1954	1955
Anopheles									
bradleyi	12	(0.2)	11	(0.2)	1.5	(*)	**	**	**
punctipennis			0.5	(*)	1.5	(*)		**	**
quadrimaculatus	799	(12.1)	739	(14.2)	441	(12.9)	0.18	0.11	0.08
spp.	4	(0.1)	45	(0.9)	3	(*)	**	**	**
Total	815	(12.4)	795.5	(15.3)	447	(13.1)	0.18	0.12	0.08
Aedes									
cantator	9	(0.1)	31	(0.6)	7	(0.2)	**	**	**
sollicitans	2	(*)	2	(*)	4	(0.1)	**	**	**
vexans	102	(1.5)	281	(5.4)	73	(2.1)	0.02	0.04	0.01
Total	113	(1.6)	314	(6.0)	84	(2.4)	0.02	0.04	0.01
Culex									
erraticus			1	(*)	1	(*)		**	**
pipiens	13	(0.2)	41	(0.8)	10.5	(0.3)	**	**	**
restuans			1003	(19.3)	0.5	(*)		0.15	**
salinarius	5297	(79.9)	2005	(38.5)	2601	(76.6)	1.22	0.30	0.51
territans	69	(1.0)	21	(0.4)	123	(3.6)	0.01	**	0.02
spp.	1	(*)	8	(0.2)	0.5	(*)	**	**	**
Total	5380	(81.1)	3079	(59.2)	2736.5	(80.5)	1.22	0.46	0.53
Minor Genera									
Culista inornata			27	(0.5)	0.5	(*)		**	**
morsitans			1	(*)				**	
spp.			0.2	(*)				**	
Psorophora ciliata	2	(*)					**		
confinnis	5	(0.1)	2	(*)	1	(*)	**	**	**
Uranotaenia sapphirina	314	(4.7)	989	(19.0)	124	(3.6)	0.07	0.14	0.02
Total	321	(4.8)	1019.2	(19.5)	125.5	(3.6)	0.07	0.14	0.02
Grand Total of Mosquitoes	6629		5208		3393				
Total Dips	4400		6600		5080				
Average per Dip[3]	1.50		0.78		0.66		1.50	0.78	0.66

[1]Unimpounded in 1953; see Table 2A.
[2]Only one impounded area sampled in 1953; figures for Raymond Pond substituted in lieu of average.
[3]Based on intended number of dips.
*Less than 0.1 per cent.
**Less than 0.01 per dip.

Table 3A. Number and per cent (in parentheses) of mosquitoes dipped in unimpounded study areas from June 29 to September 4 during 1953 to 1955.

Species	Check Area Number and Per Cent 1953	1954	1955	Bear Swamp Number and Per Cent 1953	1954	1955
Anopheles						
bradleyi	288 (3.3)	611 (6.8)	14 (0.1)	898 (23.1)	436 (39.0)	17 (2.0)
spp.	13 (0.1)	21 (0.2)		12 (0.3)	11 (0.9)	
Total	301 (3.5)	632 (7.0)	14 (0.1)	910 (23.4)	447 (40.0)	17 (2.0)
Aedes						
cantator	2606 (30.7)	2916 (32.4)	732 (7.7)	55 (1.4)	37 (3.3)	5 (0.6)
sollicitans	2610 (30.7)	1983 (22.0)	8658 (91.9)	262 (6.7)	529 (47.3)	807 (97.2)
taeniorhynchus			3 (*)			
vexans	153 (1.8)			2 (*)	1 (*)	
spp.	12 (0.1)	7 (*)	1 (*)		5 (0.4)	
Total	5381 (63.3)	4906 (54.6)	9394 (99.7)	319 (8.2)	572 (51.2)	812 (97.8)
Culex						
salinarius	2801 (32.9)	3435 (38.2)	13 (0.1)	2654 (68.3)	97 (8.6)	1 (0.1)
spp.				1 (*)	1 (*)	
Total	2801 (32.9)	3435 (38.2)	13 (0.1)	2655 (68.3)	98 (8.7)	1 (0.1)
Minor Genera						
Culiseta inornata				1 (*)		
Psorophora ciliata	5 (*)					
Total	5 (*)			1 (*)		
Grand Total of Mosquitoes	8488	8973	9421	3885	1117	830
Total Dips	1920	2000	2000	1920	1940	1500
Average per Dip[1]	4.42	4.48	4.71	2.02	0.57	0.55

Table 3A. (Continued)

Species	Shearness Area Number and Per Cent 1953		Average for Unimpounded Areas Number and Per Cent 1953		1954		1955		Average per Dip[1] 1953	1954	1955
Anopheles											
bradleyi	130	(13.9)	438.6	(9.8)	523.5	(10.3)	15.5	(0.3)	0.22	0.26	**
spp.	35	(3.7)	20	(0.4)	16	(0.3)			0.01	**	
Total	165	(17.6)	458.6	(10.3)	539.5	(10.6)	15.5	(0.3)	0.23	0.27	**
Aedes											
cantator	52	(5.5)	904.3	(20.3)	1476.5	(29.2)	368.5	(7.1)	0.47	0.74	0.21
sollicitans	36	(3.8)	969.3	(21.8)	1256	(24.8)	4732.5	(92.3)	0.50	0.63	2.70
taeniorhynchus							1.5	(*)			**
vexans			51.6	(1.1)	0.5	(*)			0.02	**	
spp.	7	(0.7)	6.3	(0.1)	6.0	(0.1)	0.5	(*)	**	**	**
Total	95	(10.1)	1931.6	(43.5)	2739	(54.2)	5103	(99.5)	1.00	1.39	2.91
Culex											
salinarius	669	(71.5)	2041.3	(46.0)	1766	(35.0)	7	(0.1)	1.06	0.89	**
spp.	6	(0.6)	2.3	(*)	0.5	(*)			**	**	
Total	675	(72.1)	2043.6	(46.0)	1766.5	(35.0)	7	(0.1)	1.06	0.89	**
Minor Genera											
Culiseta inornata			0.3	(*)					**		
Psorophora ciliata			1.6	(*)					**		
Total			1.9	(*)					**		
Grand Total of Mosquitoes	935		4436.3		5045		5125.5				
Total Dips	1910		1916.6		1970		1750				
Average per Dip[1]	0.48		2.31		2.56		2.92		2.31	2.56	2.92

[1]Based on intended number of dips.

*Less than 0.1 per cent.

**Less than 0.01 per [redacted]dip

Table 3B. Number and per cent (in parentheses) of mosquitoes dipped in impounded study areas from June 29 to September 4 during 1953 to 1955.

Species	Raymond Pond Number and Per Cent 1953	1954	1955	Shearness Pond[1] Number and Per Cent 1954	1955
Anopheles					
bradleyi	12 (0.1)		2 (0.1)	3.5 (0.1)	
quadrimaculatus	647 (10.0)	76 (9.1)	237 (15.6)	963.5 (27.1)	70 (7.0)
spp.	4 (*)	13 (1.5)	2 (0.1)	14 (0.4)	
Total	663 (10.3)	89 (10.7)	241 (15.9)	981 (27.6)	70 (7.0)
Aedes					
cantator	9 (0.1)	23 (2.7)	2 (0.1)	5.5 (0.1)	11 (1.1)
sollicitans	2 (*)	2 (0.2)	2 (0.1)	1 (*)	6 (0.6)
vexans	102 (1.5)	193 (23.3)	87 (5.7)	46 (1.2)	48 (4.8)
Total	113 (1.7)	218 (26.3)	91 (6.0)	52.5 (1.5)	65 (6.5)
Culex					
erraticus			1 (*)	1 (*)	
pipiens					3 (0.3)
restuans				1 (*)	1 (0.1)
salinarius	5258 (81.8)	513 (62.0)	1118 (74.0)	831.5 (26.0)	814 (81.8)
territans	69 (1.0)	3 (0.3)	3 (0.1)	10 (0.5)	5 (0.5)
spp.	1 (*)			5 (0.1)	1 (0.1)
Total	5328 (82.9)	516 (62.3)	1122 (74.3)	848.5 (26.6)	824 (82.8)
Minor Genera					
Psorophora ciliata	2 (*)				
confinnis	5 (*)	4 (0.4)	1 (*)		1 (0.1)
Uranotaenia sapphirina	314 (4.8)		55 (3.6)	1583 (44.1)	34 (3.4)
Total	321 (4.9)	4 (0.4)	56 (3.7)	1583 (44.1)	35 (3.5)
Grand Total of Mosquitoes	6425	827	1510	3465	994
Total Dips	2790	2850	2820	2500	2000
Average per Dip[3]	2.30	0.29	0.53	1.38	0.49

Table 3B. (Continued)

Species	Average for Impounded Areas Number and Per Cent 1953[2]		1954		1955		Average per Dip[3] 1953[2]	1954	1955
Anopheles									
bradleyi	12	(0.1)	1.7	(*)	1	(*)	**	**	**
quadrimaculatus	647	(10.0)	519.5	(24.2)	153.5	(12.2)	0.23	0.19	0.06
spp.	4	(*)	13.5	(0.6)	1	(*)	**	**	**
Total	663	(10.3)	535	(24.9)	155.5	(12.4)	0.23	0.20	0.06
Aedes									
cantator	9	(0.1)	14.2	(0.6)	6.5	(0.5)	**	**	**
sollicitans	2	(*)	1.5	(*)	4	(0.3)	**	**	**
vexans	102	(1.5)	119.5	(5.5)	67.5	(5.3)	0.03	0.04	0.02
Total	113	(1.7)	135.2	(6.3)	78	(6.2)	0.04	0.05	0.03
Culex									
erraticus			0.5	(*)	0.5	(*)		**	**
pipiens					1.5	(0.1)			**
restuans			0.5	(*)	0.5	(*)		**	**
salinarius	5258	(81.8)	672.2	(31.3)	966	(77.1)	1.88	0.25	0.40
territans	69	(1.0)	6.5	(0.3)	4	(0.3)	0.02	**	**
spp.	1	(*)	2.5	(0.1)	0.5	(*)	**	**	**
Total	5328	(82.9)	682.2	(31.7)	973	(77.7)	1.90	0.25	0.40
Minor Genera									
Psorophora ciliata	2	(*)					**		
confinnis	5	(*)	2	(*)	1	(*)	**	**	**
Uranotaenia sapphirina	314	(4.8)	791.5	(36.8)	44.5	(3.5)	0.11	0.29	0.01
Total	321	(4.9)	793.5	(36.9)	45.5	(3.6)	0.11	0.29	0.01
Grand Total of Mosquitoes	6425		2146		1252				
Total Dips	2790		2675		2410				
Average per Dip[3]	2.30		0.80		0.51		2.30	0.80	0.51

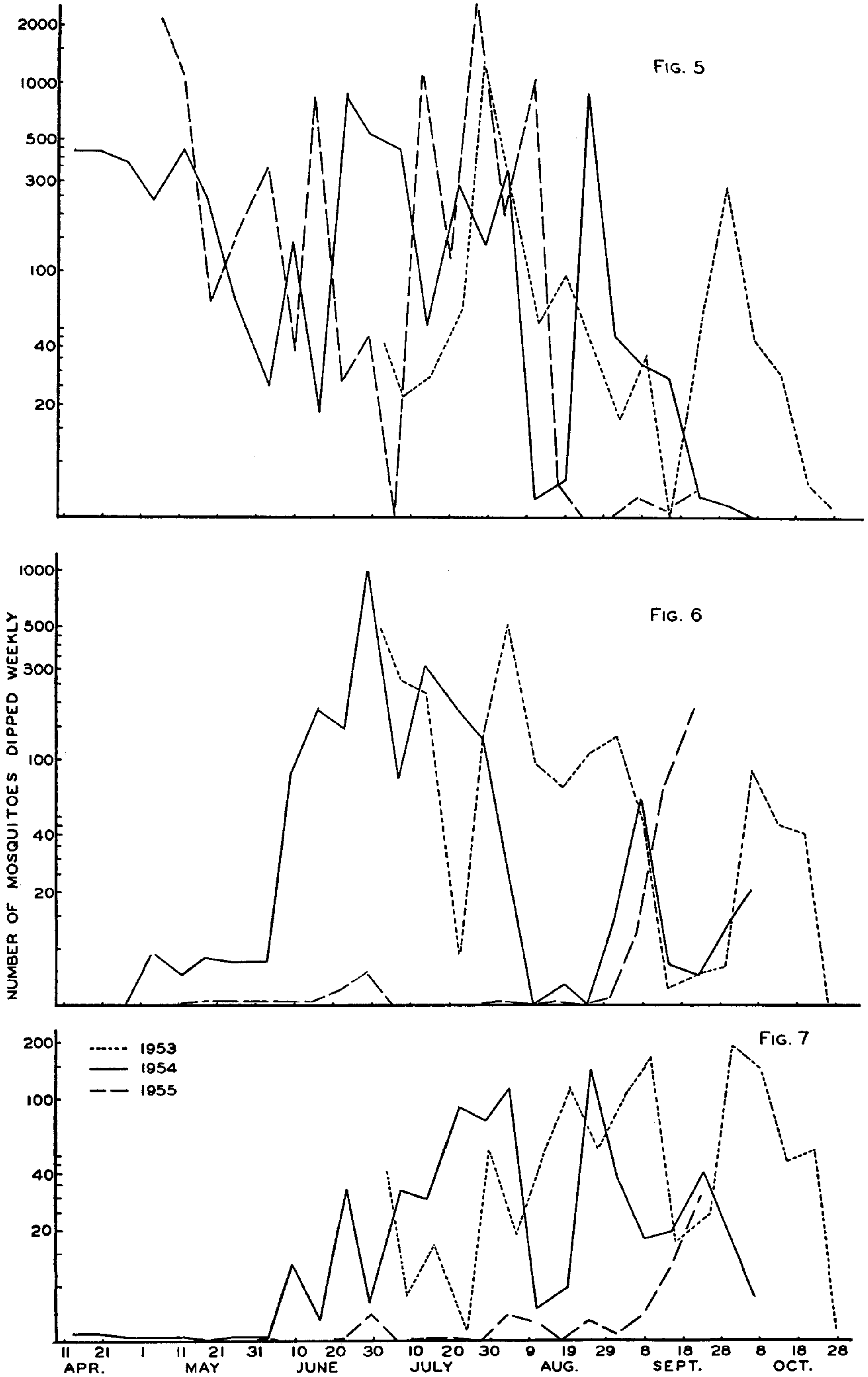
[1]Unimpounded in 1953: see Table 2B.
[2]Only one impounded area sampled in 1953; figures for Raymond Pond thus substituted in lieu of average. See Table 2B.
[3]Based on intended number of dips.
*Less than 0.1 per cent.
**Less than 0.01 per dip.

In the natural marsh, the proportions of species taken during the "control" season and the full dipping period were approximately the same, the most noteworthy difference being during the "control" season when relatively smaller numbers of *Anopheles* and of *Aedes* were dipped in 1953 and 1954, respectively, and relatively larger numbers of *Culex* were taken in 1954. These variances were due to the late fall build-up of *Anopheles,* the early spring brood of *Aedes* and the larger summer occurrences of *Culex.* Four fewer species were dipped in the salt-marshes during the "control" period. A like comparison of the impoundment record shows dissimilarity only in 1954 when *Anopheles* and *Uranotaenia* were greater and *Culex* fewer in number during the "control" season. The spring generation of *C. restuans* and the late fall increase in *C. salinarius* were chiefly responsible. Three fewer species were collected in the "control" season.

SEASONAL DISTRIBUTION. Since the dipping studies extended through most of the breeding season during the last two years, it is possible to obtain some indication of what part of the annual mosquito output actually occurs during the "control" season. In the unimpounded marshes, an average of 52 per cent of the total was taken in this restricted period, whereas in the impoundments but 40 per cent occurred during this time. It is interesting to note how much of the remaining breeding appeared before and after the "control" period. In the natural marshes, 46 per cent was spring breeding and only 2 per cent fall breeding. The impounded areas had a more even distribution, with 27 per cent of the breeding in the spring and 33 per cent in the fall. These data underline the more stable conditions and the presence of a greater number of species inhabiting the impoundments.

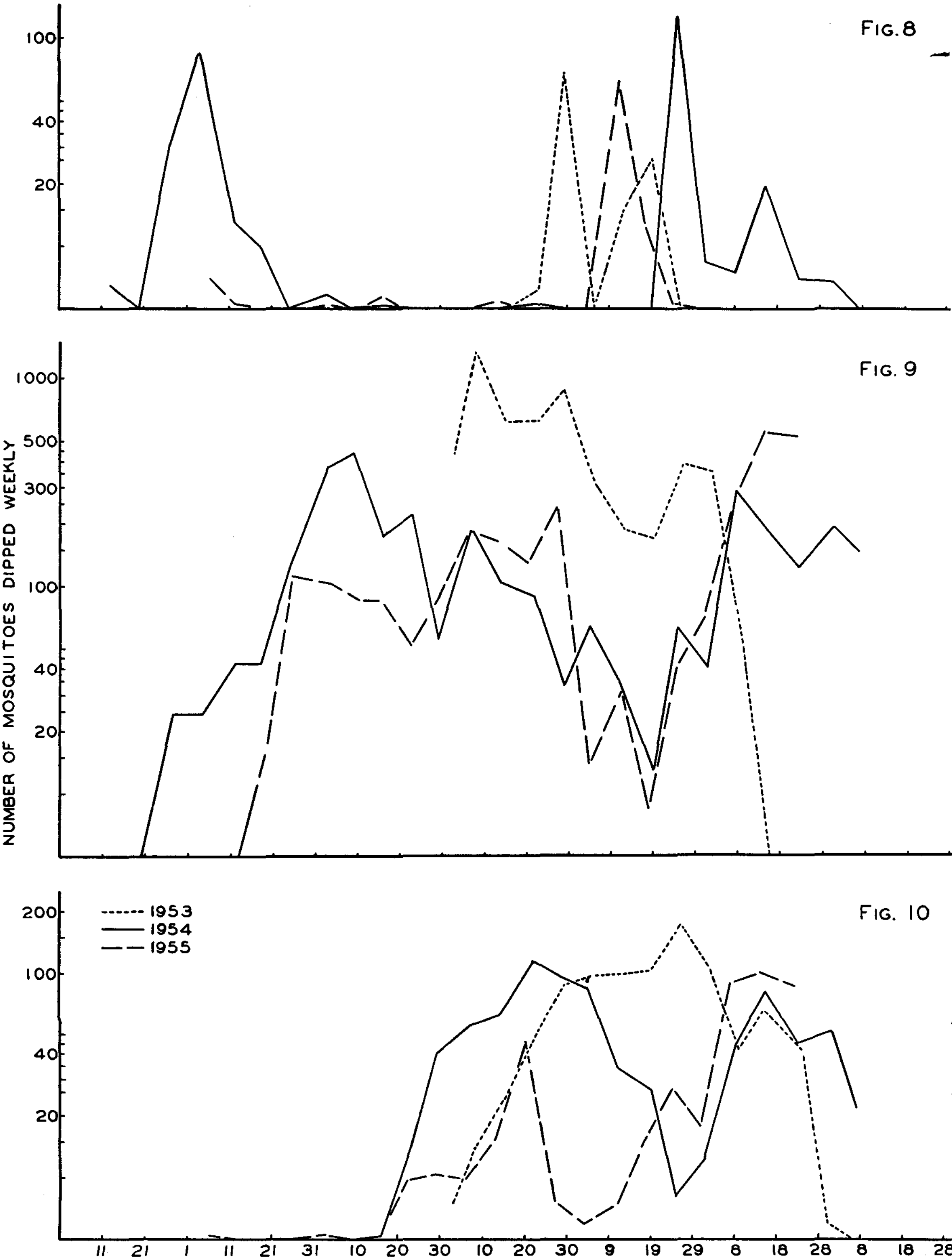
Figs. 5 and 8 show the respective seasonal distributions of *Aedes* mosquitoes in the salt marshes and in the impoundments. It appears that in the salt marsh there were five broods of *Aedes* each in 1954 and 1955, composed primarily of *A. sollicitans* and *A. cantator.* Six of these 10 broods were initiated by both rainfall and high tides, 3 by rain alone, and 1 by high tide alone. A heavy spring brood was always present in the marshes at the outset of dipping and developed slowly due to the cool seasonal temperatures. In all three years, broods occurred during the last 10 days of July. Species of this genus were collected infrequently at the margins of the fresh-water ponds. Only *A. vexans* was taken in numbers; however, it never approached the magnitude of its counterpart in the salt marsh. Their appearance was always correlated with heavy rainfall accompanied by a substantial rise of water level in the ponds.

The seasonal distribution of *Culex* in unimpounded and impounded areas is depicted in Figs. 6 and 9, respectively. Larvae of this genus were never found at the beginning of the sampling. The spring build-up was slow but breeding in fairly large numbers continued into October, as long as conditions remained favorable. In the tidal areas they bred following flooding and became numerous if successive rains or high tides kept holes filled with water. After a flooding, peaks of *Aedes* always preceded those of *Culex* (mostly *salinarius)* by at least one week. Due to an earlier lack of water in larval habitats, there was little build-up of salt-marsh *Culex* in 1955 until after the heavy mid-August rains. In the impoundments, breeding of *Culex,* Unimpounded



Figures 5 to 7. Seasonal occurrence of *Aedes* (5), *Culex* (6), and *Anopheles* (7) mosquitoes dipped in the unimpounded study areas during 1953 to 1955. Data for 1953 have been reduced by two-thirds; those for 1954 and 1955 by one-half to obtain comparative figures per study area.

Impounded



Figures 8 to 10. Seasonal occurrence of *Aedes* (8), *Culex* (9) and *Anopheles* (10) mosquitoes dipped in impounded areas during 1953 to 1955. Data for 1954 and 1955 have been reduced by one-half to obtain comparative figures per study area.

principally *salinarius,* was generally heavy. The first peak was reached around June 1.Fairly high populations, with minor fluctuations, were maintained throughout the season. The exception to this in both 1954 and 1955 occurred during the first part of August when severe drops were associated with the drying of larval breeding sites.

Seasonal *Anopheles* breeding in the natural and impounded salt marshes is shown in Figs. 7 and 10, respectively. The trends in both environments followed fairly closely those exhibited by *Culex* species. The build-up was slower and the initial highs were not reached until about a month after those of *Culex;* also, the numbers were never as great.

An interesting finding was fourth-instar larvae of *An. bradleyi* and *Culiseta inornata* (Williston) on April 13, 1954, in the salt-marsh areas. This observation and the fact that Bidlingmayer and Schoof (1956) found viable eggs of these species in Georgia salt-marsh soils during December and January lead to the conclusion that in Delaware these species may overwinter partly in the larval or egg stages. The same may be true of *C. salinarius* for these two workers also recovered this species from their sod samples, and the earliest larvae were dipped on April 26, 1954, in Shearness Pond. However, there was opportunity for hibernnating females to lay eggs since the average maximum temperature for April, 1954, was 70.1° F.

Relation to Certain Ecological Factors

VEGETATION: *Association of mosquitoes with vegetation types.* Previous studies have shown vegetation in coastal marshes to be influenced primarily by tidal fluctuations and to a lesser extent by salinity and other factors (Johnson and York, 1915); Daigh et al., 1938). These same factors also appear to have the greatest effect on mosquito breeding. For this reason, plant species and associations probably can be considered to be an expression of conditions which approximate those regulating the occurrence and abundance of mosquito sepcies. This relationship is of practical value since vegetation can serve as a means of rapidly appraising the mosquito breeding potential of an area. Also pertinent to this problem are the observations of Connell (1940) and Bidlingmayer and Klock (1955), who showed that the elevation of a marsh with respect to mean high tide is not an infallible indication of the extent of tidal flooding. According to the latter investigators, marsh flora is a more reliable index.

In the past, some attention has been devoted to correlations between types of marsh or marsh vegetation and mosquito breeding. As early as 1907, Smith recognized three general classes of marshes: (1) covered at every mean high tide—not a dangerous breeding area; (2) rarely covered by ordinary tides, but so little above mean high water that even the slightest rise results in watery cover—not a dangerous breeding site; (3) entirely above mean-high-tide level and more or less completely covered with vegetation (full moon and storm tides reach this area by trickling through the grass which acts as a barrier to fish)—prolific breeding here. Griffiitts (1929), DeVido (1936), Connell (1940) and King et al. (1944) concurred at least in part with Smith.

Table 4A. Number and per cent of mosquitoes dipped within the principal vegetation types of the unimpounded study areas during 1953 to 1955.[1]

Plant Species	Number or Per Cent	Year	*Anopheles* *bradleyi*	*Anopheles* spp.	*Anopheles* Total	*Aedes* *cantator*	*Aedes* *sollicitans*	*Aedes* *vexans*	*Aedes* spp.	*Aedes* Total
Saltgrass *(Distichlis spicata)*	Number	1953	314	3	317	333	939	63	6	1341
		1954	206	18	224	3297	1985		29	5311
		1955	27		27	1022	5834		1	6857
	Per Cent	**1953**	**15.3**	**0.1**	**15.4**	**16.2**	**45.8**	**3.0**	**0.2**	**65.5**
		1954	**3.6**	**0.3**	**3.9**	**58.3**	**35.1**		**0.5**	**93.9**
		1955	**0.3**		**0.3**	**14.8**	**84.6**		*	**99.5**
Saltmeadow Cordgrass *(Spartina patens)*[2]	Number	1953	469	8	477	506	450			956
		1954	322	12	334	1038	1218		13	2269
		1955	56		56	1969	4297			6269
	Per Cent	**1953**	**16.3**	**0.2**	**16.6**	**17.6**	**15.7**			**33.4**
		1954	**7.0**	**0.2**	**7.3**	**22.8**	**26.7**		**0.2**	**49.8**
		1955	**0.8**		**0.8**	**28.7**	**62.6**			**91.3**
Saltmarsh Cordgrass *(Spartina alterniflora)*[2]	Number	1953	194	15	209	316	413			729
		1954	168	4	172	159	481		1	641
		1955	9		9	573	1514			2087
	Per Cent	**1953**	**13.4**	**1.0**	**14.4**	**21.8**	**28.6**			**50.4**
		1954	**15.9**	**0.3**	**16.3**	**15.0**	**45.6**		*	**60.8**
		1955	**0.4**		**0.4**	**27.2**	**71.8**			**99.0**
Mixed Type I[3]	Number	1953	223	15	238	32	523	90	8	653
		1954	103	3	106	515	261		8	784
		1955[2]	10.5		10.5	89.5	985			1074.5
	Per Cent	**1953**	**20.2**	**1.3**	**21.5**	**2.9**	**47.4**	**8.1**	**0.7**	**59.2**
		1954	**9.8**	**0.2**	**10.1**	**49.1**	**24.9**		**0.7**	**74.8**
		1955	**0.9**		**0.9**	**8.2**	**90.6**			**98.8**
Phragmites *(Phragmites communis)*	Number	1953	90	40	130	35	6	2		43
		1954	35		35	198	16	3	1	219
		1955	5		5	248	22	1		271
	Per Cent	**1953**	**22.3**	**9.9**	**32.3**	**8.7**	**1.4**	**0.4**		**10.6**
		1954	**12.9**		**12.9**	**73.3**	**5.9**	**1.1**	**0.3**	**81.1**
		1955	**1.7**		**1.7**	**89.2**	**7.9**	**0.3**		**97.4**
Narrowleaf Cattail *(Typha angustifolia)*	Number	1953	63	6	69	20	8		7	35
	Per Cent	**1953**	**30.2**	**2.8**	**33.1**	**9.6**	**3.8**		**3.3**	**16.8**
Mixed Type II[3]	Number	1953	354	39	393	1				1
		1954	8	1	9	4	13			17
	Per Cent	**1953**	**81.9**	**9.0**	**90.9**	**0.2**				**0.2**
		1954	**15.6**	**1.9**	**17.6**	**7.8**	**25.4**			**33.3**
Mixed Type III[3]	Number	1953	32	51	83	18	29			47
	Per Cent	**1953**	**18.8**	**30.0**	**48.8**	**10.5**	**17.0**			**27.6**

[1]Small numbers of the following species were collected in the vegetation types during the years indicated and do not appear in the table except to be figured in the totals: *Aedes canadensis* (Theo.), 1 in phragmites, 1954; *Aedes taeniorhynchus* (Wied.), 3 in saltmeadow cordgrass, 1955; *Culex restuans* (Theo.), 1 in mixed type I, 1954; *Culex territans* (Walk.), 1 in saltmeadow cordgrass and 6 in mixed type I, 1954; *Culiseta morsitans* (Theo.), 1 in saltmarsh cordgrass, 1954.

Table 4A. (Continued)

Culex			Minor Genera						Salinity[5]		pH	
salinarius	spp.	Total	*Culiseta inornata*	*Psorophora ciliata*	Total	Grand Total	Total Dips	Average per Dip[4]	Range	Average	Range	Average
386		386		3	3	2047	880	2.32	24–64	46	3.8–7.4	6.1
113		113	5		5	5653	1300	4.34	13–51	30	6.4–7.0	6.7
3	1	4				6888	1050	6.56	27–65	46	6.4–7.6	6.8
18.8		**18.8**		**0.1**	**0.1**							
1.9		**1.9**	*		*							
*	*	*										
1426		1426	1	1	2	2861	860	3.32	26–58	40	5.8–8.2	6.7
1932	0.5	1933.5	11		11	4548	1300	3.49	6.4–42	31	6.8–8.3	7.1
534		534				6859	1050	6.53	24–63	44	6.5–7.5	6.8
49.8		**49.8**	*	*	*							
42.4	*	**42.5**	**0.2**		**0.2**							
7.7		**7.7**										
506		506				1444	860	1.67	33–58	42	6.2–7.4	6.8
231		231	8		8.5	1053	1300	0.81	9.7–56	37	6.8–7.4	7.0
10		10				2106	1050	2.00	17–65	43	6.4–7.2	6.7
35.0		**35.0**										
21.9		**21.9**	**0.7**		**0.7**							
0.4		**0.4**										
211		211		1	1	1103	880	1.25	30–57	40	3.3–7.3	6.2
150		157				1047	1300	0.80	7.0–51	27	6.8–7.9	7.4
1.5		1.5				1086.5	1050	1.03	16–69	42	5.8–7.2	6.6
19.1		**19.1**		*	*							
14.3		**14.9**										
0.1		**0.1**										
229		229				402	880	0.45	35–50	41	6.4–7.2	6.9
16		16				270	1240	0.21	7.5–46	30	6.8–7.3	7.1
2		2				278	1050	0.26	25–44	34	6.5–7.1	6.8
56.9		**56.9**										
5.9		**5.9**										
0.7		**0.7**										
103	1	104				208	840	0.24	36–50	41	6.6–7.3	6.9
49.5	**0.4**	**50.0**										
37	1	38				432	880	0.49	36–46	41	6.5–8.1	7.1
25		25				51	1300	0.03	10–50	33	6.7–7.9	7.4
8.5	**0.2**	**8.7**										
49.0		**49.0**										
35	5	40				170	810	0.20	36–50	43	6.3–7.4	6.8
20.5	**2.9**	**23.5**										

[2]These types were sampled in more than one area, but the results are expressed as the average per single area.
[3]See text for explanation of mixed types.
[4]Based on intended number of dips.
[5]Expressed as per cent of the mean salinity of Atlantic Ocean water—32,210 p.p.m.
*Less than 0.~~0~~1 per cent.

DeVido associated saltmarsh cordgrass with marsh-class 1, glasswort *(Salicornia*—probably *europea)* with marsh-class 2, and saltmeadow cordgrass and black rush *(Juncus gerardi)* with marsh-class 3. He stated that pure stands of three-square on the upland side of the third zone are not a mosquito menace, but if mixed with saltgrass favor *A. cantator*. Griffitts as well as Ferrigno and MacNamara (1957) agreed with DeVido that little breeding occurs in saltmarsh cordgrass but Cory and Crosthwait (1939) and Chapman and Ferrigno (1956) observed greater production. Saltmeadow cordgrass was found to be a heavy producer of salt-marsh *Aedes* by Ferrigno and MacNamara and by Cory and Crosthwait, although Griffitts believed it to be an unimportant type. When saltmeadow cordgrass and saltmarsh cordgrass occur in mixed strands, mosquito production is heavy (Chapman and Ferrigno, Ferrigno and MacNamara). Viereck (see Smith, 1904) observed generally little breeding in three-square, as did Chapman and Ferrigno in Olney's three-square; however, Cory and Crosthwait noted variable production in the latter type. Viereck, Britton (1912), Griffitts, King (1939) and Bidlingmayer and Klock (1955) all agreed that saltgrass is characteristic of heavy *Aedes* breeding, but the findings of Chapman and Ferrigno were not in accord. Saltgrass also was found by Griffitts (1921) to be the principal habitat of *Anopheles crucians* Wied. (= *bradleyi* of this report).

Since the sampling stations at Bombay Hook were located within stands of particular species or associations of species, the breeding potential of the dominant vegetation in the study areas could be assayed. In the natural marshes, by far the most breeding was found in saltgrass and saltmeadow cordgrass, see Table 4A. Actually, three-fourths of all larvae dipped in the salt-marsh areas were from these types. Generally, a much higher percentage of *Aedes* species was taken in saltgrass than in saltmeadow cordgrass, where *C. salinarius* and *An. bradleyi* were prevalent at times. Saltmarsh cordgrass comprised the third most productive part of the salt marsh. Fewer than half as many larvae developed here as in either of the previous two types. Furthermore, stations nearest the upland in this type and mixed with saltmeadow cordgrass had 20 to 90 times as much breeding as those farther out. The remaining types in order of decreasing productivity were mixed type I, phragmites, cattail, and mixed types II and III. The mosquito species in mixed type I (comprised primarily of a saltmeadow cordgrass—saltgrass—Olney's three-square association) compared closely with those found in pure stands of both saltmeadow cordgrass and saltgrass. Contrary to the belief of DeVido, mixed type I did not seem to be particularly attractive to *A. cantator* for in two of the three years that it was sampled, this mosquito represented only 3 and 8 per cent of the total breeding. Unfortunately, pure stands of Olney's three-square were not available for evaluation. It is interesting to note that *An. bradleyi* constituted 91 per cent of the mosquitoes taken during 1953 in mixed type II (the sprangletop-saltmeadow cordgrass-saltgrass-dwarf spikerush association).

Although the greatest production of salt-marsh mosquitoes occurred in saltgrass and saltmeadow cordgrass, certain stations or portions of stations within these types produced very few mosquitoes. The most obvious explanation appears to be local variations in topography and drainage which, in turn, influenced water relationships. This factor may account for the variation in findings of other workers on the mosquito potential of vegetation types.

In impounded salt marshes, Chapman and Ferrigno (1956) found that the greatest populations of all mosquitoes in each of three years occurred in cattail, followed by phragmites and softstem bulrush, *Scirpus validus.*

Hess and Hall (1945) have correlated breeding of *An. quadrimaculatus* with certain types of vegetation. Several important plant types recognized by these authors and the species at Bombay Hook within these categories are as follows:

Type	*Bombay Hook Representative*
Wetland:	
Erect leafy	Swampdock
Erect naked	Phragmites
Flexuous	Switchgrass, wild millet
Aquatic:	
Erect leafy	Rosemallow
Erect naked	Three-square, cattail
Submerged	Pondweeds, algae

They found that the breeding potential was high in flexuous and submerged types, medium in erect leafy plants, and low among erect naked species. Similar observations were made by Rozeboom and Hess (1944) who noted a close positive correlation between the amount of intersection line (intersection between plants and water surface) and *An. quadrimaculatus* production.

The kinds and numbers of larvae dipped within the various vegetation types associated with impounded marshes are tabulated in Table 4B. There was no one plant species in which the greatest number of larvae was found every year. In 1953, phragmites with associated scattered growth of algae and duckweed had the highest production, 93 per cent of which was *C. salinarius.* The next year, swampdock had the greatest number of mosquitoes, mostly *An. quadrimaculatus* and *U. sapphirina.* A close second that year was woods edge where *C. restuans* dominated. Both swampdock and woods edge occurred in the newly flooded Shearness Pond. The leading type in 1955 was woods edge, in which *C. salinarius* was the principal mosquito. A total of 14 species, more than in any other type, was taken in cattail, indicating favorable conditions for spring, summer and fall breeders. For the short time that the wild millet association was sampled (7 weeks), it yielded a surprising number of mosquitoes, viz., 11 species in four genera.

The production potential of *An. quadrimaculatus* in three-square, cattail, rosemallow and phragmites agreed closely with the ratings given by Hess and Hall as long as water was present in quantity. Local conditions, however, caused differences in production in the remaining types. Large numbers were present in swampdock in 1954 and appeared to be primarily a reflection of scattered associated growths of coontail *(Ceratophyllum*

Table 4B. Number and per cent of mosquitoes dipped within the principal vegetation types of the impounded study areas during 1953 to 1955[1]

Plant Species	No. or %	Year	*Anopheles* *bradleyi*	*Anopheles* *punctipennis*	*Anopheles* *quadrimaculatus*	*Anopheles* spp.	*Anopheles* Total	*Aedes* *cantator*	*Aedes* *sollicitans*	*Aedes* *vexans*	*Aedes* Total	*Culex* *pipiens*	*Culex* *restuans*	*Culex* *salinarius*
Phragmites	No.	1953	1		176	3	180			26	26			3911
(Phragmites		1954	1		9	7	17	4	0.5	78	82.5			447
communis)[2]		1955	1		79		80	2		9	11			730
	%	1953	*		4.1	*	4.2			0.6	0.6			93.2
		1954	0.1		1.6	1.2	3.0	0.7	*	14.1	14.9			81.1
		1955	0.1		9.2		9.3	0.2		1.0	1.2			85.6
Broadleaf and	No.	1953	11		74		85			46	46	13		949
Narrowleaf		1954			1	2	3	4		124	128		0.5	735
Cattail		1955		0.5	24		24.5	0.5		45	45.5	6		846
(Typha	%	1953	0.9		6.3		7.3			3.9	3.9	1.1		81.7
latifolia and		1954			0.1	0.2	0.3	0.4		14.1	14.5		*	83.7
angustifolia)[2]		1955		*	2.5		2.5	*		4.7	4.8	0.6		89.7
Switchgrass	No.	1953			189	1	190			3	3			312
(Panicum		1954	1		139	4	144	3	0.5	30	33.5		0.5	347
virgatum)[2]		1955	1	0.5	144	2	147.5	2	2	21	25			580
	%	1953			34.7	0.1	34.9			0.5	0.5			57.3
		1954	0.1		25.6	0.7	26.5	0.5	*	5.5	6.1		*	64.0
		1955	0.1	*	18.7	0.2	19.2	0.2	0.2	2.7	3.2			75.6
Rosemallow	No.	1953			228		228	9	2	27	38			125
(Hibiscus		1954												2
moscheutos)		1955	1		80	1	82							12
	%	1953			38.2		38.2	1.5	0.3	4.5	6.3			20.9
		1954												100
		1955	0.9		77.6	0.9	79.6							11.6
Pondweeds	No.	1953			75		75							
(Potamogeton sp.		1954	3		56	3	62							
and *Ruppia* sp.)		1955			83		83							
	%	1953			98.4		98.4							
		1954	4.8		90.3	4.8	100.0							
		1955			100.0		100.0							
Algae	No.	1953			57		57							1
(Rhizoclonium		1954			32	4	36					5		
sp.)		1955			13		13							
	%	1953			100.0		100.0							
		1954			86.4	10.8	97.2							2.7
		1955			72.2		72.2					27.7		
Woods Edge	No.	1954	1		14	8	23	8		0.5	8.5	80	1994	545
		1955			218		218	7	3	8	18	3	1	1582
	%	1954	*		0.4	0.2	0.8	0.2		*	0.3	2.8	70.6	19.3
		1955			10.2		10.2	0.3	0.1	0.3	0.8	0.1	*	74.0
Swampdock	No.	1954			1025	20	1045						1	
(Rumex		1955			8		8							26
verticillatus)	%	1954			35.3	0.6	36.0						*	
		1955			7.4		7.4							24.2
Wild Millet	No.	1954	11	1	51	28	91	30	3	100	133	1	8	405
(Echinochloa walteri)	%	1954	1.6	0.1	7.8	4.3	13.9	4.7	0.4	15.3	20.4	0.1	1.2	62.2
Three-square	No.	1955		1	65		66							
(Scirpus americanus)	%	1955		1.5	98.4		100.0							

[1]Small numbers of the following species were collected in the vegetation types during the years indicated and do not appear in the table except to be figured in the totals: *Culex erraticus* (D. & K.), 2 in swampdock, 1954, and 2 in rosemallow, 1955; *Culiseta morsitans* (Theo.), 1 in phragmites, 1 in cattail, and 1 in woods edge, 1954; *Culiseta* spp., 1 in woods edge, 1954; *Psorophora ciliata* (Fabr.), 2 in cattail, 1953.

Table 4B. (Continued)

Culex			Minor Genera							Salinity[4]		pH	
territans	spp.	Total	*Culiseta inornata*	*Psorophora confinnis*	*Uranotaenia sapphirina*	Total	Grand Total	Total Dips	Average per Dip[3]	Range	Average	Range	Average
14		3925			64	64	4195	800	5.24	1.5– 2.0	1.6	6.3– 8.6	7.2
1	1	449	0.5		1	2	551	1175	0.46	2.1– 7.7	4.6	5.8– 8.0	6.7
3		733			28	28	852	1050	0.81	1.3– 4.3	3.2	6.7– 9.0	7.3
0.3		**93.5**			**1.5**	**1.5**							
0.1	**0.1**	**81.4**	*		**0.1**	**0.2**							
0.3		**86.0**			**3.2**	**3.2**							
18		980			48	50	1161	800	1.45	1.5– 1.6	1.5	6.1– 7.8	6.7
0.5		736	10			10.5	878	1215	0.72	1.8– 6.7	4.3	5.1– 6.8	6.4
10		862	0.5	0.5	10	11	943	1050	0.89	1.9– 4.9	3.6	5.8– 7.4	6.7
1.5		**84.4**			**4.1**	**4.3**							
*		**83.8**	**1.1**			**1.1**							
1.0		**91.4**	*	*	**1.0**	**1.1**							
		312			39	39	544	790	0.68	1.5– 1.8	1.6	6.4– 8.9	7.2
4	0.5	352			12	12	542	1200	0.45	1.1– 6.7	3.5	4.9– 7.3	6.5
1		581		0.5	13	13.5	767	1050	0.73	3.1– 6.9	4.5	6.6– 7.8	7.3
		57.3			**7.1**	**7.1**							
0.7	*	**64.9**			**2.2**	**2.2**							
0.1		**75.7**		*	**1.6**	**1.7**							
37		162		5	163	168	596	800	0.74	1.6– 5.0	2.5	6.6– 8.5	7.0
		2					2	1300	0.001	2.7–14.0	5.2		
1		15			6	6	103	1050	0.09	3.0– 5.2	4.1	6.7– 7.8	7.2
6.2		**27.1**		**0.8**	**27.3**	**28.2**							
		100											
0.9		**14.5**			**5.8**	**5.8**							
	1	1					76	760	0.10	1.6– 2.5	2.1	6.9–10.0	7.9
							62	1140	0.05	2.6– 6.0	4.2	7.9– 9.4	8.7
							83	830	0.10	2.7– 6.1	4.1	7.1– 7.5	7.3
	1.3	**1.3**											
							57	450	0.12	1.6– 2.0	1.8	6.7– 9.2	8.0
		1					37	980	0.03	3.0– 6.5	4.4	9.2	9.2
		5					18	570	0.03	3.3– 4.7	3.9	7.0– 7.7	7.4
		2.7											
		27.7											
17	9	2645	33		111	145	2822	1300	2.17	2.4– 6.4	4.0	6.2– 6.8	6.5
192	1	1779			122	122	2137	1050	2.03	0.9– 4.1	2.8	6.5– 6.8	6.6
0.6	**0.3**	**93.7**	**1.1**		**3.9**	**5.1**							
8.9	*	**83.2**			**5.7**	**5.7**							
5	4	12			1842	1842	2899	1100	2.63	0.2– 0.7	0.3	6.2– 6.8	6.5
28		54			45	45	107	1050	0.10	0.2– 0.7	0.3	6.0– 6.5	6.2
0.1	**0.1**	**0.4**			**63.5**	**63.5**							
26.1		**50.4**			**42.0**	**42.0**							
8	1	423		4		4	651	310	2.10	4.2– 4.6	4.4	5.8– 6.7	6.2
1.2	**0.1**	**64.9**		**0.6**		**0.6**							
							66	350	0.18				

[2]These types were sampled in more than one area, but the results are expressed as the average per single area.
[3]Based on intended number of dips.
[4]Expressed as per cent of the mean salinity of Atlantic Ocean water—32,210 p.p.m.
*Less than 0.1 per cent.

demersum) and duckweed, both of which have high anopheline production potentials. The seasonal growths of pondweeds and algae provided only light breeding, and production in switchgrass and wild millet was but moderate to light due to the limited duration of flooding.

Muskrat houses occurred mainly in cattail and reed. Mosquitoes, principally *C. salinarius,* dipped immediately adjacent to houses, comprised over one-fifth of all those taken in the impounded areas. At the stations involved, 7 to 15 times more mosquitoes per dip were taken next to muskrat houses than away from them. Cover, provided by houses, and a probable ready source of blood for females, appeared to favor their production. However, the foregoing data present a distorted picture of the total impoundment output, since the houses themselves comprised but a very small portion of the total impounded marshlands.

An examination of the roots of aquatic plants for larvae of *M. perturbans* in Shearness Pond in late April, 1955, showed narrowleaf cattail to be the most productive host. An average of 0.8 larva (third and fourth instars) was obtained per stalk. Sampling the previous October (1954) revealed an average of only 0.007 larva (second instar) per stalk. However, due to their small size at this season, some probably passed through the larger-mesh screen used then. The survey in mid-April, 1956, indicated an average of but 0.008 larva (fourth instar) per stalk. No larvae were found attached to roots of swamp-dock, waterwillow or arrowhead *(Sagittaria latifolia).* No *Mansonia* larvae were found in Raymond Pond during the three years. In continuously flooded impoundments Chapman and Ferrigno (1956) noted a range of 0 to 64 larvae per cattail plant.

VEGETATION: *Associations of Mosquitoes With Each Other Within Vegetation Types.* Some authors have associated the occurrence of mosquito larvae without regard to the specific vegetational habitats. For instance, Owens (1937) and Dorsey (1944) associated all species collected within a geographical area during a certain period of time. The latter reference was concerned with the mosquito fauna of the tidal marshes and nearby upland of the lower Chesapeake Bay area, the species being very similar to those inhabiting Bombay Hook.

The larval associations within the five most heavily populated vegetation types in both the unimpounded and impounded marshes were tabulated for all three years, see Tables 5 to 9. In the areas of heaviest salt-marsh *Aedes* breeding, viz., saltgrass and saltmeadow cordgrass, *A. cantator* and *A. sollicitans* larvae were taken together many more times than alone or with another species. The same is true for *An. bradleyi* and *C. salinarius* in saltmeadow cordgrass. Of the major saline-water breeders, *A. cantator* and *C. salinarius* were least often dipped alone, except in phragmites where breeding was rather light. More species, not usually connected with tidal conditions, were found in mixed type I, the combination of saltmeadow cordgrass, saltgrass, Olney's three-square and other plants. Except in growths of three-square, algae and pondweeds, large numbers of mosquito species occurred in all the fresh-water vegetation types, with cattail having the most varied fauna. As previously noted, only *C. salinarius* was very numerous. Contrary to the record in the

Table 5. Number of times mosquito species occurred alone and with each other in saltmeadow cordgrass (upper right) and saltmarsh cordgrass (lower left) in unimpounded areas, 1953 to 1955.

	SALTMARSH CORDGRASS					SALTMEADOW CORDGRASS							
	Anopheles bradleyi	*Aedes cantator*	*Aedes sollicitans*	*Culex salinarius*	*Culiseta inornata*	*Anopheles bradleyi*	*Aedes cantator*	*Aedes sollicitans*	*Culex salinarius*	*Culiseta inornata*	*Psorophora ciliata*	*Aedes taeniorhynchus*	*Culex territans*
Anopheles bradleyi	90					34	46	64	75				1
Aedes cantator	22	10					18	93	58	6			1
Aedes sollicitans	32	46	40					47	57	4	1	1	1
Culex salinarius	44	28	32	26					11	2			2
Culiseta inornata		4	5	3									
Culiseta morsitans		1	1	1	1								

Table 6. Number of times mosquito species occurred alone and with each other in mixed type I (upper right) and saltgrass (lower left) in unimpounded areas, 1953 to 1955.

	SALTGRASS: *Anopheles bradleyi*	SALTGRASS: *Aedes cantator*	SALTGRASS: *Aedes sollicitans*	SALTGRASS: *Culex salinarius*	SALTGRASS: *Aedes vexans*	MIXED TYPE I: *Anopheles bradleyi*	MIXED TYPE I: *Aedes cantator*	MIXED TYPE I: *Aedes sollicitans*	MIXED TYPE I: *Culex salinarius*	MIXED TYPE I: *Aedes vexans*	MIXED TYPE I: *Psorophora ciliata*	MIXED TYPE I: *Culex territans*	MIXED TYPE I: *Culex restuans*
Anopheles bradleyi	25					33	10	25	15				
Aedes cantator	48	16					16	41	14			2	1
Aedes sollicitans	46	94	38					40	19	1	1		
Culex salinarius	26	26	23	2					9			1	1
Aedes vexans	2	2	2	2							1		
Psorophora ciliata	2	2	2	2	2								
Culex territans													1
Culiseta inornata		1											

Table 7. **Number of times mosquito species occurred alone and with each other in phragmites in impounded areas (upper right) and in unimpounded areas (lower left), 1953 to 1955.**

IMPOUNDED

	Anopheles quadrimaculatus	*Aedes vexans*	*Culex salinarius*	*Culex territans*	*Uranotaenia sapphirina*	*Anopheles bradleyi*	*Aedes cantator*	*Aedes sollicitans*	*Culiseta inornata*	*Culiseta morsitans*
Anopheles quadrimaculatus	15	4	15	2	7	2				
Aedes vexans		6	5	1	1		5			
Culex salinarius			49	8	12	1				
Culex territans				2	1	1	1			
Uranotaenia sapphirina					2					
Anopheles bradleyi						1				
Aedes cantator							1			
Aedes sollicitans								1		
Culiseta inornata									1	
Culiseta morsitans										1

UNIMPOUNDED

	Anopheles bradleyi	*Aedes vexans*	*Culex salinarius*	*Aedes cantator*	*Aedes sollicitans*
Aedes vexans	2				
Culex salinarius	6	1	12		
Anopheles bradleyi	28				
Aedes cantator	6	4	5	23	
Aedes sollicitans	3	2	1	16	3
Aedes canadensis	2	1	2		

Table 8. **Number of times mosquito species occurred alone and with each other in cattail (upper right) and woods edge (lower left) in impounded areas, 1953 to 1955.**

CATTAIL

	Anopheles quadrimaculatus	*Aedes vexans*	*Culex salinarius*	*Culex territans*	*Uranotaenia sapphirina*	*Anopheles bradleyi*	*Aedes cantator*	*Anopheles punctipennis*	*Culex pipiens*	*Culex restuans*	*Culiseta inornata*	*Psorophora confinnis*	*Culiseta morsitans*	*Psorophora ciliata*
Anopheles quadri-maculatus	18	2	22	6	9	1								1
Aedes vexans		21	4				4				3	1	1	1
Culex salinarius			103	12	14	2			4	1	1			1
Culex territans					2	1			1					
Uranotaenia sapphirina														
Anopheles bradleyi						1								
Aedes cantator							1				1			
Anopheles punctipennis								1						
Culex pipiens														
Culex restuans														
Culiseta inornata											1			
Culiseta morsitans														
Aedes sollicitans														

WOODS EDGE

	Anopheles quadrimaculatus	*Aedes vexans*	*Culex salinarius*	*Culex territans*	*Uranotaenia sapphirina*	*Anopheles bradleyi*	*Aedes cantator*	*Culex pipiens*	*Culex restuans*	*Culiseta inornata*
Anopheles quadri-maculatus	3									
Aedes vexans										
Culex salinarius	28	1	31							
Culex territans	11		17	2						
Uranotaenia sapphirina	17		25	8	2					
Anopheles bradleyi	1		3		2	1				
Aedes cantator			4		1		2			
Anopheles punctipennis										
Culex pipiens	1		7	1	2					
Culex restuans	2	1	34	4	6	2	2	7	12	
Culiseta inornata		1	13	2				2	12	
Culiseta morsitans			1							1
Aedes sollicitans		1					1			

Table 9. Number of times mosquito species occurred alone and with each other in switchgrass (upper right) and wild millet (lower left) in impounded areas, 1953 to 1955.

SWITCHGRASS

	Anopheles quadrimaculatus	*Aedes vexans*	*Culex salinarius*	*Uranotaenia sapphirina*	*Anopheles bradleyi*	*Aedes cantator*	*Aedes sollicitans*	*Culex territans*	*Culex restuans*	*Anopheles punctipennis*	*Psorophora confinnis*
Anopheles quadrimaculatus	50	4	31	15	1	2	2	4		1	
Aedes vexans		5	4	1		4	3				1
Culex salinarius			27	16	1	4	3	5	1		
Uranotaenia sapphirina				1	1	1	1	2			
Anopheles bradleyi					1						
Aedes cantator							2	1			
Aedes sollicitans								1			
Culex territans								1			
Culex restuans											
Psorophora confinnis											
Culex pipiens											
Anopheles punctipennis											

WILD MILLET

	Anopheles quadrimaculatus	*Aedes vexans*	*Culex salinarius*	*Anopheles bradleyi*	*Aedes cantator*	*Culex territans*
Anopheles quadrimaculatus	6					
Aedes vexans						
Culex salinarius	8	4	6			
Uranotaenia sapphirina						
Anopheles bradleyi	2		5			
Aedes cantator		5	3	1		
Aedes sollicitans		2	1	1	2	1
Culex territans		2	4	1	3	
Culex restuans	1		2	2		
Psorophora confinnis		1			1	
Culex pipiens			1			
Anopheles punctipennis	1		1			

saltmarsh, this species was more often taken alone in the impoundments, even though it also occurred with more species than any other mosquito. Its principal associates were *An. quadrimaculatus* in most vegetation types plus *C. restuans* and *U. sapphirina* in woods edge. Because of space limitations, no table of mosquito associations is presented for swampdock, in which *An. quadrimaculatus* and *U. sapphirina* were companion species.

SALINITY. Bates (1949) held that mosquito species known to breed in saline waters are characterized by a tolerance for this condition rather than a preference for it. In this connection, he regarded the chief difference between species to be their range of tolerance, and concluded that relatively few, if any, species are strictly confined to water of high salinity. In the present study, a total of 18 species was dipped from all fresh- and salt-marsh areas. Only three were found chiefly in saline waters. The total numbers dipped in the three years and the percentage of each from saline- and fresh-water situations are as follows: *A. sollicitans*—24,936 (99.0 versus 0.06), *A. cantator*—13,962 (99.3 versus 0.6), and *An. bradleyi*—3563 (98.9 versus 1.0). The other common species in the salt marsh was *C. salinarius*. A total of 26,534 were taken of which 45 per cent was from saline and 55 per cent from fresh water. Salt-marsh selectivity among ovipositing females of the first three species is obvious, but may not be true of *C. salinarius*.

The occurrence of tidal-marsh species with respect to salinity has been treated by Smith (1904), Chidester (1916), Griffitts (1929), Richards (1938), Cory and Crosthwait (1939) and Connell (1940). These workers agreed that *A. sollicitans* breeds in water of higher salinity than does *A. cantator*.

Since salinity of the water at several dipping stations in each of the vegetation types was determined on an average of but once a month during each breeding season, only those species collected on or within two days of the time that the water samples were taken were considered in the data in Table 10. The number of readings refers to the number of times that species were present when salinity values were calculated.

The average salt content of *A. sollicitans* habitat in this study compares favorably with that of 37 per cent of ocean water listed by Cory and Crosthwait, but their figures for *A. cantator, An. bradleyi* (= *crucians* of their report) and *C. salinarius* are all considerably lower than those for the Bombay Hook marshes. Vogt (1947) studied the distribution of *An. quadri*maculatus and *An. bradleyi* in relation to the salinity of waters bordering the Chesapeake Bay. He found that *An. bradleyi* and its associate, *C. salinarius,* were distributed with little regard to salinity within the levels recorded (4.3—19 per cent of ocean water), but that continuous, substantial numbers of *An. quadrimaculatus* larvae occurred only in salinities no higher than 9.4 per cent of ocean water. In one instance, they were found in quantity in water of 16 per cent of ocean salinity. At Bombay Hook, *An. quadrimaculatus* was restricted to the impoundments and was never found where the salinity exceeded 6.1 per cent of ocean water, although the highest salinity usually recorded in the ponds was only 7.4 per cent of ocean water. *An. bradleyi,* however, tolerated a salinity as high as 57 per cent of ocean water

Table 10. Salinity of mosquito habitat water in study areas, 1953 to 1955, expressed as per cent of mean ocean salinity.[1]

Species	Unimpounded				Impounded			
	Number of Readings	Lowest	Highest	Mean	Number of Readings	Lowest	Highest	Mean
Anopheles bradleyi	65	8.4	57	39	4	1.6	4.9	3.7
quadrimaculatus					42	0.2	6.1	2.9
Aedes cantator	35	7.9	61	30	5	2.4	5.1	3.4
sollicitans	47	7.9	65	35	3	1.4	5.1	3.3
vexans	1	—	—	37	8	1.6	5.3	3.1
Culex erraticus					1	—	—	5.1
pipiens					3	3.4	4.9	4.2
restuans	1	—	—	19	5	2.4	4.9	3.8
salinarius	39	7.9	51	34	37	0.2	6.9	3.7
territans	1	—	—	19	9	0.2	5.1	3.0
Culiseta inornata	2	8.4	18	13	3	2.4	3.4	2.7
morsitans	1	—	—	18	2	—	—	2.4
Uranotaenia sapphirina					15	0.2	4.9	2.2

[1]Mean salinity of the Atlantic Ocean is 32,210 p.p.m.

and the average of all readings in the natural marshes was 39 per cent of ocean water. These values agree with the statement of Bradley and King (1941) that *An. bradleyi* usually breeds in waters having a salts content of 1.5 per cent (46 per cent of ocean salinity) or less.

As pointed out by Williams (1956), a discrepancy about the use of saline versus fresh-water habitats by *C. salinarius* has accrued in the literature. The type material was collected by Prof. J. B. Smith in New Jersey, who concluded that it is essentially a salt-water species (Coquillett, 1904). Smith (1904), Symons *et al.* (1906), Headlee (1915) and Rings and Richmond 1953 reported *C. salinarius* larvae in salt as well as fresh water. Dyar (1928), Griffitts (1931), King *et al.* (1944), Dorsey (1944) and Carpenter *et al.* (1946) stated that the larvae are found in either fresh or brackish water. The salinity of oviposition sites of *C. salinarius* females was tested by Wallis (1954). He found that they actually preferred fresh water, but will tolerate a broad range of salinity concentrations extending to 1.5 per cent. Williams noted larvae in water of which the salinity was 33 to 40 per cent of ocean water. Against this accumulation of information is a number of references beginning with Dyar and Knab (1906) who believed that "this species is unfortunately misnamed, for it never lives in salt water." Howard *et al.* (1915) wrote, "This species is really not addicted to salt water, in fact it never occurs in it but in fresh water pools often far from the coast." They explained that, because *C. salinarius* was first found in the vicinity of salt marshes, it was wrongly supposed to be an inhabitant of salt water. Richards (1938) also thought that *C. salinarius* occurs only in fresh or practically fresh water, even though near or on salt marshes. As late as 1955, Horsfall said, "Earlier writers considered that this form had an affinity for salt water, but none of the latter observers agreed that it occurs in such sites."

In the present study, large *C. salinarius* populations in both salt- and fresh-water study areas made possible some significant observations on salinity relations of this species. In the three years of dipping, 12,020 larvae and pupae were taken in the tidal marshes and 14,514 in the impoundments. It may be seen in Table 10 that, for the tidal marshes, the mean salinity of the water in which immatures were collected was 34 per cent of ocean water (11,050 p.p.m.) while the highest was 51 per cent of ocean water. This indicates definitely that *C. salinarius* does inhabit waters of relatively high salinity and thrives there in great numbers. Within the salt-marsh areas at Bombay Hook, it particularly prefers the saltmeadow-cordgrass cover. The average salinity of its habitats in the freshened ponds was 3.7 per cent of ocean water (1220 p.p.m.). The confusion apparently has resulted from its unique ability to flourish equally well in tidal- and fresh-water situations. Some workers have found it in the former and some in the latter place without full knowledge of its total distribution.

An unusual recovery during the study was *Culiseta morsitans* (Theo.). Three larvae were identified from the following collections on May 3, 1954: Raymond Pond, phragmites, 1 larva in 2.4 per cent of ocean water; Shearness Pond, woods edge, 1 larva in 2.4 per cent of ocean water; check area, saltmarsh cordgrass, 1 larva in 18 per cent of ocean water (5800 p.p.m.). One additional specimen was dipped on May 11, 1954, in Raymond Pond in cattail. As far as can be ascertained, this is the first time *C. morsitans* has been found in saline waters and is also its most southerly occurrence along the Atlantic Seaboard. It was associated with *A. cantator, A. sollicitans, C. salinarius* and *C. inornata.* Chapman and Ferrigno (1956) collected it in similar impoundments in New Jersey but not in the salt marsh.

HYDROGEN-ION CONCENTRATION. It was suggested by Bates (1949) that the hydrogen-ion concentration (pH) is only indirectly related to the distribution of mosquito breeding. He reviewed the work of various scientists who showed that, if the pH were too low or too high, it inhibited the growth of microbiota on which the larvae feed. The extreme and mean pH of breeding waters inhabited by 12 species at Bombay Hook are listed in Table 11. The values for *An. quadrimaculatus* agree with those given by Bradley and King (1941). It is interesting to note that the mean pH's for *C. salinarius* habitat water in both impounded and unimpounded marshes are about the same. The marked decrease of *An. quadrimaculatus,* and possibly *U. sapphirina,* in Shearness Pond swampdock stations during 1955 (see Table 4B) appears to be related to this factor. In 1954 the pH averaged 6.5, while the following year it fell to 6.2. Hess and Hall (1945) noted one indication that breeding of *An. quadrimaculatus* was inhibited where the pH was below 6.5. The absence of *An. crucians* Wied. in the study areas may have been due to the lack of strongly acid water.

Adult Abundance Adjoining the Study Areas

SPECIES OCCURRENCE. Table 12 shows the kinds and numbers of mosquitoes taken by the light trap during the full trapping period of each year. The principal mosquitoes were *A. sollicitans, C. salinarius* and *An. crucians* complex (probably mostly *bradleyi* since no *crucians* were ever dipped in the study areas). However, their abundance varied considerably each year. *C. salinarius* was the most common in 1953, *An. bradleyi* in 1954, and *A. sollicitans* in 1955. Mosquitoes of minor importance trapped were, in order of decreasing abundance, *A. cantator, An. quadrimaculatus, A. vexans* and *U. sapphirina. A. sollicitans* accounted for almost all of the daytime biting. Although the trap was operated the fewest nights in 1955, far more mosquitoes were taken during that year than in the previous two years, due largely to the very heavy catch of *A. sollicitans.* The aforementioned minor species also were taken in largest numbers in 1955, but, to the contrary, this was the poorest year for *C. salinarius* and *An. bradleyi.* The average number of all mosquitoes per night in 1955 was 366 compared to the low of 146 during the preceding year. Females comprised 83 to 89 per cent of the take, the low also occurring in 1954.

Although only a small number of *M. perturbans* was taken in the light trap, a steady increase was reported each year. An average of 2.6 adults per square foot of cattail marsh or 0.5 adults per cattail stalk was taken in the emergence traps in Shearness Pond during 1955. This was very low compared to the emergence per square foot noted by other workers: 254 in Massachusetts (Armstrong, 1941), 80-116 (average 98) in New Jersey (Hagmann, 1953), and 37 in New Jersey (Brower, 1953).

Table 11. Hydrogen-ion concentration of mosquito habitat water in study areas, 1953 to 1955.

Species	Unimpounded				Impounded			
	Number of Readings	Lowest	Highest	Mean	Number of Readings	Lowest	Highest	Mean
Anopheles								
bradleyi	58	5.8	7.9	6.8	4	6.2	8.3	6.8
quadrimaculatus					34	6.2	9.3	7.2
Aedes								
cantator	17	5.8	7.0	6.6	2	5.8	6.8	6.3
sollicitans	35	5.8	7.5	6.6	2	5.8	6.8	6.3
vexans	1	—	—	6.8	5	5.1	7.9	6.5
Culex								
erraticus					1	—	—	7.1
pipiens					2	6.2	6.3	6.2
restuans					2	6.2	6.3	6.2
salinarius	24	5.8	7.3	6.7	16	5.8	9.0	6.8
territans					4	6.3	7.0	6.6
Psorophora								
confinnis					1	—	—	5.8
Uranotaenia								
sapphirina					9	6.2	9.0	7.1

Table 12. Number and per cent of mosquitoes trapped during 1953 to 1955[1]

Genus	Species	1953				1954				1955			
		Females	Total Adults	Per Cent of Total	Females Per Night	Females	Total Adults	Per Cent of Total	Females Per Night	Females	Total Adults	Per Cent of Total	Females Per Night
Anopheles	*crucians complex*[2]	2979	2988	9.0	19.2	7408	7575	31.7	45.4	2456	2473	4.2	17.7
	punctipennis	3	3	*	**	3	3	*	**		1	*	
	quadrimaculatus	219	223	0.6	1.4	909	934	3.9	5.5	1931	1961	3.4	13.9
	spp.	17	17	*	0.1	3	3	*	**	1	1	*	**
Total		3218	3231	9.8	20.7	8323	8515	35.6	51.0	4388	4436	7.7	31.7
Aedes	*canadensis*					5	5	*	**				
	cantator	96	96	0.2	0.6	884	1234	5.1	5.4	1896	2409	4.1	13.7
	mitchellae									1	1	*	**
	sollicitans	8258	8860	26.9	53.2	5390	6549	27.4	33.0	38873	43021	74.6	281.6
	taeniorhynchus	3	3	*	**	29	31	0.1	0.1	27	28		0.1
	triseriatus						1	*					
	vexans	471	528	1.6	3.0	321	374	1.5	1.9	1145	1595	2.7	8.2
	spp.	417	1207	3.6	2.6	30	61	0.2	0.1	74	85	0.1	0.5
Total		9245	10694	32.5	59.6	6659	8255	34.5	40.8	42016	47139	81.8	304.4
Culex	*erraticus*						1	*		1	1	*	**
	pipiens	51	51	0.1	0.3	21	42	0.1	0.1	21	30	*	0.1
	restuans	11	11	*	**	15	56	0.2	**	10	27	*	**
	salinarius	11417	11417	34.7	73.6	3569	5086	21.3	21.8	3029	4063	7.0	21.9
	territans	3	3	*	**	8	12	*	**	3	4	*	**
	spp.	5256	7236	22.0	33.9	952	1127	4.7	5.8	762	797	1.3	5.5
Total		16738	18718	57.0	107.9	4565	6324	26.4	28.0	3826	4922	8.5	27.7
Minor Genera													
Culiseta	*inornata*	10	10	*	**	52	98	0.4	0.3	7	9	*	**
	melanura		2	*	**		1	*					
	morsitans					2	2	*	**				
Mansonia	*perturbans*	1	4	*	**	26	40	0.1	0.1	63	75	0.1	0.4
Orthopodomyia	*signifera*	2	2	*	**								
Psorophora	*ciliata*					1	1	*	**	2	2	*	**
	confinnis	93	95	0.2	0.6	11	13	*	**	137	148	0.2	0.9
	discolor									18	18	*	0.1
Uranotaenia	*sapphirina*	42	48	0.1	0.2	316	619	2.5	1.9	443	857	1.4	3.2
Total		148	161	0.4	0.9	408	774	3.2	2.5	670	1109	1.9	4.8
Mutilated Specimens		32	32	*	0.2	6	6	*	**	2	2	*	**
Grand Total		29381	32836		189.5	19961	23874		122.4	50902	57608		368.8

[1]Trap was operated from May 18-October 27, 1953 (155 nights), April 16-October 10, 1954 (163 nights), May 4-September 30, 1955 (138 nights).
[2]Presumed to be *bradleyi*.
*Less than 0.1 per cent.
**Less than 0.1 female per night.

The kinds and numbers of mosquitoes taken during the "control" season are shown in Table 13. Results were similar to those obtained during the full trapping season. Only two species, *Aedes canadensis* (Theo.) and *Culiseta melanura* (Coq.), were not taken during the shorter period while relatively fewer *A. cantator* were caught. *A. sollicitans* was the dominant mosquito in 1953 and 1955, and a close second to *An. bradleyi* in 1954. The average number of all mosquitoes per trap-night varied from 692 in 1955 to 146 in 1954.

The species and relative rankings of mosquitoes trapped each year agree closely with results obtained by Chapman and Ferrigno (1956) in their upland (camp) trap near Tuckahoe, New Jersey. However, they found two fresh-water species, *A. vexans* and *M. perturbans*, to rank generally higher than in the present study. Also, these investigators took the greatest numbers of *C. salinarius* in 1955 and the most *An. quadrimaculatus* in 1953.

SEASONAL DISTRIBUTION. Differences occurred each year in the seasonal distribution and abundance of adult mosquitoes and appeared to be dependent on local breeding conditions, migration and weather. Despite these variations, certain patterns of seasonal occurrence were evident. Except as noted, these agreed closely with previous observations at Delaware City and Lewes, Delaware, Darsie *et al.* (1953).

Light-trap samples of salt-marsh *Aedes* mosquitoes showed that *A. sollicitans* was present regularly after the middle of May. Peaks of abundance were attained from July through early September, although in 1953 the largest single night's catch was at the start of the trapping period in mid-May. After the early part of September relatively few individuals were caught. *A. cantator* was taken in small numbers regularly, beginning in April. Peaks of abundance occurred from late May to mid- or late July. Thereafter, few were taken although fair numbers were trapped in late August and early September of 1955 and in late September and early October of 1954, following hurricanes. Except for scattered individuals of *An. bradleyi* in late April, the species did not occur in numbers until May. Most specimens were taken from the latter part of August to the first part of September while unusually large numbers were present in early October, 1954. Winter survival as measured by spring trap-catches was greater during the winters of 1952-53 and 1953-54 than during that of 1954-55. These observations agree with the average temperatures for December through February, which in the first two winters were 5.0 and 4.2° F., respectively, above normal and in the last winter only 0.3° F. greater than normal (see footnote 7).

Among fresh-water mosquitoes, fair numbers of *A. vexans* were usually present in the latter half of May and in June but the largest broods generally did not occur until August and September. *An. quadrimaculatus* occurred regularly from the latter part of June or early July through September or early October, the greatest numbers being present at periods from July into early September. Few overwintering individuals were ever trapped. The seasonal distribution of *U. sapphirina* was similar although this species was not taken consistently until about mid-July and, at times, goodly numbers continued through September and into early October. Peak abundance was

Table 13. Number and per cent of mosquitoes trapped from June 29 to September 4 during 1953 to 1955.[1]

Genus	Species	1953				1954				1955			
		Females	Total Adults	Per Cent of Total	Females Per Night	Females	Total Adults	Per Cent of Total	Females Per Night	Females	Total Adults	Per Cent of Total	Females Per Night
Anopheles	*crucians complex*[2]	2419	2425	19.0	37.2	3388	3455	30.2	50.5	1274	1288	2.6	20.5
	punctipennis					1	1	*	**		1	*	
	quadrimaculatus	190	191	1.4	2.9	613	621	5.4	9.1	1448	1468	3.0	23.3
	spp.	11	11	*	0.1					1	1	*	**
Total		2620	2627	20.6	40.3	4002	4077	35.7	59.7	2723	2758	5.7	43.9
Aedes	*cantator*	19	19	0.1	0.2	268	296	2.5	4.0	687	746	1.5	11.0
	mitchellae									1	1	*	**
	sollicitans	4629	4629	36.3	71.2	2639	3257	28.5	39.3	35030	38989	81.0	565.0
	taeniorhynchus	3	3	*	**	4	4	*	**	26	27	*	0.4
	triseriatus						1	*					
	vexans	273	308	2.4	4.2	81	104	0.9	1.2	906	1200	2.4	14.6
	spp.	322	769	6.0	4.9	12	17	0.1	0.1	70	79	0.1	1.1
Total		5246	5728	44.9	80.7	3004	3679	32.2	44.8	36720	41042	85.2	592.2
Culex	*erraticus*									1	1	*	**
	pipiens	24	24	0.1	0.3	10	16	0.1	0.1	5	10	*	**
	restuans					5	13	0.1	**		2	*	
	salinarius	1132	1132	8.8	17.4	1820	2526	22.1	27.1	2354	3048	6.3	37.9
	territans					7	9	*	0.1		1	*	**
	spp.	2437	3145	24.6	37.4	679	726	6.3	10.1	633	662	1.3	10.2
Total		3593	4301	33.7	55.2	2521	3290	28.8	37.6	2993	3724	7.7	48.2
Minor Genera													
Culiseta	*inornata*	1	1	*	**	3	3	*	**				
	morsitans					2	2	*	**				
Mansonia	*perturbans*	1	2	*	**	21	33	0.2	0.3	26	27	*	0.4
Orthopodomyia	*signifera*	2	2	*	**								
Psorophora	*ciliata*					1	1	*	**	2	2	*	**
	confinnis	40	42	0.3	0.6	4	4	*	**	125	133	0.2	2.0
	discolor									17	17	*	0.2
Uranotaenia	*sapphirina*	36	40	0.3	0.5	217	325	2.8	3.2	274	394	0.8	4.4
Total		80	87	0.6	1.2	248	368	3.2	3.7	444	573	1.1	7.1
Mutilated Specimens		9	9	*	0.1	1	1	*	**	2	2	*	**
Grand Total		11548	12752		177.6	9776	11415		145.9	42882	48099		691.6

[1]Trap was operated for 65 nights in 1953, 67 in 1954 and 62 in 1955.
[2]Presumed to be *bradleyi*.
*Less than 0.1 per cent.
**Less than 0.1 female per night.

attained from the latter part of August to early September. The number dipped was lowest in the first year of study.

During 1955, the first adults of *M. perturbans* were taken in the Shearness Pond emergence traps between May 24 and June 2 and the last individuals appeared between June 14 and 22. This date of initial emergence agrees with the first light-trap captures—May 26 in 1955 and June 2 in both 1953 and 1954. Scattered trappings of this species occurred each year into early or late September with the highest number in June and August. Similar observations from northern Delaware were reported by Darsie *et al.* (1953).

As previously noted, *C. salinarius* is both a fresh- and salt-water mosquito. Adults generally were present from mid- or late May through September. Although the peak in 1954 and 1955 was from mid-August to early September, in 1953 it occurred in the latter part of May and the first part of June.

The light-trap records of all species considered together show peak numbers in late August and early September in 1954 and 1955 and in the latter part of May and early June in 1953.

Comparison of Larval and Adult Populations

In the past, most surveys of mosquito occurrence have relied entirely on sampling by light-trapping. While this technique provides valuable information on the adult mosquito populations within the vicinity of the trap, it has serious limitations since it does not indicate where these mosquitoes originated or how representative the light-trap catch is of local breeding conditions. Even though dipping and light-trapping were carried on concurrently in this study, comparisons are only approximate since dipping was not carried on in much of the tidal marsh nearest the trap and no attempt was made to equate the extent of breeding in the fresh-water ponds and in the tidal marsh.

During the three years of study, a total of 24 species of the known forty in Delaware (Darsie *et al.,* 1951; Bickley, 1957) were collected. Every species occurred in the light trap, but six—*Aedes mitchellae* Dyar, *Culiseta melanura* Coq., *Psorophora discolor* Coq., *Aedes triseriatus* Say, *M. perturbans,* and *Orthopodomyia signifera* Coq.—were not dipped. Because of their habits, the latter three would not be expected to be taken in surface dipping of marshes.

There was general correlation between the relative numbers of each species taken by dipping and by trapping (Table 14); however, discrepancies were evident for certain species. Relatively more larvae than adults were collected of *A. cantator* in all years, *C. restuans* in 1954, *C. salinarius* and *C. territans* in 1953 and 1955 and *U. sapphirina* in 1953 and 1954; whereas the reverse was true of *An. bradleyi* and *A. sollicitans* in all years, *A. vexans* in 1955 and *Psorophora confinnis* (L.A.) in 1953 and 1955. The records of the *Culex* and *Uranotaenia* species probably can be explained by their relatively limited dispersals and those of *A. sollicitans, A. vexans* and *P. confinnis* by their characteristically longer migrations. *A. cantator,* although

Table 14. Comparison of numbers and per cent of mosquitoes collected by hand-dipping and light-trapping during 1953 to 1955.[1]

Genus	Species	Dipped Number 1953	Dipped Number 1954	Dipped Number 1955	Dipped Per Cent 1953	Dipped Per Cent 1954	Dipped Per Cent 1955	Trapped Number 1953	Trapped Number 1954	Trapped Number 1955	Trapped Per Cent 1953	Trapped Per Cent 1954	Trapped Per Cent 1955
Anopheles	*crucians complex*[2]	3,080	1,354	130	12.9	4.7	0.5	2,663	7,575	2,473	19.5	31.7	4.3
	punctipennis		1	3		*	*	2	3	1	*	*	*
	quadrimaculatus	799	1,477	881	3.3	5.2	3.2	223	934	1,961	1.6	3.9	3.4
	spp.	235	144	6	1.0	0.5	*	14	3	1	0.1	*	*
Total		4,114	2,976	1,020	17.2	10.4	3.8	2,902	8,515	4,436	21.3	35.6	7.7
Aedes	*canadensis*		1			*			5			*	
	cantator	2,914	6,472	4,577	12.1	22.6	16.8	25	1,234	2,409	0.1	5.1	4.2
	mitchellae									1			*
	sollicitans	4,098	5,678	15,159	17.1	19.8	55.7	4,705	6,549	43,021	34.6	27.4	74.7
	taeniorhynchus			3			*	3	31	28	*	0.1	*
	triseriatus								1			*	
	vexans	257	565	148	1.1	2.0	0.5	331	374	1,595	2.4	1.5	2.8
	spp.	21	66	1	0.1	0.2	*	782	61	85	5.7	0.2	0.1
Total		7,290	12,782	19,888	30.4	44.6	73.1	5,846	8,255	47,139	43.0	34.5	81.8
Culex	*erraticus*		2	2		*	*		1	1		*	*
	pipiens	13	81	21	0.1	0.3	0.1	47	42	30	0.3	0.1	*
	restuans		2,006	1		7.0	*	4	56	27	*	0.2	*
	salinarius	12,129	8,640	5,765	50.6	30.1	21.2	1,279	5,086	4,063	9.4	21.3	7.1
	territans	69	50	247	0.3	0.2	0.9		12	4		*	*
	spp.	8	18	1	*	0.1	*	3,409	1,127	797	25.0	4.7	1.4
Total		12,219	10,797	6,037	51.0	37.7	22.2	4,739	6,324	4,922	34.8	26.4	8.5
Minor Genera													
Culiseta	*inornata*	1	98	1	*	0.3	*	1	98	9	*	0.4	*
	melanura								1			*	
	morsitans		3			*			2			*	
	spp.		1			*							
Mansonia	*perturbans*							2	40	75	*	0.1	0.1
Orthopodomyia	*signifera*							2			*		
Psorophora	*ciliata*	7			*				1	2		*	*
	confinnis	5	4	2	*	*	*	43	13	148	0.3	*	0.3
	discolor									18			*
Uranotaenia	*sapphirina*	314	1,979	248	1.3	6.9	0.9	47	619	857	0.3	2.5	1.5
Total		327	2,085	251	1.3	7.3	0.9	95	774	1,109	0.6	3.2	1.9
Mutilated Specimens								10	6	2	*	*	*
Grand Total		23,950	28,640	27,196				13,592	23,874	57,608			

[1]The length of time samples were taken are as follows: 1953—June 30 to October 27; 1954—April 12 to October 8; 1955—May 4 to September 22.

[2]All larvae identified as *bradleyi;* adults presumed to be the same species.

*Less than 0.1 per cent.

thought to be capable of extended flights, does not appear to be attracted to light as readily as its salt-marsh associate, *A. sollicitans*. Both breed in large numbers in the nearby check area. Stabler (1945) also noted that relatively few *A. cantator* were taken by light trap. The record for *An. bradleyi* appears to reflect disproportionate sampling. No dippings were made in the marsh lying nearest the trap, which was part of the check area, and probably produced considerable numbers of this species, as was undoubtedly the case in other parts of the adjoining extensive tidal marsh.

For some species, such as *An. bradleyi* and *C. salinarius* in all years, *An. quadrimaculatus* and *U. sapphirina* in 1954 and 1955, *C. inornata* in 1954 and *A. vexans* and *P. confinnis* in 1955, the seasonal occurrence of adults in the light trap generally was correlated with preceding peaks of abundance of larvae and pupae as determined by dipping. This was to be expected since the average length of flight of the first four species is probably limited and most of the trap catch could be presumed to be of local origin. Furthermore, *A. vexans* generally occurred in discontinuous broods, and the fresh-water impoundments were the largest areas near the light trap which were suitable for their aquatic development. Oftentimes, though, fewer adults than expected were taken in late April, May, September and October. Undoubtedly, cooler temperatures during these periods resulted in slower larval development and in reduced nocturnal activity of adults. In the latter part of June, 1955, following the heavy rain on June 8 a large number of *A. vexans* was caught in the trap. However, few larvae were dipped in the impoundments, suggesting that the main portion of the brood came from other sources. A similar occurrence of *P. confinnis* was observed in the latter part of August, 1955, following rains earlier in that month.

Correlation between the seasonal occurrence of immature and adult stages of other species, including *A. cantator* and *A. sollicitans* in all years, *C. restuans* in 1954 and *An. quadrimaculatus* and *U. sapphirina* in 1953, was less definite. Sometimes during the summer a close correlation existed, but at other times only small numbers of adults of all but *A. sollicitans* were trapped. For *A. cantator,* the attraction of light appeared to wane during the middle of the summer even though broods of larvae continued to be produced. Statements in the literature indicating that this species breeds only in the spring may be erroneous if they are based entirely on light-trap catches. Migration of *A. sollicitans* from other areas probably accounted, in part, for the generally poor correlation between larval and adult counts. A case in point was the large trap catch of this species and of *A. cantator* at the end of August and in early September, 1955. Obviously, these mosquitoes originated outside the study areas since the last previous local brood of larvae was observed between two and three weeks earlier. Furthermore, males, which are believed to move shorter distances than females, comprised only one to four per cent of the trap catch.

The poor seasonal correlation between dipping and trapping counts of *An. quadrimaculatus* and *U. sapphirina* in 1953 in contrast to greater correspondence during the two subsequent years appears to be related to the construction of Shearness Pond at the end of the 1953 mosquito season. This impoundment provided an extensive new breeding area with sufficient adults to make an adequate comparison of data. Even though breeding of both species in Shearness Pond declined from 1954 to 1955, the increase in production in Raymond Pond apparently compensated for this.

The remaining species of mosquitoes were dipped and trapped in such low numbers that a valid comparison on a seasonal basis was not possible.

An analysis of the seasonal dipping and trapping results from 1953 to 1955 indicates that most of the *C. salinarius* which were trapped appeared to have come from the extensive tidal marsh rather than from the two fresh-water impoundments. Further evidence is supplied by the fact that noticeably fewer larvae and pupae of this species were dipped in the impounded marsh in 1954 than in 1953, while the breeding in the tidal marsh decreased but little and showed a closer relation with the number of adults taken by the light trap (see Tables 3A, B and 13). When data from 1954 and 1955 are compared, a reverse situation occurred. More immatures were taken in the impoundments in the latter year, but the number of adults decreased, corresponding to reduced breeding in the natural unimpounded marsh.

Comparison of Wildlife Utilization in Natural and Impounded Marshes

Table 15 shows the utilization of the unimpounded and impounded study areas by water birds and by other conspicuous birds that are associated with wetland habitats, such as hawks and eagles. Important game species, such as geese, ducks, rails, gallinules, American coots *(Fulica americana)* and common snipe *(Capella gallinago)*, are listed individually while all others are presented under group headings except where there is but one representative in the group.

Fifty-five species of water birds were observed in Bear Swamp Marsh and the check area while additional species were recorded in other unimpounded marshes. The most important groups and the principal representative of each were the surface-feeding ducks—black duck *(Anas rubripes)*, shorebirds—willet *(Catoptrophorus semipalmatus)*, and rails—clapper rail *(Rallus longirostris)*. Considerable difference was evident between the extent of utilization of Bear Swamp Marsh and the check area. Because of greater expanses of water in Bear Swamp Marsh, more species and individuals frequented this area than the check area. Although moderate numbers of black ducks, willets, clapper rails and a few additional species bred in the area, the greatest utilization was by migrant and wintering species.

In the impounded marshes 86 kinds of water birds were recorded. Fifty-three of these were the same as in the unimpounded marshes. Two species in the unimpounded areas, the common loon *(Gavia immer)* and the clapper rail, were not recorded in the fresh-water ponds. The principal groups in the impoundments were geese, ducks, and shorebirds, the dominant species being the Canada goose *(Branta canadensis)*, pintail *(Anas acuta)*, mallard *(Anas platyrhynchos)*, black duck, American wigeon *(Mareca americana)*, semipalmated sandpiper *(Ereunetes pusillus)*, and greater yellowlegs *(Totanus melanoleucus)*. Most species of birds frequented both ponds, but Raymond Pond was more attractive to Canada geese, diving ducks, mer-

Table 15. Numbers of water and wetland birds utilizing unimpounded and impounded study areas during 1954-55 and 1955-56.[1]

Birds[2]	Unimpounded				Impounded			
	Bear Swamp		Check Area		Raymond Pond		Shearness Pond	
	1954-55	1955-56	1954-55	1955-56	1954-55	1955-56	1954-55	1955-56
Loons and Grebes		10	3	12	2,700	740	1,760	540
Double-crested Cormorant					16	30	4	11
Herons and Bitterns	940	370	210	220	9,280	2,720	5,490	5,300
Glossy Ibis					55		4	3
Whistling Swan					710	250		9
Geese (total)		50			316,330	315,748	78,010	117,980
Canada Goose		50			315,270	315,740	77,960	117,850
Snow Goose					890			30
Blue Goose					170	8	50	100
Surface-feeding Ducks (totals)	31,920	43,060	4,015	8,630	146.220	192,920	196,450	212,930
Mallard	2,550	3,960	120	260	13,830	79,450	59,440	49,210
Black Duck	23,000	27,740	3,700	7.930	20,730	15,810	58,610	23,480
Gadwall	320	1,690	100	160	10,040	12,750	4,860	6,870
Pintail	1,680	400			32,770	62,640	29,860	103,790
Green-winged Teal	3,330	6,170			18,060	2,120	8,260	7,030
Blue-winged Teal	600	570	65	120	6,620	1,120	1,590	950
American Wigeon	50	890			31,750	18,240	25,530	20,520
Shoveler	390	1,640	30	160	12,310	790	8,090	980
Wood Duck					110		210	100
Diving Ducks (total)		15			1,900	967	603	314
Redhead					100	22		
Ring-necked Duck					220	550	350	230
Canvasback					720	65		
Lesser Scaup					190		8	13
Common Goldeneye					120			
Bufflehead					460	40	65	6
Ruddy Duck		15			90	290	180	65
Mergansers (total)	60	76		7	8,590	1,924	307	618
Hooded Merganser	60	30		7	590	180	70	60
Common Merganser		35			8,000	1,730	230	550
Red-breasted Merganser		11				14	7	8
Hawks and Eagles	280	440	200	140	690	480	600	700
Rails and Coots (total)	1,520	1,170	2,459	2,620	830	820	90	430
King Rail	610	350	15	230	680	610	10	330
Clapper Rail			2,060	2,030				
Virginia Rail	550	500	210	190		45		
Sora	120	90	4		150	160	80	100
Black Rail	240	230	170	170		5		
Gallinule						14	250	24
American Coot			4		8,730	5,540	27,130	6,140
Shorebirds (total)	5,620	4,470	390	544	75,400	27,790	5,350	6,610
Common Snipe	960	470		14	360	100	90	50
Other Shorebirds	4,660	4,000	390	530	75,040	27,690	5,260	6,560
Gulls and Terns	40	190	50	19	25,200	12,620	390	1,870
Belted Kingfisher	90	55	55	60	150	35	100	40
Total	40,470	49,906	7,386	12,252	596,801	562,598	316,538	353,519

[1]Utilization is expressed as bird-days per 100 acres. Observation periods extended from April 1 to March 31.

[2]Game species in italics.

gansers, shorebirds, gulls and terns while Shearness Pond was more heavily utilized by surface-feeding ducks as a whole. As in the unimpounded marshes the principal utilization was in the fall, winter and spring seasons.

Far more water birds frequented the impoundments than the natural tidal marshes, the over-all utilization being more than 16 times as great. This was especially true of grebes, herons, Canada geese, most surface-breeding ducks, common mergansers *(Mergus merganser)*, American coots, most shorebirds in Raymond Pond, gulls and terns. Less increase in the impoundments compared to the unimpounded marsh was noted in numbers of whistling swans *(Olar columbianus)*, geese (other than Canada geese), diving ducks, mergansers (other than common merganser), gallinules, shorebirds in Shearness Pond and certain birds of restricted occurrence, such as double-crested cormorants *(Phalacrocorax auritus)*, and glossy ibises *(Plegadis falcinellus)*. In some instances, more black ducks and green-winged teal *(Anas carolinensis)* utilized Bear Swamp Marsh than the fresh-water impoundments. Construction of the ponds had little effect on the number of hawks, bald eagles *(Halioeetus leucocephalus)* or belted kingfishers *(Megaceryle alcyon)* but reduced the numbers of most rails, common snipe and willets.

Because of the difficulty in making complete counts, detailed records were not kept of the utilization of the areas by songbirds and other small birds. Species which appear to have benefited by diking and flooding include swallows, water pipits *(Anthus spinoletta)*, and savannah sparrows *(Passerculus sandwichensis)*. Little effect was noted on numbers of crows, marsh wrens *(Telmatodytes palustris)* and redwings *(Agelaius phoeniceus)* but certain characteristic salt-marsh species, such as the sharp-tailed sparrow *(Ammospiza caudacuta)* and seaside sparrow *(Ammospiza maritima)*, were eliminated by impoundage.

Aerial censuses of muskrat houses revealed the following number of animals per 100 acres[9]: Bear Swamp Marsh—1952 (158), 1953 (42), 1954 (23); check area—1952 (27), 1953 (4), 1954 (9); Raymond Pond—1952 (30), 1953 (21), 1954 (13); and Shearness area—1952 (44), 1953 (63), 1954 (79). Counts in the areas are incomplete due to an unknown number of additional muskrats inhabiting burrows in banks. The muskrat population in the Shearness area increased for one year after the completion of the dike and initiation of flooding despite a general downward trend in the other areas. Although no subsequent aerial counts were made, ground observations in 1955 revealed a decrease in population over much of Shearness Pond due to the high water level. An exact comparison of populations in the tidal marshes with those in the fresh-water ponds is not possible, but it appears that impoundage somewhat lowered the number of these animals. River otters *(Lutra canadensis)* were observed occasionally in both the tidal marshes and the impoundments.

Fishes present in the tidal streams and ponds included American eels *(Anguilla bostoniensis)*, golden shiners *(Notemigonus chrysoleucas)*, carp

[9]The average number of muskrats per house was considered to be five (see Dozier, 1948).

(Cyrpinus carpio), mummichogs *(Fundulus heteroclitus)*, variegated minnows *(Cyprinodon variegatus)* and white perch *(Morone americana)*. All these species plus brown bullheads *(Ameiurus nebulosus)*, redfin pickerels *(Esox americanus)* and pumpkin-seeds *(Lepomis gibbosus)* were plentiful in the impoundments, and the presence of young of most species indicated they reproduced successfully. Some diamond-back terrapins *(Malaclemys terrapin)* and blue crabs *(Callinectes sapidus)* utilized the larger tidal streams, several of which formerly entered the pond sites. No terrapins were ever noted in the impoundments nor blue crabs in Raymond Pond. Although a few large blue crabs survived in Shearness Pond for at least two years after flooding, they were unsuitable for eating because of their thin, watery flesh. Although absent in the tidal marsh, both bullfrogs *(Rana catesbeiana)* and snapping turtles *(Chelydra serpentina)* appeared in the impoundments following flooding.

Water-Management Relationships

MOSQUITO PRODUCTION. During the three years of study, natural climatic and tidal factors provided a wide range of mosquito-breeding conditions. As a result, findings are considered typical of the area. They showed that the principal production of nuisance *Aedes* mosquitoes in the natural tidal marsh occurred at the upland edges in poorly drained sites subject to alternate drying and flooding by high tides and heavy rains. Impoundage and maintenance of several feet of fresh water in this ecological zone reduced salinity and largely prevented numerous fluctuations in the water level favorable for the oviposition and development of flood-water species. As a result, *A. sollicitans* and *A. cantator,* the two most important pest mosquitoes of the area by reason of their large broods, long migrations and daytime-biting habits, were almost entirely eliminated. Similar findings in areas subjected to diking and flooding were reported by Philen and Carmichael (1956). A less important salt-marsh pest, *An. bradleyi,* also was greatly reduced in number but a fourth species, *C. salinarius,* continued to thrive due to its broad ecological tolerance. Impoundage favored breeding of certain other mosquitoes including *An. quadrimaculatus, U. sapphirina, A. vexans, C. territans,* and, sometimes *C. restuans*. Neither *U. sapphirina* nor *C. territans* is known to attack humans. *An. quadrimaculatus* has a limited flight range, as is probably the case with the other *Culex* species; all are nighttime biters. The occurrence of *An. quadrimaculatus*, an important vector of malaria, in the United States is no longer considered critical from an epidemiological standpoint since the disease has been virtually eliminated in this country (New England-New York Inter-Agency Report, 1955; Boyd, 1949). Where malaria is a problem, impoundments of the type discussed herein should not be constructed without adequate water-level management facilities. *A. vexans* is an important pest at times but was not taken in large numbers and occurred mostly before or after the critical summer season when control is desired. The net result of impoundment in this study was a large decrease in the production of mosquitoes capable of causing a nuisance beyond a several-mile radius.

Differences in precipitation and in the physiography and permanent water supplies of the two ponds resulted in considerable variation in water levels during the three years and, consequently, in mosquito breeding. Maintenance of a high, fairly stable water level in Raymond Pond during the early part of 1953 and in Shearness Pond during 1954 flooded emergent vegetation and resulted in the production of large numbers of *Culex, Anopheles* and *Uranotaenia* mosquitoes and only a few *Aedes*. Conversely, recession of the water level from the vegetated margin of Raymond Pond after the mid-summer of 1953 and during much of 1954 followed by occasional partial reflooding by rains, reduced breeding of the permanent-water species but caused an increase in *Aedes* production. In 1955, maintenance of a fairly stable water level of medium height in both ponds until mid-August caused only moderate flooding of marginal vegetation and resulted in a medium production of permanent-water mosquitoes and in the lowest numbers of *Aedes*.

Lowering of the water level below the roots of host plants during each summer in Raymond Pond effectively prevented breeding of *M. perturbans*. In the new Shearness impoundment this species became established within a year after fresh-water flooding. However, the population was very low and will probably remain so as long as the water level is manipulated to prevent any great increase in the stands of cattails and other plants providing suitable attachment sites.

During July of 1953, filamentous algae (mostly *R. hieroglyphicum),* which had been growing on the bottom of shoal areas in Raymond Pond, floated to the surface, rapidly blanketing and supressing the growth of pondweed beds utilized by waterfowl. These mats also served as a breeding site for *An. quadrimaculatus*. Probably, partial exposure of the bottom of the pond in previous summers contributed to the problem by permitting the growth of emergent plants and enrichment of the water following their decomposition. It seems likely, too, that the low salinity in the pond that year, caused in part by the heavy precipitation in May, provided more favorable growing conditions for the algae.

Below-normal precipitation through July of both 1954 and 1955 and the incidental admission of some salt water in 1954 raised the salinity slightly. During these years algae constituted only a minor problem. The higher salinity appeared to have another desirable effect in stimulating the growth of such submerged waterfowl food plants as sago pondweed *(P. pectinatus),* horned pondweed *(Z. palustris)* and wigeongrass *(R. maritima)*. It also may have been responsible for the slight increase from 1953 to 1954 in the number of salt-marsh *Aedes* (mostly *cantator).*

EFFECT OF IMPOUNDING ON WILDLIFE UTILIZATION. It is apparent that the impoundments were highly successful in their primary function of improving habitat for ducks and geese. Increases of these and other water birds can be attributed to the more favorable food, cover and resting conditions created by diking and fresh-water flooding. Because of the small acreage of the impoundments in relation to the surrounding tidal marsh, the reduction in numbers of a few species of wildlife in these marshes was of relatively little importance.

Differences in the wildlife utilization of the impoundments in response to water-level management practices were noted. However, results were partially influenced by major changes in the numbers of certain species within the Atlantic Flyway, as measured by the annual Federal and State winter survey (Addy, 1956).

The natural lowering of the water level in Raymond Pond during the early summer of 1954 resulted in the germination and growth of stands of millet, cyperuses, fall panicum and smartweeds. Reflooding made these available to waterfowl and seems to have accounted for the increased numbers of black ducks, American wigeons, teal and shovelers *(Spatula clypeata)* in 1954-55 compared to 1955-56. To a lesser extent this appears to have been true in Shearness Pond also, although the semi-floating nature of the islands permitted growth of plants regardless of the height of the water. The initial flooding of the Shearness area made formerly inaccessible moist- or dry-soil food plants available and caused the development of extensive mats of duckweed, which were attractive to those species of ducks and to mallards and American coots.

During the following year, the stands of annual plants were much smaller in extent due to the maintenance of high water levels throughout the summer. This condition favored the growth of pondweeds and seems to have accounted for the increase of gadwalls *(Anas strepera)* despite a 14 per cent Flyway decrease in their numbers from the previous year. The larger populations of mallards in Raymond Pond and pintails in both ponds appeared to be a manifestation of increases throughout the Flyway, while the lower number of American mergansers corresponded with the 52 per cent decrease recorded for all species of mergansers in the Flyway. Also, the greater use of Shearness Pond by Canada geese in 1955 than 1954 probably is less related to water management than to increased acceptance of a new resting and feeding location by these birds, which are noted for their adherence to traditional areas.

During 1955, the reductions of herons (particularly the short-legged species) in both Raymond and Shearness Ponds and of shorebirds, gulls and terns in Raymond Pond can be correlated with the higher water levels which placed mud flats and loafing spots at unfavorable depths. The lack of suitable areas for shorebirds, gulls and terns in Raymond Pond this year appears to have accounted, in turn, for their increased utilization of Shearness Pond. Here, semi-floating islands provided feeding and resting sites. The decrease of Pied-billed grebes *(Podilymbus podiceps)* in 1955 also may be associated with the higher water levels and a resultant reduction of vegetational cover desired by this species.

Management Recommendations

From the findings of this and other studies cited herein, certain recommendations can be made for the construction and management of wildlife impoundments in tidal marshes in order to reduce mosquito breeding to a low-nuisance level. It should be recognized, however, that these recommendations apply primarily to areas with physicochemical and biological charactertics similar to those of the Bombay Hook impoundment.

The primary requisite for control of mosquito breeding in impoundments is satisfactory regulation of the water level. This fact emphasizes the need for an adequate supply of water and of provision for ready disposal of excess quantities. Ordinarily, in impoundments adjoining the upland, the flow from streams, supplemented by precipitation, serves as the principal means of flooding. In other situations, release of water from storage ponds, flow from artesian wells, or introduction of flood tides serve effectively, depending upon the kinds of vegetation and wildlife to be managed. Pumping, also, has proved economically feasible where other benefits, such as mosquito control, are of important consideration.

Even wildlife impoundments subject to considerable, unregulated fluctuation of the water level are acceptable if located at greater distances from areas of moderate to high human population than the effective flight range of the mosquitoes produced. According to the U. S. Public Health Service (New England-New York Inter-Agency Report, 1955) such impoundments in the Northeast should be preferably three miles (five miles along the coast) from recreational areas and urban and suburban developments. Presumably, these limits pertain primarily to wide-ranging *Aedes* mosquitoes. Where only *An. quadrimaculatus* is involved, this limit is set at one mile (Bishop and Hollis, 1947).

If impoundments are situated closer to centers of population than the dispersal range of flood-water *Aedes* mosquitoes, but have water levels which can be kept constant or closely regulated, the following recommendations are made. Flooding during the first growing season should be to a height of about two feet to kill unwanted tidal-marsh vegetation. Sometimes two years are required to drown water-tolerant plants. During this transition period a high water level that covers most emergent vegetation generally prevents mosquito production except along the edge. If woody plants are present in the area, it is recommended that they be removed or burned prior to flooding. Elimination of such vegetation, in addition to being generally of value in waterfowl management, helps to prevent the accumulation of debris along the shore which is apt to provide favorable breeding sites for permanent and semi-permanent water species.

After completion of the first step, it is believed that, as a general rule, the peak water level should be attained before the start of the principal mosquito control season. Thereafter, depending upon the desired wildlife-management plan, the water can be maintained at a level of one to three feet to favor submerged aquatic plants and to set back established emergent vegetation or can be drawn off to encourage emergent annual or perennial species (Addy and MacNamara, 1948; Steenis *et al.,* 1954). Under either plan, it is inadvisable from a mosquito abatement standpoint to permit re-flooding of extensive areas during the "control" season. In Delaware, this period extends from the latter part of June to the first week of September. Before and after this interval, average lower temperatures reduce both human outdoor activity and mosquito biting nuisance.

If a high water level is desired to foster the growth of submerged pond-weeds for waterfowl, it is recommended that this be kept stable during the summer. Under such conditions, few flood-water *Aedes* will be produced. A slight lowering of the pond level also should reduce breeding of *Culex, Anopheles* and most other permanent or semi-permanent water species by drawing water away from marginal vegetation, although the partial exposure of dense beds of submerged pondweeds may increase the production of the latter. It should be pointed out, too, that the value of even a minimum reduction of the water level may be negated by the advance of weeds which could cause a plant-control problem. If possible, then, lowering should be no more than necessary to prevent this situation. It is advisable, also, to maintain depths of at least a foot or more in the central, flooded portion during the summer since shallower water is apt to become heated and kill the leaves and stems of pondweeds. When feasible, pond construction should be such that lowering of the water by evaporation and transpiration would not reduce the level below the outlet structure, where it would be impossible to drain off excesses due to heavy rains. Restoring water to the previous level following such rains will tend to strand larvae of flood-water mosquitoes or to draw them out of vegetation and expose them to greater fish predation and harmful wave action. If the above measures are not successful in reducing marginal breeding of mosquitoes, it may be advantageous to deepen tbe back edge of the pond by dynamiting or excavating a ditch and connecting it to deeper water, such as the borrow pit at the dike.

Impoundments rich in nutrients may form undesirable mats of filamentous algae. Thickest growths occur where wave action and water depths are least. Not only do these mats shade out desirable growths of pondweeds but they also serve as a breeding site for *An. quadrimaculatus*. Maintenance of a high water level may be helpful in combating these plants. If this is not successful, then copper sulfate or some other suitable algicide could be used (Surber 1949). An increase in the salinity of the water also may be helpful for this purpose.

Drawing down the water level to expose mud flats encourages the germination of moist-soil vegetation. Included would be plants utilized by waterfowl and muskrats as well as species considered to be weeds from a wildlife point of view. This later vegetation also may contribute to a mosquito problem. Reflooding during the drawdown period by rains or other means, whether intentional or not, may cause the development of flood-water mosquitoes unless this water is disposed of within a short period. A week is usually the minimum time required for emergence of adults during the summer months; proportionately longer intervals are needed in cooler weather. Depressions in the impoundments may be impossible to drain within these periods and may produce mosquitoes. Also, under a drawdown system there are few or no predators to cope with such mosquito breeding. Deepening of these poorly drained areas by construction of ditches and potholes has been shown by Chapman and Ferrigno (1956) to greatly reduce breeding. To minimize further the mosquito problem, it is recommended that the time of drawdown be delayed until as late in the summer as is possible without interfering with maturation of seed-bearing annuals. Reflooding, likewise, should be postponed until as far into the "control" season as permissible. If it is necessary to flood back earlier because of the threat of a pest-plant problem or for other reasons, this should be done as soon as possible after dewatering to reduce deposition of flood-water mosquito eggs. However, a drawdown period of two to six weeks is usually required to assure germination and initial growth of plants. It should be realized that permanent-water mosquitoes probably also will be produced upon reflooding under these conditions. If large numbers of perennial weeds are produced during either a full or partial drawdown, it may be necessary to maintain a high water level the following year to suppress their growth.

Drawing down the water level below the roots of host plants for a several-week period during the summer has been found to be very effective in curbing the development of *M. perturbans.* Cattails, one of the principal plants utilized by *Mansonia,* are a prime muskrat food but are considered to be weeds in many areas where waterfowl management is the principal objective. Under the latter circumstances, the judicious control of these plants (Martin *et al.,* 1957) may permit replacement by species more desirable to waterfowl and may eliminate this source of *Mansonia* breeding.

Where practical, a combination of the flooding and drawdown systems would appear to be most advantageous in minimizing the mosquito nuisance and in providing conditions at least partly favorable for waterfowl. Under such a program a peak water level would be attained in the spring. This would be kept high as long as possible but would be gradually lowered during the summer when precipitation is reduced and the evaporation rate is high, still leaving a central, flooded area. Reflooding of exposed shore line could be undertaken after the mosquito control season, or as near to its termination as possible. This water-management plan would favor both submerged aquatics and emergent food and cover plants, as well as many kinds of small animal life, and should provide conditions attractive to the greatest variety and numbers of waterfowl, herons, shorebirds and many other marsh birds.

Under either the permanent-flooding or drawdown system, or a combination of the two, mosquito-eating fishes comprise an important part of the control program. Ordinarily, species such as the mummichog and variegated minnow are included in a tidal area when it is diked off. If fish are absent, it is recommended that the above and other important species, including the gambusia *(Gambusia affinis),* striped killifish *(Fundulus diaphanus),* and other killifishes be introduced. It is important in a drawn-down impoundment to maintain fish so that they can combat mosquito breeding caused by reflooding. For this purpose, sump areas below the general level of the pond bottom, which still retain water during the drawdown period, are needed. The construction of borrow ditches and potholes, as previously described, would serve this purpose and assist these predators in reaching mosquito-breeding sites.

While the impoundments in this study were of the fresh-water type, flooding also could be accomplished with salt or brackish water and managed for saline-tolerant plants and animals. This method likewise would kill or reduce the number of carp which often infest fresh or slightly brackish water. In addition to rooting up vegetation, utilized by waterfowl, these fish can create breeding sites for permanent and semi-permanent water mosquitoes in the flotage thus formed. Other methods of controlling carp include installation of screens in sluices, completely drawing down the water level in the summer, or treatment of the pond with rotenone or other suitable poison.

Even though water management can usually reduce mosquito production in impoundments, it may not be sufficiently effective under all conditions. Two additional methods are suggested. The use of herbicides may be advisable to control undesirable plants which contribute to the mosquito problem. Also, it may be necessary to apply insecticides when a significant number of mosquitoes is produced within the effective flight range of heavily populated towns, summer camps or agricultural operations involving large numbers of people. Under these conditions, it is recommended that only those chemicals, formulations, and dosages be employed that have been shown to provide effective control with minimum damage to wildlife (Rudd and Genelly, 1956; Springer, 1956 and 1957).

Although this study was undertaken to determine the extent of mosquito breeding in wildlife impoundments, and to find satisfactory methods of limiting nuisance populations in such places, it showed that diking and flooding could be employed for the primary purpose of effectively controlling pestiferous salt-marsh *Aedes* and *Anopheles* mosquitoes. If an impoundment program for mosquito control were undertaken, it could have the important related benefit of improving marshland habitat in some situations for waterfowl and other wildlife. A program with dual functions would possess the distinct advantage of increased public support. Philen and Carmichael (1956) have pointed out that diking for mosquito control could be accomplished in Florida at "only a fraction of the cost that would have been incurred for ditching or filling, on an acreage basis." Their dikes were constructed to exclude tides with relatively small fluctuations (about one foot). Where tides are higher, correspondingly larger structures would be involved. Even if diking should be too costly for mosquito control alone, the expense probably could be justified on the basis of improvement of wildlife habitat and development of recreational areas. It should be emphasized, however, that competent engineering advice should be obtained before the construction of water-control facilities. Equally important is provision for adequate maintenance of projects.

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