A STUDY OF THE EFFECTS OF THREE MOSQUITO CONTROL MASRH MANAGEMENT TECHNIQUES ON SELECTED PARAMETERS OF THE ECOLOGY OF A CHESAPEAKE MAY TIDEWATER MARSH IN MARYLAND

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MARSH MANAGEMENT TECHNIQUES ON SELECTED
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CHESAPEAKE BAY TIDEWATER
MARSH IN MARYLAND

A Final Report of the Project Titled:

The Effects of Open Marsh Water Management on the Ecology
of Chesapeake Bay High Marsh Wetlands

Submitted to: Maryland Department of Natural Resources,
Coastal Zone Unit

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control headquarters, provided an account of his remembrances of the Davis Island study area as it existed 50 years ago.

ABSTRACT

A study was conducted to determine the effects of three mosquito control marsh management techniques on selected parameters of the ecology of a Distichlis spicata/Spartina patens dominated marsh in Somerset County, Maryland. The three water management techniques evaluated were: (1) open plot - ditches coupled to the estuary to allow unrestricted tidal exchange; (2) water control - structures placed in the outlet ditches to restrict tidal exchange; and (3) closed - not connected to the estuary by ditches. Two unditched areas served as controls.

The three management systems each provided excellent mosquito control. Mosquito breeding was significantly ($P < 0.05$) greater on the control sites than on the treatment plots. Contemporaneous studies on secondary study sites in Somerset and Dorchester Counties showed that closed systems were not effective for mosquito control when used on marshes with a deep peat soil or containing standing surface water mosquito breeding sites.

Each of the three management techniques provided habitat for fish, shrimp and crabs. The fish species composition varied between the plots, however, Fundulus heteroclitus was dominant on each plot. Water quality on each primary study plot was sufficient to maintain fish populations throughout the study period. Fish kills were observed on closed ditch systems on the secondary study areas due to very low levels of dissolved oxygen.

The mean water table elevation on the open plot was significantly ($P < 0.05$) lower than on the other primary study plots in 1979. In 1980,

the mean water table elevation on the open plot did not differ significantly from the closed or control plot. The water control plot maintained a higher mean water table elevation than the other plots in 1980. The drainage caused by tidal ditches, and natural tidal creeks, is greatest within 10 meters of the bank.

Because of the observed failure of closed ditch systems to control mosquito breeding and the negative impact on fishes on the secondary study plots, it is recommended that no large scale closed ditch systems be constructed in the future for mosquito control in Maryland. Small scale closed projects such as the construction of ponds and pond radials is an acceptable management technique.

The combination of tidal and semi-tidal ditches and non-tidal ponds and pond radials should be used for mosquito control on Chesapeake Bay salt marshes in Maryland. When necessary to mitigate undesirable vegetation changes, which may result from lowering the water table elevation, water control ditches should be used.

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INTRODUCTION

Tidewater marshes are a unique and highly important component of the Chesapeake Bay ecosystem in Maryland. These marshes provide essential habitat for numerous wildlife species, produce the nutrients necessary to sustain the aquatic life of the Bay, and provide esthetic retreats for many who look for wild, undeveloped lands in the midst of the urban/ suburban corridor of the mid-Atlantic region. The marshes are of immense economic value to Maryland's coastal zone as well; providing storm protection to adjacent uplands, as a place of industry for the fur trapping trade, and as a nursery and food producer for the Bay's commercial harvest of fish, oysters, and crabs.

Portions of Maryland's Chesapeake Bay marshes also provide breeding habitat for mosquitoes. The mosquito species most generally associated with tidewater marshes in Maryland is *Aedes sollicitans*, the salt marsh mosquito. The breeding zone for this mosquito is located in relatively high areas of marsh which are subjected to a tidal flooding frequency of four to eight days, or less, per month (Connell, 1940; Provost, 1977). The breeding zone is most commonly vegetationally characterized by *Distichlis spicata* (salt grass), *Spartina patens* (salt hay), and short form *Spartina alterniflora* (salt meadow cordgrass). To a lesser degree, *Ae. sollicitans* breeding is also associated with *Scirpus robustus* (salt marsh bullrush) and *Phragmites communis* (feathergrass) in Maryland.

Specific breeding sites within the high marsh include depressions and swales which are intermittently wet and dry. Permanent ponds on the salt marsh do not provide a major breeding site for *Ae. sollicitans*.

Aedes sollicitans eggs are laid on the moist soil of the depressions and swales (not on the water surface), where they undergo an obligatory conditioning period which can last from a few days to many months. A portion of the eggs will hatch on the first flooding, but some will remain in diapause until subsequent floodings trigger them to hatch, thus providing protection for the species from any catastrophic event which might destroy a larval generation. Larvae pass through four instar stages before becoming pupae and then adults. The cycle from egg eclosion to adult normally takes five to ten days in Maryland during typical summer temperatures.

The most vulnerable life stage of the salt marsh mosquito is the larva. As larvae, the Ae. sollicitans population is subject to predation by fish (primarily common killifish; Fundulus heteroclitus; in Maryland), and to drying of the breeding sites which kills the larva by desiccation. Larvae can also be flushed from the swales and depressions by tidal inundation and carried to unsuitable sites for their development or consumed by killifish moving with the flood tide. Aedes sollicitans larvae are also predated by insect predators, such as dragonfly naiads and predaceous diving beetle larvae. Waterfowl and shorebirds also consume mosquito larvae. However, Ae. sollicitans larvae are not documented to be key elements in any salt marsh or estuarine food chain.

Aedes sollicitans is the principle mosquito pest in the tidewater areas of Maryland. It is a ferocious biter both day and night and has an effective flight range from its breeding site of 20 miles or more. Migratory flights as far as 100 miles have been recorded for this species (Carpenter and LaCasse, 1955). The nuisance created by

Ae. sollicitans depreciates real estate values and makes the sale of some property impossible during the mosquito season. Moderate to large populations of Ae. sollicitans detract from local economies based on agriculture, outdoor recreation or tourism.

Salt marsh mosquitoes are also involved in the transmission of disease to humans and domestic animals. Aedes sollicitans is a major epidemic vector of eastern equine encephalitis (Crans, 1977) and dog heartworm (Johnson and Crans, 1980). An outbreak of impetigo in children in southern Dorchester County, Maryland in the summer of 1981 is thought to have been caused by infected mosquito bites as a consequence of the extremely high population of Ae. sollicitans.

The largest populations of Ae. sollicitans in Maryland are found in Dorchester and Somerset Counties. These two counties contain 55,335 hectares of tidewater marsh, which is approximately 64% of the tidal marsh in Maryland (Darmody and Foss, 1978). Of the total tidal marsh area in Dorchester and Somerset Counties, approximately 10,432 hectares have been identified as primary breeding habitat for Ae. sollicitans by the Maryland Department of Agriculture integrated pest management (IPM) mosquito control program. The southern Eastern Shore region of Maryland harbors one of the worst Ae. sollicitans problems remaining in the United States (Lesser et al., 1978b).

The public demand for Ae. sollicitans control in the southern Eastern Shore region of Maryland is great and an IPM mosquito control program is currently underway in the area (see Lesser et al., 1978a). The salt marsh mosquito control program operated by the Maryland

Department of Agriculture integrates water management (comprising both physical control and biological control) with chemical control. Chemical control poses several problems, including: environmental contamination, increasing cost, temporary results, and eventual resistance by the mosquitoes. Therefore, control of salt marsh mosquitoes by water management is the preferred technique.

The first, and most widely practiced, mosquito control water management technique is ditching. Smith (1904) recommended ditching as a control technique for mosquito species breeding on salt marshes; particularly Ae. sollicitans. The purpose of this ditching was to drain surface water from the marsh in such a length of time that Aedes mosquito larvae could not complete development to adulthood (ca. 5-7 days after egg eclosion). Ditching was begun on a small scale in New Jersey in 1906. In 1912 New Jersey's law code provided for the expansion of the ditching program (Headlee, 1945). The engineers in charge of the ditching program in New Jersey proposed a systematic parallel scheme of ditching that would theoretically be the most efficient means of regulating the water level of the marshes and controlling mosquitoes. Basically this system consisted of ditches 24 inches wide by 20 inches deep, constructed parallel to one another, and spaced 150-200 feet apart.

Parallel ditching became the principal means of salt marsh mosquito control in the early 1900's. It reached a peak during the depression years when thousands of men were employed by state and federal agencies to dig the ditches. Regrettably, a great deal of this ditching may have been unnecessary from the mosquito control standpoint. Smith (1904) advocated that a preliminary survey be done to ascertain those areas of marsh that were producing sufficiently high numbers of mosquitoes to warrant control and then only those areas of marsh be ditched. Smith's plan would result not only in less marshland being disturbed, but also better mosquito control and less expenditure of funds. However, partly because of the potential for large public works projects during the depression and partly because of the lack of trained biological/entomological personnel, entire sections of marsh were ditched without knowledge of their roles as mosquito producers.

In the early 1930's mosquito control workers in general had but one objective: the elimination of mosquitoes. Little or no consideration was given to the ecological consequences of ditching. However, concern about our nation's dwindling wildlife resources was gaining popular support at the time when a great deal of ditching was being done by relief workers. Cottam et al., (1938) strongly disagreed with the notion of digging ditches to provide work for those on relief. Urner (1935) and Bradbury (1938) reported that many waterfowl and shorebirds were adversely affected by mosquito control projects. Cottam and associates (Cottam et al., 1938; Bourn and Cottam, 1950 and Cottam and Bourn, 1952) advised that parallel ditching decreases the abundance and diversity of salt marsh invertebrates; particularly crustaceans and molluscs; and causes undesirable changes in the salt marsh plant community structure. Stearns et al., (1940) found parallel ditching to be deleterious to muskrat production due to the elimination of choice food plants. A more complete list of references on the impact of mosquito control practices on tidewater marshes can be found in Daiber (1974) and the publication, Impacts of Mosquito Control Practices: A Bibliography (U.S. Dept. of the

Interior, 1977).

Today it is generally accepted that indiscriminate parallel ditching is not a desirable management technique for mosquito control. Some studies have found that parallel ditching does not always cause the serious ecological consequences attributed to it (Kuenzler and Marshall, 1973; and Lesser et al., 1976). Provost (1977) also points out the numerous short comings of Bourn and Cottam's (1950) work which has unfortunately been uncritically accepted by conservationists as a "classic". However, the need to provide a management technique which limits alteration to mosquito breeding marshes only, and to directly effect the specific mosquito breeding sites within those marshes, largely precludes the use of parallel ditch systems.

A more recent water management technique has been formally advocated by Ferrigno and Jobbins (1968). This technique is termed open marsh water management (OMWM). The significance of OMWM is that it is based on an ecological approach because mosquito control, like wildlife management, is a form of applied ecology. However, instead of attempting to minimize the limiting factors affecting game populations as in wildlife management, OMWM is attempting to maximize the limiting factors controlling larval mosquito production; e.g. enhancing tidal inundation and bringing larvivorous fish to the mosquito breeding areas of the marsh. Excessive drainage of subsurface water is not the principle of OMWM. As previously pointed out, a common fault with parallel ditching was that large sections of marsh were needlessly ditched. In contrast, OMWM confines any management work to the higher sections of marsh which are responsible for mosquito production. The lower sections of marsh characterized by the growth of tall form *Spartina alterniflora* and broad zone *Juncus Roemerianus* are not altered unnecessarily. A strict set of standards for management that constitutes OMWM is presented by Bruder (1980).

In New Jersey, it has been demonstrated that OMWM is highly effective in controlling salt marsh mosquitoes, reducing insecticide use and enhancing the productivity of the treated marshes (Ferrigno, 1970; Ferrigno et al., 1975; Shisler and Jobbins, 1977). The results obtained in New Jersey are not entirely applicable to Chesapeake Bay marshes in Maryland when standard New Jersey OMWM techniques are used (Lesser and Saveikis, 1979). While Lesser and Saveikis reported good mosquito control and an increase in aquatic organism use of the OMWM plots, they also found lowered water tables and significant changes in plant species composition on those plots treated according to the New Jersey standards for OMWM. Lesser and Saveikis (1979) concluded that modifications of the New Jersey standards for OMWM were necessary for the successful implementation of an OMWM program in Maryland's Chesapeake Bay tidal marshes. The objective of the study reported here is to continue and expand the basic investigation of Lesser and Saveikis (1979) on the ecological impact of various forms of OMWM on Chesapeake Bay marshes in Maryland.

This report is divided into two major subdivisions. One part of the report examines the impacts of three strategies of OMWM on mosquito populations, emergent marsh macroinvertebrates, fish and aquatic invertebrates, and water tables. The investigation for this part of the report was conducted by the Maryland Department of Agriculture and the results are presented here. The other portion of this study examined the effects of the same management techniques on vegetation ecology and nutrient exchanges between the marsh and the estuary. That portion of the study was conducted by the Chesapeake Bay Center for Environmental Studies, Smithsonian Institution, and the results are presented in a separate report.

STUDY AREA

Field studies were conducted on a portion of the 4,050 hectare Deal Island Wildlife Management Area in Somerset County, Maryland (Figs. 1 and 2). This area is owned by the Maryland Department of Natural Resources and is administered by the Maryland Wildlife Administration to provide habitat for waterfowl and to serve as a public hunting area. All of the marsh within the Deal Island Wildlife Management Area is classified as submerged upland type marsh by Darmody and Foss (1978). The dominant high marsh vegetation on the area is D. spicata, S. patens, and Scirpus robustus. The Deal Island Wildlife Management Area is one of the most prolific breeding areas for Ae. sollicitans in Somerset County. Approximately 830 hectares provide breeding habitat for Ae. sollicitans on the area.

The study area consists of a 250 hectares (approx.) tract of land known as Davis Island (Fig. 2). Davis Island is located between Broad Creek and Geanquakin Creek, two tributaries of the Manokin River. The dominant salt marsh vegetation on this area is D. spicata and S. patens in the higher zones and J. Roemerianus in the lower elevations. Two upland sites exist on Davis Island. These sites are vegetated by loblolly pines (Pinus Taeda) and associated undergrowth. A long-time resident of the area recalls that most of Davis Island was forested with loblolly pines 50 years ago (W. Hopkins, pers. comm.). However, timber harvesting, burning and a rising sea level have resulted in the conversion of Davis Island from an upland to a high phase marsh.

The mosquito breeding sites on Davis Island consist mostly of

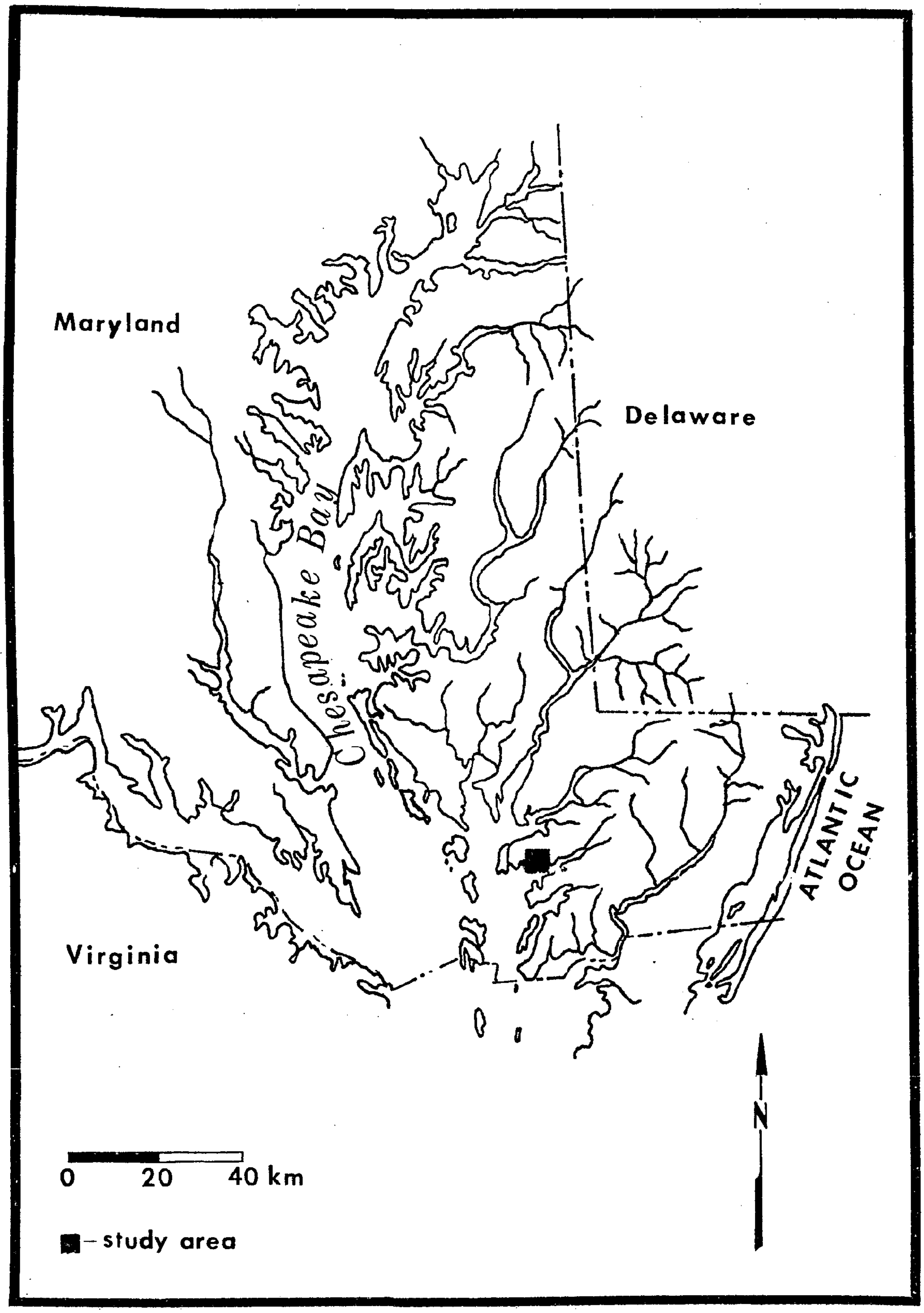


Fig. 1. Chesapeake Bay area of Maryland showing location of study area.

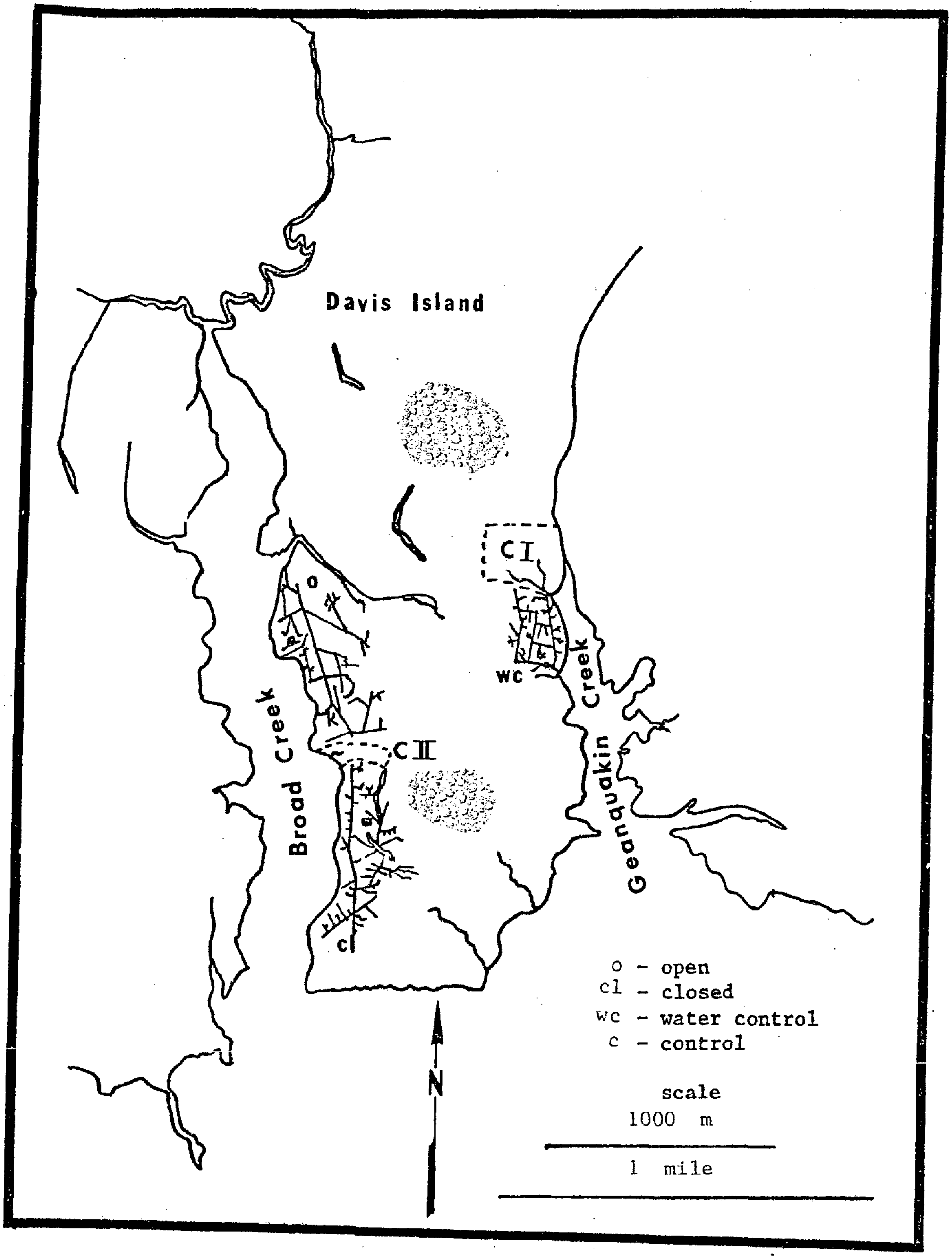


Fig. 2. Davis Island study plots.

depressions in the *D. spicata* and *S. patens* zone. The breeding depressions consist of well defined, roughly circular shaped holes 10 to 30 cm. in depth. The diameter of these depressions ranges from approximately 30 cm. to 100 cm. The depressions are uniformly scattered through the mosquito breeding portion of the marsh. Under the soil at the bottom of the depressions there is often found well preserved main tap roots of loblolly pine trees. It is speculated, from this observation, that the origin of many of these depressions can be traced back to holes that remained after loblolly pine trees died and decayed.

Prior to the initiation of this study, there is no history or evidence of mosquito control water management practices on Davis Island. However, on a portion of Davis Island not included in the study area, there does exist drainage ditches and dikes constructed for agricultural purposes. The age of these agricultural features is unknown.

The mean tide range between high and low tide in the Manokin River near Davis Island is 0.64 meter; the spring tide range is 0.76 meter (U.S. Dept. of Commerce, 1980).

PREPARATION OF THE STUDY SITES

Ideally, a study such as this should gather baseline data on all treatment and control plots for at least one year before management is initiated. By compiling baseline data of the test parameters prior to treatment, and comparing these data to post treatment data, a more reliable estimate of the impact of the treatment can be made. However, due to time and funding limitations, collection of pre-treatment data was not possible. Therefore, the impact of the treatments on the test parameters was estimated by comparing results on treatment plots to similarly collected data on untreated control plots.

A control plot (no OMWM treatment) of approximately 8.09 hectares in size was established in the northeast quadrant of Davis Island at the initiation of this study in 1978 (Fig. 2). This control was monitored throughout 1979, the first year of field data collection. A review of the 1979 data indicated that the control site was not a representative area for comparison to the treatment plots. The control plot was subjected to a much greater frequency of tidal floodings than were the treatment plots. This had an impact on all of the study parameters and this control site was abandoned at the end of 1979.

A new control plot was established on the western side of Davis Island between the open and closed plots (Fig. 2). This control is approximately 4.05 hectares in size. The new control (designated Control II) was established as a mosquito larvae dipping check in July, 1979, as an adjuvant to the original control (designated Control I). Control II was adopted for all sample parameters in January, 1980.

Control II provides representative mosquito breeding habitat, a small tidal creek and a natural pond.

Construction of the OMWM plots began on September 27, 1978 and was completed on March 30, 1979. Three treatment plots were subjected to different management techniques. These techniques are described as follows:

(1) Open system - This plot covers approximately 20.23 hectares (Fig. 3). All ditches were constructed according to New Jersey OMWM standards (Bruder, 1980), so as to provide unimpeded tidal circulation throughout the ditch system. The open system is connected to Broad Creek by three ditches. In addition to the ditches, one non-tidal pond, 0.02 hectare in size, was constructed.

(2) Water control system - The water control plot is approximately 10.12 hectares in size (Fig. 4). Ditches were constructed according to OMWM principles, but the outlet ditches were modified so as to have a controlling influence on the degree of tidal ebbing and flooding within the system. This system is connected to Geanquakin Creek by two outlet ditches. At each of the outlets three pipes were installed to serve as water level regulators. The pipes are made of PVC plastic and are ca. 3 meters long with a 10.16 cm. inside diameter.

The last three meters of each outlet ditch was graded up from a normal depth of approximately 0.76 meter to a depth of approximately 0.25 meter below the marsh surface. The pipes were placed in these elevated ditches and spoil was packed around them up to marsh level to hold them in place. All of the tidal water

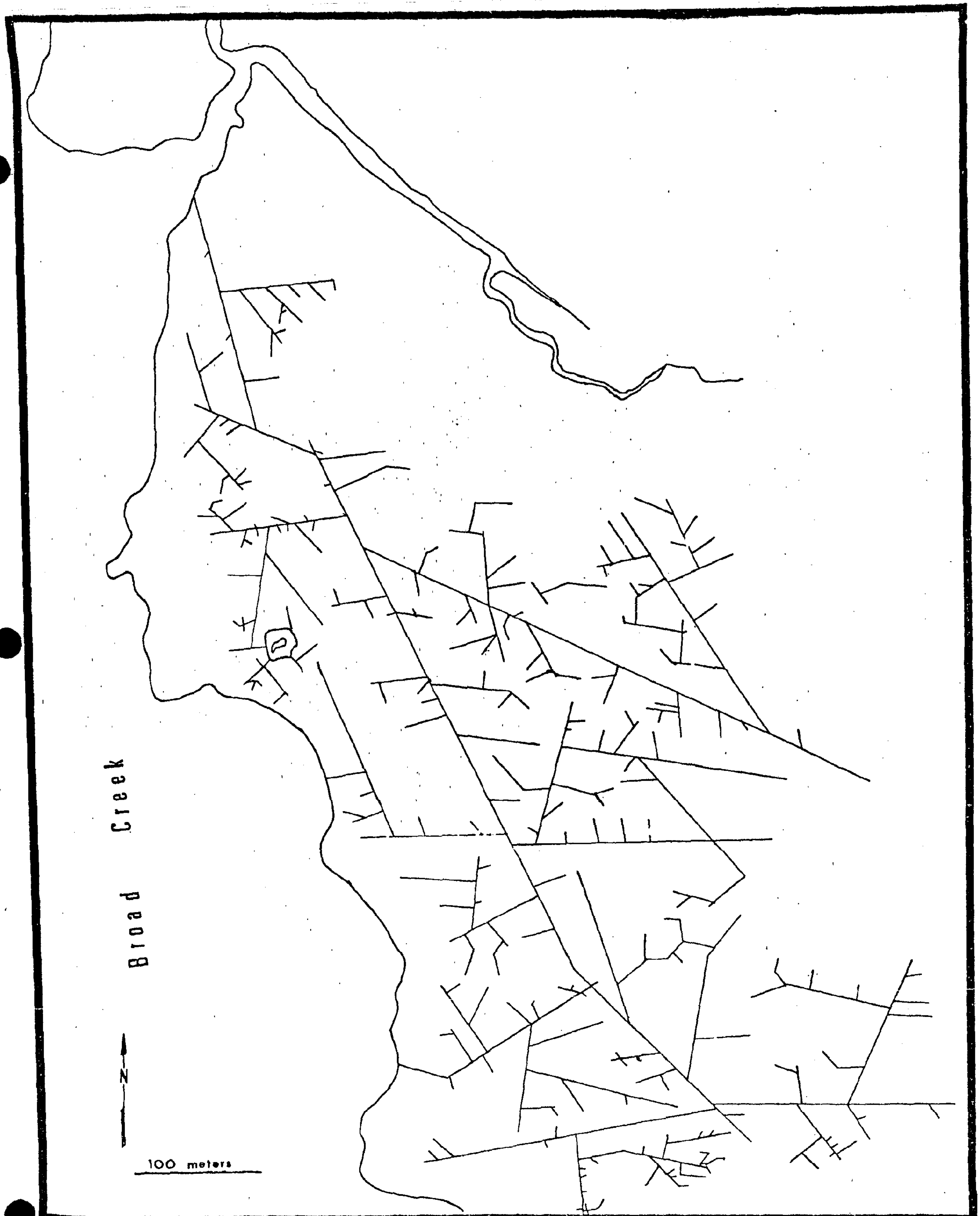


Fig. 3. Open system study plot.

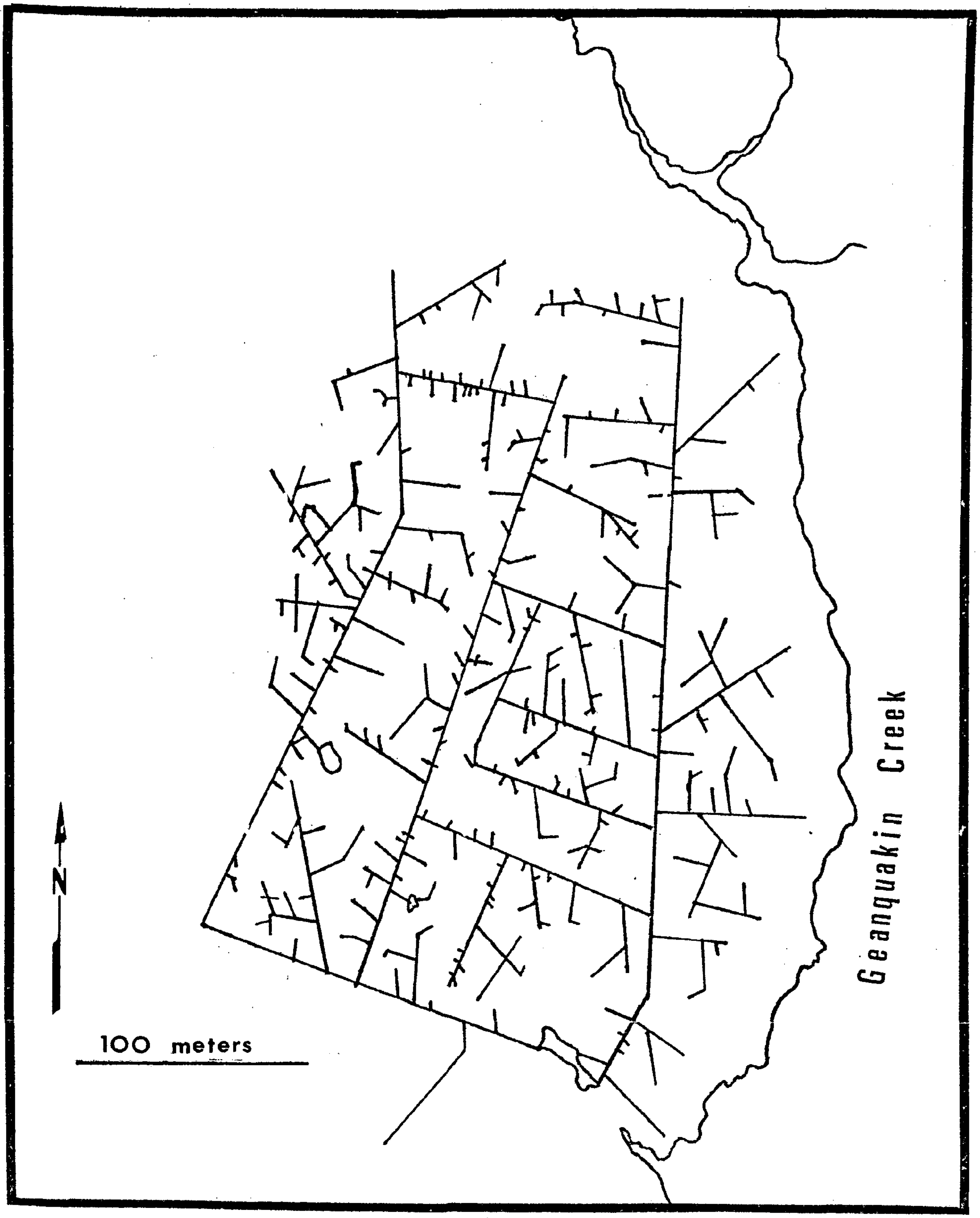


Fig. 4. Water control system study plot.

that entered or exited the system had to pass through these pipes; except for lunar tides or storm tides when the entire marsh surface was flooded.

One pond was constructed on the water plot. This pond is not connected to the ditch system.

(3) Closed system - The closed system is approximately 12.14 hectares in size (Fig. 5). The ditch system constructed here attempted to interconnect all of the mosquito breeding sites on the plot. Ditches radiated from three natural ponds. In addition five deep reservoir pools were constructed and incorporated into the ditch system. This system was not connected to tidewater by the ditches. The ditches terminated in the high marsh zone. Theoretically, tidal flooding could occur only as a result of spring or storm tides.

The majority of the ditches on all of the plots were excavated by a rotary ditcher. In addition, the pond on the open plot was constructed with a rotary ditcher. The rotary ditcher is an amphibious unit. It employs a rotary cutting head which cuts and lifts away the soil encountered in ditch construction. Ground water, or tidewater is mixed with the soil to form a slurry which, by centifugal force, is thrown out a chute to the right hand side of the direction of travel of the unit. The spoil travels up to 15 meters through the air. The spoil is deposited in a thin, unconsolidated layer within a 10-15 meter wide band along the ditch. No spoil grading is necessary. The rotary ditcher constructs a ditch that is 76 cm. wide and from 60 cm. to 90 cm. deep, with nearly verticle sides and a slightly rounded bottom. It can excavate

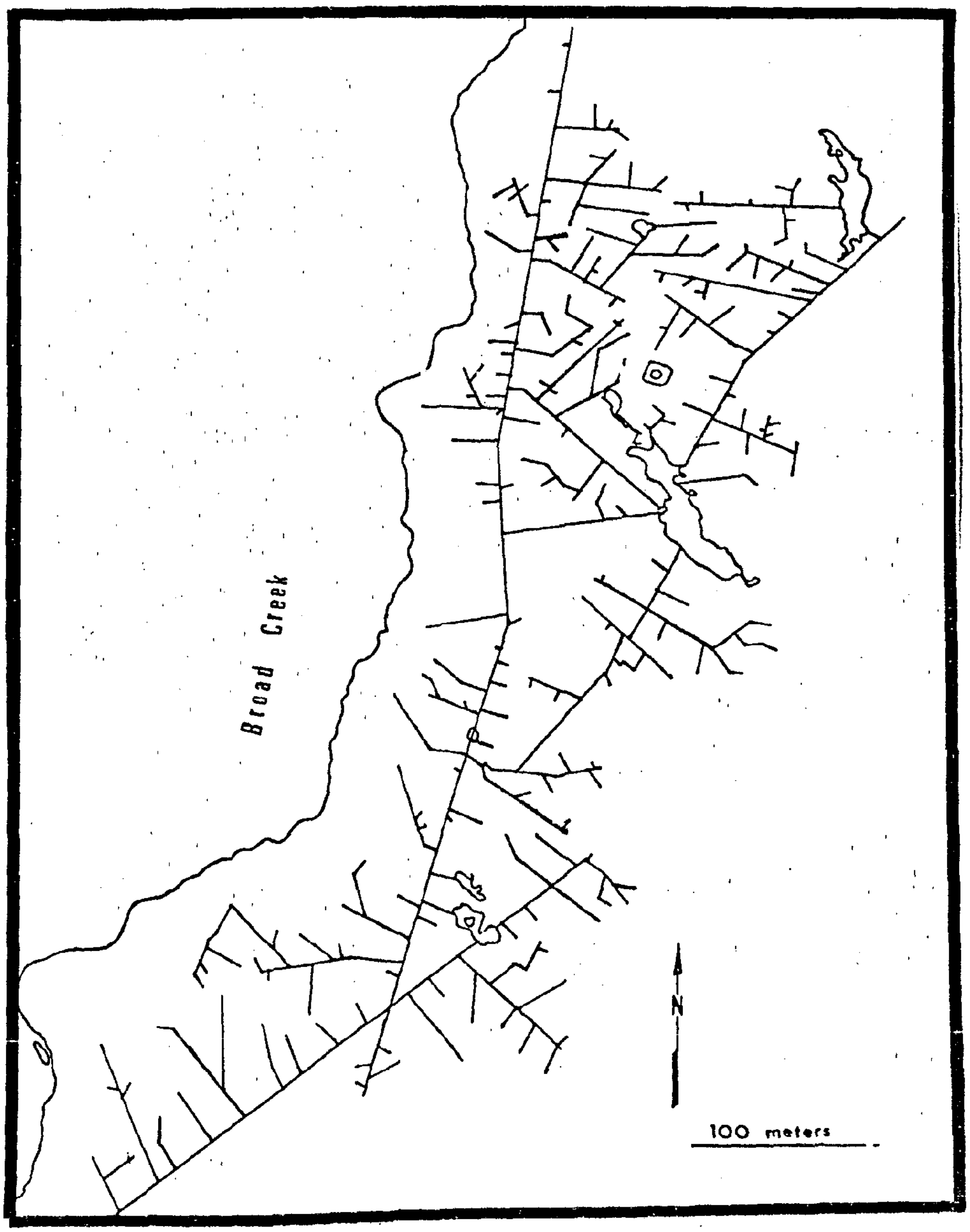


Fig. 5. Closed system study plot.

approximately 245-300 meters of completed ditch per hour of operation and is the most productive, efficient type of heavy equipment currently used to construct ditches for salt marsh mosquito control programs.

The backhoe was also used for excavations on the treatment plots. This unit was used to dig small lateral ditches, to uproot underground stumps encountered in the path of a ditch, and to dig ponds. The backhoe digs a ditch approximately 50 cm. wide by 91 cm. deep. Spoil excavated by the backhoe is graded to near marsh level. A backhoe can construct approximately 30-40 meters of ditch per hour, however, additional time is needed to level spoil.

Rationale of study plot design - The primary intent of this project is to gather data for decision making as to what type of mosquito control marsh management technique best suits the peculiar characteristics of Chesapeake Bay marshes in the southern Eastern Shore area of Maryland. To do this, several management strategies had to be evaluated.

The open system is the oldest, most widely practiced form of mosquito control marsh management. The open system of ditching, when properly and discriminately used, has been documented to effectively eliminate salt marsh mosquito breeding (Ferrigno, 1970). The open system is also the most criticized form of marsh management by some conservationists who claim that deleterious effects result to the marsh as a result of a lowered water table.

The water control system was evaluated to determine if mosquito control could be achieved by the limited tidal circulation provided by the ditches and biological control provided by fish; while not causing the negative environmental impacts sometimes associated with open tidal ditches.

The closed system theoretically provides no tidal circulation or drainage of surface water. Mosquito control is achieved by the biological control provided by fish. Wildlife managers in Maryland favor the closed system, as they feel that it will have the least harmful impact on the marsh. But, the effectiveness of closed systems in controlling mosquitoes has been challenged by entomologists.

METHODS

Measurement of physical alteration by OMWM systems - All OMWM modifications (ditches and ponds) were mapped by aerial photography and ground truth. Measurements were made of the size of each study area, and the total length of the ditches on each area, the total surface area covered by the ditches, the number of constructed ponds, the surface area of the ponds and the amount of spoil excavated in the construction of the ditches and ponds.

Mosquito larvae populations - The number and species composition of the mosquito larvae population on the study area was determined by the standard dipping technique. A series of 50 sample stations was established on each study plot. The sample stations on each of the three treatment plots were regularly sampled during the mosquito breeding season (April through October) in 1979, 1980, and 1981. The sample stations on control I were sampled from April through October in 1979. The sample stations on control II were sampled from July through October, 1979, and on all subsequent sample times in 1980 and 1981.

The sampling technique consisted of taking three dips of water with a 350 ml. dipper from each station. The dips were taken along a water/vegetation edge when possible because of mosquito larvae's preference for such habitat. Each of the three dips was taken sufficiently far apart in time or space so that the larvae at the point of the (xth) dip would not display avoidance behavior induced by the disturbance caused by the (x-1th) dip. This precaution reduced the probability of a non-random collection. Care was also exercised in the approach to a sampling site so that the larvae were not alerted to the sampler's presence by shadows or vibrations caused by heavy footsteps. The larvae obtained from the samples were pooled as a collection from each study plot for each sample time. The collection was returned to the laboratory for identification to species and counting.

Data obtained for the number of larvae/species/sample time were logarithmically transformed to Z=(x+1) log 10, to stabilize variance (Steel and Torrie, 1960). The transformed data were analyzed by a one-way analysis of variance, with sample time as the replicate, to determine the effectiveness of each of the OMWM treatments, as compared to the controls, to control *Aedes sollicitans*, *Aedes cantator*, *Aedes taeniorhynchus*, *Anopheles bradleyi*, *Culex salinarius*, and *Culisetta inornata*. If the analysis of variance showed a significant difference within a species, interplot comparisons were made by Tukey's procedure (Steel and Torrie, 1960).

All means for mosquito larvae expressed in the following text and tables resulted from the logarithmic transformation of field data, subsequently inversely transformed after averaging. Bidlingmayer (1969) pointed out the necessity of such a procedure to obtain a centrally located mean of field populations.

Emergent marsh macroinvertebrates - Population density and frequency of occurrence were determined for selected species, or groups of marsh surface macroinvertebrates. These included the coffee-bean snail (*Melampus bidentatus*), fiddler crabs (*Uca* spp.), the salt marsh periwinkle (*Littorina irrorata*), the mussel (*Brachidontes recurvus*), Isopods, and

Amphipods.

Sampling for these invertebrates was done monthly from May through October, 1979 and June through August, 1980. In 1979, the sampling design was completely random with ten quadrats selected for sampling within each plot, each month. In 1980, a transect sampling design was used. The design provided for quadrats to be located at 0, 1, 5, and 10 meters from a ditch bank or the edge of the control creek. Five transect lines were located at random on each study plot, each month. This provided for five replicates per distance per month on each study plot.

A quadrat frame of 50 cm. X 50 cm. (0.25 m^2) was selected. Vegetation within the quadrat frame was clipped to near marsh level. Before being removed, the plant material was examined for invertebrates. The invertebrates found within the quadrat frame were collected, identified, counted and released. *Uca* are agile and fast, therefore difficult to sample by direct count. Because of this, *Uca* densities were determined by counting burrow holes within the quadrats. The correlation between burrow hole density and individual crab density was found to be satisfactory by Krebs and Valiela (1978) for estimation of population density.

Field data for the density of each sampled invertebrate species or group per quadrat were logarithmically transformed to Z=(x+1) log 10 to stabilize variance. All means for the invertebrates which are expressed in this paper are means resulting from this logarithmic transformation, subsequently inversely transformed. All statistical analysis was done using the logarithmic transformations. The 1979 random point data were analyzed as a one-way analysis of variance for each species or group with the sample time as the replicate source. The 1980 transect data were analyzed as a 4 X 4 factorial analysis of variance (4 distances and 4 plots) for each species or group (Steel and Torrie, 1960). Specific treatment comparisons were made by Tukey's procedure.

Benthic infauna - The population densities and species composition of benthic infauna of the OMWM ditches and control creek were determined in 1979 and 1980. Samples were taken monthly in June and July, 1979 and in June, July and August, 1980. Five quadrats for benthic infauna were selected at random in each study plot per month. Samples were made with an Eckman dredge which sampled a 15 cm. X 15 cm. (0.0225 m^2) surface area. Samples were taken to a depth of 2.5 to 5 cm. The vegetation, soil and debris obtained in the sample was washed and screened in two wash frames in series. The top wash frame has a screen of 5 mm. X 5 mm. The bottom wash frame has a screen of 1.25 mm. X 1.25 mm. All invertebrates found in the sample were put in 10% formalin, returned to the laboratory for identification to the lowest taxon possible and counted.

The field collection data were logarithmically transformed to Z=(x+1) log 10 to stabilize variance. Statistical analysis for differences within species, between plots, of the transformed data was by a one-way analysis of variance. Specific comparisons between plot means were made by Tukey's procedure. The means presented in the text and tables are decoded; i.e. inversely transformed from the (x+1) log 10 transformation.

Fishes and shallow-water macro-epibenthos - The use of OMWM ditches and the control creeks by fishes, and the macro-epibenthonts grass shrimp (Palaemonetes pugio) and blue crabs (Callinectes sapidus), was monitored biweekly from April, 1979 through January, 1980 and March, May, June, July and August, 1980.

A 25 meter long section of ditch in each treatment plot and a 25 meter long section of the control creeks were selected for sampling with seine nets. Sample stations were located well away from the outlet discharges in the open and water control plot and from the natural ponds on the closed plot. The sampled section of the ditches were not intersected with lateral ditches. The sample stations on control creek I and control creek II were located at points where the depth and width approximated the depth and width of the OMWM ditches. At the point of sampling, control creek I is approximately 1.5 to 2 meters wide and 1.0 to 1.5 meters deep. Control creek II is approximately 1.5 meters wide and 1.0 meters deep. Both creeks have a soft mud bottom of 10-16 cm. in depth overlaying a hard strata of silt and clay. The bank slope between the mean high water mark and the bottom of each creek is approximately 20^{o}. The bottom and sides of both creeks were characterized by irregular relief, most pronounced along the banks where currents had sculptured undercuts several centimeters deep.

At each seine sample station a seine net was placed at the ends of the 25 m. section. The nets had a mesh size of 4 mm. X 4 mm., were 1 meter in depth, and $\geq$ 2 meters in length. The area between the block nets was seined with a similar size net at least three times to insure that most of the fishes, shrimp and crabs were collected. All of the collected specimens were identified and counted by species, and length/frequency distributions were taken on a random assortment of 50 individuals for each species (if less than 50 individuals of a given species were collected, then all individuals were measured for length). Fish were measured for total length, carapace length for crabs and tip of rostrum to tip of telson length for shrimp. In 1980, the collections were similarly analyzed, and, in addition, the collections were weighed (live wet weight) on a field scale (Douglas Homs Corp. Model 1000).

An attempt was made to process the collections in the field and return the specimens to the water alive. When unknown fishes were collected, samples were preserved in 10% formalin and returned to the laboratory for indentification using the keys provided by Hildebrand and Schroeder (1928) and Mansueti (1950).

Because of the time required to collect and process each sample (1 to 2 hours) tide levels varied between stations during each collection period. All collections were made during daylight.

The fish collection data for the ditches and creeks were analyzed for interplot comparisons of species composition, species dominance, number of individuals, number of species, seasonal occurrence of selected species, length/frequency distribution for selected species, species diversity, and species evenness. The species diversity measure used was that of Brillouin (Poole, 1974). Interplot comparisons of the number of individual fishes (all species) and the number of individuals for selected species were analyzed by one-way analyses of variance and Tukey's procedure. In some cases it was necessary to transform the data to Z=(x+1) log 10 to obtain homogeneous variances for analysis.

One constructed pond on each treatment plot and one natural pond on the control plots were sampled for fish use. Seining was found to be an ineffective sampling technique for the constructed ponds, because the deep reservoir ditches in the ponds provided a means of escape and a habitat impossible to adequately sample with seine nets. Consequently, sampling in the ponds was by the passive technique of trapping. Commercially available funnel-entrance minnow traps, baited with small amounts of dry dog food, were used (one per pond). The traps were modified for our use by the addition of a 1/16 inch mesh screen covering the inside walls and funnels of the traps. This helped to insure the retention of small fish which might otherwise escape. The traps were left in place for approximately 24 hours for each sample time. Samples were taken biweekly on approximately the same schedule presented for the seine samples. The collections were identified to species and counted.

The collections of fish from the ponds were analyzed for interplot comparisons of species composition, species dominance, number of individuals, number of species, species diversity (Brillouin's measure), and species evenness (Poole, 1974).

<u>Water quality</u> - Measurements of dissolved oxygen, salinity and water temperature in the OMWM ditches and ponds, and the control creeks and ponds were taken in 1979 and 1980. These measurements were taken at a depth of approximately 16 cm. below the water surface. Water quality measurements were made at the time and place of the fish and epibenthont

collections discribed above.

Dissolved oxygen and water temperature were determined with a Yellow Springs Instrument Company Model 57 dissolved oxygen meter. Salinity was measured with an American Optical Corp. refractometer.

Water quality data were analyzed by one-way analyses of variance.

Water table elevations - To determine the effect of the OMWM treatments on the elevation of the ground water table, monitoring wells were established on all of the study plots. The wells consist of 1 meter lengths of 4.0 cm. diameter PVC plastic pipe, capped at the bottom, with a series of 1.27 cm. holes drilled in the lower 67 cm. of the pipe. The pipes were buried to an approximate depth of 75 cm., leaving approximately 25 cm. exposed above the marsh surface. Elevations (cm. above mean sea level) of the top of each well were determined by a transit line run from a U.S. Coast and Geodetic Survey benchmark approximately four miles distant from the study area.

Each treatment plot received twenty water wells. Ten wells were established along two transect lines (5 wells per transect) located perpendicular to OMWM ditches. The wells were established along the transects at 1 meter, 5 meters, 10 meters, 25 meters, and 50 meters from the ditches. An additional ten wells were established at random within each treatment plot.

The control plots each received ten water wells. Five wells were placed along a transect at 1 meter, 5 meters, 10 meters, 25 meters, and 50 meters from the creeks. Five wells were established at random points within the control plots. The water wells on control plot I were monitored in 1979. The water wells on control plot II were monitored in 1980.

Measurements of the water table elevations were made weekly from May through December, 1979 and from March through September in 1980. A meter stick was used to measure the distance (to the nearest half cm.) between the top of the well and the top of the water column in the well. This measurement was adjusted by a correction factor for each well to determine the absolute elevation, in relation to mean sea level, of the water table at that point. For each week of sampling the values of the random well readings were averaged to determine the average water table depth for each plot. The transect well values were averaged to determine the mean water table depth at each transect distance for each month of sampling.

Random water table data for each year were analyzed by one-way analyses of variance. Specific plot comparisons of mean water table depths for each year were made by Tukey's procedure. Transect water table data for each year were analyzed by a 4 X 5 factorial analysis of variance (4 plots and 5 distances) with the sample time as the replicate source. Specific comparisons of plot means, distance means, and plot/distance interaction means were made by Tukey's procedure.

Soil classification - Soil on all study plots was classified by personnel from the U.S. Department of Agriculture, Salisbury, Maryland. Soil samples were taken at random throughout the study area. Soil material was taken to an approximate depth of 150 cm. in 5 cm. increments.

At each sample site the following observations were recorded: location; consolidation; H_2S odor; depth and fiber content of the organic material; and depth, color and texture of the mineral soil.

Rainfall - One rain gauge was maintained on the study area. Rainfall was reocrded weekly from April, 1979 to October, 1981.

RESULTS AND DISCUSSION

Measurement of physical alteration by OMWM systems - The degree of alteration resulting from each OMWM treatment is presented in Table 1. The amount of disturbance per hectare is greatest on the closed system plot and least on the open plot. The degree of disturbance on the water control plot falls between the values for the open and closed plots. Five times the number of deep reservoirs were dug on the closed plot than on the open plot. The reservoirs were necessary to maintain fish populations in the closed system during times of drought and winter freezes.

Because mosquito control in a closed system is achieved only by the biological control provided by larvivorous fish, the amount of ditching will normally be greater than the amount required on an open tidal system which provides physical control by drainage of surface water as well as biological control by fish. The difference between the degree of alteration on a closed system versus an open system will be relatively small when the systems are compared on marshes where most mosquito breeding is confined to well-defined potholes (as on the Davis Island study area). However, the difference will be greatly magnified when the systems are compared on marshes where large sheet water breeding zones are found.

Mosquito larvae populations - The results of the mosquito larvae collections from each plot are shown in Tables 2 through 5.

Aedes sollicitans was the most abundant mosquito species sampled. Significantly fewer *Ae. sollicitans* larvae were collected from the treatment plots as compared to the controls during each year of study.

Table 1. Size of the study plots and the degree of water management/plot.

	PLOT		
	Open	Water Control	Closed
Total area of marsh (ha)	20.23	10.12	12.14
Total length of ditches (m)	8535.00	4440.00	5506.00
Total area of ditches (ha)	0.65	0.34	0.42
% of marsh occupied by ditches	3.21	3.36	3.46
Number of constructed ponds	1.00	2.00	5.00
Area of constructed ponds (ha)	0.02	0.025	0.027
% of marsh occupied by ponds	0.01	0.25	0.23
Cubic meters of spoil excavated	5043.00	2690.00	3374.00
Approximate % of marsh covered by spoil	42.19	43.87	45.35

No significant difference existed between the number of Ae. sollicitans larvae collected per treatment plot per collection date in any year of this study. The treatments were, therefore, all equally effective in controlling the production of Ae. sollicitans.

The closed plot had the lowest collection of Ae. sollicitans larvae from the treatment plots in 1979, followed by the open and water control plots (0.15, 1.04 and 1.09 larvae/plot/collection date, respectively). However, in 1980 and 1981, the closed plot produced the highest collections of Ae. sollicitans larvae from the treatment plots followed by the water control and the open plots in descending order (Tables 3 and 4).

Mosquito breeding was severely depressed in 1980 because of prolonged drought conditions and an absence of flooding tides during most of the mosquito breeding season (see Whigham et al., 1982).

More Ae. sollicitans larvae were collected in 1981 than in any other year of this study. This is due primarily to the large collections made on the control plot. The number of larvae taken from the treatment plots was relatively low. The weather pattern in 1981 was highly favorable for Ae. sollicitans breeding due to a repetitive cycle of drawdown and flooding which allowed the development of several generations.

Graphical representations of the Ae. sollicitans larval populations on each study plot for each year of study are presented in Figs. 6 through 18.

Aedes cantator and Ae. taeniorhynchus were also collected from the study plots, but in relatively low numbers. Aedes cantator was found

Table 2. The mean number of mosquito larvae collected/plot (50 stations/ plot X 3 dips/station) /collection date in 1979.

Species	PLOT				
	Open	Water Control	Closed	Control I	Control II
Ae. sollicitans	1.04^{a}	1.09^{a}	0.15^{a}	8.69^{b}	9.56^{b}
Ae. cantator	0.02^{a}	0.10^{a}	0.01^{a}	1.38^{b}	0.01^{a}
Ae. taeniorhynchus	0.80^{a}	0.63^{a}	0.41^{a}	3.91^{b}	5.36^{b}
An. bradleyi	1.44^{a}	1.20^{a}	1.47^{a}	5.89^{b}	6.98^{b}
Cx. salinarius	0.52^{a}	0.08^{a}	0.56^{a}	0.93^{b}	1.41^{b}

a,b - Those mean numbers within a species not having the same letter are significantly different at $P < 0.05$.

Table 3. The mean number of mosquito larvae collected/plot (50 stations/plot X 3 dips/station) /collection date in 1980.

Species	PLOT Open	Water Control	Closed	Control II
Ae. sollicitans	0.13^{a}	0.30^{a}	0.52^{a}	5.34^{b}
Ae. cantator	0.02^{a}	0.01^{a}	0.01^{a}	1.01^{b}
Ae. taeniorhynchus	0^{a}	0^{a}	0^{a}	1.37^{b}
An. bradleyi	0^{a}	0^{a}	0^{a}	0.17^{b}
Cx. salinarius	0^{a}	0^{a}	0^{a}	0^{a}
Cs. inornata	0^{a}	0^{a}	0^{a}	0.01^{b}

a, b - Those mean numbers within a species not having the same letter are significantly different at $P < 0.05$.

Table 4. The mean number of mosquito larvae collected/plot (50 stations/ plot X 3 dips/station) /collection date in 1981.

	PLOT			
Species	Open	Water Control	Closed	Control II
Ae. sollicitans	0.15[a]	0.32[a]	1.18[a]	20.23[b]
Ae. cantator	0.07[a]	0.12[a]	0.67[a]	3.08[b]
Ae. taeniorhynchus	0.02[a]	0.31[a]	0.42[a]	3.74[b]
An. bradleyi	0.83[a]	0.98[a]	0.62[a]	8.41[b]
Cx. salinarius	0.01[a]	0.25[b]	0.31[b]	2.20[c]
Cs. inornata	0[a]	0[a]	0[a]	0.04[b]

a, b, c - Those mean numbers within a species not having the same letter are significantly different at P 0.05.

Table 5. Percent frequency of occurrence (no. positive dip stations/ total no. dip stations) of *Aedes* spp. larvae/plot in 1979, 1980 and 1981.

	PLOT				
Year	Open	Water Control	Closed	Control I	Control II
1979	1.47%	1.47%	1.20%	15.06%	24.89%
1980	0.20%	0.20%	0.60%		20.90%
1981	0.40%	0.60%	1.20%		39.00%

primarily in the early season; from April through June. No Ae. cantator larvae were collected on the study area after early July, with most being found in April and May. Aedes taeniorhynchus was found on the study area in the latter part of the mosquito season. No Ae. taeniorhynchus larvae were collected before mid-June. Both Ae. taeniorhynchus and Ae. cantator larvae were found in association with Ae. sollicitans. Significantly fewer Ae. taeniorhynchus larvae were collected on the treatment plots as compared to the controls in each year of study. There was no significant difference between the number of Ae. taeniorhynchus collected from the treatment plots within any year of study. In 1979, significantly fewer Ae. cantator larvae were collected from control II as compared to control I and no significant difference existed between the treatment plots and control II. This is because control II was not sampled until early July in 1979, when the population of Ae. cantator was low. Significantly lower numbers of Ae. cantator larvae were collected from the treatment plots, as compared to control II, in 1980 and 1981. No significant difference existed between the collections of Ae. cantator larvae from the treatment plots within any year of this study.

Anopheles bradleyi was the second most abundant mosquito species collected. No significant difference existed between the number of An. bradleyi larvae collected per treatment plot per collection date in any year of study. Significantly fewer An. bradleyi larvae were collected from the treatment plots as compared to the control plots during each year of this study.

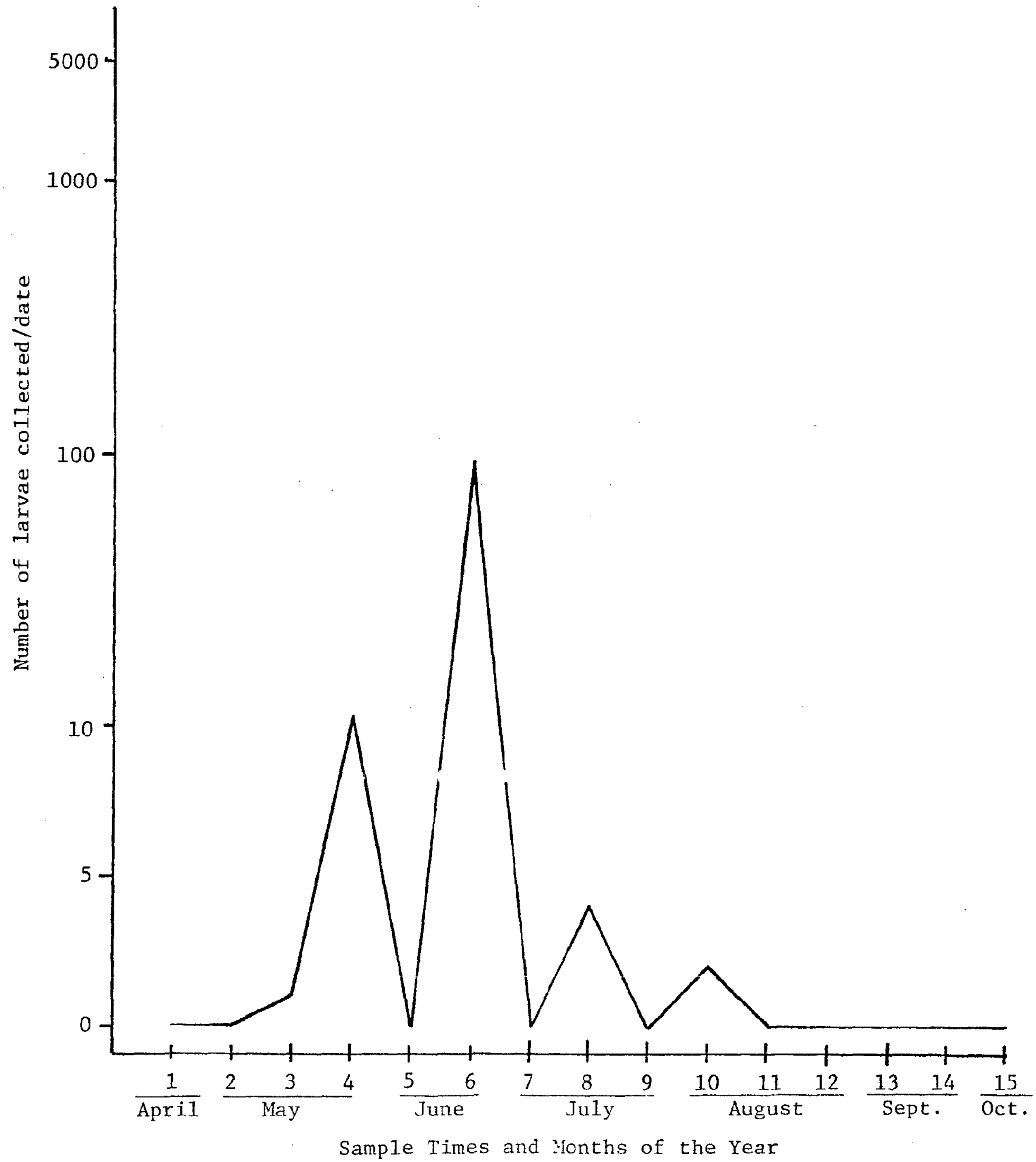


Fig. 6. Number of *Aedes sollicitans* larvae collected on the open plot in 1979.

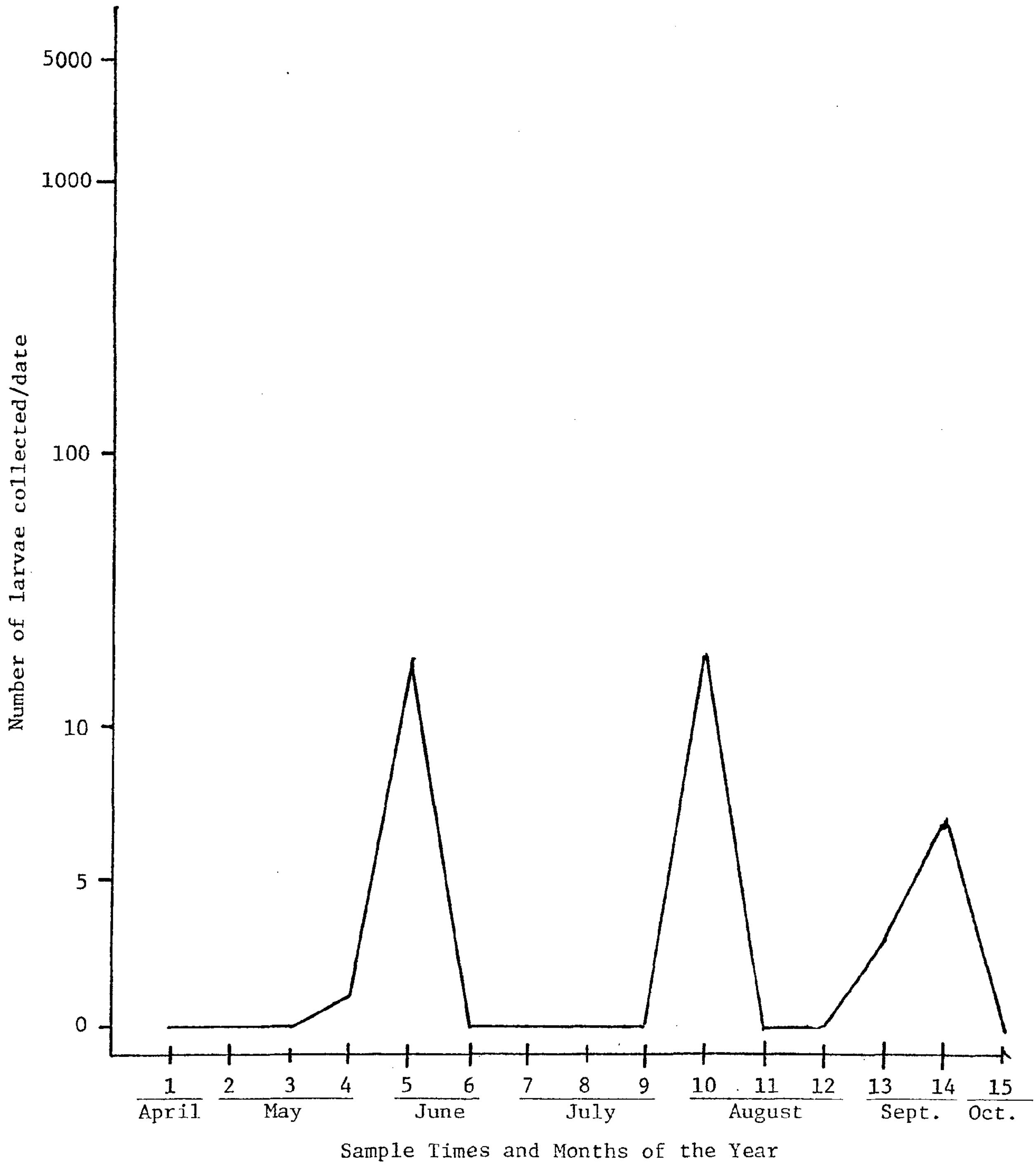


Fig. 7. Number of *Aedes sollicitans* larvae collected on the water control plot in 1979.

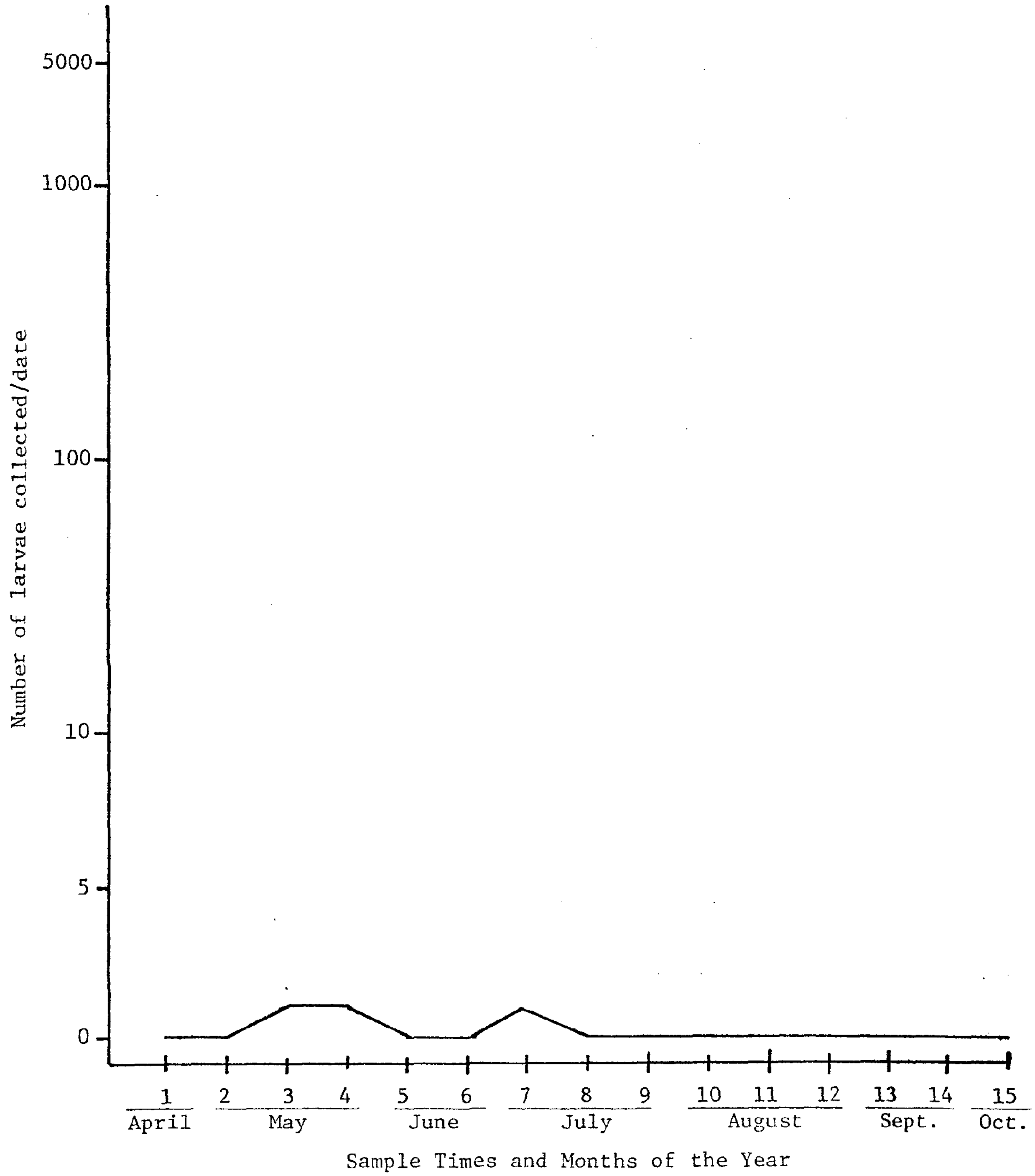


Fig. 8. Number of *Aedes sollicitans* larvae collected on the closed plot in 1979.

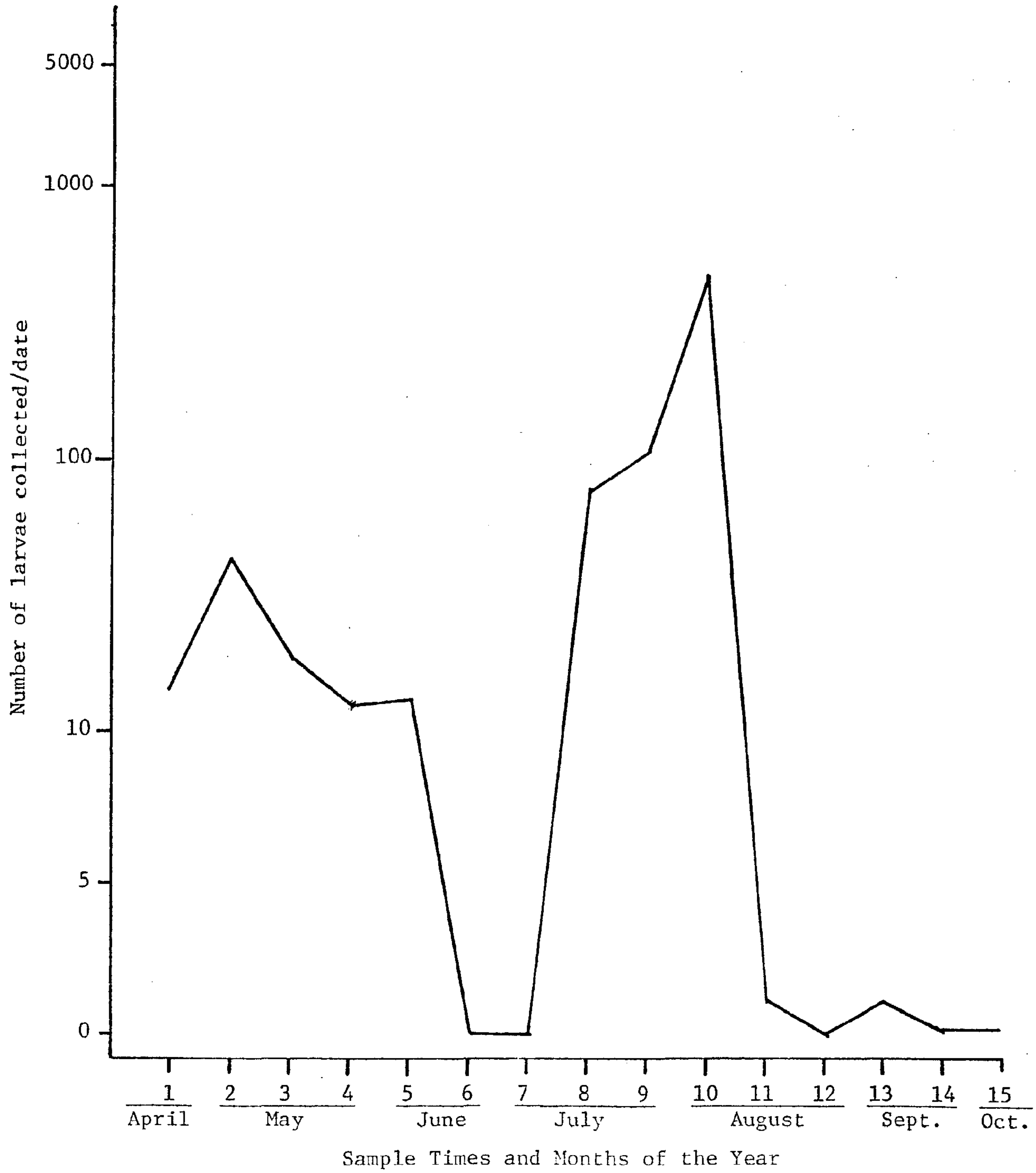


Fig. 9. Number of *Aedes sollicitans* larvae collected on the control I plot in 1979.

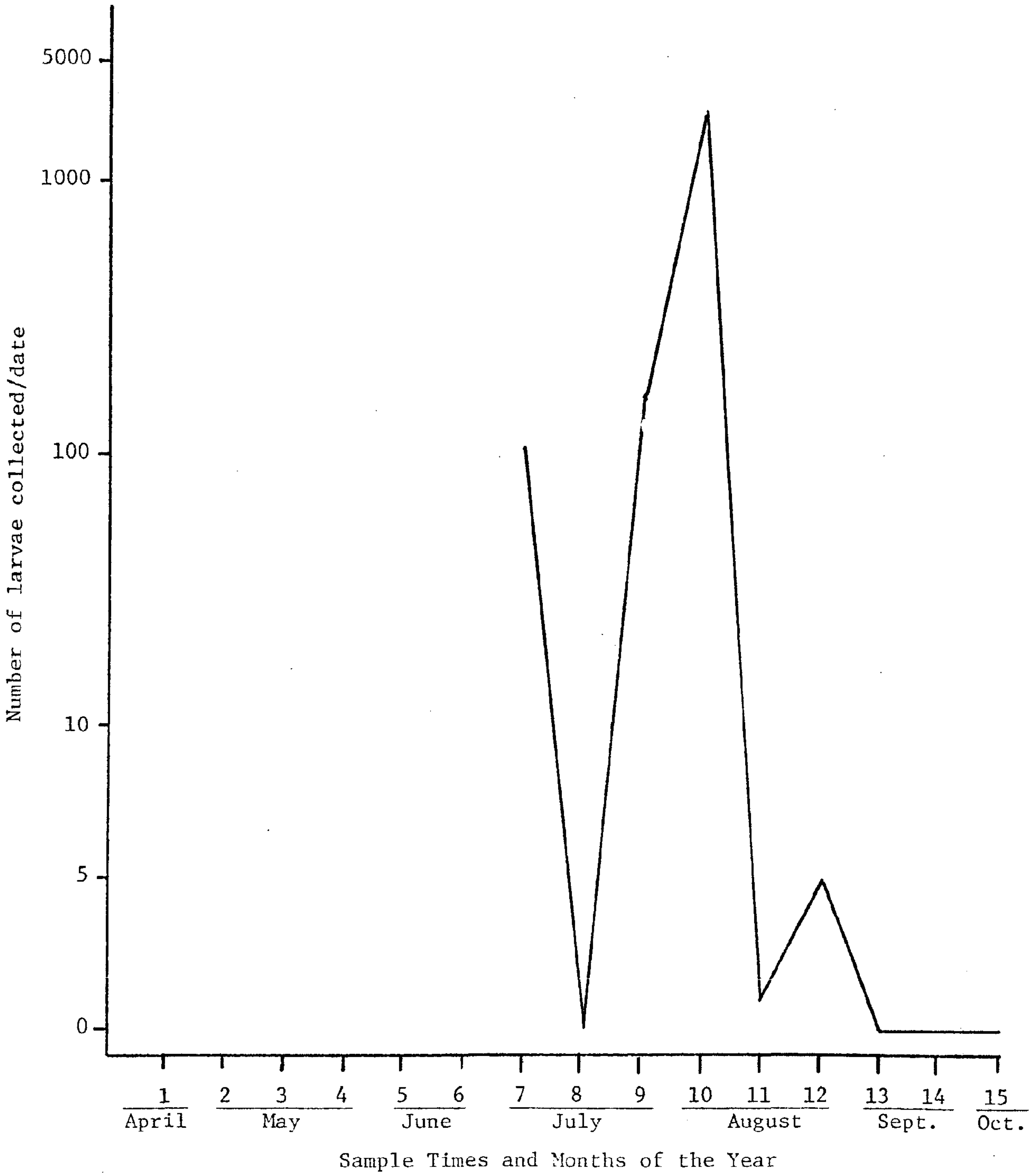


Fig. 10. Number of *Aedes sollicitans* larvae collected on the control II plot in 1979.

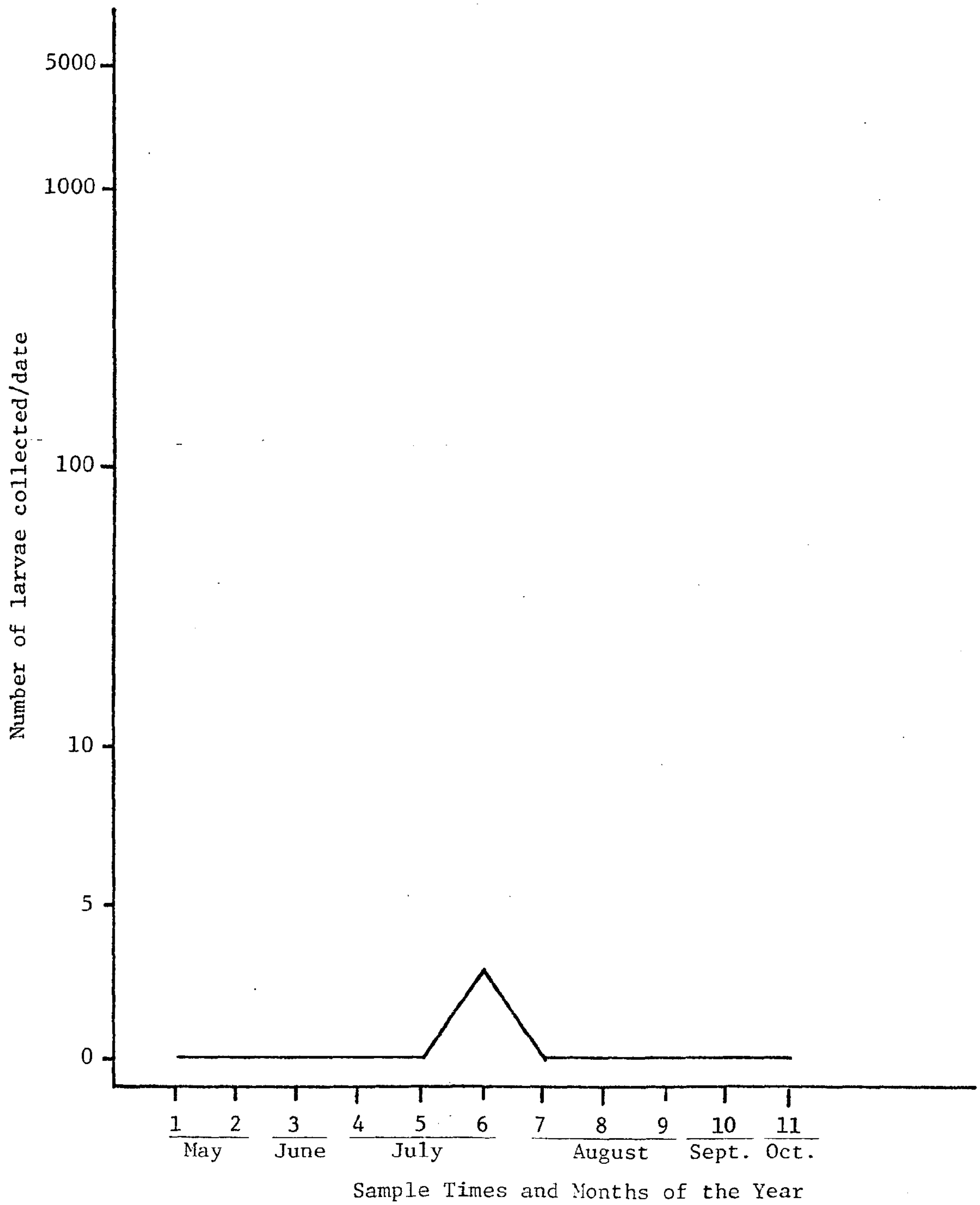


Fig. 11. Number of *Aedes sollicitans* larvae collected on the open plot in 1980.

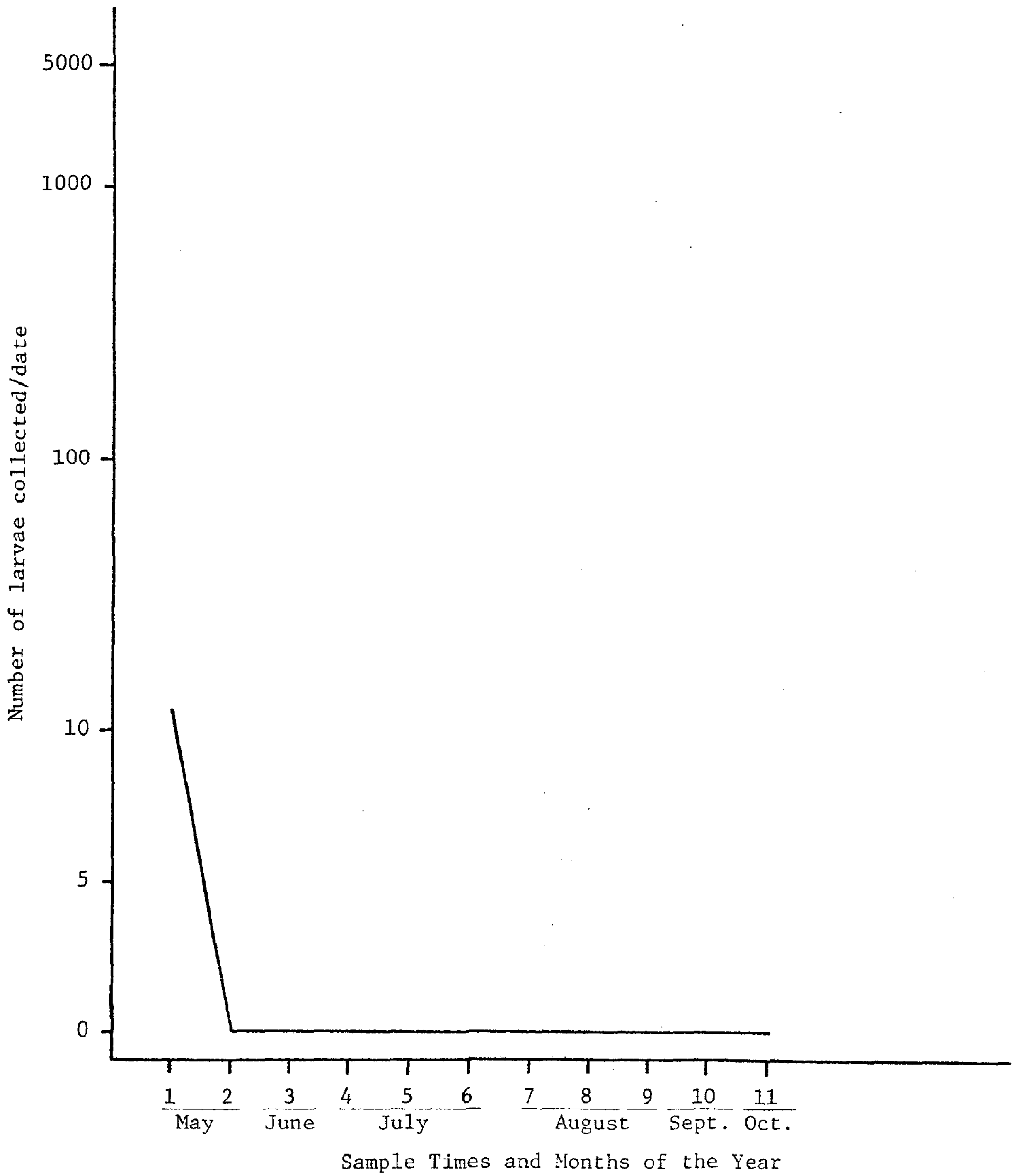


Fig. 12. Number of *Aedes sollicitans* larvae collected on the water control plot in 1980.

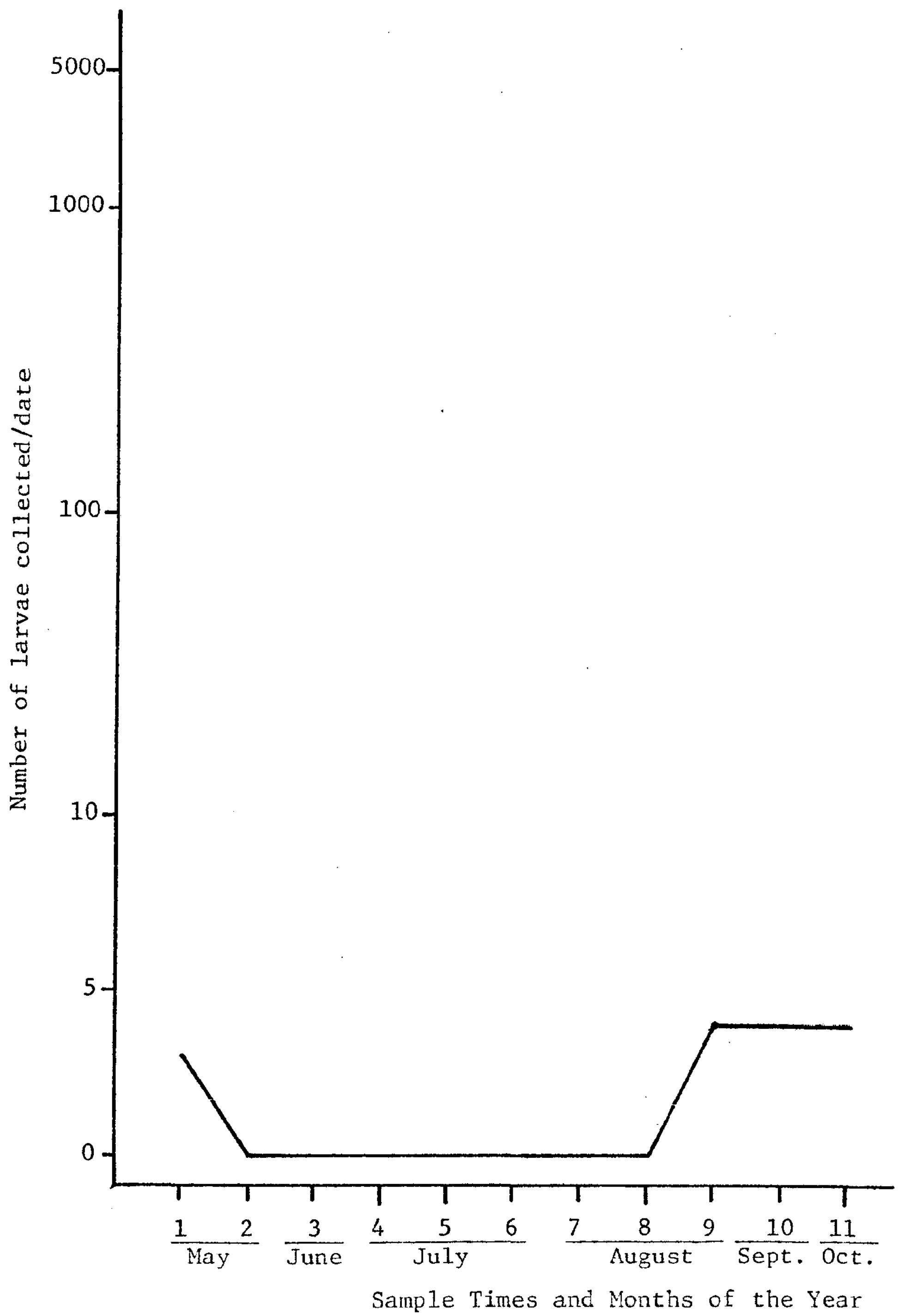


Fig. 13. Number of *Aedes sollicitans* larvae collected on the closed plot in 1980.

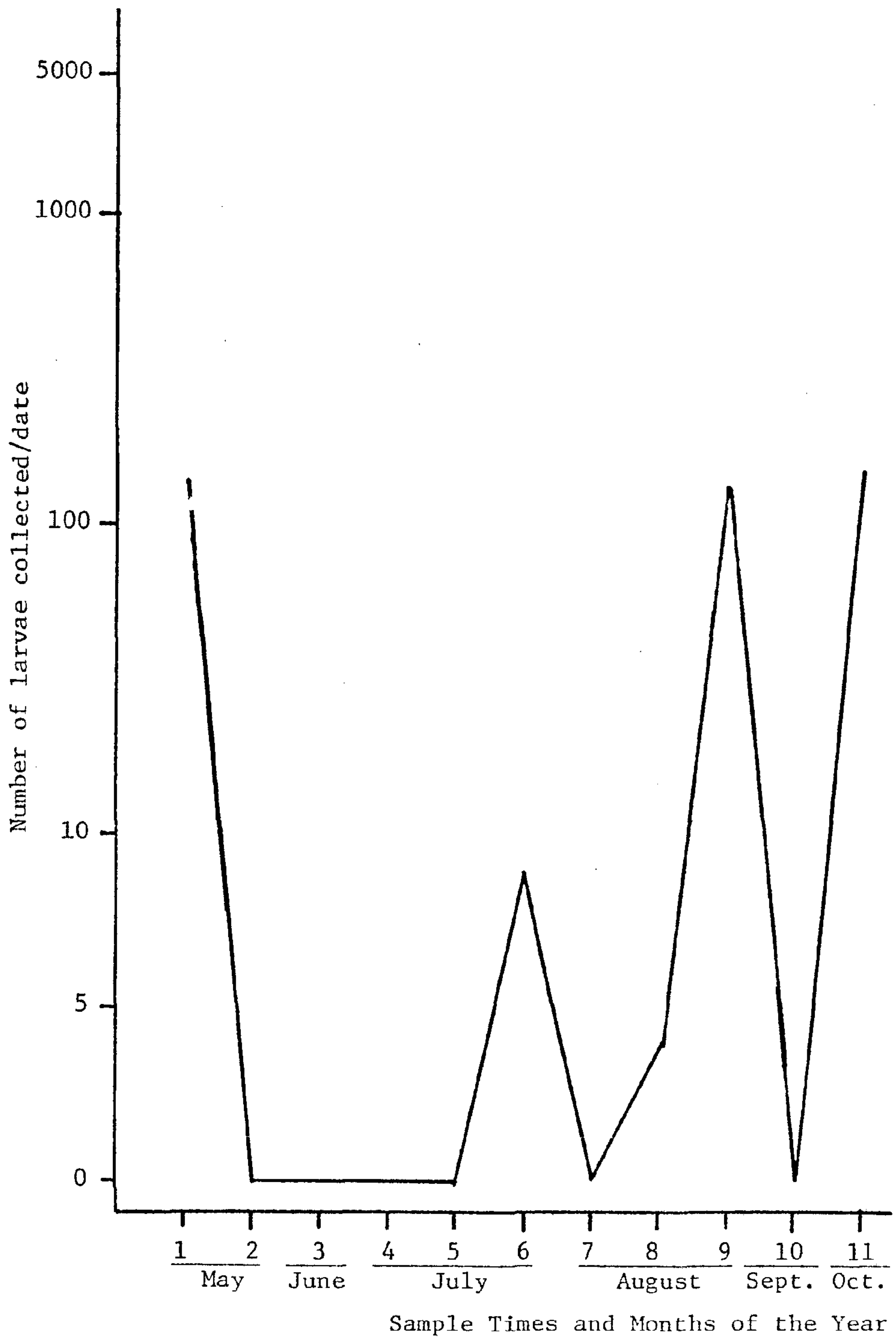


Fig. 14. Number of Aedes sollicitans larvae collected on the control II plot in 1980.

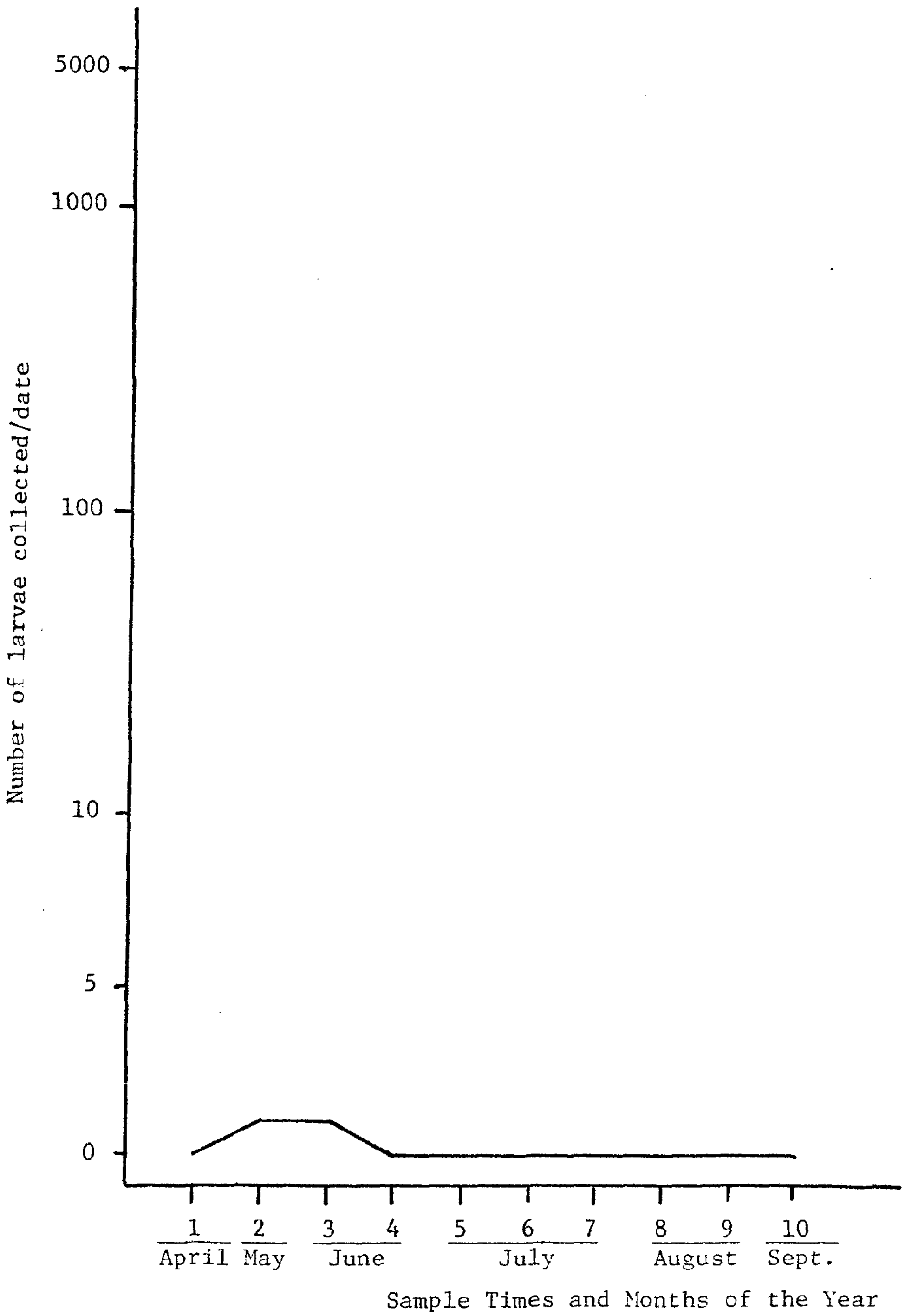


Fig. 15. Number of Aedes sollicitans larvae collected on the open plot in 1981.

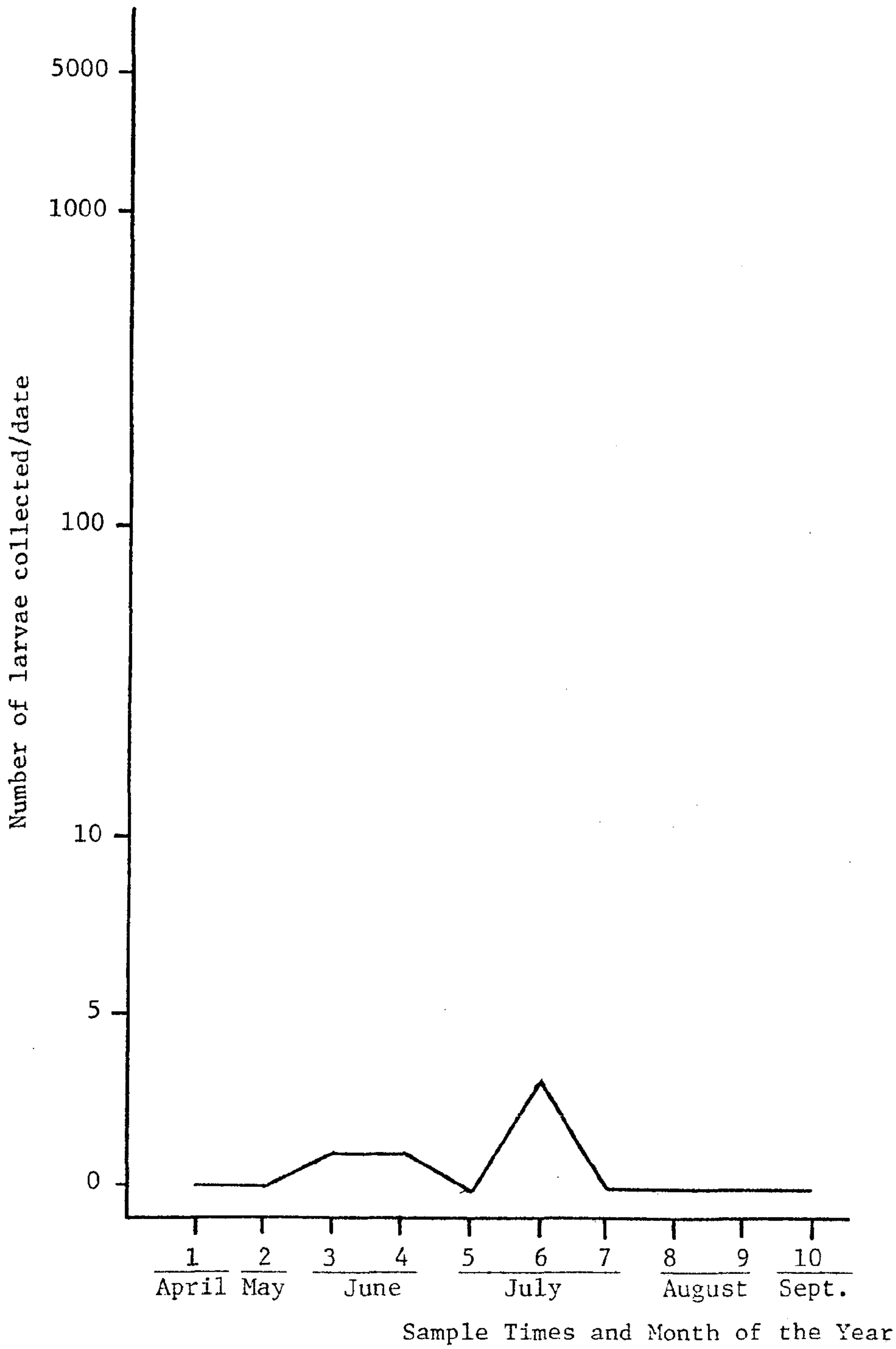


Fig. 16. Number of *Aedes sollicitans* larvae collected on the water control plot in 1981.

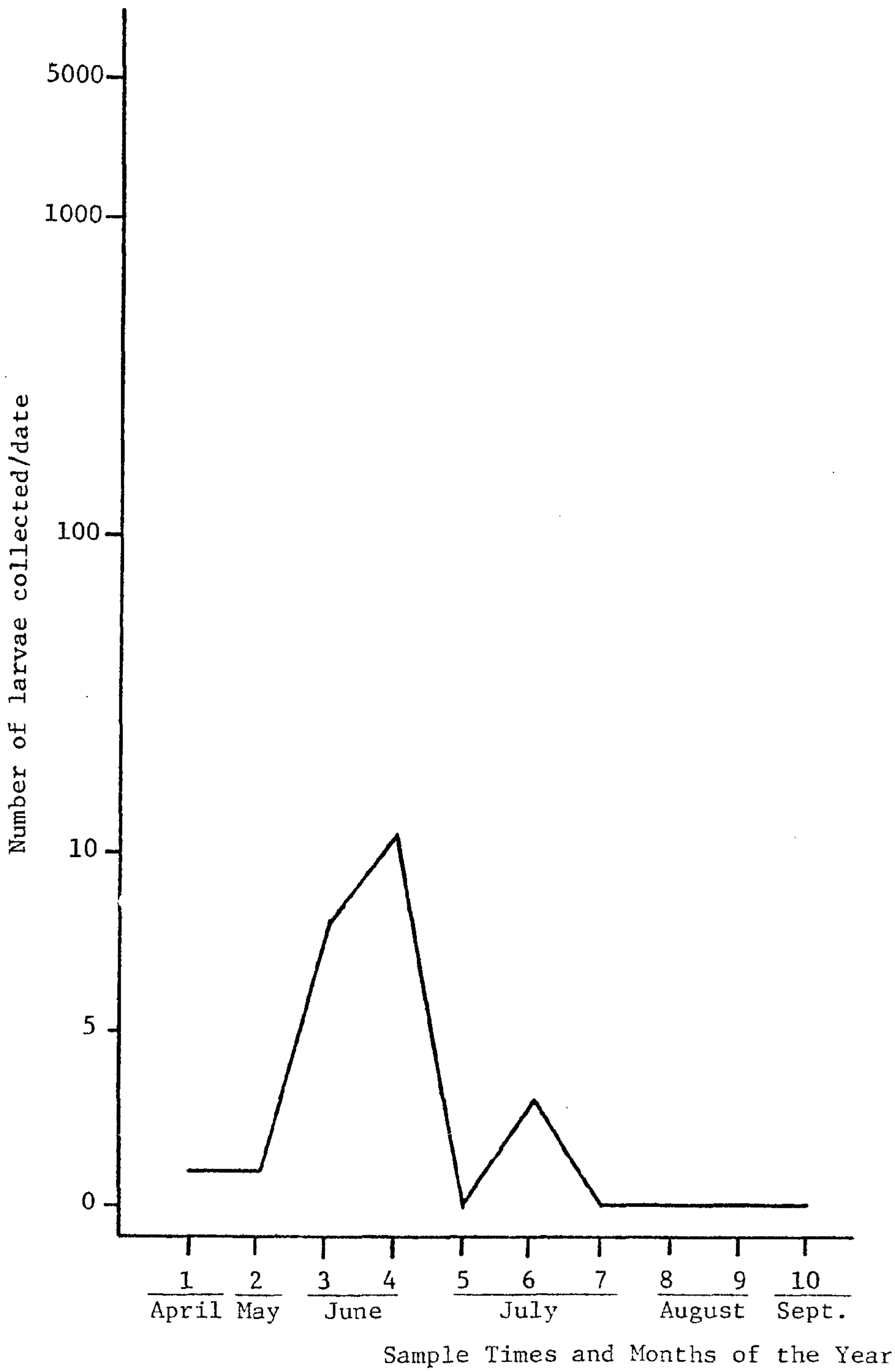


Fig. 17. Number of *Aedes sollicitans* larvae collected on the closed plot in 1981.

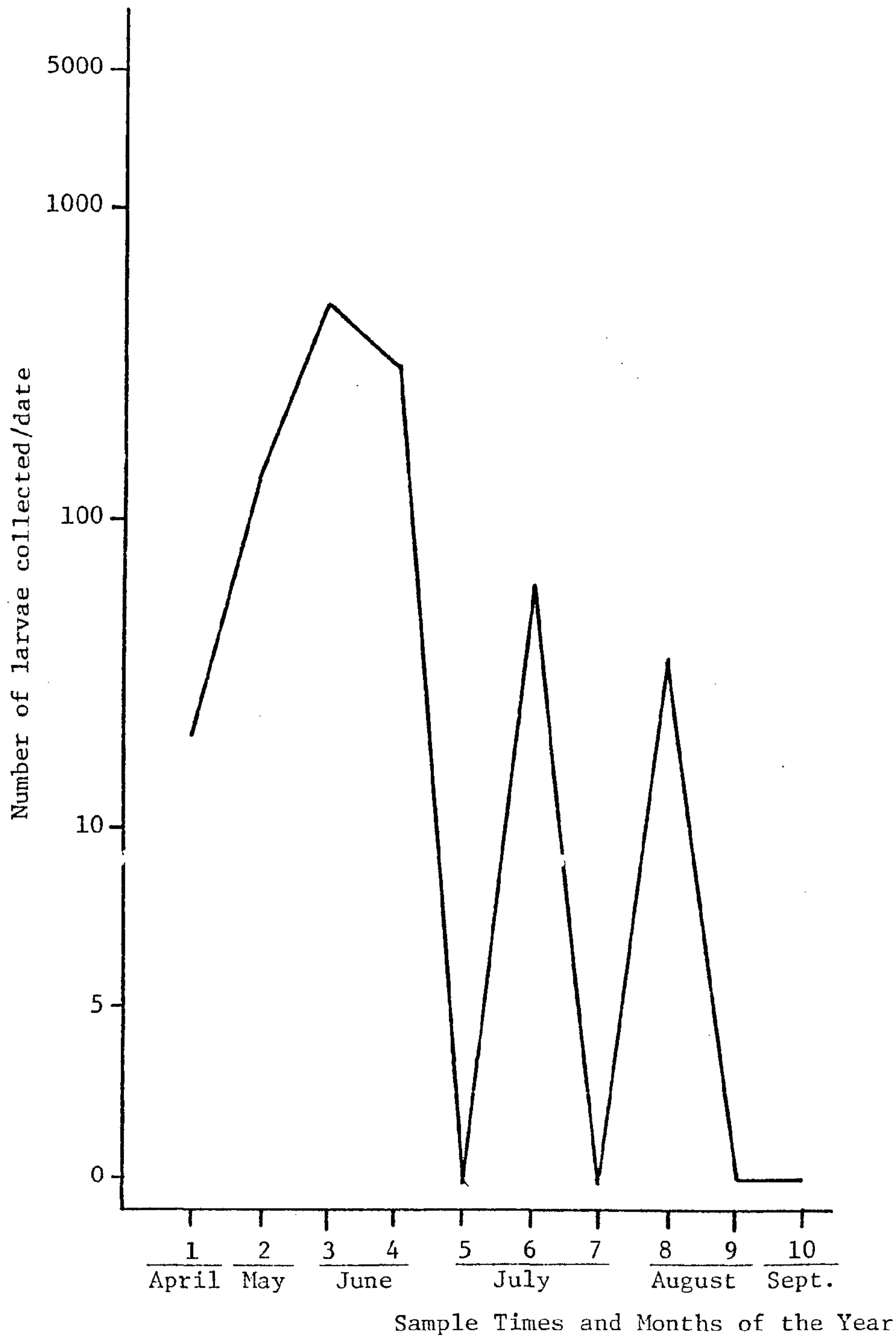


Fig. 18. Number of Aedes sollicitans larvae collected on the control II plot in 1981.

Culex salinarius larvae were collected in relatively low numbers on all of the study plots; ranging from a high of 2.20 larvae per collection date for control II in 1981 to 0 larvae collected from all plots in 1980. Significantly fewer *Cx. salinarius* larvae were collected from the treatments plots as compared to the controls in 1979 and 1981. No difference existed between plots in 1980 because no larvae were collected. There was no significant difference between the treatment plots in the number of *Cx. salinarius* larvae collected in 1979 and 1980. In 1981 significantly fewer *Cx. salinarius* larvae were collected from the open plot (0.01 larvae per collection date) as compared to the closed and water control plots (0.31 and 0.25 larvae per collection date, respectively).

Culisetta inornata larvae were rarely collected on the study area. They were found only at two collection stations on control II, and only in April.

The data presented here support the hypothesis that the three treatment types evaluated are equally effective in controlling all species of salt marsh breeding mosquitoes. Because of these data and similar data presented by Lesser and Saveikis (1979), the Maryland Department of Agriculture began a program of widescale use of closed ditching systems in the fall of 1979. These systems were constructed on salt marshes documented as breeding habitat for *Ae. sollicitans*, and associated mosquito species, and owned by the Maryland Department of Natural Resources, Wildlife Administration. The Wildlife Administration required the use of closed ditching systems on their lands.

In the Deal Island Wildlife Management Area, Somerset County, a closed ditching project was constructed on approximately 96 hectares on Pigeonhouse Creek marsh. This project began in November, 1979 and was completed in June, 1980. To date, this closed ditching project has been ineffective for Ae. sollicitans control. In the fall of 1980, it was necessary to aerially larvicide the Pigeonhouse Creek marsh on two occasions to control large broods of Ae. sollicitans. In 1981, Ae. sollicitans larvae were found in the closed system ditches and adjacent sheet water zones on 11 of 15 inspections. Six distinct broods of Ae. sollicitans developed in the Pigeonhouse Creek marsh closed ditch system in 1981, requiring six aerial applications of larvicide and one aerial application of adulticide.

The failure of the Pigeonhouse Creek closed ditch system to control mosquito breeding is due to several factors. The most important factor is that standing surface water is not removed by the closed ditches. Pigeonhouse Creek marsh has a lower topography than the Davis Island study area and mosquito breeding occurs in both temporary pools of surface water and depressions. Large areas of the Pigeonhouse Creek marsh provide surface water breeding habitat. I have observed that fish do not penetrate far enough into the pools of surface water from the closed system ditches to be effective biological control agents. The emergent vegetation on this marsh is predominately D. spicata and Scirpus robustus. The stem density of these plants probably restricts the movement of fishes from the ditches to the surface pools containing the mosquito larvae.

Fish survival is low in the closed systems in Pigeonhouse Creek marsh. In 1981, dead fish, or the absence of live fish, was frequently observed. In some such instances Ae. sollicitans larvae were numerous within the ditches. A probable reason for the poor fish survival is low levels of dissolved oxygen. On July 21, 1981 the oxygen level in the closed ditch system on Pigeonhouse Creek marsh was monitored every two hours from 0600 hours to 1000 hours and from 1800 hours to 2100 hours. A Yellow Springs Instrument Company, Model 57 dissolved oxygen meter was used. Dissolved oxygen (DO) levels were extremely low at 0600 hours, ranging from 0 ppm. at 4 stations to 0.5 ppm. at one station. The level of DO increased at subsequent readings in the morning, averaging 0.4 ppm. and 1.2 ppm. at 0800 and 1000 hours, respectively. At 1800 hours the DO levels had increased and a mean of 2.7 ppm. was recorded. At 2000 hours the mean DO level was 2.8 ppm. At 2100 hours the mean DO level had fallen to 1.1 ppm.

From this information, it appears that the lowest, and potentially lethal, levels of DO in the ditches occur during the night. This is most likely caused by a high biological oxygen demand (BOD). The high BOD would result from the high level of organic material present in the ditches on Pigeonhouse Creek marsh. Most of the organic matter is derived from the dense growth of wigeongrass, Ruppia maritima, which grows throughout the ditches. The decay of the dead Ruppia consumes oxygen. During the daylight hours the oxygen produced by photosynthesis by the live Ruppia will increase the DO, while at night BOD will reduce DO levels.

In the winter of 1981, an additional marsh owned by the Maryland Wildlife Administration was ditched with a closed system. This marsh is known as Covington Marsh and is part of the Fishing Bay Wildlife

Management Area in Dorchester County, Maryland. Approximately 75 hectares were ditched using a closed system. Covington Marsh is topographically dissimilar to the Davis Island study area. It has numerous large areas of temporary pools of surface water and the dominant vegetation is short form Spartina alterniflora. The peat layer is well developed on this marsh and extends below the depth of mosquito control ditches.

A study was initiated on Covington Marsh in the summer of 1981 to evaluate the effectiveness of the closed ditching system to control Ae. sollicitans on such a marsh type. Fifty sampling stations were located in each of three habitat types on the Covington study area: (1) ditches; (2) surface water pools adjacent to the ditches; and (3) an unditched control adjacent to the treated area. These stations were sampled 14 times from June 1 through August 31. The data were logarithmically transformed to Z=(x+1) log 10 and analyzed by a one-way analysis of variance. The mean number of Ae. sollicitans larvae collected per habitat type per collection date are 12.97 larvae, 32.91 larvae and 46.25 larvae for the ditches, surface water pools and control respectively. These values are not significantly different from each other, therefore, no significant control of Ae. sollicitans was provided by the closed ditch system on Covington Marsh.

The failure of the closed ditch system on Covington Marsh to control mosquitoes is due to the same reasons cited for Pigeonhouse Creek marsh; i.e. inability of the ditches to remove standing surface water breeding habitat; failure of fish to move from the ditches into adjacent pools of surface water because of the density of grass stems; and poor fish survival in the ditches. Fish survival in the ditches was not as acute a problem on Covington Marsh as on Pigeonhouse Creek marsh. Covington Marsh was subject to more frequent tidal floodings (approx. 3-4 days per month of study) and the fish population was therefore replenished more frequently than on Pigeonhouse Creek marsh. Low dissolved oxygen levels (below 1 ppm.) were recorded from the Covington Marsh ditches. There is no growth of submerged aquatic vegetation in these ditches, as there is on Pigeonhouse Creek marsh, but a high biological oxygen demand results from the decomposition of the organic peat layer.

Bruder (1980) gives the three major objectives of open marsh water management. These are: (1) control the breeding of all salt marsh mosquitoes; (2) reduce the use of insecticides; and (3) enhancement of the salt marsh food web. It is obvious that closed ditching cannot fulfill the first two objectives on a wide range of marshes in the Chesapeake Bay region. This problem was speculated on by Lesser and Saveikis (1979).

The mosquito data obtained on the Davis Island study area cannot be extrapolated beyond the marsh type found there. Closed ditch system for mosquito control should only be considered for use on marshes where mosquito breeding is confined to well-defined potholes only because of the closed ditches inability to remove temporary surface water breeding habitat and the apparent inability of fish to invade the surface water pools. Furthermore, closed ditch systems should only be used on marshes with a thin peat layer overlaying a mineral soil base. If used on deep peat layer marshes the dissolved oxygen levels in the ditches may be too low (because of a high BOD) to sustain fish populations. Also, closed ditch systems should only be used on marshes subject to a high degree of tidal flooding. The closed plot on the Davis Island site was flooded more frequently than the other study plots (see Whigham et al., 1982). Frequent tidal floodings will replenish fish populations and improve ditch water quality and offset high BOD problems associated with the growth of submerged aquatic vegetation.

The open tidal ditch system is the most effective technique for the control of salt marsh breeding mosquitoes over a wide range of conditions and should be the preferred management technique when mosquito control is the primary management objective. If conditions mitigate the use of open systems; water control, or semi-tidal, systems should be employed. These water control systems should not employ pipes as described for the Davis Island study area. The installation of pipes is time consuming and costly. Furthermore, the pipes restrict tidal flow, and the embankment they are placed in is subject to erosion by wave action and muskrat "engineering". A graded ditch, forming a sill, should be used at the outlets to regulate water levels in the ditches. The level of this sill should be such that regular tidal circulation occurs throughout the ditch system, thereby allowing for the removal of temporary pools of surface water, the maintenance of good water quality and replenishment of fish populations. A plan for a sill ditch design is presented in Appendix A.

Emergent marsh macroinvertebrates - The results of sampling for emergent marsh macroinvertebrates are presented in Tables 6 through 11.

Melampus bidentatus was the most commonly collected species. In 1979, significantly more *M. bidentatus* were collected from the closed plot (8.11 snails/0.25 m^2), followed by control I (3.10/0.25 m^2).

Table 6. The mean number of emergent marsh macroinvertebrates/0.25 m^2/plot/collection date from random point samples in 1979.

Species	PLOT			
	Open	Water Control	Closed	Control I
Melampus bidentatus	1.13^{a}	0.50^{a}	8.11^{b}	3.10^{c}
Orchestia grillus	0.56^{a}	0.05^{b}	0.96^{a}	0.11^{b}
Isopoda	0.10^{a}	0.03^{b}	0.50^{c}	0.01^{b}

a, b, c - Those mean numbers within a species not having the same letter are significantly different at P 0.05.

Table 7. Percent frequency of occurrence (no. positive samples/total no. of samples) of emergent marsh macroinvertebrates/plot from random point samples in 1979.

Species	PLOT			
	Open	Water Control	Closed	Control I
Melampus bidentatus	37.33%	26.66%	68.00%	64.00%
Orchestia grillus	28.00%	5.33%	42.66%	12.00%
Isopoda	8.00%	2.66%	32.00%	1.33%

Table 8. The mean number of emergent marsh macroinvertebrates/0.25 m^2/plot/transect distance/collection date in 1980.

Species	Plot: Distance from Ditch (m):	Open				Water Control				Closed				Control II			
		0	1	5	10	0	1	5	10	0	1	5	10	0	1	5	10
Melampus bidentatus		4.37	0.66	-0-	0.05	0.56	0.38	0.22	-0-	1.98	1.64	0.62	6.34	1.93	5.01	6.03	15.32
Orchestia grillus		0.51	0.32	0.51	0.62	-0-	0.20	0.32	0.26	0.17	0.45	0.29	0.74	0.29	0.41	0.58	1.09
Isopoda		0.38	0.51	0.05	0.26	-0-	-0-	-0-	-0-	0.38	0.20	0.48	0.38	-0-	0.05	0.29	0.66
Littorina irrorata		-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	2.94	2.64	0.41	0.05
Uca spp. (burrow density)		-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	10.75	9.23	1.75	0.55
Brachidontes recurvus		-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	0.05	-0-	-0-	-0-

Table 9. Analysis of variance for the mean number of emergent marsh macroinvertebrates/0.25 m^2/ plot/transect distance in 1980.

Melampus bidentatus

Source of variation	df	MS	F
Plots	3	6.02	26.17**
Distances	3	0.64	2.78*
Plots X Distances	9	1.24	5.39**
Error	210	0.23	

Orchestia grillus

Source of variation	df	MS	F
Plots	3	0.17	2.13ns
Distances	3	0.17	2.13ns
Plots X Distances	9	0.03	0.38ns
Error	210	0.08	

Isopoda

Source of variation	df	MS	F
Plots	3	0.20	4.35*
Distances	3	0.03	0.65ns
Plots X Distances	9	0.07	1.52ns
Error	210	0.046	

* - significantly different at $P < 0.05$.
** - significantly different at $P < 0.01$.
ns - no significant difference.

Table 10. Array of the mean numbers of *Melampus bidentatus*/0.25 m^2/transect distance/collection date in 1980.

Plot/Distance (m)	Array of Means in Descending Order
Control II/10	15.32^{a}
Closed/10	$6.34^{a,b}$
Control II/5	$6.03^{a,b}$
Control II/1	$5.01^{a,b,c}$
Open/0	$4.37^{a,b,c,d}$
Closed/0	$1.98^{b,c,d,e}$
Control II/0	$1.93^{b,c,d,e}$
Closed/1	$1.64^{b,c,d,e}$
Open/1	$0.66^{c,d,e}$
Closed/5	$0.62^{c,d,e}$
Water Control/0	$0.56^{c,d,e}$
Water Control/1	$0.38^{d,e}$
Water Control/5	0.22^{e}
Open/10	0.05^{e}
Open/5	$-0-^{e}$
Water Control/10	$-0-^{e}$

a,b,c,d,e - Those mean numbers not having the same letter are significantly different at $P < 0.05$.

Table 11. The mean number of emergent marsh macroinvertebrates/ 0.25 m^2/ plot/collection date in 1980.

Species	PLOT: Open	Water Control	Closed	Control II
Melampus bidentatus	0.75^{a}	0.27^{a}	2.11^{b}	5.71^{c}
Orchestia grillus	0.48^{a}	0.20^{a}	0.38^{a}	0.58^{a}
Isopoda	0.29^{a}	$-0-^{b}$	0.35^{a}	$0.23^{a,b}$
Littorina irrorata	$-0-^{a}$	$-0-^{a}$	$-0-^{a}$	1.14^{b}
Uca spp. (burrow density)	$-0-^{a}$	$-0-^{a}$	$-0-^{a}$	3.76^{b}
Brachidontes recurvus	$-0-^{a}$	$-0-^{a}$	$-0-^{a}$	0.02^{a}

a,b,c - Those mean numbers within a species not having the same letter are significantly different at $P < 0.05$.

Significantly fewer Melampus snails were collected from the open (1.13/ 0.25 m^2) and water control (0.50/0.25 m^2) plots.

The Amphipod *Orchestia grillus* was collected in moderate numbers in 1979. The closed plot and open plot yielded significantly higher collections of *O. grillus* (0.96/0.25 m^2 and 0.56/0.25 m^2, respectively) than did the control plot I and the water control plot (0.11/0.25 m^2 and 0.05/0.25 m^2, respectively).

Isopod species were found in low numbers on all plots, however, significantly greater number of Isopods were collected on the closed plot (Table 6).

In summary, the 1979 random collection data show that significantly higher numbers of *M. bidentatus* and Isopods were collected from the closed plot. The frequency of occurrence of all the emergent marsh macroinvertebrates was greatest for the closed plot (Table 7).

No other species of emergent marsh macroinvertebrates were collected in 1979.

The results of the 1980 program of emergent marsh macroinvertebrates sampling, using a stratified transect sample design, are presented in Tables 8-11. A highly significant ($P < 0.01$) difference was found between plots and plots X distance interaction for *M. bidentatus* (Table 9). Significantly more *M. bidentatus* were collected from the control plot (5.71/0.25 m^2/collection date) than from the other plots. Significantly more *M. bidentatus* were collected from the closed plot (2.11/0.25 m^2/collection date) than from the open and water control plots (0.75 and 0.27/0.25 m^2/collection date, respectively).

Plot X distance interaction for *M. bidentatus* is displayed in Table 10. Significantly more snails were collected at the control plot at 10 meters (15.32/0.25 m^2/collection date) than at any other plot X distance interaction. The lowest numbers of *M. bidentatus* were collected at water control/10 meters, open/5 meters, open/10 meters and water control/5 meters.

Significantly more *M. bidentatus* were collected at the 10 meter distance (average of all plots) than at the 5 meter distance (2.35 and 0.93/0.25 m^2/collection date, respectively). Densities of *M. bidentatus* at the 0 meter and 1 meter distances averaged 1.92 and 1.46/0.25 m^2/ collection date, respectively.

The analysis of variance of the *Orchestia grillus* data showed no significant difference between plots, distances, or plot X distance interactions (Table 9).

Significantly greater numbers of Isopods were collected on the closed, open and control plots (0.35, 0.29, and 0.23/0.25 m^2/collection date, respectively) than on the water control plot (0/0.25 m^2/collection date).

Littorina irrorata, *Uca* spp. burrows and *Brachidontes recurvus* were found only on the control plot (Table 8). Significantly more *L. irrorata* and *Uca* burrows were found at the 0 meter and 1 meter distances. *Brachidontes recurvus* was represented by only one specimen collected at the 0 meter distance.

In summary, results of the 1980 data show that there is stratification of some species of emergent marsh macroinvertebrate species in relation to the ditches and creek. The stratification is much more well defined in relation to the creek than to the ditches. Species richness and the number of individuals is greater near the creek than on the treatment plots, indicating that the ditches do not truly mimic the habitat importance of the creek. Habitat features that may be important to the distribution of salt marsh invertebrates that are not supplied by the ditches are the creek bank slope and berm, and the stability of long term existence.

The closed plot had significantly higher mean densities of M. bidentatus than the other treatment plots in both years of this study. Whether this is due to the effect of the management techniques or an inherent difference which always existed at the location of the plots is impossible to determine without pretreatment data.

In general, the results reported here for the density sampling of emergent marsh macroinvertebrates indicate relatively low population densities on the Davis Island study area. This is possibly due to the relatively young age of the marsh and a consequent lack of stability. It is difficult to determine, from the data presented here, what impact the various techniques of mosquito control marsh management techniques will have on emergent marsh invertebrate species on Chesapeake Bay marshes.

Benthic infauna - The results of benthic infauna sampling of the treatment ditches on the control creeks are presented in Tables 12-14. Chironomid midge larvae were the dominant infauna collected in both

Table 12. The mean number of benthic infauna/15 cm X 15 cm Eckman dredge sample/plot/collection date in 1979.

	PLOT			
Group	Open	Water Control	Closed	Control I
Chironomidae	32.10^{a}	43.09^{b}	47.42^{b}	5.63^{c}
Amphipoda	$-0-^{a}$	$-0-^{a}$	$-0-^{a}$	0.20^{b}
Isopoda	$-0-^{a}$	$-0-^{a}$	$-0-^{a}$	0.12^{b}

a,b,c - Those mean numbers within a group not having the same letter are significantly different at $P < 0.05$.

Table 13. The mean number of benthic infauna/15 cm X 15 cm Eckman dredge sample/plot/collection date in 1980.

	PLOT			
Species or Group	Open	Water Control	Closed	Control II
Chironomidae	$4.35^{a,b}$	18.05^{a}	29.22^{a}	0.98^{b}
Isopoda	0.81^{a}	$-0-^{b}$	$-0-^{b}$	0.36^{a}
Amphipoda	0.12^{a}	0.17^{a}	0.07^{b}	0.07^{b}
Polychaeta	0.41^{a}	0.25^{b}	0.12^{c}	0.17^{b}
<u>Macoma balthica</u>	0.41^{a}	$-0-^{b}$	$-0-^{b}$	0.34^{a}
Gastropoda	$-0-^{a}$	$-0-^{a}$	$-0-^{a}$	0.07^{b}

a,b - Those mean numbers within a species or group not having the same letter are significantly different at $P < 0.05$.

Table 14. Percent frequency of occurrence (no. of positive samples/total no. of samples) of benthic infauna/plot in 1979 and 1980.

Plot:	Open		Water Control		Closed		Control I	Control II
Species or Group / Year:	1979	1980	1979	1980	1979	1980	1979	1980
Chironomidae	100%	80%	100%	90%	100%	100%	100%	30%
Amphipoda	-0-%	10%	-0-%	10%	-0-%	10%	16.66%	10%
Isopoda	-0-%	50%	-0-%	-0-%	-0-%	-0-%	16.66%	10%
Polychaeta	-0-%	40%	-0-%	20%	-0-%	10%	-0-%	10%
Macoma balthica	-0-%	30%	-0-%	-0-%	-0-%	-0-%	-0-%	30%
Gastropoda	-0-%	-0-%	-0-%	-0-%	-0-%	-0-%	-0-%	10%

1979 and 1980. More Chironomids were collected in the closed and water control ditches in 1979 and 1980 than in the open ditch and control creek. There was a decrease in the number of midge larvae collected in 1980 as compared to 1979 in all of the treatment plots.

Species richness of benthic infauna increased in the treatment plots in 1980. Whereas in 1979 only Chironomids were collected, in 1980 Amphipods and Polychaets were present in all of the treatment plots, and Isopods, and the fingernail clam (Macoma balthica) were recovered from the open plot.

No definitive conclusions can be drawn on the impact of mosquito control marsh management techniques on benthic infauna from the data reported here.

Fishes and shallow-water macro-epibenthos - The results of fish sampling in the ditches and creeks are presented in Tables 15-24.

Fundulus heteroclitus was the dominant species collected on all plots, being especially abundant in the open system. Fundulus heteroclitus populations were resident in the study area throughout the year, with the largest numbers present in the summer and the lowest populations in the late winter. There is no significant difference in mean number of F. heteroclitus collected/plot/collection date between plots in 1979 and 1980 (Tables 23 and 24). There is no significant difference in the mean length of F. heteroclitus collected/plot. The individual fish averaged slightly longer on in the control creeks (57.3 mm.) as compared to the open plot (51.7 mm.), water control plot (47.8 mm.), and closed plot (42.8 mm.).

Table 15. Species list of fishes collected on the Davis Island study area ditches and creeks, April, 1979 to August, 1980.

Species	Common Name	PLOT: Open	Water Control	Closed	Control I[a]	Control II[b]
Fundulus heteroclitus	Common Killifish	X	X	X	X	X
Fundulus luciae	Spotfin Killifish	X	X	X		X
Fundulus majalis	Striped Killifish	X	X	X		X
Lucania parva	Rainwater Killifish	X	X	X	X	X
Cyprinodon variegatus	Sheepshead Minnow	X	X	X	X	X
Gambusia affinis	Mosquito Fish	X	X	X	X	X
Menidia beryllina	Silverside	X	X	X	X	X
Anguilla rostrata	American Eel	X	X	X	X	
Leiostomus xanthurus	Spot	X	X	X	X	X
Pomatomus saltatrix	Bluefish	X				
Brevoortia tyrannus	Menhaden		X		X	
Elopus saurus	Ladyfish		X			
Cynoscion nebulosus	Weakfish	X				
Mugil cephalus	Striped Mullet	X				
Lepomis gibbosus	Pumpkin Seed Sunfish			X		X

a - sampled in 1979 only
b - sampled in 1980 only

Table 16. Total number of fishes collected from the Davis Island study area ditches and creeks, April, 1979 to August, 1980.

Species	PLOTS				
	Open	Water Control	Closed	Control I[a]	Control II[b]
Fundulus heteroclitus	1346	893	863	204	592
Fundulus luciae	8	138	104	-0-	19
Fundulus majalis	2	7	1	-0-	91
Lucania parva	48	313	733	2	11
Cyprinodon variegatus	110	478	692	15	92
Gambusia affinis	42	456	554	5	31
Menidia beryllina	17	908	643	9	59
Anguilla rostrata	7	13	31	1	-0-
Leiostomus xanthurus	355	3	7	48	52
Pomatomus saltatrix	3	-0-	-0-	-0-	-0-
Brevoortia tyrannus	-0-	1	-0-	63	-0-
Elopus saurus	-0-	1	-0-	-0-	-0-
Cynoscion nebulosus	1	-0-	-0-	-0-	-0-
Mugil cephalus	1	-0-	-0-	-0-	-0-
Lepomis gibbosus	-0-	-0-	80	-0-	1

a - sampled in 1979 only.
b - sampled in 1980 only.

Table 17. Number of species, number of individuals, Brillouin's measure of species diversity and species evenness values for the total collection of fishes from the Davis Island study area ditches and creeks from April, 1979 to August, 1980.

Plots	No. of Species	No. of Individuals	Species Diversity	Species Evenness
Open	12	1940	0.9988	0.4052
Water Control	11	3211	1.6744	0.7018
Closed	10	3708	1.7900	0.7806
Control I[a]	8	347	1.1937	0.5892
Control II[b]	9	948	1.3053	0.5061

a - sampled from April, 1979 through January, 1980 only.
b - sampled from March, 1980 through August, 1980 only.

Table 18. Relative abundance of fish species collected from the open plot ditches, April, 1979 to August, 1980.

Species	Rank	No. Collected	% Frequency	Relative Abundance
Fundulus heteroclitus	1	1346	96.55	129,956.30
Leiostomus xanthurus	2	355	62.07	22,034.85
Cyprinodon variegatus	3	110	48.28	5,310.80
Lucania parva	4	48	44.83	2,151.84
Gambusia affinis	5	42	37.93	1,593.06
Menidia beryllina	6	17	34.48	586.16
Funaulus luciae	7	8	24.14	193.12
Anguilla rostrata	8	7	20.69	144.83
Pomatomus saltatrix	9	3	6.90	20.70
Fundulus majalis	10	2	6.90	13.80
Mugil cephalus	10	2	6.90	13.80
Cynoscion nebulosus	11	1	3.45	3.45

Table 19. Relative abundance of fish species collected from the water control plot ditches, April, 1979 to August 1980.

Species	Rank	No. Collected	% Frequency	Relative Abundance
Fundulus heteroclitus	1	893	93.10	83,138.30
Menidia beryllina	2	908	82.76	75,146.08
Cyprinodon variegatus	3	478	82.76	39,559.28
Gambusia affinis	4	456	72.41	33,018.96
Lucania parva	5	313	79.31	24,824.03
Fundulus luciae	6	138	53.62	8,089.56
Anguilla rostrata	7	13	17.24	224.12
Fundulus majalis	8	7	13.79	96.53
Leiostomus xanthurus	9	3	10.34	31.02
Brevoortia tyrannus	10	1	3.45	3.45
Elopus saurus	10	1	3.45	3.45

Table 20. Relative abundance of fish species collected from the closed plot ditches, April, 1979 to August, 1980.

Species	Rank	No. Collected	% Frequency	Relative Abundance
Fundulus heteroclitus	1	863	75.86	65,467.18
Lucania parva	2	733	86.21	63,191.93
Cyprinodon variegatus	3	692	79.31	54,882.52
Menidia beryllina	4	643	72.41	46,559.63
Gambusia affinis	5	554	65.52	36,298.08
Fundulus luciae	6	104	44.83	4,662.32
Lepomis gibbosus	7	80	27.59	2,207.20
Anguilla rostrata	8	31	27.59	855.29
Leiostomus xanthurus	9	7	13.79	96.53
Fundulus majalis	10	1	3.45	3.45

Table 21. Relative abundance of fish species collected from the control plot I creek from April, 1979 to January, 1980.

Species	Rank	No. Collected	% Frequency	Relative Abundance
Fundulus heteroclitus	1	204	43.75	8,925.00
Leiostomus xanthurus	2	48	31.25	1,500.00
Brevoortia tyrannus	3	68	12.50	787.50
Cyprinodon variegatus	4	15	18.75	281.25
Menidia beryllina	5	9	25.00	225.00
Gambusia affinis	6	5	6.25	31.25
Lucania parva	7	2	12.50	25.00
Anguilla rostrata	8	1	6.25	6.25

Table 22. Relative abundance of fish species collected from the control plot II creek, March to August, 1980.

Species	Rank	No. Collected	% Frequency	Relative Abundance
Fundulus heteroclitus	1	592	90.91	53,818.72
Fundulus majalis	2	91	90.91	8,272.81
Cyprinodon variegatus	3	92	63.64	5,854.88
Menidia beryllina	4	59	27.27	1,608.93
Leiostomus xanthurus	5	52	27.27	1,418.04
Fundulus luciae	6	19	54.55	1,036.45
Lucania parva	7	11	27.27	299.97
Gambusia affinis	8	31	9.09	281.79
Lepomis gibbosus	9	1	9.09	9.09

Table 23. The mean number of *Fundulus heteroclitus* and *Gambusia affinis* collected/plot/collection date from the treatment plot ditches and the control plot I creek from April, 1979 through December, 1979.

Species	PLOTS			
	Open	Water Control	Closed	Control I
Fundulus heteroclitus	43.19[a]	30.38[a]	27.00[a]	12.75[a]
Gambusia affinis	1.06[a]	5.06[b]	21.19[b]	0.31[a]

a,b - Those mean numbers within a species not sharing the same letter are significantly different at $P < 0.05$.

Table 24. The mean number of *Fundulus heteroclitus* and *Gambusia affinis* collected/plot/collection date from the treatment plot ditches and the control plot II creek from January, 1980 through August, 1980.

Species	PLOTS			
	Open	Water Control	Closed	Control II
Fundulus heteroclitus	50.39[a]	31.31[a]	33.15[a]	45.54[a]
Gambusia affinis	1.92[a]	28.85[b]	16.54[b]	2.36[a]

a,b - Those mean numbers within a species not sharing the same letter are significantly different at $P < 0.05$.

The open system ditch produced the largest number of fish species and the lowest number of individuals of the treatment plots. In addition to the dominant F. heteroclitus, several juvenile (mean length 62.6 mm.) Leiostomus xanthurus were collected from the open system. Leiostomus xanthurus were present only during the summer and early fall. Very few L. xanthurus were collected from the water control or closed plots. Other commercially important species collected as juveniles on the open plot are Pomatomus saltatrix, Cynoscion nebulosus, and Mugil cephalus. These species were infrequently collected, and in low numbers, but their presence indicates that the open tidal ditches provide additional nursery habitat for these species. No P. saltatrix, C. nebulosus, or M. cephalis were collected from the other study plots. Cyprinodon variegatus was present in stable, low populations on the open system. Gambusia affinis was collected in low populations from the open plot. Significantly fewer G. affinis were collected/plot/collection date from the open plot ditch on control creeks as compared to the water control and closed ditches in both 1979 and 1980 (Tables 23 and 24). The mean length of the G. affinis collected from the open ditch (31.4 mm.) was significantly greater than from the closed plot (29.4 mm.) and water control plot (30.1 mm.), suggesting that most of the G. affinis utilizing the open ditch system were adults.

The closed system produced the greatest number of fishes. The water control ditch yielded a slightly lower number of individual fish, but was similar to the closed system in species composition (Tables 15, 16, and 17). The closed and water control ditches maintained high populations of Lucania parva, C. variegatus, G. affinis, and Menidia beryllina.

Except for *M. beryllina*, these species were most common on the closed plot. Moderate numbers of young *Anguilla rostrata* were taken from the closed system. A relatively high population of juvenile *Lepomis gibbosus* were collected from the closed plot. One *Elopus saurus* was collected from the water control plot.

Relatively low numbers of fish were collected from the control creeks. *Fundulus heteroclitus* was the dominant species in both control creeks. *Fundulus majalis* were relatively common in control creek II. The small collections from the creeks were caused by various factors. At the lowest tides there was very little water remaining in control creek I. At high tides, both creeks would flood out of their channels, making them difficult to sample. The irregular contours of the creek banks and bottoms also provided numerous refuges for fishes from the seine nets. Because of this I feel that the data presented in Tables 16, 17, 21, and 22 underestimate the population of fish species in the creeks.

There was a significant difference in the mean number of individual fish (all species combined) collected/plot/collection date from the treatment ditches and the control creeks. The closed and water control ditches yielded significantly ($P < 0.05$) larger collections than the other plots (127.96 and 110.72 fish/plot/collection date, respectively). The control II creek and the open ditch produced significantly ($P < 0.05$) greater collections that the control I creek (72.92, 66.90, and 21.69 fish/plot/collection date, respectively). The lower mean number of fish per collection from the tidal ditch and creeks was caused by fluctuations in fish abundance as a result of varying water depths caused by tidal movement.

The mean standing crop estimates (grams live weight) of the fish populations/plot/collection date was not singificantly different between plots (Table 28).

Species diversity and species evenness values were highest for the closed and water control ditches (Table 17). The diversity and evenness values for the control creeks were less than those of the closed and water control plots, but greater than that of the open plot. The open plot yielded the lowest diversity and evenness values because of the overwhelming dominance of *F. heteroclitus*.

Factors which influence species diversity include the stability and heterogeneity of the habitat. The closed and water control systems provide more stable environments than the open ditches on control creeks because of the absence, or reduction, of tidal dynamics. The greater occurrence of submerged aquatic vegetation on the closed and water control plots (see Whigham, et al., 1982) will provide greater environmental heterogeneity than found on the open system. The aquatic vegetation provides shading, niche partitioning, and cover which mitigates predatory and competitive interactions between species.

The number of fish collected, the number of species, and species diversity was greatest on all plots in the summer and lowest in late winter.

The results of the collections of *Palaemonetes pugio* and *Callinectes sapidus* are presented in Tables 25-27. The mean number of

P. pugio collected/plot/collection date was greater on the open plot than the other plots in 1979 and 1980. The open and water control plots yielded the highest average collections of C. sapidus. Callinectes sapidus were not collected during the winter. Palaemonetes pugio were collected throughout the year, but the largest collections were in the summer. All of the C. sapidus collected were immature. The P. pugio collected ranged from 10 mm. to 52 mm. There was no significant difference in the mean standing crop estimate of the P. pugio collected/plot/collection date in 1980 (Table 29).

The results of fish sampling in the ponds is presented in Tables 30-36. Fundulus heteroclitus is the dominant species collected from all plots. The open system pond produced the lowest number of species, and the greatest number of individual fish. The closed system pond produced a greater number of species and a lower number of individual fish than the other treatment plot ponds.

The results presented here indicate that the aquatic habitat created by OMWM practices benefits certain species of fishes and shallow-water macro-epibenthonts. The importance of an abundant and widespread population of F. heteroclitus in the ditches and ponds is realized in light of that species role as a major predator of mosquito larvae (Harrington and Harrington, 1961; Hildebrand and Schroeder, 1928). In addition, Schmelz (1964) suggests F. heteroclitus as being a major link in the estuarine food chain. The presence of large numbers of P. pugio in the study plots is an important addition to the estuarine food web because of the role of P. pugio as a primary processor of plant material into detritus (Welsh, 1973).

Table 25. The mean number of *Palaemonetes pugio* and *Callinectes sapidus* collected/plot/collection date from the treatment ditches and the control plot I creek from April, 1979 through December, 1979.

Species	PLOTS			
	Open	Water Control	Closed	Control I
Palaemonetes pugio	206.25^{a}	$71.13^{a,b}$	$117.38^{a,b}$	2.31^{b}
Callinectes sapidus	1.25^{a}	1.81^{a}	0.94^{a}	0.63^{a}

a,b - Those mean numbers within a species not sharing the same letter are significantly different at $P < 0.05$.

Table 26. The mean number of *Palaemonetes pugio* and *Callinectes sapidus* collected/plot/collected date from the treatment ditches and the control plot II creek from January, 1980 through August, 1980.

Species	PLOTS			
	Open	Water Control	Closed	Control II
Palaemonetes pugio	191.15^{a}	20.00^{b}	23.77^{b}	$67.92^{a,b}$
Callinectes sapidus	0.31^{a}	0.46^{a}	0.08^{a}	0.08^{a}

a,b - Those mean numbers within a species not sharing the same letter are significantly different at $P < 0.05$.

Table 27. Total number collected and percent frequency of occurrence of _Palaemonetes pugio_ and _Callinectes sapidus_ from the Davis Island study plots from April, 1979 through August, 1980.

	PLOTS				
Species	Open	Water Control	Closed	Control I[a]	Control II[b]
Palaemonetes pugio	5785(100%)	1398(89.7%)	2187(96.5%)	37(37.5%)	883(92.3%)
Callinectes sapidus	24(34.48%)	35(55.2%)	16(27.6%)	10(31.3%)	1(7.7%)

a - sampled in 1979 only.
b - sampled in 1980 only.

Table 28. Mean standing crop estimates (live weight in grams) of fishes collected/plot/collection date from 25 meter long seining stations from January through August, 1980.

	PLOTS			
Mean ($\pm$/s.d.)	Open	Water Control	Closed	Control II
Actual Field Data (x)	188.73(130.02)	211.50(200.75)	269.88(271.29)	232.27(253.31)
log 10 (x+1) transformation	86.25[a](7.8)	92.86[a](5.98)	74.70[a](9.92)	10.11[a](10.69)

a - No significant difference between plots.

Table 29. Mean standing crop estimates (live weight in grams) of *Palaemonetes pugio* collected/plot/collection date from 25 meter long seining stations from January through August, 1980.

	PLOTS			
Mean ($\pm$1s.d.)	Open	Water Control	Closed	Control II
Actual Field Data (x)	32.52(68.66)	4.85(5.04)	7.15(6.57)	15.34(18.53)
log 10 (x+1) transformation	5.78[a](4.03)	2.76[a](1.82)	4.86[a](1.42)	8.06[a](2.24)

a - No significant difference between plots.

Table 30. Species list of fishes collected on the Davis Island study area ponds from April, 1979 to August, 1980.

		PLOTS				
Species	Common Name	Open	Water Control	Closed	Control I[a]	Control II[b]
Fundulus heteroclitus	Common Killifish	X	X	X	X	X
Fundulus luciae	Spotfin Killifish			X	X	X
Lucania parva	Rainwater Killigish	X		X	X	X
Cyprinodon variegatus	Sheepshead Minnow	X	X	X	X	X
Gambusia affinis	Mosquito Fish			X	X	X
Menidia beryllina	Silverside		X	X		
Anguilla rostrata	American Eel	X	X	X		
Gobiosoma bosci	Clinging Goby		X	X		
Gasterosteus aculeatus	Three-spined Stickle Back				X	
Lepomis gibbosus	Pumpkin Seed Sunfish		X			

a - sampled in 1979 only.
b - sampled in 1980 only.

Table 31. Relative abundance of fish species collected from the open plot pond from April, 1979 through August, 1980.

Species	Rank	No. Collected	% Frequency	Relative Abundance
Fundulus heteroclitus	1	1438	100.00	143,800.00
Cyprinodon variegatus	2	155	37.50	5,812.50
Lucania parva	3	49	37.50	1,837.50
Anguilla rostrata	4	1	6.25	6.25

Table 32. Relative abundance of fish species collected from the water control plot pond from April, 1979 to August, 1980.

Species	Rank	No. Collected	% Frequency	Relative Abundance
Fundulus heteroclitus	1	1164	100.00	116,400.00
Cyprinodon variegatus	2	100	50.00	5,000.00
Menidia beryllina	3	3	6.25	18.75
Gobiosoma bosci	4	2	6.25	12.50
Anguilla rostrata	5	1	6.25	6.25
Lepomis gibbosus	5	1	6.25	6.25

Table 33. Relative abundance of fish species collected from the closed plot pond from April, 1979 through August, 1980.

Species	Rank	No. Collected	% Frequency	Relative Abundance
Fundulus heteroclitus	1	728	93.75	68,250.00
Cyprinodon variegatus	2	34	31.25	1,062.50
Lucania parva	3	19	31.25	593.75
Gambusia affinis	4	19	25.00	475.00
Menidia beryllina	5	26	12.50	325.00
Gobiosoma bosci	6	12	25.00	300.00
Fundulus luciae	7	8	18.75	150.00
Anguilla rostrata	8	1	6.25	6.25
Gasterosteus aculeatus	8	1	6.25	6.25

Table 34. Relative abundance of fish species collected from the control plot I pond from April, 1979 through January, 1980.

Species	Rank	No. Collected	% Frequency	Relative Abundance
Fundulus heteroclitus	1	707	100.00	70,700.00
Cyprinodon variegatus	2	71	83.33	5,916.43
Lucania parva	3	8	25.00	200.00
Gambusia affinis	4	10	16.67	166.70
Fundulus luciae	5	1	8.33	8.33

Table 35. Relative abundance of fish species collected from the control plot II pond from May, 1980 through August, 1980.

Species	Rank	No. Collected	% Frequency	Relative Abundance
Fundulus heteroclitus	1	79	100	7900
Gambusia affinis	2	41	50	2050
Cyprinodon variegatus	3	7	75	525
Lucania parva	4	10	50	500
Fundulus luciae	5	1	25	25

Table 36. Number of species, number of individuals, Brillouin's measure of species diversity and species evenness values for the total collection of fishes from the Davis Island study ponds from April, 1979 through August, 1980.

Plots	No. of Species	No. of Individuals	Species Diversity	Species Evenness
Open	4	1643	0.4442	0.3223
Water Control	6	1271	0.3100	0.1745
Closed	9	848	0.6507	0.3001
Control I[a]	5	797	0.4211	0.2643
Control II[b]	5	138	1.0028	0.6510

a - sampled from April, 1979 through January, 1980 only.
b - sampled from May, 1980 through August, 1980 only.

The results presented here should not be extrapolated beyond Davis Island or marshes of a very similar type. As related in an earlier section of this report (mosquito larvae populations) closed system ditches do not always support large and varied fish populations and, in some cases, large fish kills have been observed in closed system ditches due to extremely low levels of dissolved oxygen.

<u>Water quality</u> - Water quality data for the ditches and creeks are presented in Table 37. Water quality data for ponds is presented in Table 38.

There is no significant difference within the measured water quality parameters between stations. However, these data should not be extrapolated beyond the Davis Island study plots. As previously recounted (mosquito larvae populations section) dissolved oxygen levels in closed system ditches can fall to lethal levels to fish under conditions of high biological oxygen demand.

<u>Water table elevations</u> - The random point water table elevation data are presented in Table 39. In 1979, the plots were each significantly ($P < 0.05$) different from each other. The water table elevation on the open plot was significantly lower than on the other plots. The control plot displayed the highest water table of the treatment plots.

In 1980, the open plot again had the lowest mean water table elevation, based on random well data, however, it was not significantly different from the closed or control plots (Table 39). The water control plot maintained a significantly ($P < 0.05$) higher mean random well water table elevation than the open plot in 1980. The mean random well water

Table 37. Average water quality values/plot/collection date in the treatment ditches and control creeks from April, 1980 through August, 1980.

Water Quality Parameter	PLOTS				
	Open	Water Control	Closed	Control I[a]	Control II[b]
Dissolved oxygen	7.67	6.03	6.75	7.08	8.72
Salinity	11.77	10.33	10.81	8.89	11.00
Temperature	20.29	19.82	21.26	20.22	21.00

a - sampled in 1979 only.
b - sampled in 1980 only.

Table 38. Average water quality values/plot/collection date for the ponds from April, 1979 through August, 1980.

Water Quality Parameter	PLOTS				
	Open	Water Control	Closed	Control I[a]	Control II[b]
Dissolved oxygen	5.10	4.92	6.88	4.94	7.33
Salinity	12.23	11.92	13.85	9.44	20.25
Temperature	25.00	24.15	24.08	24.00	32.00

a - sampled in 1979 only.
b - sampled in 1980 only.

table elevation on the water control plot was significantly different than on the closed or control plots in 1980.

The mean water table elevations, resulting from the random point well readings, on the open and closed plots were significantly ($P < 0.05$) lower in 1980 than in 1979. There was no significant difference in the mean random well water table elevation between years on the water control plot.

The results of the transect water table elevation data are presented in Tables 40-44. In 1979, there was a highly significant ($P < 0.01$) difference between plots (Table 44). The mean transect water table elevation was significantly higher on the water control and closed plots (41.58 and 40.65 cm. above MSL, respectively). The open and control plots were not significantly different from each other (39.05 and 37.93 cm. above MSL, respectively).

The analysis of variance of the 1979 water well transect data also showed a highly significant difference between transect distances and plots X distances interaction (Table 44). The 50 meter and 25 meter distances maintained significantly higher mean water table elevations (45.95 and 44.84 cm. above MSL, respectively) than the other distances. The 10 meter, 5 meter, and 1 meter distances were significantly different from each other (40.74, 36.27 and 31.21 cm. above MSL, respectively). This indicates that in 1979, the stations closest to the ditches or creek were subject to the greatest degree of drainage. The plots X distances interactions for 1979 are displayed in Table 41.

An analysis of variance of the mean water table elevation/plot/ transect distance in 1980 is presented in Table 45. There was a highly significant ($P < 0.01$) difference between the plots. Each plot was significantly different from the others. The water control plot displayed the highest mean water table elevation (34.46 cm. above MSL). The mean water table elevations on the control, open and closed plots were 28.51, 23.77, and 18.47 cm. above MSL, respectively, in 1980.

A highly significant ($P < 0.01$) difference was also found between distances in 1980 (Table 45). The 1 meter distance displayed a mean water table elevation of 20.64 cm. above MSL, which is significantly lower than the water table elevations at the 10 meters, 5 meters, 25 meters, and 50 meters distances (29.13, 27.43, 27.18 and 27.13 cm. above MSL, respectively). This is a significant difference from the results obtained in 1979, when the stations farthest from the ditches and creeks displayed the highest water tables. It is probable that the drought in 1980 caused this change.

There was a significant difference between plots X distances interactions in 1980. These data are presented in Table 43.

In summary, it can be concluded that the open system plot displayed the lowest water table elevations, and that drainage is greatest within 10 meters of the open ditch. The water control system maintained the most stable water table elevation between years. The closed system experienced the widest range of water table elevations between 1979 and 1980. The lack of rainfall in 1980 led to a highly significant ($P < 0.01$) decrease in the mean water table elevation on the closed plot in 1980

Table 39. The mean water table elevation (cm above mean sea level)/plot /sample time as determined by the randomly located wells in 1979 and 1980.

	PLOTS				
Year	Open	Water Control	Closed	Control I	Control II
1979	30.55^{a}	35.73^{b}	39.58^{c}	43.52^{d}	
1980	22.15^{a}	34.06^{b}	$27.95^{a,b}$		$29.24^{a,b}$

a,b,c,d - Those mean numbers within a year not having the same letter are significantly differert at $P < 0.05$.

Table 40. The mean water table elevation (cm above mean sea level)/plot /transect distance/sample date in 1979.

	PLOTS			
Distance (m)	Open	Water Control	Closed	Control I
1	31.11	36.04	37.79	19.90
5	35.48	41.32	38.63	29.67
10	38.47	42.55	41.16	40.78
25	44.13	41.97	43.06	50.21
50	46.07	46.03	42.61	49.08

Table 41. Array of the mean water table elevations (cm above mean sea level)/plot/transect distance/sample date in 1979.

Plot/Distance (m)	Array of Means in Descending Order
Control/25	50.21[a]
Control/50	49.08[a]
Open/50	46.07[b]
Water Control/50	46.03[b]
Open/25	44.13[b,c]
Closed/25	43.06[b,c]
Closed/50	42.61[c]
Water Control/10	42.55[c]
Water Control/25	41.97[c]
Water Control/5	41.32[c,d]
Closed/10	41.16[c,d]
Control/10	40.78[c,d]
Closed/5	38.63[d,e]
Open/10	38.47[d,e]
Closed/1	37.79[e]
Water Control/1	36.04[e]
Open/5	35.48[e]
Open/1	31.11[f]
Control/5	29.67[f]
Control/1	19.90[g]

a,b,c,d,e,f,g - Those mean numbers not having the same letter are significantly different at $P < 0.05$.

Table 42. The mean water table elevation (cm above mean sea level)/plot /transect distance/sample date in 1980.

	PLOTS			
Distance (m)	Open	Water Control	Closed	Control II
1	15.27	32.31	14.14	20.94
5	25.63	34.75	21.04	28.30
10	25.05	40.59	19.41	31.46
25	25.67	34.18	17.02	31.84
50	27.21	30.59	20.76	30.01

Table 43. Array of the mean water table elevations (cm above mean sea level)/plot/transect distance/sample date in 1980.

Plot/Distance (m)	Array of Means in Descending Order
Water Control/10	40.59[a]
Water Control/5	34.75[b]
Water Control/25	34.18[b]
Water Control/1	32.21[b,c,d]
Control/25	31.84[b,c,d]
Control/10	31.46[b,c,d]
Water Control/50	30.59[c,d,e]
Control/50	30.01[c,d,e]
Control/5	28.30[d,e,f]
Open/50	27.21[e,f]
Open/25	25.67[f]
Open/5	25.63[f]
Open/10	25.05[f]
Closed/5	21.04[g]
Control/1	20.94[g]
Closed/50	20.76[g]
Closed/10	19.41[g,h]
Closed/25	17.02[h]
Open/1	15.27[h]
Closed/1	14.14[h]

a,b,c,d,e,f,g,h - Those mean numbers not having the same letter are significantly different at $P < 0.05$.

Table 44. Analysis of variance for the mean water table elevation (cm above mean sea level)/plot/transect distance in 1979.

Source of variation	df	MS	F
Plots	3	106.0	12.0**
Distances	4	1203.0	136.7**
Plots X Distances	12	200.0	22.7**
Error	133	8.8	

** - significantly different at $P < 0.01$.

Table 45. Analysis of variance for the mean water table elevation (cm above mean sea level)/plot/transect distance in 1980.

Source of variation	df	MS	F
Plots	3	1623.0	63.15**
Distances	4	299.0	11.63**
Plots X Distances	12	54.0	2.10*
Error	114	25.7	

* - significantly different at $P < 0.05$.
** - significantly different at $P < 0.01$.

compared to 1979. The lack of rain was mitigated on the open and water control plots because of tidal replenishment. However, the ground water lost due to drainage during the low tides on the open plot was not entirely replenished during normal high tides. Because the level that the tide can fall to in the water control ditch is regulated by the height of the outlet, drainage cannot occur to the extent it does on the open plot. By proper regulation of the water level in the ditches of a water control system it would be possible to remove surface water which serves as mosquito breeding area, but still maintain a relatively high water table.

The results of the various water management practices on water table elevations presented here should not be extrapolated beyond the Davis Island study area due to differences in marsh elevation and tidal ranges.

Soil classification - The soil of all the study plots has characteristics that are within the range of the suborder Terric Sulfihemist. The soil is deep and poorly drained. The organic layer of the soil is formed primarily from decomposed salt marsh vegetation. The organic layer overlays older mineral soils which were formerly uplands. The soil has organic horizons at least 41 cm. thick and contains sulfidic materials due to inundation with brackish water. Bulk density of the organic soil was less than 1.0 g./cc., while the mineral soil has a density of greater than 1.5 g./cc.

The upper tier of the organic soil has 50% to 80% fiber content with approximately 10% silt loam by volume and is slightly acid. The thickness of tier 1 ranged 20 to 36 cm., but most frequently 30 cm. Tier

2 of the organic soil is dark colored, loosely consolidated material and is ca. 16 cm. thick.

A general description of the soil in the study area is as follows:

0 - 30 cm.	- dark brown peat; many fine and medium size live roots and rhizomes; about 10% volume silt loam; slightly acid.
30 - 46 cm.	- black mucky peat; less than 20% volume silt loam; neutral pH.
46 - 81 cm.	- gray silt loam; friable in place; neutral pH.
81 - 127 cm.	- gray mottled heavy silt loam; somewhat firm in place; neutral pH.
127 - 152 cm.	- light gray loamy sand; very friable to loose; neutral pH.

Rainfall - Rainfall data for the Davis Island study area from April, 1979 through October, 1981 is presented in Table 45.

Rainfall in 1979, during the summer and early fall was greater than normally expected. This created abnormally wet conditions which had an impact on all study parameters, most notably mosquito populations and water table elevations.

In 1980, drought conditions existed on the study area from May through December. This lowered water tables on all study plots.

In 1981, rainfall was at, or above, normal. Rain was intermittent. Heavy rains following short dry periods created highly favorable breeding conditions for *Aedes sollicitans* in 1981.

Table 46. Precipitation data for the Davis Island study area from April, 1979 through October, 1981.

Year	Month	Total precipitation (mm)
1979	April	31.75[a]
	May	90.00
	June	119.40
	July	73.70
	August	121.90
	September	58.40
	October	68.60
	November	114.30
	December	78.70
1980	January	71.10
	February	66.00
	March	29.70
	April	23.00
	May	50.00
	June	11.00
	July	14.00
	August	7.00
	September	29.70
	October	80.00
	November	38.00
	December	N.D.
1981	January	N.D.
	February	N.D.
	March	N.D.
	April	101.60
	May	71.12
	June	93.98
	July	97.79
	August	114.30
	September	53.34
	October	43.18

a - partial reading, from April 18 to 30.

SUMMARY AND CONCLUSIONS

During this study, it was demonstrated that water management can be highly effective in controlling salt marsh breeding mosquitoes. Each of the three management techniques evaluated provided equal mosquito control on the Davis Island study area. However, the closed system technique was found to be ineffective for mosquito control on secondary study sites where mosquito breeding was found in surface water swales or there was a deep peat soil.

The use of the management systems by marsh surface macroinvertebrates such as *Melampus* snails, Amphipods and Isopods was measured, but no clear conclusions can be made as to the impact of the management techniques on these organisms. Populations of these animals are relatively low on the Davis Island study area.

The water management systems each provided additional habitat for fish, shrimp, and crabs, and was used by a large and varied population of these animals. Because of this, marsh management practices may enhance production in the estuarine food web. However, on secondary study areas in the Deal Island and Elliott Island areas, fish kills were observed in closed ditch systems. The cause of the fish kills is thought to be low levels of dissolved oxygen. The dissolved oxygen content of the water in the closed ditches was observed to be near zero ppm during early morning and evening. The low dissolved oxygen level is speculated to have been caused by a high biological oxygen demand caused by decay of organic matter in the ditches. The origin of this organic matter was either the peat layer the ditches were constructed in, large stands of submerged aquatic vegetation, or a combination of both.

The drainage impact of the open tidal ditches caused significantly lower water table elevations on the open plot as compared to the other treatment plots and the control plots. The closed plot displayed a wide range of water table elevations between years, as a function of the amount of rainfall received on the study area. The water control system maintained the most stable water table elevation between the years of study.

To achieve the desired level of mosquito control on Chesapeake Bay salt marshes it will be necessary to employ a tidally influenced water management technique. A combination of open and water control ditches will provide effective mosquito control with the minimum degree of alteration to the wetlands, and produce the least negative environmental impact. In conjunction with a system of tidal and semi-tidal ditches, ponds should be constructed to provide habitat diversity and improve wildlife habitat. These ponds can vary in size, but should not exceed 0.08 hectare.

Large scale closed ditching projects should not be employed in future mosquito control water management projects on Maryland's Chesapeake Bay wetlands because of the observed failure of closed systems to control mosquitoes and negative impacts on fish. Small closed ditching projects such as pond radial ditches, in conjunction with tidal or semi-tidal ditches are an acceptable and encouraged management technique.

As a result of this study and the study of Lesser and Saveikis (1979), the Maryland Mosquito Control Advisory Committee has been able to draft standards for what constitutes acceptable marsh management techniques for mosquito control in Maryland. A draft of these standards is presented in Appendix A. These standards are very different from the standards presented by Bruder (1980) for open marsh water management in New Jersey. Therefore, the techniques used in Maryland should not, in the future, be termed open marsh water management. A more proper term for the water management program in Maryland would be Maryland open marsh water management (MOMWM).

REFERENCES CITED

Bidlingmayer, W.L., 1969. The use of logarithms in analyzing trap collections. Mosq. News. 29: 635-640.

Bourn, W.S. and C. Cottam. 1950. Some biological effects of ditching tidewater marshes. U.S. Fish and Wildl. Serv., Resrch. Rept. 19. 30 p.

Bradbury, H.M., 1938. Mosquito control operations on tide marshes in Massachusetts and their effect on shorebirds and waterfowl. J. Wildl. Mgmt. 2: 49-52.

Bruder, K.W., 1980. The establishment of unified open marsh management standards in New Jersey. Proc. N.J. Mosq. Control Assoc., Inc. 67: 72-76.

Carpenter, S.J. and W.J. LaCasse, 1955. Mosquitoes of North America (North of Mexico). Univ. of Calif. Press. Berkeley, California. 360 p. (+127 plates).

Connell, W.N., 1940. Tidal inundation as a factor uniting distribution of Aedes spp. on a Delaware salt marsh. M.S. Thesis. Univ. of Minnesota. 30 p.

Cottam, C. and W.S. Bourn. 1952. Coastal marshes adversely affected by drainage and drought. Trans. M. Amer. Wildl. Conf. 17: 414-421.

Cottam, C., W.S. Bourn, F.C. Bishopp, L.L. Williams, Jr., and W. Voght. 1938. What's wrong with mosquito control? Trans. N. Amer. Wildl. Conf. 3: 81-107.

Crans, W.J., 1977. The status of Aedes sollicitans as an epidemic vector of eastern equine encephalitis in New Jersey. Mosq. News. 37: 85-89.

Daiber, F.C., 1974. Salt marsh plants and future coastal salt marshes in relation to animals. In R.J. Reimold and W.H. Queen (eds.), Ecology of Halophytes. Academic Press. p. 475-508.

Darmody, R.G. and J.E. Foss. 1978 Tidal marsh soils of Maryland. Maryland Agr. Exp. Sta. Univ. of Maryland, College Park, Maryland. 69 p.

Ferrigno, F., 1970. Preliminary effects of open marsh water management on the vegetation and organisms of the salt marsh. Proc. N.J. Mosq. Exterm. Assoc. 57: 79-94.

Ferrigno, F. and D.M. Jobbins. 1968. Open marsh water management. Proc. N.J. Mosq. Exterm. Assoc. 55: 104-115.

Ferrigno, F., P. Slavin, and D.M. Jobbins. 1975. Salt marsh water management for mosquito control. Proc. N.J. Mosq. Exterm. Assoc. 62: 30-38.

REFERENCES CITED

Harrington, R.W. and E. Harrington. 1961. Food selection among fishes invading a high subtropical marsh: from onset of flooding through the progress of a mosquito brood. Ecol. 42: 646-660.

Headlee, T.J., 1945. The Mosquitoes of New Jersey and Their Control. Rutgers Univ. Press, New Brunswick, N.J. 326 p.

Hildebrand, S.F. and W.C. Schroeder. 1928. Fishes of Chesapeake Bay. Smithsonian Institution Press, Washington, D.C. 388.

Johnson, W.M. and W.J. Crans. 1980. Aedes sollicitans (Walker) (Diptera: Culicidae) as a vector of filarial worms in New Jersey. Proc. N.J. Mosq. Control Assoc., Inc. 67: 98.

Krebs, C.T. and I. Valiela. 1978. Effect of experimentally applied chlorinated hydrocarbons on the biomass of the fiddler crab, Uca pugnax (Smith). Estuarine and Coastal Mar. Sci. 6: 375-386.

Kuenzler, E.J. and H.L. Marshall. 1973. Effects of mosquito control ditching on estuarine ecosystems. Univ. of N.C. Water Resources Res. Inst. Rept. No. 81. 83 p.

Lesser, C.R. and D. Saveikis. 1979. A study of the impacts of a mosquito control integrated pest management program on selected parameters of the ecology of Chesapeake Bay high marsh communities in Maryland. Final Rept., Md. Dept. of Agric., EPA Grant No. X003147-01. 194 p.

Lesser, C.R., F.J. Murphy, and R.W. Lake. 1976. Some effects of grid system mosquito control ditching on salt marsh biota in Delaware. Mosq. News. 36: 69-77.

Lesser, C.R., R.M. Altman, and L.F. George. 1978a. Open marsh water management in Maryland. Proc. N.J. Mosq. Control Assoc., Inc. 65: 41-46.

Lesser, C.R., R.M. Altman, M.L. Cropper, R.A. Berry, and K.W. Ludlam. 1978b. An analysis of Aedes sollicitans and Aedes taeniorhynchus populations on the Eastern Shore of Maryland in 1977. Proc. N.J. Mosq. Control Assoc., Inc. 65: 217-225.

Mansueti, R., 1950. Tentative key to the adult freshwater fishes and fish-like vertebrates of Maryland and the District of Columbia. Univ. of Maryland (Dept. of Zoology), College Park, Maryland. 46 p (mimeo).

Poole, R.W., 1974. An Introduction to Quantitative Ecology. McGraw-Hill, Inc., New York. 532 pp.

Provost, M.W., 1977. Source reduction in salt-marsh mosquito control: past and future. Mosq. News. 37: 689-698.

REFERENCES CITED

Schmelz, G.W., 1964. A natural history study of the mummichog, Fundulus heteroclitus (Linnaeus), in Canary Creek marsh. M.S. Thesis. Univ. of Delaware. 65 p.

Shisler, J.K. and D.M. Jobbins. 1977. Salt marsh productivity as affected by the selective ditching technique, open marsh water management. Mosq. News. 37: 631-636.

Smith, J.B., 1904. Report of the New Jersey Agricultural Experiment Station upon the mosquitoes occurring within the State, their habits and life history. Rutgers Univ., New Brunswick, N.J. 482 p.

Stearms, L.A., D. MacCreary, and F.C. Daigh. 1940. Effects of ditching on the muskrat population of a Delaware tidewater marsh. Univ. of Delaware Agric. Exper. Sta. Bull. No. 225. 55 p.

Steel, R.G.D. and J.H. Torrie. 1960. Principles and Procedures of Statistics: With Special Reference to the Biological Sciences. McGraw-Hill Book Co., Inc. New York. 481 p.

Urner, A., 1935. Relation of mosquito control in New Jersey to bird life of the salt marshes. Proc. N.J. Mosq. Exterm. Assoc. 22: 130-136.

U.S. Dept. of Commerce. 1980. Tide Tables-1980-high and low water predition. East Coast of North and South America. NOAA. National Ocean Survey. 293 p.

U.S. Dept. of the Interior. 1977. Impacts of mosquito control practices: a bibliography. Fish and Wildlife Service. Gulf South Research Inst. Baton Rouge, LA. 97 p.

Welsh, B.L., 1973. The role of the grass shrimp, Palaemonetes pugio, in a tidal marsh ecosystem. Ph.D. Thesis, Univ. of Rhode Island. Kingston, R.L. 90 p.

Whigham, D., M. McWethy, and J. O'Neil. 1982. Final report: The effects of open marsh water management on the ecology of Chesapeake Bay high marsh wetlands. (in preparation). Chesapeake Bay Center for Environ. Studies. Edgewater, MD.

APPENDIX A

STANDARDS FOR MARYLAND OPEN MARSH WATER MANAGEMENT (MOMWM)

DRAFT

The need and demand for improved control of salt marsh mosquitoes; primarily Aedes sollicitans; exists in many parts of Maryland, particularly the southern Eastern Shore region. It is accepted that the fundamental requisite for the control of Ae. sollicitans is the control of the larvae by either chemical means (larviciding) or physical means (water management). Whereas chemical control poses several problems; including environmental contamination, high cost, temporary results, and eventual resistance by the mosquitoes; it is concluded that control by water management is the preferred control technique.

The basic principle of water management mosquito control techniques is to facilitate access of larvivorous fish to the mosquito breeding areas and/or cause removal of water from the breeding areas before the mosquito larvae can complete their development.

The Maryland Mosquito Control Advisory Committee has investigated various strategies of water management for use in the State since 1976. In order to identify the management technique(s) most suited for use in Maryland, certain standards are necessary. These standards were developed through practical experience and comprehensive ecological studies and shall be used as a guide in future water management projects and be incorporated in all permits issued for mosquito control marsh management projects. These standards will be periodically reviewed and revised if necessary.

I. Objective

A. The primary objective is to provide a management technique that will control the larval production of all species of salt marsh breeding mosquitoes: Aedes sollicitans, Aedes taeniorhynchus, Aedes cantator, Anopheles bradleyi and Culex salinarius.

B. Reduction in the use of insecticides - After the completion of a water management project, mosquito control will be achieved, therefore the use of larvicides on that area will be eliminated.

C. The application of MOMWM shall, to the extent possible, minimize the negative impact on floral and faunal composition of the salt marsh/estuarine ecosystem.

D. The technique must be cost effective - Inasmuch as public funds will pay for this management it is essential that these funds be used to provide the intended results at a reasonable cost.

II. Need: The use of MOMWM will be based entirely on the need for mosquito control as determined by larval inspections.

III. Implementation

A. Because the ecological requirements necessary for the breeding of all genera of salt mosquitoes are reflected in the vegetational character of the marsh, this character can be used to determine potential breeding marshes. In Maryland, the plant species associated with high marsh, i.e. infrequently flooded by rains, spring or storm tides; therefore indicative of mosquito breeding habitat are: *Distichlis spicata*; *Spartina patens*; short form *Spartina alterniflora*; small areas of *Juncus Roemerianus*, *Scirpus Olneyi* and *Typha* spp. in association with the previous three species; *Phragmites communis*, *Scirpus robustus*, and (in some instances) *Panicum* spp. Water management will not be employed on marshes subject to regular floodings (greater than 8 days per month) or daily tides. Non-breeding marshes are vegetationally characterized by tall form *Spartina alterniflora*; *Zizania aquatica*; extensive stands of either *Typha* spp., *Scirpus Olneyi* or *Juncus Roemerianus*; and similar species of vegetation. Permanent ponds on the salt marsh do not provide breeding sites for mosquitoes and will not be drained.

B. All alterations must directly affect mosquito breeding sites.

C. An experienced mosquito control entomologist, wetland biologist, or both shall stake out all of the alterations to be constructed. The amount of construction done will be the minimum required to satisfy the objectives of MOMWM.

IV. Alterations: Four types of alterations (tidal ditches, semi-tidal ditches, ponds and pond radials) will be used. To a degree, the type of alteration used will be dependent on the type of marsh being managed. Darmody and Foss (1978) define three types of marsh in Maryland: Coastal, Submerged Upland and Estuarine.

Coastal type marshes have a higher salt content in the soil than the other marsh types and are characterized by vast swards of *S. alterniflora* and *S. patens*. Coastal marshes occur along the margins of Chincoteague and Assawoman Bays in Worcester County. It is the dominant marsh type in Worcester County and constitutes all of that county's mosquito breeding salt marsh.

Submerged upland type marshes have developed over areas which were formerly uplands and are being submerged by the slowly rising sea level. These marshes are characterized by relatively thin organic soils overlaying older mineral soils developed from wind-blow silts or sands. The dominant vegetation consists of J. Roemerianus, S. patens, D. spicata, S. alterniflora, S. Olneyi and P. communis. It is the dominant marsh type in Maryland, and is found primarily in Dorchester and Somerset Counties where it is the predominant mosquito breeding marsh type.

The estuarine type marsh occurs in all counties along Chesapeake Bay and the Atlantic Coast. This marsh type is found primarily along streams and rivers which drain into Chesapeake Bay. The marshes develop from the silting in of streams, estuaries or bays. They may also develop from the accumulation of sediments in tidal streams as estuarine meanders. The dominant vegetation in the brackish and saline areas of this marsh type is S. alterniflora, S. patens, D. spicata, Spartina cynosuriodes, S. Olneyi and J. Roemerianus. This is the dominant marsh type for salt marsh mosquito breeding in the Western Shore region and is also common along Pocomoke Sound in Somerset County and Fishing Bay in Dorchester County.

A. Tidal Ditches

1. Tidal ditches are the most effective alteration to eliminate mosquito breeding and are the preferred type of ditch to be used on coastal marshes and on some estuarine marshes. On submerged upland marshes the use of tidal ditches will be restricted to the upland edge as a "band ditch" and when existing upland drainage ditches outlet to the marsh that part of the ditch traversing the marsh to a tidal drain may be cleaned so as to assure tidal flow.*

2. All tidal ditches will be dug with suitable equipment, preferably with a rotary ditcher. When a rotary ditcher is not available or cannot be used other equipment types, such as amphibious cranes or backhoes, are acceptable provided that spoil taken from the ditches is graded to as near marsh level as possible. Spoil dug with a crane or backhoe should be placed on opposite sides of the ditch so as not to form a continuous line of spoil which would impede water movement across the marsh surface.

3. Tidal ditches should be dug to a depth of two to three feet, with the deeper ditches being preferred.

4. Main tidal ditches are used to provide tidal circulation through large areas. The ditches can be connected to a tidal source at one or more points. The location of the main ditch is determined by the distribution of mosquito breeding sites and the proximity of a tidal source.

5. Lateral tidal ditches connect breeding sites to main ditches, natural tidal creeks or other laterals. Such laterals often dead end at a breeding site.

6. All previously constructed mosquito or other ditches that are breeding sites will be cleaned.

7. Wherever possible, spoil taken from a tidal ditch will be used to fill nearby mosquito breeding depressions.

*underlined sections will be discussed by the membership of the Advisory Committee.

B. Semi-tidal Ditches

1. Semi-tidal ditches are the preferred type of ditch to be used on submerged upland marsh that can be classified as open marsh, i.e. not bordering the upland edge and not under the impounding influence of old dikes or roads. Semi-tidal ditches may also be used on estuarine marshes.

2. Semi-tidal ditches will be constructed according to the specifications given for tidal ditches except that the outlet of main ditches will contain a sill which will not allow complete drainage. This sill will be approximately 100 feet long and 6 to 10 inches below the marsh surface (see Fig. 1).

3. The semi-tidal ditches will allow drainage of excess surface water, thus eliminating sheet water breeding sites, and flood frequently enough by spring or storm tides to maintain a water quality sufficient for fish survival. If these results are not achieved, the depth of the sill shall be lowered.

C. Ponds

1. Where numerous mosquito breeding depressions are concentrated in a limited area, a pond alteration will be utilized.

2. Pond construction is accomplished by a rotary ditcher, amphibious crane, backhoe or other suitable equipment.

3. Ponds should be 18 inches or 24 inches in depth to promote waterfowl and wading bird use and the growth of submerged aquatic vegetation.

4. To ensure fish survival in the ponds during droughts a resevoir ditch of at least three feet depth shall be constructed along at least two sides of the pond edge.

5. Pond shape may be either linear or take the shape of the breeding area.

6. Islands shall be left in the pond when possible to provide additional edge cover within the pond.

7. Pond spoil should be graded as low as possible without undue disturbance to the nearby non-breeding marsh surface. Pond spoil shall be used to fill mosquito breeding depressions when possible.

D. Pond Radial Ditches

1. Mosquito breeding sites located near a permanent natural or constructed pond shall be connected to the pond by pond radial ditches. These radial ditches will provide access for fish to devour mosquito larvae at the breeding sites.

2. All pond radials shall be constructed with the type of equipment previously mentioned for tidal and semi-tidal ditches.

3. Spoil from the radial ditches shall be disposed of in a similar manner as described for tidal and semi-tidal ditches.

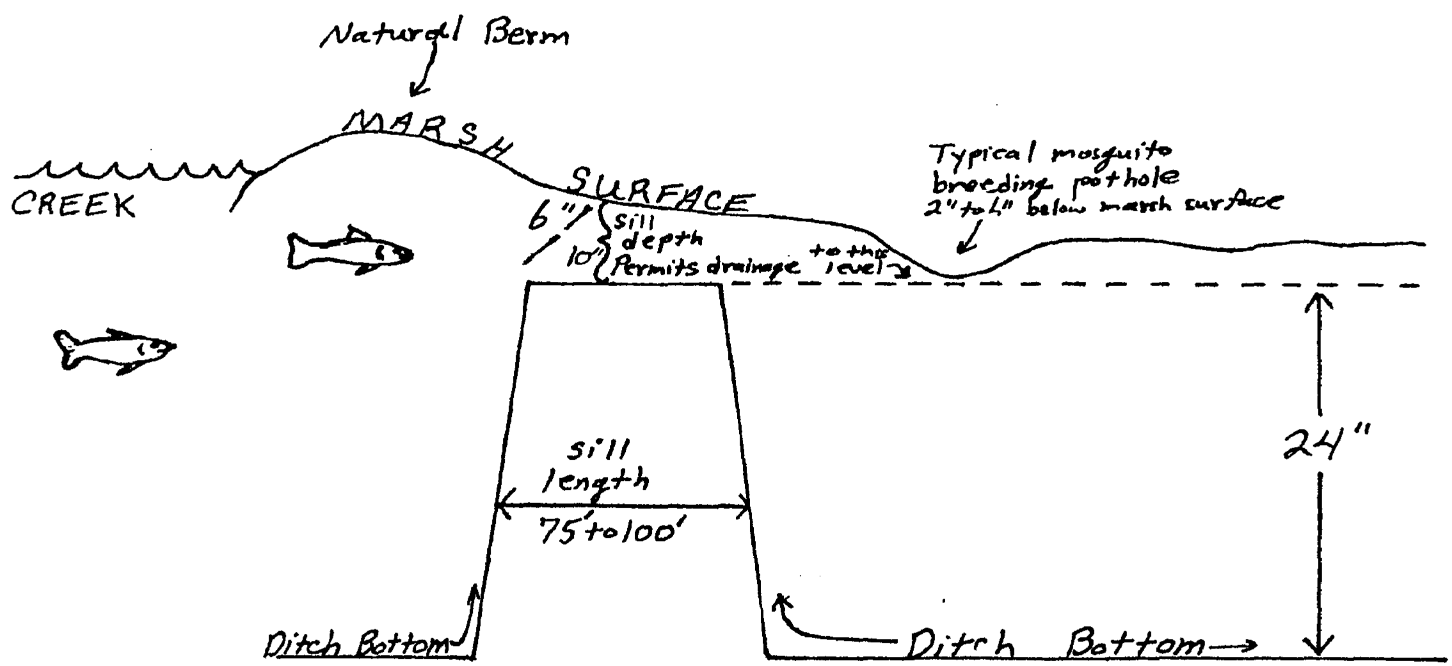
4. To prevent drainage of a natural permanent or constructed pond by muskrats, or other natural factors, all pond radials shall end no closer than 50 feet from a tidal ditch or creek.

V. Other Techniques: Impoundments, closed ditch systems and other types of management not described here are not MOMWM.

REFERENCE CITED

Darmody, R.G. and J.E. Foss. 1978. Tidal Marsh Soils of Maryland. Maryland Agr. Exp. Sta. Univ. of Maryland, College Park, Maryland. 69 pp.

PLAN FOR SILL DITCH CONSTRUCTION



APPENDIX B

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