1041

SOME BIOLOGICAL EFFECTS OF DITCHING TIDEWATER MARSHES

RESEARCH REPORT 19

FISH AND WILDLIFE SERVICE
UNITED STATES DEPARTMENT OF THE INTERIOR

ABSTRACT

Studies conducted over a 12–year period, 1935–47, of the biological effects of ditching tidewater marshes in Delaware for mosquito control showed that marked ecological changes in the floral cover and invertibrate fauna followed such operations. These studies revealed that systematic ditching, which has proved useless as a permanent mosquito-control measure, resulted in shrubby growths succeeding the marshes' natural vegetation and greatly reduced invertibrate populations so important as waterfowl food.

SOME BIOLOGICAL EFFECTS OF DITCHING TIDEWATER MARSHES

By WARREN S. BOURN, *Biologist, and*
CLARENCE COTTAM, *Assistant Director*

RESEARCH REPORT 19

Fish and Wildlife Service, Albert M. Day, *Director*
United States Department of the Interior, Oscar L. Chapman, *Secretary*

UNITED STATES GOVERNMENT PRINTING OFFICE : 1950

For sale by the Superintendent of Documents, United States Government Printing Office
Washington 25, D. C. - Price 60 cents

CONTENTS

Figure 1.—Aerial view of Mispillion River marshes. River and white line mark boundaries of study area. (See page 3.)

SOME BIOLOGICAL EFFECTS OF DITCHING TIDEWATER MARSHES

Just a century ago some 625,000 acres of salt, brackish, and fresh-water marshes bordered the Atlantic coast from Maine to Virginia. As early as 1885, however, work was begun to reclaim for agriculture considerable acreages of the fresher tidal lands, particularly along Delaware Bay and in a few places along the Massachusetts coast. Such reclamation attempts consisted primarily in the construction of systems of dikes and ditches. In addition, small acreages of the higher salt-marsh lands were ditched at various points along the coast to facilitate the harvesting of *Spartina patens* and *Juncus gerardi*, known locally as salthay. Except as they aided in maintaining haying areas and in developing a few cranberry bogs, many of these early reclamation attempts had little effect on agricultural production, and today no noticeable traces remain. On other areas, however, as those in New Castle County, Delaware, where the dikes have been well maintained and stable aquatic conditions kept, the lands where found unsuited for agricultural crops are used in muskrat production.

The foregoing briefly outlines the slight impact that ditching for agricultural purposes had made on the tidal marshes of the Atlantic coast until after the turn of the present century. But in 1912 extensive ditching of tidewater lands of New Jersey to control mosquitoes was begun. Although this work was more or less restricted to metropolitan districts for a great many years, it was greatly expanded in 1933 when relief labor, organized as a result of the economic depression, became available. Headlee (1937) in discussing mosquito-control problems in the State of New Jersey in 1937 stated that at that time there were 38,394,464 linear feet of ditches, 32.5 miles of dikes, 1,562 square feet of tidegate outlets, and 6,907,024 linear feet of ditches of varying widths in upland marshes and swamps. From an economic angle it is interesting to note that he estimated the annual maintenance of these ditches and structures at $250,000, based on cost accounting in 1937.

By 1938, similar mosquito-control activities in other coastal States had brought the total area of marshlands ditched along the Atlantic coast to 562,500 acres or approximately 90 percent of the original tidewater lands lying between Maine and Virginia. At this time practically all the coastal marshes except those of a few islands and some marshland bordering Delaware River and Bay were crisscrossed by a great network of drainage canals.

With the acceleration of the mosquito-control drainage programs in 1933, sportsmen and conservationists began to raise objections. During the 1933 convention of the New Jersey Mosquito Extermination Association, R. F. Engle (1933) presented the objections of the South Jersey Sportsmen's Association as outlined at a protest meeting of that group with a select committee of the Extermination Association. The sportsmen objected to the ditching of the marshes on the grounds that it released water-polluting gases that killed young fish and the spawn of the game fishes, that it drained the ponds where the wild ducks fed, and that the drainage ditches acted as death traps for young waterfowl. Farmers in the group reported that sods cut from the ditches floated over the marshes and made the cutting of hay tedious and uneconomical; and oystermen stated that the scattering of sods by high tides and wind smothered oyster beds and prevented the "floating" of the oysters.

Dr. Thurlow C. Nelson (1934), specialist in oyster culture at Rutgers University, addressing the 21st Annual Meeting of the New Jersey Mosquito Extermination Association called attention to the destruction of oyster beds following ditching by the "long string of sods, which, drying out after deposit on the meadow, have been floated by storm tides over the oyster beds in the creeks and open bay, there to soak up water and sink, forming a barricade which rapidly silts up on either side. Our difficulty has been mainly excessive amounts of mud and the presence of much hydrogen sulfide gas."

Objections to the drainage of the coastal marshes came not only from local conservation groups but also from some of such national prominence as the National Association of Audubon Societies. By 1933 they had increased to such an extent that requests were made to the U. S. Bureau of Biological Survey (now the Fish and Wildlife Service) to initiate intensive studies on the effects of mosquito-control operations along the Atlantic coast on the wildlife and its habitat.

Many birds, both migratory and nonmigratory, numerous fur-bearing mammals, myriads of invertebrate animals, and other valuable forms of wildlife are indigenous to tidewater marshes, and are dependent directly or indirectly upon the plant life found there. Treaties with the Governments of Great Britain and Mexico for the protection of migratory birds of the North American Continent impose on the Fish and Wildlife Service the obligation to provide means for the preservation of these birds and their habitats in this country. With a view to securing data bearing on the relation of drainage to wildlife habitat the authors of this paper began observations in December 1933, and in 1935 undertook intensive and detailed studies of the effects on wildlife of mosquito-control operations along the Atlantic coast. These studies continued through 1946. The results obtained are here set forth.

Many employees of the Fish and Wildlife Service helped materially in making quadrat counts of invertebrate organisms and field studies of vegetational changes, and in the preparation of floral maps. Among those participating in the study were C. E. Addy, John H. Buckalew, Dwight Cromer, N. R. Fortier, Robert Gensch, R. E. Griffith, Warren E. Hall, C. E. Harness, John F. Herholdt, Neil Hotchkiss, Horton Jensen, R. E. Johnston, Willie Johnson, L. M. Llewellyn, and L. W. Saylor. Dr. Herbert L. Dozier took most of the photographs.

STUDY AREAS ESTABLISHED

Although general observations were made each year from 1933 through 1936 relative to the effects of ditching on wildlife and its habitat along the Atlantic coast, detailed and systematic studies from 1935 through 1946 were confined to the tidewater marshes of Kent County, Del. More specifically, the study areas were as follows: (1) A marsh tract of some 600 acres at Cains Landing, bordering the north side of the Mispillion River (fig. 1), about 10 miles northeast of Milford, Del.; and (2) two smaller tracts bordering Herring Creek (fig. 26), one located on the Bombay Hook National Wildlife Refuge, the other lying directly across Herring Creek about 100 feet from a similar tract that had been ditched for mosquito control.

These study sites were chosen for several reasons: All were easily accessible; experimental plots with check areas could be properly controlled on the Bombay Hook National Wildlife Refuge; and the Mispillion marshes were especially advantageous for studying vegetative changes induced by ditching because the vegetation had been type-mapped by the Delaware Mosquito Control Commission in 1935 before ditching began in 1935–36. Another advantage of conducting the studies in Delaware lay in the fact that ditching had been stopped in that State at a time when considerable acreages of marshland still remained in a more or less undisturbed condition.

The study areas were located in typical Delaware tidal marshes. The tide range on the Mispillion River at Cains Landing averages 3.5 feet and that on Herring Creek bordering the Bombay Hook National Wildlife Refuge about 4.5 feet. The salinity of the Mispillion marsh ranges from 30 to 90 percent sea water during the growing season and that of the Herring Creek areas from 20 to 50 percent, depending on tidal and precipitation factors.

During the course of these studies the vegetation of the Mispillion marshes was type-mapped in 1936, 1938, 1939, 1941, and again in 1946. In 1936 and 1941 this mapping was aided by levels taken in each plant association, as shown in figure 33. The boundaries of the various plant associations on the Mispillion marsh and on the two Herring Creek tracts were accurately established by engineers using transits.

As later to be discussed in detail, quadrats were established from time to time during the course of the studies in the four major plant associations on the unditched study areas of the Bombay Hook Refuge and on adjacent areas ditched recently for mosquito control, to determine the effects of ditching on the invertebrate populations. The quadrats were 6 feet square and the total invertebrate populations were actually counted to a depth of about 1 inch. The plant and animal foods of the various birds collected on the study areas were determined by stomach analyses.

Salinity readings of the various waters were secured by titration with a 1/10 N. silver nitrate solution, using potassium chromate as an indicator. A salinometer was not used to determine salinities because of colloids in solution and suspended silt and organic matter in the water samples. The pH of soil samples was tested with a LaMotte colorimeter field kit.

EFFECTS OF DRAINAGE

CHANGES IN THE MARSHES

Before ditching was completed in April 1936, more than 90 percent of the vegetation on the Mispillion marsh (fig. 27) was composed of a single species, *Spartina alterniflora* (saltmarsh cordgrass). This plant occupied the marsh between elevations 1.88 and 2.93 feet above mean sea level. Small patches of saltgrass (*Distichlis spicata*) were found between elevations 2.35 and 2.90 feet above mean sea level, depending upon their distance from the Mispillion River and protection from daily inundation. Next in order, saltmeadow cordgrass (*Spartina patens*) occupied higher island spots and a fringe around the marsh at elevations 2.58 to 3.32 feet above mean sea level (fig. 2). Mixed with these three grasses and occupying a border fringe above *Spartina patens*, between elevations 2.38 and 3.29 feet above mean sea level, was the hightide-bush (*Iva frutescens*). Associated with the hightide-bush, but usually occupying slightly higher land, between elevations 2.59 and 3.35 feet above mean sea level, was the groundselbush (*Baccharis halimifolia*). These two woody species were confined primarily to the river bank, along the banks of the small creeks, and around the extreme upper edge of the marshes bordering agricultural land. Other plants occurring very sparingly on the Mispillion marsh before ditching were saltbush (*Atriplex patula*) at an elevation of 2.73 feet, tidemarsh waterhemp (*Acnida cannabina*) at 2.70 feet, saltmarsh bulrush (*Scirpus robustus*) at 2.75 feet, glasswort (*Salicornia europea*) at elevations 2.58 to 3.08 feet (on bare bald spots), Olney's three-square (*Scirpus olneyi*) (figs. 3, 4, 5) at elevations 2.06 to 2.59 feet, and cattail (*Typha angustifolia*) at elevations 1.89 to 2.91 feet above mean sea level. These last six plants occurred in the extreme northern part of the marsh where there was considerable freshwater drainage, as well as seepage from the uplands.

Changes in the vegetation of the Mispillion marsh resulting from mosquito-control drainage operations early in 1936, before the beginning of the growing season, were extensive, as shown in figures 4 through 8. As indicated in figure 4, the greater percentage of the *Spartina alterniflora* growth had disappeared by the end of 1936, although in 1935, before ditching, it had covered more than 90 percent of the total acreage (fig. 27). At lower marsh elevations where the substratum was composed of soft mud, all specimens of this plant had died, and even on some higher and firmer areas the species was seriously affected and few living plants could be found. By the end of the first growing season most of the areas from which *Spartina alterniflora* had been driven were invaded by extensive stands of a composite weed, saltmarsh fleabane (*Pluchea camphorata*), as shown in figure 6. In late fall its growth was so extensive over the marsh that the white seed heads gave the area as a whole the appearance of a vast sheep fleece.

Next in importance as an invader was *Iva frutescens* (fig. 7). This plant had spread along the spoil banks of the ditches which were placed at 150-foot intervals, and in many places it already had begun to establish itself in the spaces between the ditches. *Baccharis halimifolia* was extending its range into the higher areas from seedling growth of the year, and in one spot near the center of the tract a stand of aster (*Aster subulatus*), another composite weed, had appeared (fig. 8).

By 1938 the firm establishment and extension of *Baccharis halimifolia* over the higher parts of the marsh had become evident (fig. 9). There was less fleabane in central areas of the marsh where the drainage ditches had received no maintenance since they were dug in 1936. Over the lower parts of the marsh the clogged ditches had begun to hold enough water to support reinvasion by *Spartina alterniflora*, as shown in figure 29.

During the cold winter of 1938–39 rather extensive stands of *Baccharis halimifolia* died, particularly at the lower elevations. This may have been due in part to gradual subsidence of these areas resulting from the decaying of thick root masses of *Spartina* underlying the invading *Baccharis*, as the 1941 survey revealed an average drop of 2 to 4 inches over a great part of the marsh formerly occupied by *Spartina alterniflora.* On the other hand, *Baccharis* has a shallow root system and in a few places died out, whereas more deeply rooted species, such as red cedar and loblolly pine, survived. It is believed, therefore, that death of this shrub during that cold winter may be attributed primarily to winterkill and to higher water levels resulting from unmaintained ditches (see figs. 10 through 16).

Other species that had appeared on the Mispillion marsh in 1938 were *Hibiscus moscheutos*, *Limonium carolinianum*, *Solidago sempervirens*, and *Erechtites hieracifolia.* These were found for the most part in the northern and higher areas of the marsh, except *Hibiscus*, which invaded the northern ponded section.

In 1939 the further spread and establishment of the shrub *Baccharis halimifolia* into the higher elevation of the marsh at the expense of such herbaceous species as *Aster*, *Solidago*, and *Limonium* became quite evident (fig. 30). There were still appreciable but less-extensive growths of *Pluchea camphorata* in 1939. The dominant growths for the 1939 season, however, were *Baccaris halimifolia*, *Iva frutescens*, and *Spartina alterniflora*, with the latter confining its reoccupation to low areas where it had occurred before 1936.

The continued spread of *Baccharis halimifolia* and *Iva frutescens* in 1941 can be observed by reference to figure 31. That season there were still appreciable areas overgrown with *Aster subulatus* and *Pluchea camphorata*. A considerable stand of *Iva frutescens* had died out just west of the wooded peninsula in the upper center of the marsh, and *Spartina alterniflora* had reappeared. A detailed survey that same year, including the second running of levels, showed that definite changes had occurred in the vertical ranges of certain plant species comprising the Mispillion-marsh vegetation (fig. 15), and that some species not present formerly had become established on the marsh. These changes are presented in table 1.

The whole floral picture of the Mispillion marsh had changed by 1946 (fig. 32) from that of a decade before, when *Spartina alterniflora* in pure stand covered 90 percent of the area. In 1946 the shrub *Baccharis halimifolia* was the dominant plant, with *Spartina alterniflora* limited to low areas near the center of the marsh. Even there, *Iva* and *Baccharis* had spread along the ditches, and in time, with the deposition of silt and the accumulation of organic matter, these species might be expected to take over the intervening spaces between ditches. The spread of *Baccharis* was accelerated in the later years of the study by the erosion of the ditches near their points of discharge into the river (fig. 21). Originally 20 inches wide and about 20 inches deep, some of these ditches eroded until they were several feet in both width and depth near their mouths. Some became clogged at the upper ends, holding enough water to support persistent growths of *Spartina alterniflora*.

Table 1.—Effects of drainage on the vertical ranges of certain plant species as shown in surveys made in 1936 and 1941 on the Mispillion marshes

Species	Feet above mean sea level	
	1936	1941
Spartina alterniflora	1.88–2.93	1.78–2.93
Distichlis spicata	2.35–2.90	2.35–2.76
Spartina patens	2.58–3.32	1.74–3.26
Iva frutescens	2.38–3.29	1.99–3.11
Baccharis halimifolia	2.59–3.35	1.81–3.33
Typha angustifolia	1.89–2.91	1.98–2.28
Scirpus robustus	2.75	2.20–2.56
Scirpus olneyi	2.06–2.59	2.00–2.33
Pluchea camphorata	2.04–2.93	1.88–2.92
Limonium carolinianum	(1)	2.35–2.61
Aster subulatus	(1)	1.92–2.74
Solidago sempervirens	(1)	2.20–2.75
Hibiscus moscheutos	(1)	1.89–2.28
Atriplex patula	2.73	2.56–2.73
Acnida cannabina	2.70	2.70
Echinochloa walteri	(1)	2.01–2.12
Panicum virgatum	(1)	2.50–2.98
Polygonum pennsylvanicum	(1)	2.01–2.42
Erechtites hieracifolia	2.70	2.70
Andropogon virginicus	(1)	2.25–2.75
Juniperus virginiana	(2)	2.09–2.68
Pinus taeda	(2)	2.17–2.49
Liquidambar styraciflua	(2)	2.49
Acer rubrum	(2)	2.63
Crataegus sp	(2)	2.96

[1] No data for 1936.
[2] Not present at time of 1936 survey.

EFFECTS ON INVERTEBRATES

On the Bombay Hook National Wildlife Refuge, high natural dikes (fig. 18) have been formed around the outer edge of the marshes and along the banks of the small estuaries penetrating the marshes, by the action of tides, wind, ice, and the accumulation of drift. These dikes are largely responsible for maintaining stable water conditions by holding on the marshes the water that enters through the small creeks during ordinary tides. Only very high storm tides flow over these natural dikes.

All marsh tracts of the Federal refuge are dominated by *Spartina alterniflora* with smaller percentages of *Distichlis spicata, Spartina patens*, and *Scirpus robustus*, dependent on water, tide, and salinity relations, occurring in saltmarsh vegetative associations. The *Spartina alterniflora* association alone is inundated by the daily tides and some water usually remains on the plants the major part of the day. *Distichlis spicata* is flooded by the higher tides occurring twice a month, and *Spartina patens* by storm or extremely high tides that occur in spring and fall. Tidewater seldom stands over *Spartina patens* during the growing season, but when it does for any appreciable length of time the plant is killed. Where patches of this plant are killed by standing water, accumulated drift, mats of algae, or other factors during the growing season, bare spots appear in the stand. *Salicornia europea* usually becomes a temporary invader in these openings. In some areas, however, the water may stand so long as to cause complete decay of root masses beneath the marsh surface and thus create a marsh pond.

The Bombay Hook Refuge served as a check area in these investigations, inasmuch as it would not be drained and because just across Herring Creek, within a hundred feet of the study areas established on the refuge, were comparable areas that had been ditched for mosquito control. The flora as well as elevations of the smaller marsh tracts in both the Bombay Hook Refuge and the drained study areas across from it bordering on Herring Creek are shown in figure 26. The scale of these maps is sufficiently large to permit the nature of the plant species and the extent of the stands to be grasped readily by the reader without further discussion.

The foregoing description of natural marsh conditions prevailing on the Bombay Hook National Wildlife Refuge is characteristic of most of the typical marshes along the Atlantic coast. Exceptions are those receding because of some unusual condition, as where a storm has formed an inlet through the coastal barrier beaches and the outer marsh has been exposed to undercutting wave action.

Summarized in table 2 are data resulting from the quadrat studies conducted in 1936, 1937, and 1938 on the natural marshes of the Bombay Hook National Wildlife Refuge and the drained Herring Creek areas (fig. 26) to determine quantitatively the invertebrate populations in four major plant associations as related to mosquito-control drainage. This information was collected during the months of December, April, June, July, September, and November, and is considered representative of the invertebrate forms occurring on a tidewater marsh of that particular latitude during the various seasons. The findings are quite applicable to the Mispillion marsh in the immediate vicinity.

In comparisons of ditched and unditched areas in the *Spartina alterniflora* zone—the lowest elevation in the Bombay Hook and Herring Creek marsh study area—it was found in December 1936 that mosquito-control operations had reduced the invertebrate populations 43.9 percent on the ditched areas; in April 1937 the reduction was 39.3 percent; in July, September, and November, 1937, the reductions were 41.9 percent, 34.5 percent, and 82.2 percent, respectively; and in June and September 1938 they were 65.7 and 55.5 percent, despite the lack of ditch maintenance. These figures include all species of invertebrates found, many of which were characteristic of drier situations. Included in the list are mollusks and crustaceans, the most important of all marsh-animal species as a source of food for fish and bird life. From the standpoint of wildlife conservation, therefore, the reduction of

Table 2.—Invertebrate populations in 6-foot-square quadrats in relation to mosquito-control ditching in four vegetation types on the Bombay Hook–Herring Creek marshes, 1936 to 1938

(D=ditched area; U=unditched area)

Plant association and date of quadrat study	Mollusks		Crustaceans		Spiders and mites		Leaf-hoppers		Beetles		Miscellaneous		Totals		Number of species	
	U	D	U	D	U	D	U	D	U	D	U	D	U	D	U	D
***Spartina alterniflora* association:**																
1936: Dec. 20	58	76	8	0	63	9	63	32	19	1	3	2	214	120	17	9
1937: April 2	181	8	8	1	47	106	1,400	270	186	56	19	78	1.841	519	16	21
July 23	1,826	1,069	399	453	564	132	918	510	84	41	79	44	3,870	2,249	38	25
Sept. 12	592	183	274	38	435	334	5,200	271	93	44	10,505	10,337	17,099	11,207	35	21
Nov. 12	353	21	0	41	38	47	5,000	896	89	4	8	27	5,844	1,038	11	15
1938: June 8	485	29	118	73	99	75	50	75	84	26	9	12	845	290	21	12
Sept. 23	317	78	93	28	55	46	108	34	39	59	40	45	652	290	22	18
***Distichlis spicata* association:**																
1937: April 2	403	13	284	37	118	30	21	12	109	11	11	10	946	113	22	13
July 23	441	35	388	111	114	167	42	35	15	7	21	16	1,021	371	32	23
Sept. 12	825	67	301	103	127	57	5	17	10	3	5	11	1,273	258	19	14
1938: June 8	804	35	390	42	30	23	75	25	10	9	4	25	1,313	159	16	21
Sept. 25	484	65	237	12	46	37	8	8	20	27	22	5	817	154	19	19
***Spartina patens* association:**																
1937: April 2	180	1	811	0	202	10	40	21	20	1	12	1	1,265	34	21	6
July 23	485	106	334	57	80	43	35	35	10	3	16	17	960	261	30	17
Sept. 12	392	75	279	38	196	60	0	47	27	2	14	20	908	242	27	19
Nov. 12	97	7	127	5	41	86	6	12	7	1	6	5	284	116	13	11
1938: June 8	356	13	667	2	44	9	50	10	9	4	2	41	1,128	79	14	17
Sept. 25	180	115	91	8	67	72	12	26	93	12	9	33	452	266	15	20
***Scirpus robustus* association:**																
1937: April 2	116	44	2,111	55	56	43	34	116	38	11	8	47	2,363	316	23	22
July 23	4,213	20	267	28	196	50	60	15	19	14	39	18	4,794	145	30	27
Sept. 12	35	6	1,209	20	198	20	224	53	30	6	114	4	1,810	109	26	13
1938: June 8	412	41	554	22	20	49	100	75	18	6	11	8	1,115	201	17	16
Sept. 25	56	39	145	46	41	21	12	10	6	7	22	19	282	142	14	15

these forms is more significant than that of other invertebrates. At the time the first quadrat counts were made in late December 1936, the undrained check area in this low-level plant association was covered with water and ice so that finding all the mollusks and crustaceans present in the frozen mud was physically impossible. On the other hand, the surface of the drained experimental area was dry enough that all forms could easily be found and recorded, and consequently the counts at that time revealed 13.1 percent more mollusks and crustaceans in the *Spartina alterniflora* zone on the drained than on the undrained plots. During those months when the marsh was not frozen, however, the results were quite different. In April 1937, the reduction of mollusks and crustaceans on the drained plot was 95.24 percent; in July 1937, 31.6 percent; in September and November of the same year, 74.4 and 82.4 percent, respectively; and in June and September 1938, 83.3 and 74.2 percent.

In the *Distichlis spicata* zone, next highest in elevation above *Spartina alterniflora*, the association just described, the losses in invertebrate production attributable to mosquito-control drainage were even more significant from the standpoint of wildlife conservation. Quadrats were first established on drained and undrained areas and invertebrate-population counts made in this and other plant associations, subsequently described, in April 1937. At that time there was shown a reduction on drained areas of 81.1 percent in the total number of invertebrates of all species found, and 92.4 percent in mollusks and crustaceans. In July 1937, the reductions were 63.7 percent for all invertebrates and 82.4 percent for mollusks and crustaceans; in September 1937, 71.9 percent for all invertebrates and 94.3 percent for mollusks and crustaceans; in June 1938, 87.9 percent for all invertebrates and 92.7 percent for mollusks and crustaceans; and in September 1938, 81.2 percent for all invertebrates and 89.3 percent for mollusks and crustaceans.

In the *Spartina patens* zone, occupying the highest elevations on the marsh in which quadrat studies were made, the quantitative losses in invertebrate production continued to be highly significant. In April 1937, the reduction of all invertebrate forms on drained areas was 97.3 percent, and of mollusks and crustaceans 99.9 percent; in July 1937 these figures were 72.8 and 80.1 percent, respectively; in September 1937 they were 73.3 and 80.8 percent; in November 1937, 59.2 and 94.6 percent; in June 1938, 93 and 98.1 percent; and in September 1938, 41.2 and 54.6 percent. The last figures, undoubtedly, were influenced greatly by a long period of exceptionally heavy rainfall.

But for the smaller acreages involved, the effects of drainage would probably be more significant in the *Scirpus robustus* association than in any of the previously discussed plant zones, as the open nature of its stands make the invertebrate forms more readily available as food for the birds. Frequently interspersed among other plant stands where the soil is rather porous, patches of *robustus* usually occur rather extensively along or in the vicinity of small estuaries and seepage areas where crustacean burrows are found. The plant is particularly favored by a wet spring and an early summer. Probably as a result of greater porosity of the soil in which it grows, the effects of mosquito-control drainage on this plant association, and particularly on its invertebrate populations, are quite pronounced. The comparative ease of collecting individual specimens of invertebrates in this association contributed to the accuracy of the counting. The losses on drained areas, as contrasted with undrained, in April 1937, were for all invertebrates 86.6 percent, and for mollusks and crustaceans 95.5 percent; in July 1937 they were 97 and 93.2 percent respectively; in September 1937, 94 and 98 percent; in June 1938, 82 and 94.4 percent; and in September 1938, 49.6 and 57.6 percent. With the exception of the small difference in population numbers for September 1938, which undoubtedly was due to high tides and an extended period of above-normal precipitation, these figures show almost a total loss in production of invertebrate forms on the marsh areas occupied by *Scirpus robustus* that had been drained for mosquito control.

An accurate interpretation of the comparative data on the invertebrate-animal populations of ditched and unditched areas presented in table 2 requires recognition of the fact that the rainfall on the study areas during the summers of 1937 and 1938 was about 50 percent above normal. This, undoubtedly, made it possible for a much higher proportion of individuals to persist on the ditched areas than otherwise could have done so. Most of the gastropods, amphipods, and isopods, and many of the insects occurring in tidewater marshes are absolutely dependent upon a damp or wet habitat, and must migrate or perish if the water table drops. Therefore, heavy precipitation may have permitted many to remain temporarily to be counted in these studies. As will be shown later, however, the reduction in populations and species of invertebrates for those years was considerable in each of the main plant associations, as a result of mosquito-control ditching.

The importance of invertebrate life as food of waterfowl on tidewater marshes is indicated in the studies of Cottam (1939) on the food habits of North American diving ducks. These studies revealed that invertebrate forms make up as much as 84 percent of the total food of the juvenile American goldeneye, more than 40 percent of that of adult scaup, over 10 percent of the food of the redhead, 19 percent of the ring-necked duck's diet, and 19 percent of the food of the canvasback.

Stomach analyses of fourteen species of birds common to the tidewater marshes, including rails, sandpipers, yellowlegs, and willets, collected on or in the immediate vicinity of the experimental-study areas, showed that about 84 percent of their food was animal and 16 percent vegetable. Based upon volumetric percentages, the data are tabulated as follows:

	Percentage
Animal foods:	
Gastropods	4.3
Crustacea	18.0
Beetles and weevils	24.0
True bugs	4.2
Spiders	6.5
Flies	11.3
Bees and wasps	5.0
Butterflies and moths	5.0
Ostracods	3.0
Other insects	3.0
Total	84.3
Plant foods:	
Cordgrasses (*Spartina* spp.)	1.3
Saltmarsh hemp (*Acnida cannabina*)	3.4
Wigeongrass (*Ruppia maritima*)	1.2
Smartweeds (*Polygonum* spp.)	1.0
Miscellaneous grasses	7.4
Other plants	1.4
Total	15.7

DESTRUCTION OF WILDLIFE HABITAT

In the drainage of the Delaware marshes, the mosquito-control ditches were cut through the marshes according to blueprint plans drawn from aerial photographs, with the standard 20-inch-wide ditches laid out at 150-foot intervals, regardless of marsh elevation or vegetative cover. According to Corkran (1935), *Spartina alterniflora* dominated 22,133 acres, or 58.8 percent, of the Delaware tidewater marshes before ditching, and was an abundant plant on 27,181 acres, or 68.5 percent of the State's total marsh acreage.

When a salt marsh is drained to the extent that vegetative succession is initiated, invasion by new plants *usually* occurs first in the *Spartina alterniflora* zone, then in the zone of *Distichlis spicata,* and last in that of *Spartina patens.* This is true even though all three grasses are killed at the same time through the excessive removal of surface and underground water upon which they depend, owing primarily to a distinct difference in their morphological and growth characteristics.

The coarsest of the three grasses is *Spartina alterniflora*, the culms of which remain erect, even though they are the old dead growth of a previous season. The culms of *Distichlis spicata* are slenderer and leafier than those of *Spartina alterniflora*, are denser in the stand, and have a tendency to mat—a characteristic that gives rise in some localities to its common name of "rosemary bent." Consequently, the dead mats, although not nearly so dense as those of *Spartina patens*, afford considerable check to invaders producing minute seeds such as *Pluchea*, *Aster*, *Iva*, and *Baccharis*, by shading out the seedlings that may develop until decay of the *Distichlis spicata* mats is practically complete. The slenderest and finest culms of the three species, however, are found in *Spartina patens*. This plant produces the densest stands and its most distinguishing characteristic is the large formation of mats that gives the stand the appearance of a wind-blown grainfield. The density and thickness of these mats of dead plants are such as to prevent the invasion of herbaceous and small-seeded plants into the *Spartina patens* zone during the many years required for the decay or destruction of these mats by fire, flood, or other means. This fact is well illustrated in figure 19, in which the plants in the foreground had been dead for 10 years at the time the picture was taken but the shading effect of the old stand continued to prevent further plant succession. When drainage killed this stand in 1936 a patch was tramped through it by the CCC boys who were digging the drainage ditches. With the natural canopy thus removed, the process of plant succession began immediately in the narrow lane. That same autumn the path became marked by a long, narrow line of *Pluchea camphorata* growth, to be followed in 1937 by *Baccharis halimifolia*, which formed the tree-like growth in the background of the picture. The shrub growth served as a protective windbreak, otherwise the dead grass might have blown away long ago, to be replaced by the jungle-like growth characteristic of *Baccharis*.

With these changes in the character of the marsh vegetation, plants worthless to wildlife for either food or cover replace valuable species. *Spartina alterniflora* is an important food plant of snow geese and is used to considerable extent for food or cover by other waterfowl. All the ponds shown on the maps of the Mispillion marsh formerly contained excellent growths of wigeongrass (*Ruppia maritima*), the principal duck food occurring naturally in salt-marsh ponds. This aquatic disappears as soon as the ponds are tapped by ditches, as it cannot tolerate exposure to sun and air.

Besides the changes brought about in the vegetative cover, mosquito-control drainage has produced an extreme change in wildlife habitat along much of the Atlantic coast, with the drainage of many ponds containing wigeongrass (*Ruppia maritima*) throughout the tidewater marshes. This has deprived waterfowl of an essential element in their habitat and a major source of food. The forms of wildlife so affected are described by McAtee (1941). The cutting of ditches into such ponds opens them to the ebb and flow of the tides, and at ebb tide the succulent, submerged wigeongrass is killed by exposure to sun and air. Several thousand acres of these ponds have been destroyed in New Jersey alone. The significance of this is apparent when it is realized that even small ponds in a salt marsh add greatly to the attractiveness and value to waterfowl of the entire marsh for resting, nesting, and feeding.

Important studies of the effect of mosquito-control ditching on wildlife habitat in Delaware were carried on by Stearns (State entomologist of Delaware), MacCreary, and Daigh in 1939 and 1940. Findings of these investigations demonstrated that such ditching was very destructive to muskrat habitat. Their data show that there is a rapid lowering of the water table when a muskrat marsh is effectively ditched for mosquito control; and within a short time this is sufficient to effect a radical change in the existing vegetation.

Some idea of the extent of damage to muskrat and other wildlife habitat in Delaware may be gained from the fact that between October 1933 and November 1938, approximately 2,199 miles, or 11,609,664 linear feet, of ditches were dug on an area estimated at 44,468 acres, or 44.7 percent of the marsh area of that State. To the original cost of these operations, estimated at more than $5,000,000, must be added the loss in natural resources. Most of the ditched area was rendered practically worthless as a wildlife habitat, particularly for muskrats and waterfowl, by altering the vegetative cover from food plants to worthless weeds, such as the shrubby groundselbush. The value of the muskrat can be appreciated when it is recalled that for a 20-year period, 1919 to 1939, the income to Delaware trappers from the sale of muskrat pelts averaged $200,000 a year. To this income should be added the return from the sale of carcasses, averaging eight carcasses for a dollar, which amounts to a considerable sum.

There have been sporadic attempts to preserve some wildlife habitat in connection with mosquito-control operations along the Atlantic coast by impounding water on a few marsh areas. This was done in Maryland and Delaware during the depression era by the Civilian Conservation Corps. No provisions were ever made for the maintenance of these dikes and water-control structures, however, and such areas now have little value as wildlife habitat because of the deterioration of dams and tide gates.

Attempts also were made, at least on an experimental scale, to control mosquito breeding by sump drainage, where ditches radiate from a pond into the surrounding marsh to permit the flow of surface or sheet water into the central area without lowering ground water levels by emptying into a tidal estuary.

Experimental work on the Bombay Hook National Wildlife Refuge in Delaware indicates that breeding of mosquitoes on a tidal marsh may be controlled effectively by the impoundment of water to provide stable levels and by proper sump drainage that removes sheet water without lowering ground water levels. Control of mosquito breeding by these methods can be practiced without detrimental effects on wildlife habitat, *provided* the systems are adequately constructed, operated, and maintained. This system is also designed to make shallow-water areas accessible to predaceous minnows that devour mosquito larvae. In this case, just as in that of impoundments, the effectiveness of sump drainage in controlling mosquito production and in preserving wildlife habitat depends upon maintenance. Figures 20 to 25 show the results of a change from sump drainage to gravity drainage because the system was not maintained. Muskrat burrowing around a ditch plug permitted drainage of the area into a tidal river (fig. 20). Apart from lack of maintenance, a serious mistake was made in cutting a ditch so near a major drainage outlet. The change to gravity drainage resulted in destruction of the marsh, which had included three good-sized ponds and several

889234 O—50——2

smaller ones, all containing luxuriant growths of wigeongrass and accommodating many waterfowl during the migration season. All of the ponds were ruined by the drainage, and the marsh proper was taken over by almost impenetrable thickets of *Baccharis* and *Iva*.

IMPORTANCE OF RESEARCH

Too frequently, research is not initiated sufficiently in advance of land management to serve as the latter's guide. This is well illustrated in the useless drainage of permanent marsh ponds, inasmuch as subsequent studies failed to show that they were significant in mosquito production. Without question, drainage to prevent the production of mosquitoes and other insect pests has its place and should be applied as required for the protection of human health and comfort, but it is indeed unfortunate that many extensive drainage programs have been carried on without the guidance of research. The intelligent use of drainage requires understanding of the consequent over-all benefits and damages, both immediate and future, to all interests.

Connell's (1940) experimental results with the breeding of *Aedes* mosquitoes on tidewater marshes of Delaware would seem to indicate that ditching of this plant association was unnecessary. Connell found no breeding of *Aedes* on a marsh flooded by tides 25 days in a lunar month. The *Spartina alterniflora* zone is inundated by the tide twice daily. Neither is there valid evidence that mosquitoes breed in salt-marsh ponds, including those in the Mispillion-marsh study area, because of the presence of larvivorous killifish and top minnows. Cornell's important results point to the fact that thousands of acres of tidewater marshes along the Atlantic coast—the importance of which for wildlife has been admirably described by Vogt (1937)—may have been needlessly damaged as wildlife habitat by mosquito-control drainage. Tidal marshlands not only are a vital habitat for various species of migratory waterfowl, shore birds, and muskrats, but also are exceedingly important in producing food for fish, crabs, oysters, and other economically important marine or littoral life that normally abound in coastal waters. Drainage enterprises have resulted in immeasurable losses of wildlife habitat and have disrupted important food chains linking the lower invertebrate forms with commercially important shellfish, fish, waterfowl, and other marine and littoral fauna. Research has much to teach us yet of the intricate chain of ecological relationships that exist between the marshes and the marine crop which is of such great importance in our national economy.

A properly guided control program takes into consideration all known methods and adopts procedures that will be the most specific, afford the greatest protection, and at the same time keep unfavorable results to a minimum.

A fair appraisal of the mosquito-control problem requires consideration of three factors: The enormous costs involved in the drainage of tidewater marshes and the maintenance of ditches along the Atlantic coast; the vast acreage of wildlife habitat destroyed by such drainage; and the funds required to restore even a 100-acre unit of drained marsh as a suitable natural resource. These operations for the purpose of mosquito control in many instances have caused great destruction of an important natural resource in the form of basic wildlife habitat, yet the ditching systems over many areas, particularly in Delaware, have not been effectively maintained to produce any appreciable degree of mosquito control. Further drainage of tidewater marshes for mosquito control should be held in abeyance until adequate research indicates the necessity of such operations in protecting human health and comfort, and even then the methods employed should safeguard wildlife and its many related interests that contribute so much to public welfare.

SUMMARY

As the result of studies conducted over a 12-year period, 1935–1947, of the biological effects of ditching tidewater marshes in Delaware for mosquito control, it was found that marked ecological changes occurred in the floral cover and in the invertebrate fauna of the areas after ditching. Shrubby growths of groundselbush and marsh elder largely replaced the marshes' natural grass associations, and the invertebrate populations so important as food items for waterfowl, shore birds, and fish were appreciably reduced as the result of drainage.

In the *Spartina alterniflora* zone, the lowest with respect to elevation above mean sea level, the reductions in all forms of invertebrates on drained areas ranged from 39.3 to 82.2 percent, depending on the season. Their reductions in the succeeding plant zones with relation to elevation ranged as follows: *Distichlis spicata* zone, 63.7 to 87.9 percent; *Spartina patens* zone, 41.2 to 97.3 percent; and *Scirpus robustus* zone, 49.6 to 97 percent.

More significant from the standpoint of wildlife conservation, however, were the losses in the populations of mollusks and crustaceans, which are important items in the diet of the clapper rail, the greater yellowlegs, and many marine animals. The losses of mollusks and crustaceans as a result of mosquito-control drainage varied in *Spartina alterniflora* associations from 31.6 to 95.2 percent, depending on seasonal conditions, in *Distichlis spicata* associations from 82.4 to 94.3 percent, in *Spartina patens* associations from 54.6 to 99.9 percent, and in *Sicrpus robustus* associations from 57.6 to 98 percent.

These reductions in invertebrate populations are serious when it is considered that by the end of 1938 some 90 percent, or 562,500 acres, of the total original acreage of tidewater marshland along the Atlantic coast from Maine to Virginia had been ditched.

BIBLIOGRAPHY

COTTAM, CLARENCE
1939. Food habits of North American diving ducks. U. S. Dept. Agr. Tech. Bull. 643. 139 pp., illus.

CORKRAN, W. S.
1935. The relation of mosquito control to the muskrat industry on the salt marshes. Proc. 22d Ann. Meet., N. J. Mosquito Extermin. Assoc., pp. 19–23.

CONNELL, W. A.
1940. Tidal inundation as a factor limiting distribution of *Aedes* spp. on a Delaware salt marsh. Proc. 27th Ann. Meet., N. J. Mosquito Extermin. Assoc., pp. 2–15.

DAIGH, F. C., DONALD MACCREARY, and L. A. STEARNS
1938. Factors affecting the vegetation cover of Delaware marshes. Proc. 25th Ann. Meet., N. J. Mosquito Extermin. Assoc., pp. 209–215.

DEVIDO, LEWIS A.
1936. Salt-marsh vegetation and its relation to mosquito control. Proc. 23d Ann. Meet., N. J. Mosquito Extermin. Assoc., pp. 196–203.

ENGLE, R. F.
1933. Report of the committee on conferences with the South Jersey sportsman associations. Proc. 20th Ann. Meet., N. J. Mosquito Extermin. Assoc., pp. 112–114.

HEADLEE, THOMAS J.
1936. Mosquito control facts taught by the passing years. Proc. 23d Ann. Meet., N. J. Mosquito Extermin. Assoc., pp. 204–209.

——1937. Mosquito problems. Proc. 24th Ann. Meet., N. J. Mosquito Extermin. Assoc., pp. 228–236.

——1938. Review of economic results of mosquito control; work accomplished; benefits derived from the Mosquito Association. Proc. 25th Ann. Meet., N. J. Mosquito Extermin. Assoc., pp. 88–100.

——1939. Relation of mosquito control to wildlife. Proc. 26th Ann. Meet., N. J. Mosquito Extermin. Assoc., p. 8.

JOHNSON, DUNCAN S., and HARLAN H. YORK
1915. The relation of plants to tide levels. A study of factors affecting the distribution of marine plants. Carnegie Inst., Washington. 150 pp., illus.

MARTIN, A. C., and F. M. UHLER
1939. Food of game ducks in the United States and Canada. U. S. Dept. Agr. Tech. Bull. 634. 156 pp., illus.

MCATEE, W. L.
1941. Wildlife of the Atlantic coast salt marshes. U. S. Dept. Int. Fish and Wildlife Service Wildlife Circ. 11. 32 pp., illus.

NELSON, THURLOW C.
1934. The habits of shellfish of New Jersey waters adjacent to the salt marshes. Proc. 21st Ann. Meet., N. J. Mosquito Extermin. Assoc., pp. 149–150.

OSTERHOUT, W. J. V.
1906. On the importance of physiologically balanced solutions for plants. I. Marine plants. Bot. Gaz. 42: 127–134.

REILEY, FRED A.
1934. Mosquito work of the Civil Works Administration in Atlantic County. Proc. 21st Ann. Meet., N. J. Mosquito Extermin. Assoc., pp. 89–90.

SPERRY, CHARLES C.
1940. Food habits of a group of shorebirds: woodcock, snipe, knot, and dowitcher. U. S. Dept. Int. Wildlife Res. Bull. 1. 37 pp., illus.

STEARNS, L. A., DONALD MACCREARY, and F. C. DAIGH
1939. Water and plant requirements of the muskrat on a Delaware tidewater marsh. Proc. 26th Ann. Meet., N. J. Mosquito Extermin. Assoc., pp. 212–221.

——1940. Effect of ditching for mosquito control on the muskrat population of a Delaware tidewater marsh. Del. Agr. Exp. Sta. Bull. 225 (Tech. Bull. 26). 55 pp., 24 figs.

TAYLOR, NORMAN
1938. A preliminary report on the salt marsh vegetation of Long Island, New York. N. Y. State Mus. Bull. 316, pp. 7–84.

——1939. Salt tolerance of Long Island salt marsh plants. N. Y. State Mus. Circ. 23. 42 pp., illus.

URNER, CHARLES A.
1935. Relation of mosquito control in New Jersey to bird life of the salt marshes. Proc. 22d Ann. Meet., N. J. Mosquito Extermin. Assoc., pp. 130–136.

VOGT, WILLIAM
1937. Thirst on the land. A plea for water conservation for the benefit of man and wildlife. Nat. Assoc. Audubon Socs. Circ. 32. 32 pp.

Figure 2.—View of undrained tidal marsh, Kent County, Del., showing zonation of vegetation. *Spartina alterniflora*, in the foreground, occupies the lowest elevation on the marsh relative to tide, by which it is inundated twice daily. Next in vertical distribution, *Distichlis spicata*, where the man is standing, is found at an elevation normally covered only twice a month by tidewater. The browner plants in the background are *Spartina patens*, the zone of which is high enough above sea level to prevent inundation except for short periods. August 1946.

Figure 3.—View of the upland edge of an undrained salt marsh showing the seepage zone between the salt marsh and upland supporting a luxuriant stand of *Scirpus olneyi*. Kent County, Del., August 1946.

Figures 4 and 5.—Belt of *Scirpus olneyi* behind normal plant zonation on a salt or brackish marsh. The growth of this plant is supported by fresh-water seepage from higher ground. Unditched marsh along St. Jones River, Kent County, Del. October 1946.

Figure 6.—Invasion of *Pluchea camphorata* in *Spartina alterniflora* association on Mispillion River marsh, Kent County, Del., in 1937 following drainage of the area for mosquito control early in 1936. Drainage resulted in the death of the *Spartina alterniflora* and the taking over of the area temporarily by *Pluchea*.

Figure 7.—*Iva frutescens* replacing a solid stand of *Spartina alterniflora* on Mispillion Marsh following drainage for mosquito control early in 1936. The tall shrubs in the background are *Baccharis halimifolia*. Dead *Spartina patens* appear in the foreground. Kent County, Del., August 1946.

Figure 8.—Luxuriant stand of *Aster subulatus* that succeeded growths of *Pluchea camphorata* that temporarily had taken over an area of dead *Spartina alterniflora* following mosquito-control drainage in 1935–36. The *Aster* in turn will be crowded out by the thrifty *Iva* and *Baccharis* seen in the background. Mispillion marsh, Kent County, Del., August 1946.

Figure 9.—*Baccharis halimifolia* in bloom (right) and *Iva frutescens* fruiting (left). Mispillion marsh, Kent County, Del., October 1946.

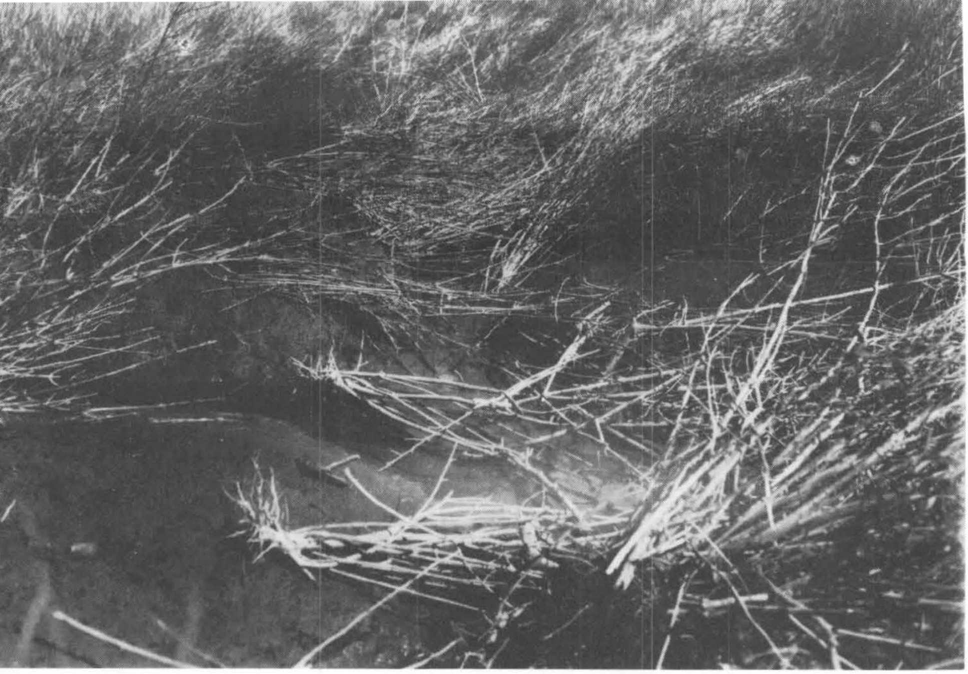


Figure 10.—The clogging of drainage ditches by debris from dead *Baccharis* and *Iva* accelerates the restoration of normal water relations on parts of Mispillion marshes. Bare spots are being reoccupied by *Spartina alterniflora*.

Figure 11.—View of a section of Mispillion marshes showing *Spartina alterniflora* reoccupation after the once-dense growth of *Iva frutescens* had been killed by restored water relations through clogging of drainage ditches. *Distichlis spicata* may be seen above in the background.

Figure 12.—View of Pickering Beach Marsh, Kent County, Del. after mosquito-control drainage in 1936, this marsh was completely taken over by a jungle-like growth of *Baccharis halimifolia*. Through lack of ditch maintenance, nearly normal water levels have been restored, resulting in the death of *Baccharis* and the return of the former plant occupants. In the immediate foreground is a remnant of the shrub blooming along the side of a causeway, beyond which is a luxuriant stand of *Scirpus robustus*, and farther on saltmarsh grasses. August 1946.

Figure 13.—Reoccupation of its former zone by *Spartina alterniflora* after removal of its competitor, *Iva frutescens*, by restored water levels, resulting from the non-maintenance of mosquito-control drainage ditches. Broadkill Beach, Sussex County, Del., October 1946.

Figure 14.—View of Port Mahon marshes, Kent County, Del., showing dead *Iva frutescens*, restoration of water level, and reoccupation of the area by the three grasses normally found in such situations. August 1946.

Figure 15.—Vegetational zones on one part of Mispillion marshes on which the water conditions were restored more or less to the original through the filling of ditches. *Spartina alterniflora* in the foreground, interspersed with dead *Iva frutescens* which had taken over the *Spartina alterniflora* zone while the drainage ditches functioned. Next beyond is *Distichlis spicata*, low, with light appearance, occupying the elevation between *Spartina alterniflora* and *Spartina patens*. The latter appears next in order, behind which is a belt of *Iva frutescens* (rather indistinguishable) and *Baccharis halimifolia*. This belt is in front of *Juniperus virginiana*. This photograph illustrates the plant successions and associations on much of the marshland along the Atlantic coast where seepage and other factors do not operate to support growths of bulrushes and other plants.

Figure 16.—A Sussex County, Del., marsh 10 years after being drained for mosquito control. A dense stand of *Panicum virgatum* has become established where formerly existed belts of *Spartina patens* and *Distichlis spicata*. October 1946.

Figure 17.—View of what was in 1935 a 20- x 20-inch ditch cut through the natural barrier dike to drain the Mispillion marsh into the river. The degree of erosion is indicated by comparison with the size of the man. It is not economically feasible to attempt restoration of a marsh systematically drained with ditches such as this spaced 150 feet apart. Small sections of the upper marsh may be restored by stopping up the ditches, but far the greater acreage will never return to the marsh condition so long as the ditches function as do this one and hundreds more draining the area. Mispillion marsh, Kent County, Del., August 1946.

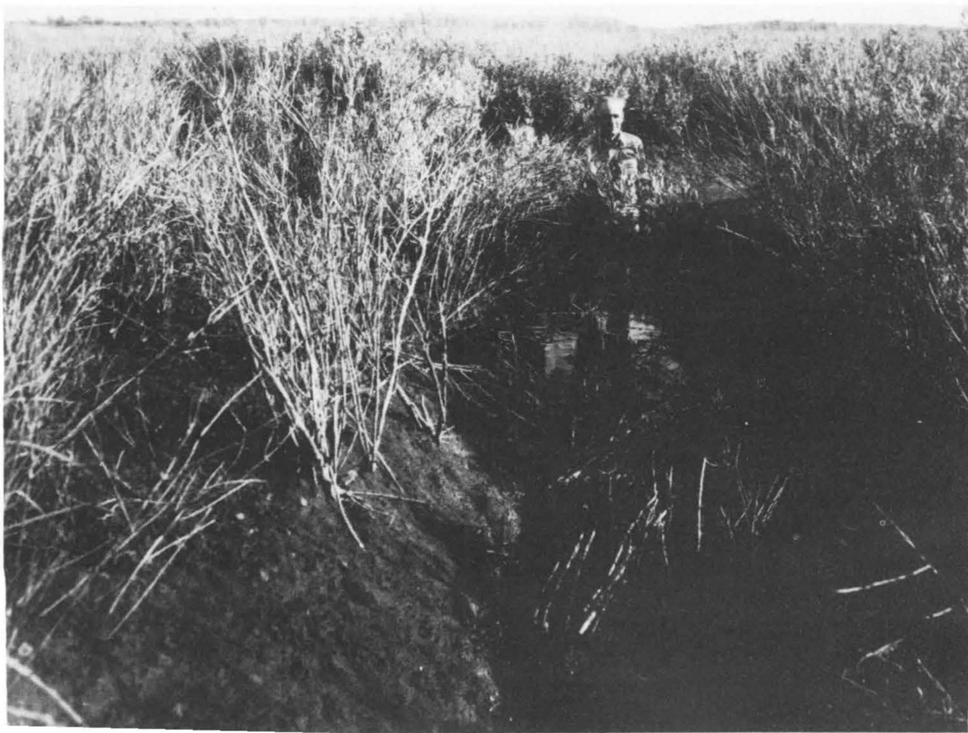
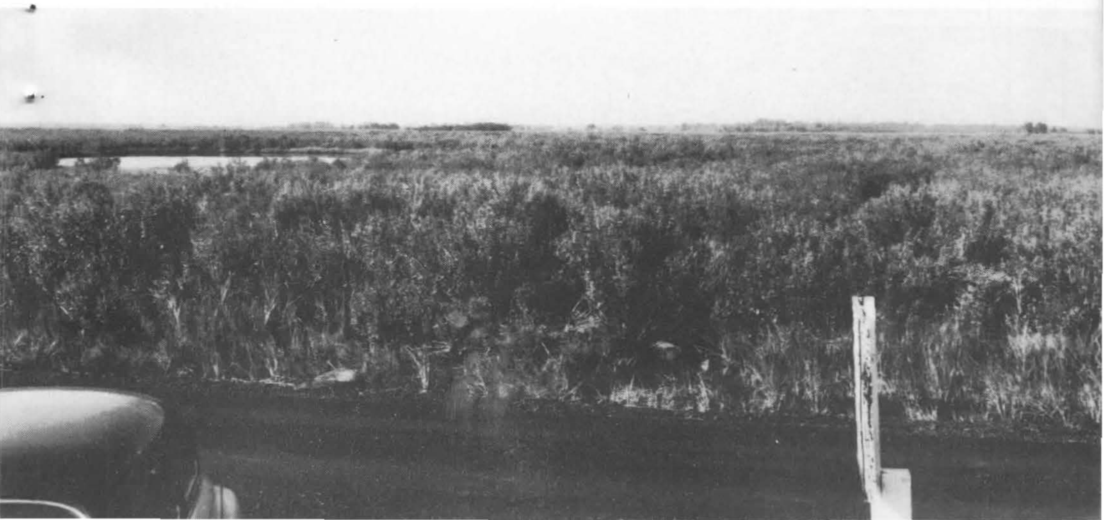


Figure 18.—Natural dike along tidal stream operating to maintain stable water conditions and support the growth of marsh grasses behind it. On the "dike" may be seen among others *Baccharis, Iva, Solidago,* and *Spartina cynosuroides*, the seed heads of which extend skyward in the center background.

Figure 19.—A jungle-like growth of *Baccharis halimifolia* sprang up immediately after a trail was tramped through a dead growth of *Spartina patens* (in foreground) in 1936 on Mispillion marsh. Kent County, Del., August 1946.

Figure 20.—View of South Bowers marsh, Kent County, Del., showing the results of an attempt to control mosquito breeding by "sump" drainage. From the "sump" a ditch was dug to an outlet to Murderkill River, but was plugged with the board structure seen in the foreground. Muskrats cut around this structure and "sump" drainage became "gravity" drainage. This resulted in the destruction of the marsh, including three ponds of appreciable size and some smaller ones containing luxuriant growths of wigeongrass, and accommodating quite a few waterfowl during the migratory season. The marsh proper has been taken over by impenetrable thickets of *Baccharis* and *Iva*. August 1946.

Figure 21.—The transformation of "sump" to "gravity" drainage for mosquito control resulted in the loss of the area to waterfowl and the shrubby succession of *Baccharis* and *Iva*, replacing marsh grasses. August 1946.



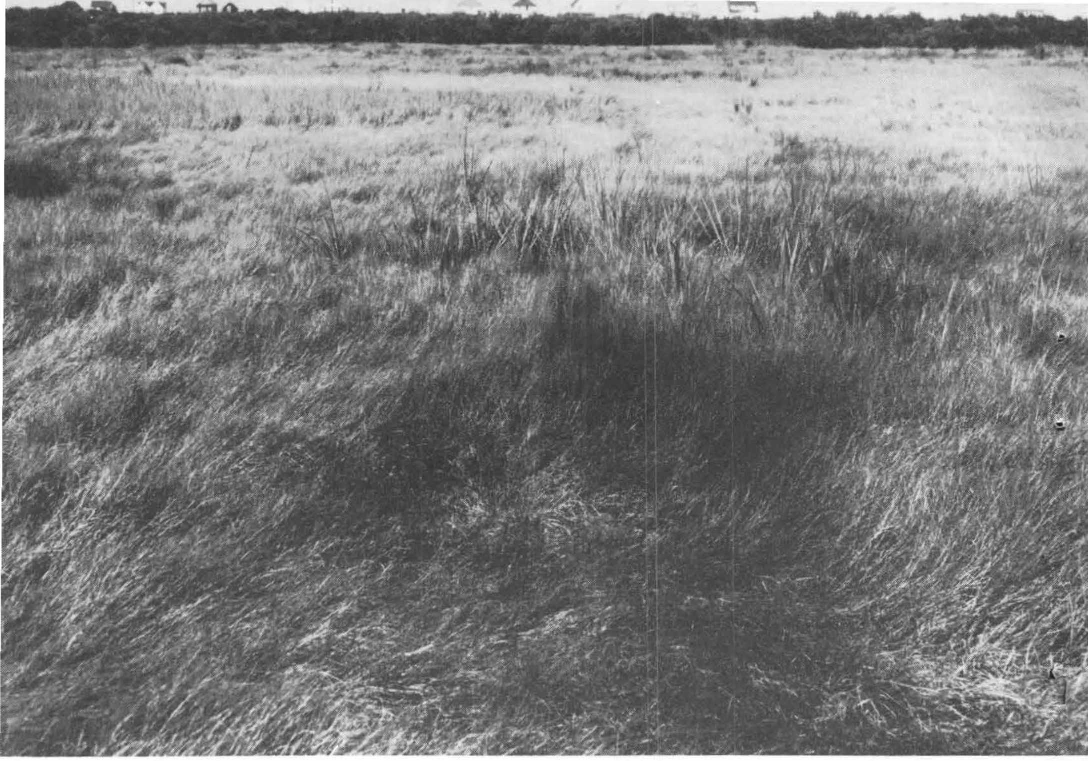


Figure 22.—View of natural marsh looking across *Spartina patens* and *Distichlis spicata* zones to the drained part of the marsh where these plants have been replaced by the jungle of *Baccharis* and *Iva* seen in the background. South Bowers, Kent County, Del., August 1946.

Figure 23.—*Pluchea camphorata* succeeding dead *Spartina patens* on a marsh drained for mosquito control through a recent failure of "sump" drainage that resulted in the drying out of the marsh. South Bowers, Del., August 1946.

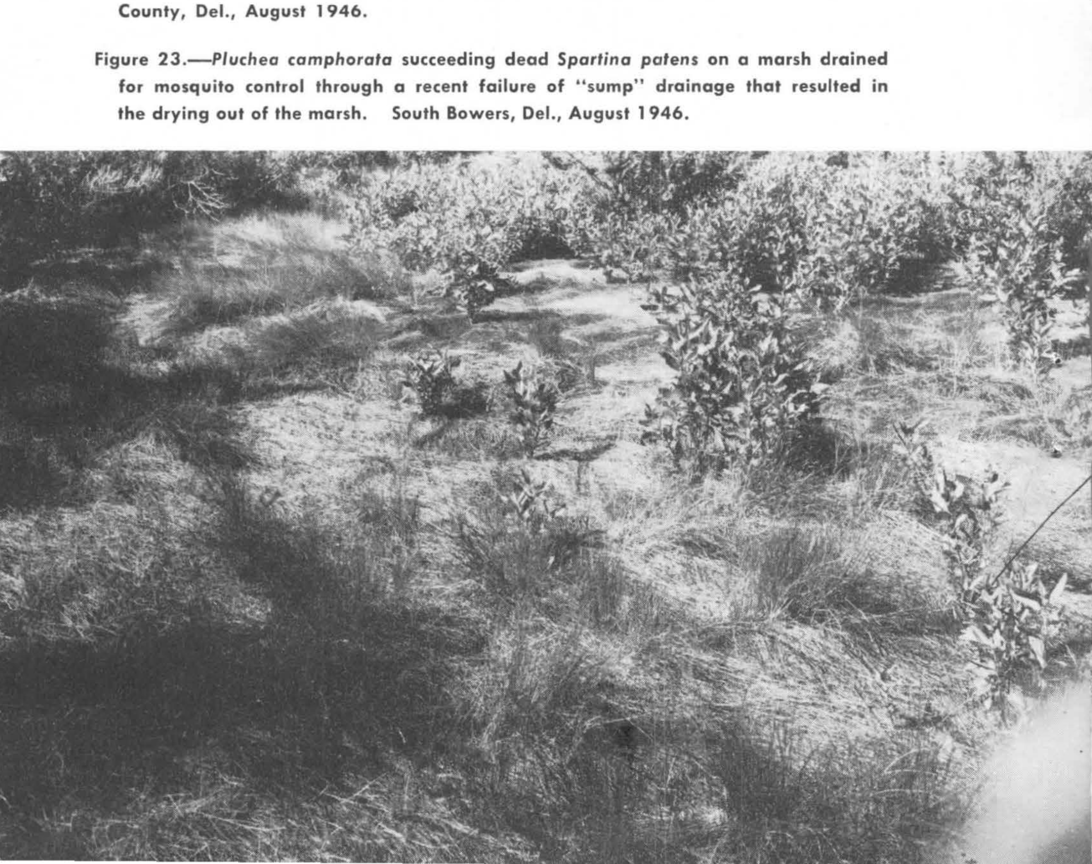


Figure 24.—View of wigeongrass pool destroyed by mosquito-control drainage. South Bowers, Kent County, Del., August 1946.

Figure 25.—View of what formerly was a good duckpond filled with wigeongrass on Mispillion marsh. This pond appears in the center of the peninsula, near the bottom of the floral maps. Mosquito-control drainage in 1935 reduced it to a mud flat. What appears to be water is only soft mud. Kent County, Del., August 1946.

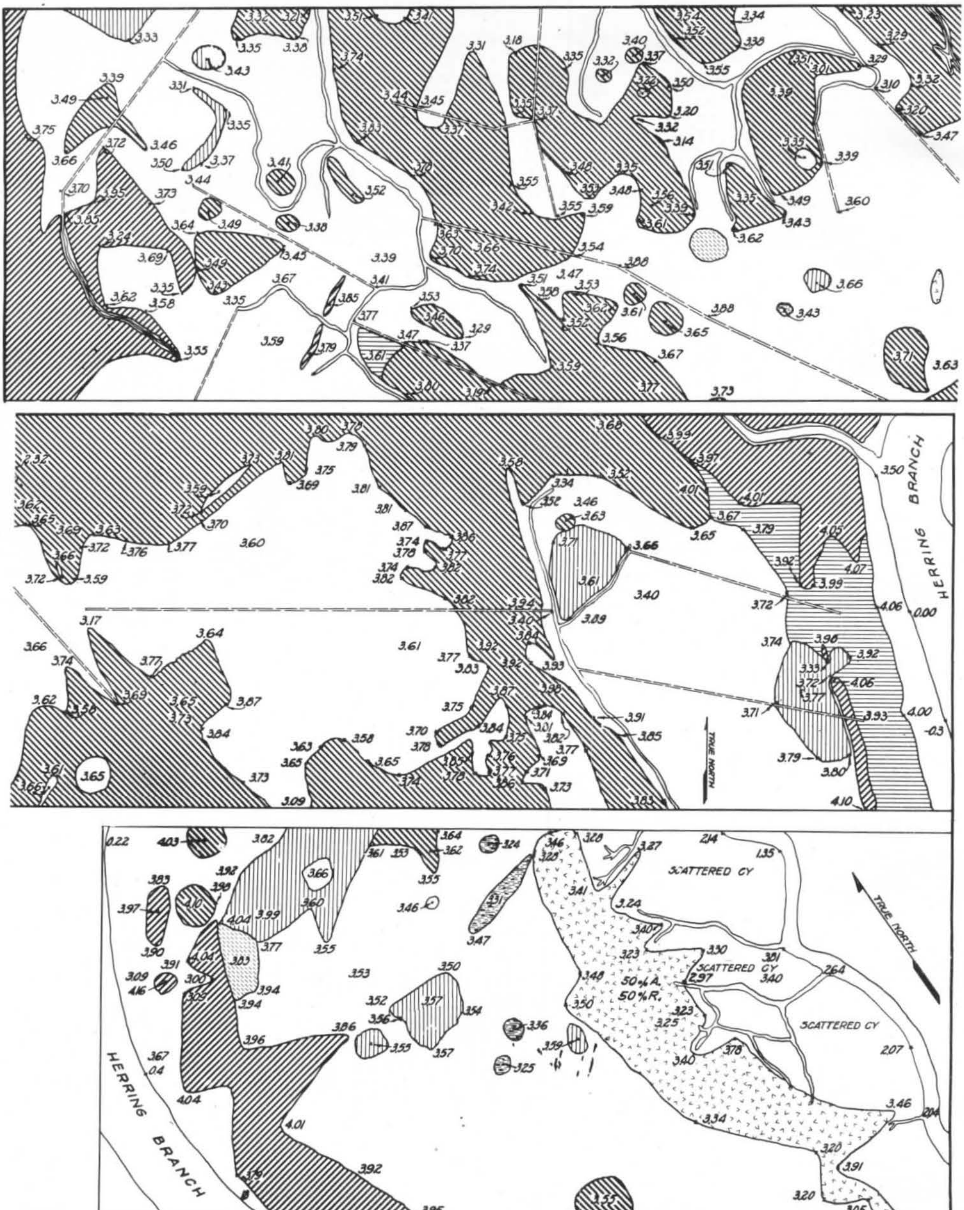


Figure 26.—Study areas on Herring Creek, Kent County, Del. Upper two sections (the second is a continuation of the first) show the ditched marsh; lower section shows the unditched marsh across the creek. **(See p. 3.)**

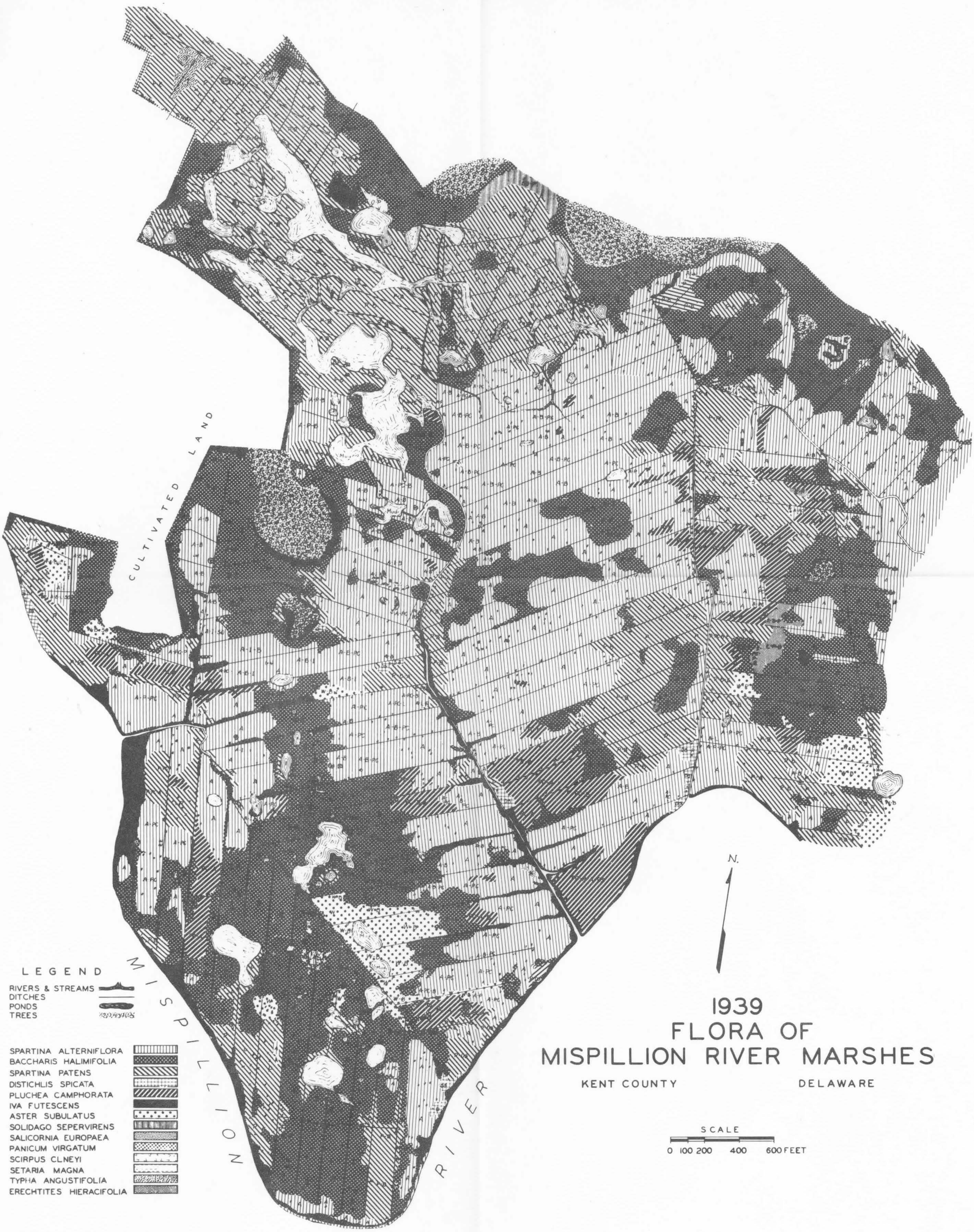


Figure 30.—Cover type map of the study area in the tidewater marshes on the Mispillion River (Kent County, Del.) in 1939, at the end of 4 growing seasons after ditching and drainage for mosquito control. The extension of the shrub invasion since the previous season may be noted.

889234 O - 50 (In back pocket) No. 4

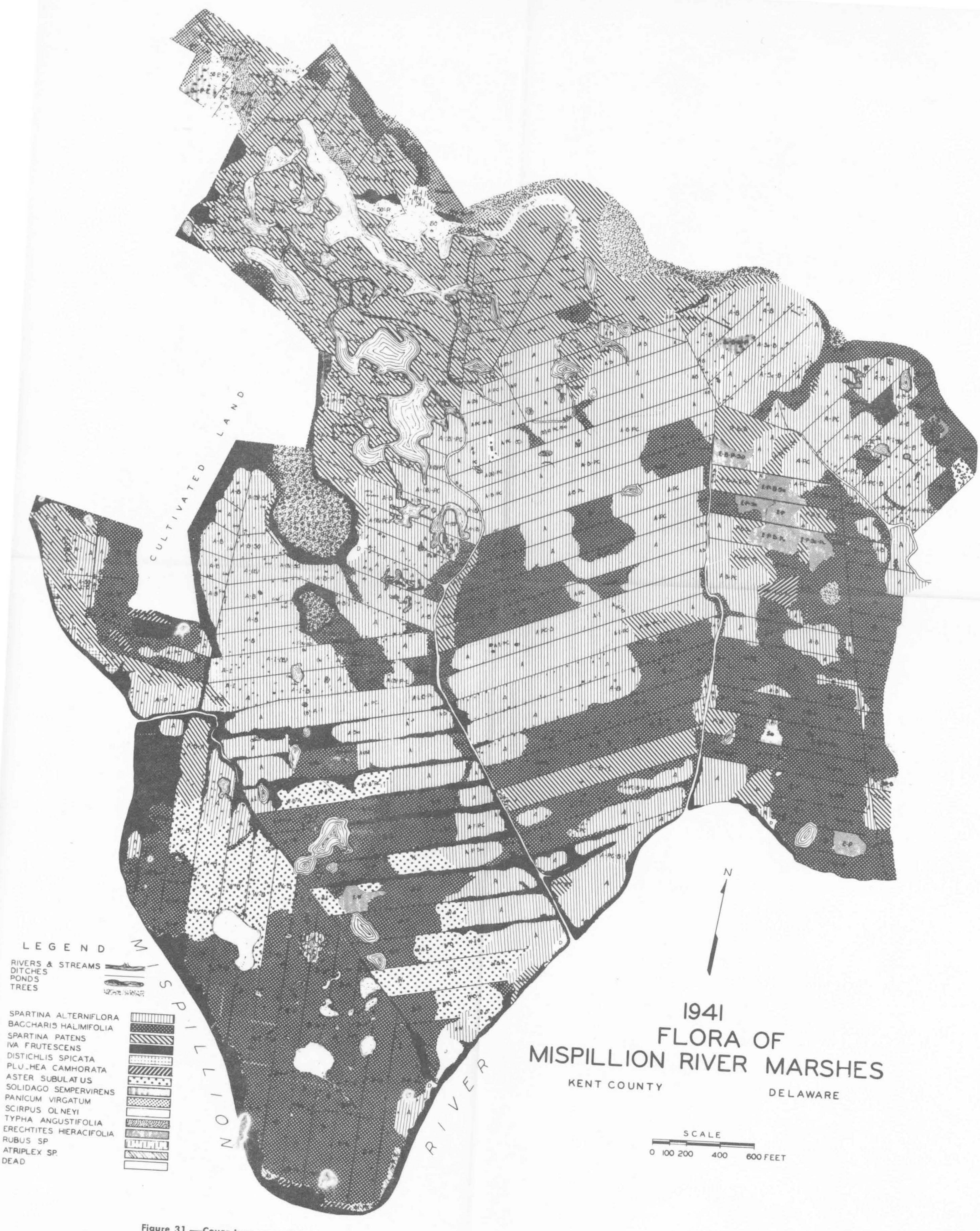


Figure 31.—Cover type map of the study area in the tidewater marshes on the Mispillion River (Kent County, Del.) in 1939, at the end of 6 growing seasons after ditching and drainage for mosquito control. The higher areas are being taken over by the shrub *Baccharis halimifolia*, while some of the lower parts of the marsh are reverting to *Spartina alterniflora* as a result of filling of ditches through lack of maintenance.

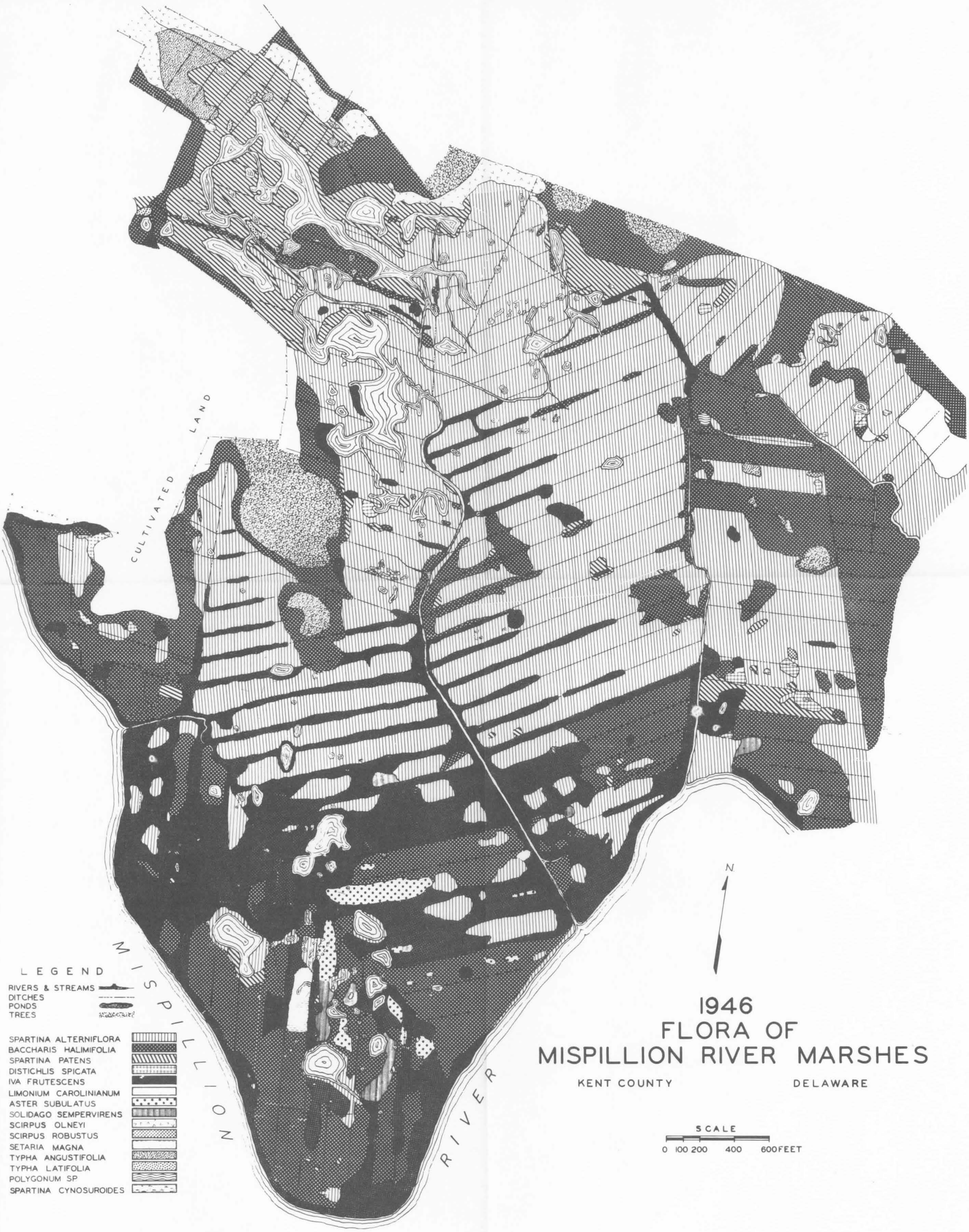


Figure 32.—Cover type map of the study area in the tidewater marshes on the Mispillion River (Kent County, Del.) in 1946, at the end of 11 growing seasons after ditching and drainage for mosquito control. Much of the area formerly occupied by *Spartina alterniflora* apparently is now permanently taken over by shrubby groundselbush and marsh elder. Lower parts of the marsh have reverted to *Spartina alterniflora* because of ditch stoppage through lack of maintenance. The entire area now has little or no value as a wildlife habitat.

889234 O - 50 (In back pocket) No. 6

Figure 29.—Cover type map of the study area in the tidewater marshes on the Mispillion River (Kent County, Del.) in 1938, at the end of 3 growing seasons after ditching and drainage for mosquito control. The beginning of an extensive invasion by shrubby growth can be observed. The encircled letters signify a mixture with less than 40 percent of the plant designated by the letter in the circle.

889234 O - 50 (In back pocket) No. 3

Figure 28.—Cover type map of the Mispillion River tidewater-marsh area made one season after the area was drained for mosquito control. Already, marked changes in the floral cover of the marsh had begun to take place, and the *Spartina alterniflora* had died below the lower half of its vertical range.

889234 O - 50 (In back pocket) No. 2

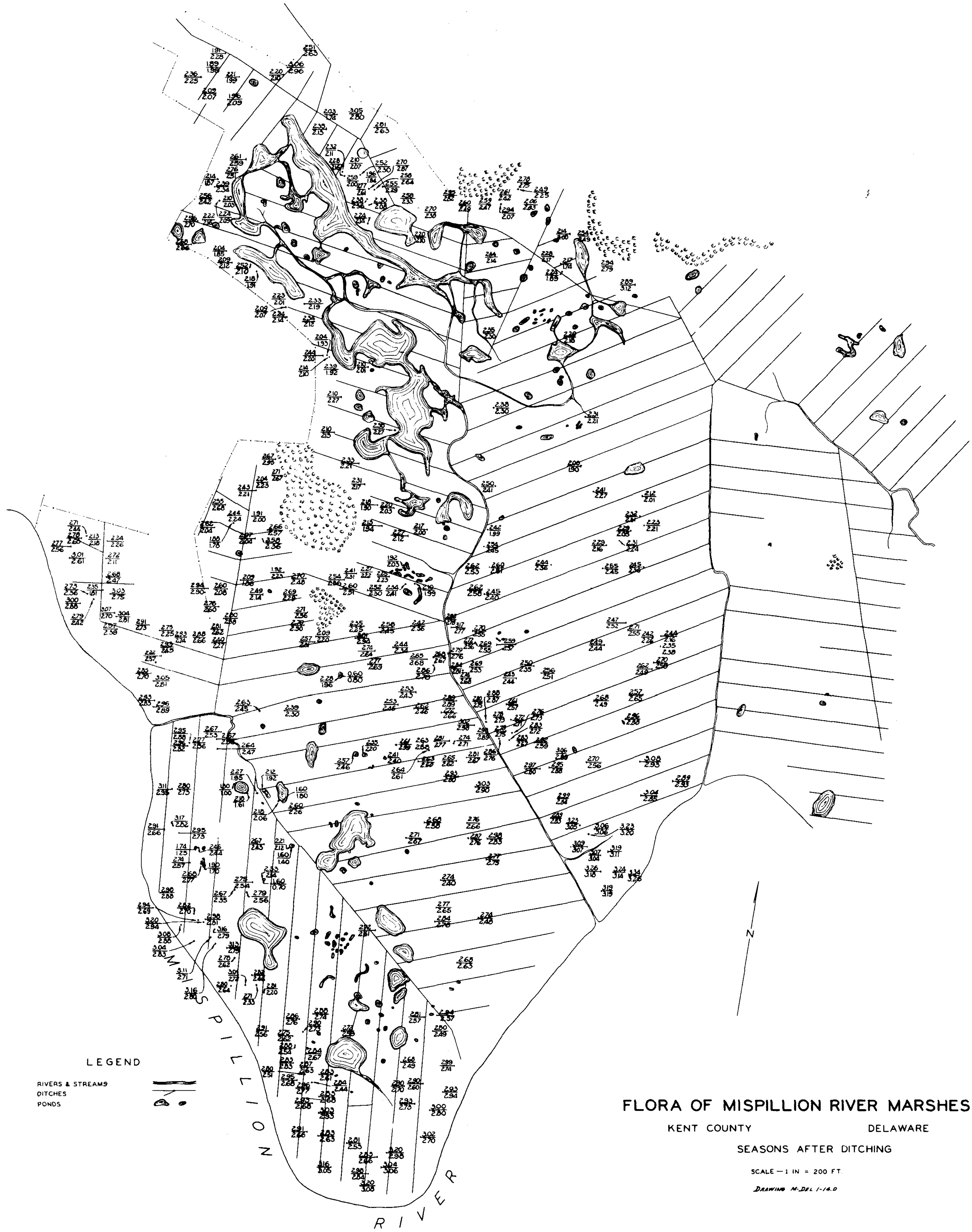
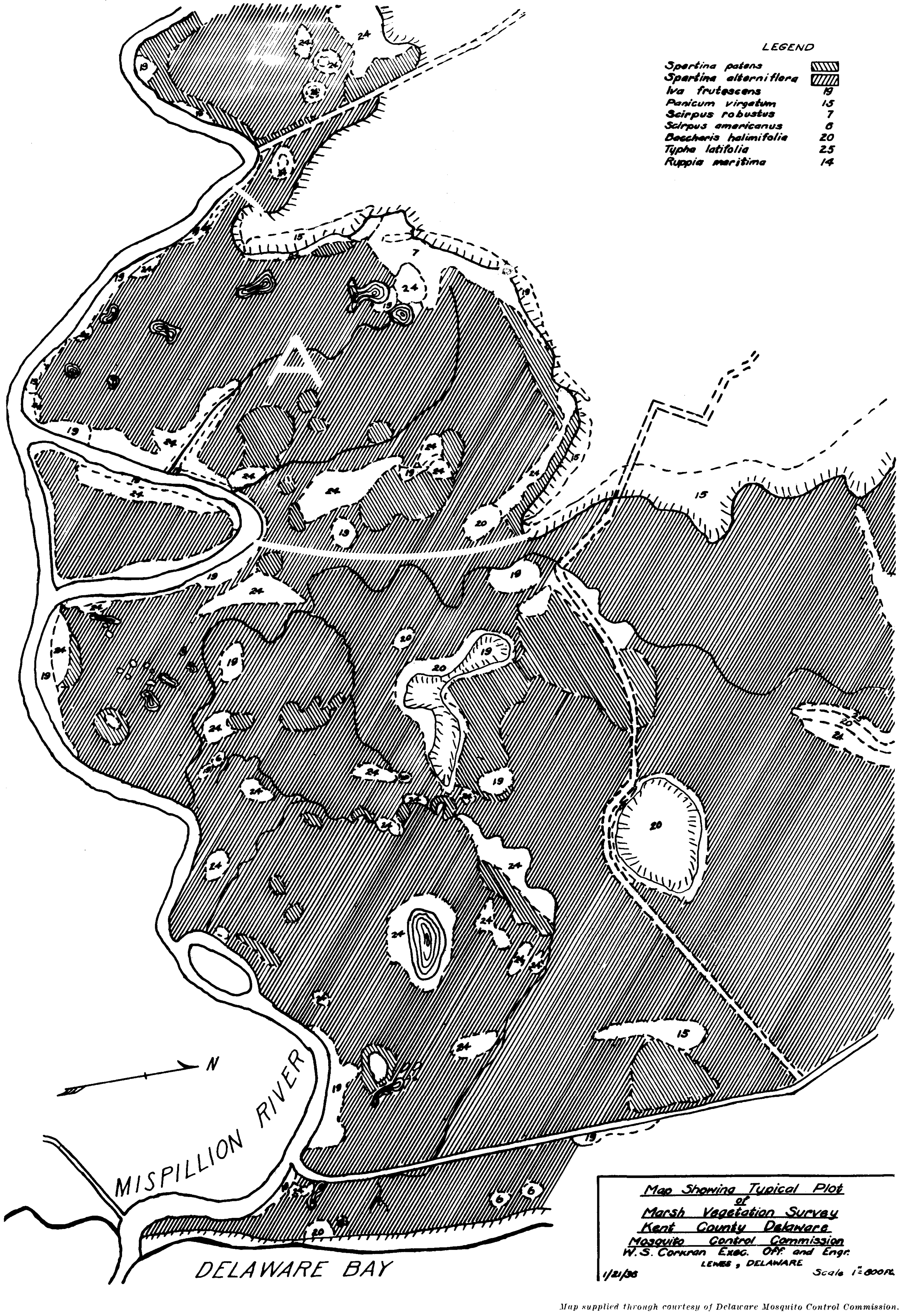


Figure 33.—Marsh levels in the Mispillion River study area. The top figures pertain to levels taken in 1936, at the end of the first growing season after ditching, and the bottom ones to 1941 levels, taken at the end of 5 seasons after ditching. The levels refer to mean sea level.



Map supplied through courtesy of Delaware Mosquito Control Commission.

Figure 27.—Cover type map showing the floral composition of tidewater marshes along the northside of the Mispillion River, Kent County, Del., prepared by the Delaware Mosquito Control Commission in 1935–36, before ditching the marshes. The study area—to determine the effects of drainage on the flora—is marked by the letter "A." It can be readily seen that *Spartina alterniflora* covered more than 90 percent of the acreage before ditching.

889234 O - 50 (In back pocket) No. 1