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AN HYDROMETRIC INVESTIGATION OF THE INFLUENCE OF SEA WATER ON THE DISTRIBUTION OF SALT MARSH AND ESTUARINE PLANTS.

(PLATES XX AND XXI.)

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(*Read April 22, 1910.*)

Elsewhere[1] I have discussed the general character of the vegetation of the salt marshes of the northern New Jersey coast and the factors controlling the distribution of marsh plants in that area. This earlier study was based largely on physiographic and floristic considerations, although reference is made on page 379 of that paper to the use of the hydrometer in the investigation of the actual influence of sea water, or salty soil, on the distribution of a limited number of plants. The investigation begun in 1909 has been continued until sufficient facts have accumulated to warrant their publication.

The use of a special kind of hydrometer was suggested as a simple but efficient method of investigating the salt content of salt marsh soils and of the estuarine water which, at first strongly saline, becomes largely diluted, as it mingles with that of streams flowing in a seaward direction. This is the first actual use of the hydrometer

[1] Harshberger, John W., "The Vegetation of the Salt Marshes and of the Salt and Fresh Water Ponds of Northern Coastal New Jersey," *Proceedings Academy of Natural Sciences of Philadelphia*, 1909, 373–400, with 6 figures.

in phytogeographic and phytoecologic investigation. The method is applicable not only to a study of salt marsh soils, but also to an investigation of salt lakes and alkaline soils, which are found in many parts of our western arid districts and in other parts of the world (Fig. 1). The use of the hydrometer supplements, if it does

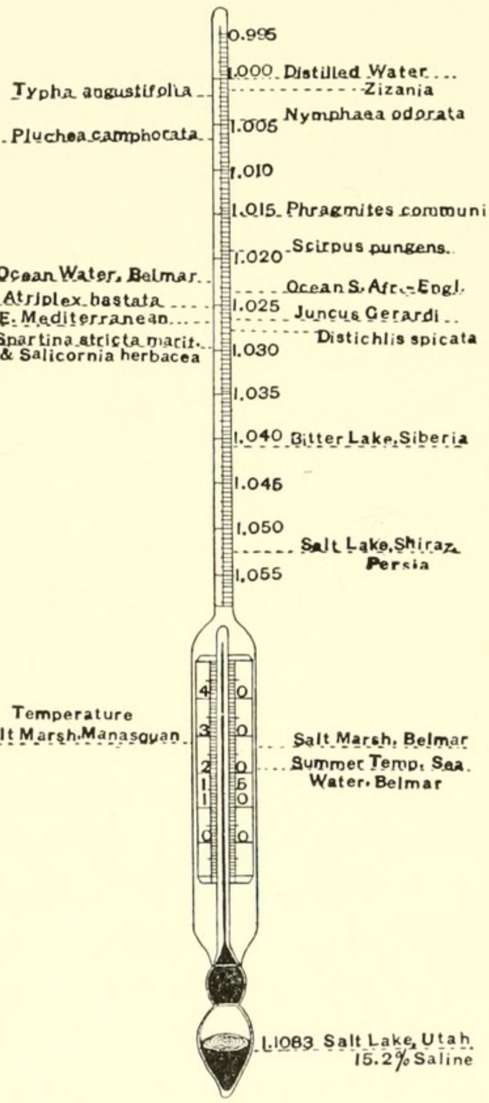

FIG. 1. Special hydrometer and thermometer used in the investigation of the salt marsh vegetation of the New Jersey coast. The names of plants are arranged along the scale to graphically represent the maximum density of salt water to which these plants are subjected in their marsh environment. Other data are given for comparison.

not replace, the employment of the more expensive and cumbersome apparatus which determines by electric means the salt content of soils. Although this investigation was made in the salt marshes of northern coastal New Jersey, the results obtained are equally applicable to the same salt marsh species as they are found distributed along our eastern Atlantic coast. For stretching from the Bay of Fundy along the New England, middle and southern Atlantic coasts, as far south as Jupiter Inlet in Florida, are extensive salt marshes covered with a vegetation which consists with minor differences of almost the same and characteristic species.

Possible Methods of Investigations.

There are four possible methods open to the investigator of the salt content of salt marsh soils and estuarine waters. These methods have been used by chemists, soil analysts and plant physiologists.

Method of Titration.—The determination of salt content by volumetric analysis has been the favorite one of chemists. For this purpose, a tenth-normal silver nitrate volumetric solution is used, prepared as follows: Dissolve 16.869 grams of silver nitrate, which previous to weighing has been pulverized and dried in a covered porcelain crucible in an air-bath at 130° C. (260° F.) for one hour in sufficient water to measure at 25° C. (77° F.), exactly 1,000 c.c. This solution is kept in dark amber-colored, glass-stoppered bottles, carefully protected from dust and sunlight. A tenth-normal potassium bichromate test solution is prepared by dissolving 4.8713 grams of pure potassium bichromate, which has been pulverized and dried at 120° C. (248° F.) in sufficient water to measure at 25° C. (77° F.) exactly 1,000 c.c. To a definite volume of salt water, sufficient potassium bichromate test solution is added to impart a yellow tint, then the tenth-normal silver nitrate solution is slowly added from a burette, stirring or agitating until the mixture acquires a permanent tint, due to the formation of red silver chromate. The fluid to be tested must be neutral, as free acids dissolve the silver chromate. The cubic centimeters of silver nitrate solution used must now be multiplied by .005850 Fresenius (.005837 Sutton, .005806 National Dispensatory) to give the weight of the sodium chloride, because .005850 Fresenius (.005837 Sutton, .005806 N. D.) grams of sodium chloride is the equivalent of one cubic centimeter of tenth-normal silver nitrate volumetric solution.[2] This is the method adopted I am told by the botanists at Johns Hopkins University in studying the salt marsh vegetation of Maryland, the results of which investigation have not yet been published.

Method of the Electric Bridge.—The Bureau of Soils, United States Department of Agriculture, adopted some years ago the principle of the slide wire bridge to the measurement of the salt content of soils.[3] The earlier instruments have been described in various bulletins and the results obtained with them are scattered through various publications of the bureau. Since 1899, when the electric bridge was put first into practical use, various improvements have been made, so that the improved instrument is the result of the experience gained by its use in the actual field study of soils. The use of the electric methods for determining the soluble content of a soil depends on the fact that the electric current is conducted by the salt in solution and that the conduction of the solution, or conversely, its resistance to the passage of the current, is largely determined by its concentration. The magnitude of current that will pass is increased by an increase of salt in solution; or the resistance to the passage of the current decreases with the increase of salt. The experience gained by the use of the modified instrument is embodied in the recent bulletin of the Bureau of Soils noted above and its general utility in the study of alkali soils, the salt content of irrigation and seepage waters is given.

Method of Plasmolysis.—It is a well-known physiologic fact that dilute solutions of potassium nitrate, sodium chloride and cane sugar cause a removal of water from living plant cells, so that the protoplasm contracts away from the inside of the cell wall. The per-

[2] Consult Hare, Hobart A., Caspari, Charles, Rusby, H. H., "The National Standard Dispensatory," 1905, 1684; Fresenius, C. Remigius, "A System of Instruction in Quantitative Chemical Analysis," 1894, 430; Sutton, Francis, "A Systemic Handbook of Volumetric Analysis," 1890, 124; Fraps, G. S., see bibliography.

[3] Davis, R. O. E., and Bryan, H., "The Electrical Bridge for the Determination of Soluble Salts in Soils," Bull. 61, Bureau of Soils, 1910, where reference is made to previous bulletins; Cannon, W. A., "On the Electrical Resistance of Salt Plants and Solutions of Alkali Soils," *The Plant World*, 11, 10–14.

centage of substance in solution necessary to cause plasmolysis varies not only with the plasmolyzing substance, but also with the plant used in the experiments. The protoplasm in some plants plasmolyzes quickly; in other cases with difficulty, so that stronger solutions are necessary to produce a change in the more refractory plants. If we know, therefore, that a certain percentage strength of sodium chloride in solution will produce plasmolysis in say the cells of the staminal hairs of *Tradescantia,* then if raw or diluted sea water be used and a similar plasmolysis occurs, the percentage of sodium chloride in the sea water must be equivalent to that of the salt solution known to produce similar plasmolytic effects. A comparative table can be constructed by which the varying percentages of sea water can be ascertained. An extensive literature, part of it noticed in the bibliography, is concerned with such plasmolytic studies.[4]

Hydrometric Method.—The use of the hydrometer in determining the salt content of salt marsh soils suggested itself to me, as a simple but efficient method of making a phytogeographic survey of the vegetation of salt marshes upon purely ecologic lines. The advantage of the hydrometer is that it is light, can be carried easily from place to place and lends itself to immediate use, the record depending upon two simple readings, one of specific gravity and one of temperature. The hydrometer is plunged into a vessel containing the water to be tested.

Styles of Hydrometers.—After a simple hydrometer had been used in a number of preliminary tests, search was made for a hydrometer which would record accurately the density of sea water. It was found that there are many kinds of hydrometers in use to test acids, alcohol, alkali, ammonia, bark liquor (tannometer), beer, benzine, chlorine, cider, coal oil, ether, gasoline, glycerine, milk (lactometer), naptha oil, salt solutions (salimeter), silver solution, sugar, sugar and syrup. Some are constructed with Baume's scales, others with Richter and Trolle's scales and those used to test sugar with Balling's and Brix's scales. Finally, after testing several different kinds of

[4] Drabble, E., and Lake, H., "The Osmotic Strength of Cell-sap in Plants growing under Different Conditions," *The New Phytologist,* October, 1905, 189; Duggar, B. M., "The Relation of Certain Marine Algae to Various Salt Solutions," *Trans. Acad. Sci. St. Louis,* XVI., 473–479.

hydrometers, one was obtained which fulfilled all the conditions of experimentation most perfectly. The hydrometer purchased of Arthur H. Thomas Company is one designed to test the specific gravity of liquids heavier than water. The scale reads from 0.995 to 1.065 and is divided into single units and half units (Fig. 1). For example, beginning at 1.0000, the divisions of the scale read as follows: 1.0005, 1.0010, 1.0015, 1.0020, 1.0025, 1.0030, 1.0035, 1.0040, 1.0045, 1.0050. The last figure is the next prominent figure on the scale printed in black letters. Altogether 140 separate readings can be made from this scale, and if the observer wished to test the salinity of the water of Salt Lake, Utah, the length of the scale would have to be increased to the point indicated in Fig. 1, and the size of the bulbs would have to be increased correspondingly. There are three bulbs blown in the hydrometer tube. The lower one is the sinker with metallic mercury. The middle one carries the mercury of the thermometer, which is inclosed in the third and upper bulb. The thermometer scales reads from — 5° C. to + 45° C., and is divided into degrees with the fifteenth marked in red. With this instrument temperature and specific gravity can be determined simultaneously.

Corrections to Readings.—In actual use, the experimenter finds that the hydrometric readings vary with the temperature of the water, and that to make the results harmonious all of the readings for specific gravity must be reduced to the uniform temperature of 15° C. No table exists by which the reduction can be made directly without calculation. Such a table for all temperature degrees and degrees of specific gravity is a desideratum. A mechanic rule, or sliding scale, might be constructed from which corrected readings might be taken directly by adjusting the movable parts of the scale to corresponding degrees of specific gravity and of temperature. In the absence of such a table and mechanic scale after a prolonged search through theoretic text-books of chemistry, the following one was discovered, which enabled me to standardize all of the readings made by the hydrometer by reference to the specific gravity at 15° C.

Table for the Reduction of Specific Gravity at any Temperature to the Specific Gravity at 15° C.

(Table B, Landolt-Börnstein Physikalisch-Chemische Tabellen, Berlin, 1905, page 323.)

"Reducktion der Dichte $d\frac{t}{4}$ auf die Dichte bei 15° nach den Beob. von Dittmar" (Challenger Exped.), Ekman (*Vetensk. Handl.*, 1870), Lenz u. Reszof (*Mém. Petersb.*, 1881), Thorpe u. Rücker (*Phil. Trans.*, 166, II; 1876), Tornoë (Norw. Atlantic Exped., 1880) berechnet von Makarof (J. Russ, *Phys. Chem. Ges.*, 23, 30; 1891). Auszug.

	0°	5°	10°	15°	20°	25°	30°
Dest Wasser	0.99988	99979	99974	99915	99828	99714	99577
Seewasser	1.00077	00087	00060	00000	99911	99796	99659
"	1.01130	01120	01075	01000	00898	00774	00630
"	1.02182	02152	02090	02000	01886	01751	01600
"	1.03228	03179	03102	03000	02876	02732	02572

This fact should be noted in connection with the use of the above table, viz., the specific gravity of a sample of sea water is the number representing its weight as compared with an equal volume of pure water at the same temperature. The latter is usually called 1.000 so that the specific gravity of a sample of sea water may be some such number as 1.025. The density is the weight in grams of one cubic centimeter of water at the temperature in situ ($t°$) compared with that of 1 c.c. of pure water at 40° C. It is usually expressed as $D\frac{t°}{4°}$. The salinity is the total weight in grams of the matter dissolved in 1,000 grams of water.

Mathematic Calculation.—Through the kindness of a graduate student, Mr. John C. Bechtel, to whom my thanks are due, I was relieved of the labor of making the mathematic calculations necessary to reduce the hydrometric readings to 15° C. His method of procedure is herewith given in a sample case.

To determine density at 15° C. of salt water whose density at 23° is 1.0155.

From the table we see that this corresponds to a solution whose density at 15° lies between 1.01 and 1.02.

We therefore find figures for density of salt water at 23°, if density at 15° is 1.01, and also if density is 1.02.

Density at 20° is 1.00898 for first and 1.01886 for second.

Density at 25° is 1.00774 for first and 1.01751 for second.

For first, the change in density for 5° is

$$1.00898 - 1.00774 = .00124.$$

For 3° it is $\frac{3}{5}$ of .00124 = .00740.

Hence density is 1.00898 — .00740 = 1.00824 at 23°.

For second change in density for 5° is

$$1.01886 - 1.01751 = .00135.$$

For 3° it is $\frac{3}{5}$ of .00135 = .00081.

Hence density at 23° is equal to density at 20° — loss for 3° or 1.01805.

We now have densities at 15° as 1.01 and 1.02 as limits and from observations we see that at 23° the density of our solution is 1.0155.

We also have this proportion which will give a sufficiently approximate result:

If y is the density of this solution at 15°

$$\frac{y - 1.01}{1.02 - 1.01} = \frac{1.0155 - 1.00824}{1.01805 - 1.00824},$$

$$\frac{y - 1.01}{.01} = \frac{.00726}{.00981},$$

$$y = 1.01 + .0074,$$

$$y = 1.0174,$$

therefore density at 15° = 1.0174.

As the above computation is a rather long one and must be made for each of the actual readings obtained by the hydrometer, it has been thought advisable to give the entire set of original readings at various temperature and the corrected specific gravity at 15° C. Such a table may enable future workers in the same field to make their corrections at once by omitting the long computation otherwise necessary. The numbers in the first column of the table refer to the observations as recorded in the field note book and which have been added as subnumbers to the specific gravities placed on the map of Shark River and Bay which comprises Fig. 4 of the text.

Table Giving Hydrometric Observations on Salt Marsh Plants of New Jersey with Corrections at 15° by Mr. John C. Bechtel.

No.	Observed Sp. Gr.	Temp. °C.	Sp. Gr. at 15°.	No.	Observed Sp. Gr.	Temp. °C.	Sp. Gr. at 15°.
71	1.0155	23	1.0174	108	1.0005	14	1.0004
72	1.0160	23	1.0179	109	1.0025	24	1.0044
73	1.0180	21	1.0194	110	1.0025	20	1.0034
75	1.0170	20	1.0182	112	1.0120	28	1.0153
76	1.0175	19	1.0184	113	1.0035	25	1.0057
77	1.0260	29	1.02996	114	1.0015	25	1.0036
78	1 0150	22	1.0166	115	1.0000	23	1.0016
80	1.0165	19	1.0174	116	0.9990	25	1.0011
81	1.0160	26	1.0188	117	1.0005	21	1.0016
82	1 0105	21	1.0117	118	1.0160	27	1.0181
83	1.0090	20	1.0102	119	1.0165	26	1.0193
84	1.0020	20	1.0029	120	1.0160	27	1.0191
85	1.0010	20	1.0019	121	1.0415	24	—
86	1.0000	18	1 0005	—	1.0150	25	1.0175
87	1.0140	25	1.0164	124	1.0155	29	1.0192
88	1.0030	23	1.0046	125	1.0010	22	1.0024
89	1.0000	22	1.0014	126	1.0190	23	1.0210
90	1.0000	20	1.0009	127	1.0110	21	1.0022
91	1.0005	20	1.0014	128	1.0035	22	1.0049
92	1.0140	22	1.0156	129	1.0205	23	1.0225
93	1.0205	20	1.0217	130	1.0255	20	1.0267
94	1.0200	20	1.0212	131	1.0065	20	1.0075
95	1.0215	19	1.0224	132	1.0110	19	1.0180
96	1.0050	19	1.0058	133	1.0250	21	1.0265
97	1.0110	19	1.0118	134	1.0205	22	1.0222
98	1.0165	18	1.0172	135	1.0250	21	1.0265
99	1.0215	18	1.0223	136	1.0240	20	1.0252
100	1.0180	18	1.0187	—	1.0210	22	1.0224
101	1.0210	21	1.0224	137	1.0245	27	1.0278
102	1.0245	20	1.0257	138	1.0215	24	1.0238
103	1.0185	20	1.0196	139	1.0180	25	1.0205
104	1.0195	21	1.0209	140	1.0055	20	1.0065
107	1.0150	25	1.0175				

After having discussed the theoretic methods, we must next consider the actual study of the vegetation in the field by the use of the hydrometer.

Aids to Field Study.—The equipment which was carried into the field for the study of the edaphic conditions under which salt marsh vegetation grows was accommodated in a light basket and consisted of a meter measure, reading to decimeters, centimeters and millimeters; a narrow, but deep, glass cylinder to hold the water upon which the specific gravity determinations were made; a tin dipper to collect the water and a field note book. A narrow trenching spade was carried in the hand and by this spade it was possible to dig deep holes in the tough resisting marsh sod. The water for study was dipped either directly from holes in the marsh or taken from the ocean and open bays along the New Jersey coast. The hole was dug in all cases deep enough to allow the soil water to percolate into it, and upon this water the specific gravity readings were made. The region especially traversed in this way extended from Manasquan Inlet on the south to Sandy Hook Bay on the north, and thus an insight was obtained of the problems concerned in the distribution of the various species of salt marsh plants.

Field Observations and Data.

Altogether sixty readings were made with the first style of salinometer used. This type had such a small range of scale divisions that it was discarded as being too inaccurate for the purposes of the salt marsh investigation where the total salt content of the water increased, or decreased, by almost inappreciable amounts. Although many of these observations are of interest, they are not incorporated here. The second style of hydrometer was like the final one adopted, as to the divisions of the scale, but it lacked a thermometer. The data obtained by this hydrometer are considered here, but they are only of comparative value, because they lack the accuracy of the later readings which were made for both specific gravity and temperature. They are of value because they give habitat relationships not included in the more accurate data obtained later.

For the above reasons the field observations will be considered under two heads: (1) the readings made by the hydrometer without the thermometer, and (2) the readings which include both hydrometric and thermometric measurements.

Hydrometric Readings without Thermometer.—The readings which are numbered consecutively from 1–70 inclusive are arranged geographically as affording more interesting comparative data. They stand as follows: Beginning in the north readings were obtained along the Shrewsbury River, starting at the railroad bridge connecting Highland Beach with the Navesink Highlands proper. Plum Island, where the first measurements were made, is a small island back of the Sandy Hook peninsuula in Sandy Hook Bay. Undoubtedly, the water of this bay is less strongly saline because influenced by large fresh water rivers, such as the Hudson River.

55. *Spartina stricta maritima*, association on Plum Island. Sp. gr. 1.016.

56. *Baccharis halimifolia*, association with *Salicornia herbacea, Suaeda maritima*, water covering plants at high tide two inches deep. Sp. gr. 1.0155.

57. Salt Pond on Plum Island, fringed by *Spartina stricta maritima*. Sp. gr. 1.016.

59. Water from a hole two feet deep in tension strip between *Spartina stricta maritima* and *Baccharis halimifolia*. Sp. gr. 1.018.

60. Water from hole eighteen inches deep in middle of a *Spartina patens* association. Sp. gr. 1.020.

61. Water from a hole eighteen inches deep on the tension line between *Spartina patens* and *Spartina stricta maritima*. Sp. gr. 1.019.

62. Water from a hole on the tension line between *Spartina patens* and *Baccharis halimifolia*. Sp. gr. 1.0185.

64. Water from a hole eighteen inches deep in the middle of an association of *Salicornia mucronata, Limonium carolinianum, Spartina patens* and near by on the same level *Atriplex hastata, Suaeda maritima* and *Baccharis halimifolia*. Sp. gr. 1.003.

The following observations were made in ascending the Shrewsbury River toward Pleasure Bay:

53. Salt water at Highlands Pier. Sp. gr. 1.019.[5]

66. Water surrounding *Spartina stricta maritima* fringing beach in front of the Navesink Highlands. Sp. gr. 1.0185.

68. At the confluence of the Navesink and Shrewsbury rivers with a lot of *Fucus vesiculosus* attached to pilings and also *Spartina stricta maritima*. Sp. gr. 1.0185.

69 and 70. At this point water submerged an association of *Limonium carolinianum, Suaeda maritima, Spartina patens, Salicornia herbacea, Plantago maritima* and *Atriplex hastata*. Sp. gr. 1.018.

Ascending the Shrewsbury River, the head of navigation is reached at Pleasure Bay. From here to the head of the bay the

[5] For comparison, the sea water from the ocean at Belmar read sp. gr. 1.0215 at Temp. 20.6° C. corrected to 15° the sp. gr. = 1.0224.

water becomes gradually fresher and the salt marsh vegetation is replaced gradually by fresh water marsh plants.

32. Water from Pleasure Bay at the head of navigation. Sp. gr. 1.010.

33. Water from ditch two feet deep in middle of *Spartina patens* association. Sp. gr. 1.010.

35. Water at head of small ditch with *Scirpus pungens, Cicuta maculata, Scirpus robustus.* Sp. gr. 1.005.

37. Slue with *Baccharis halimifolia* and *Spartina stricta maritima.* Sp. gr. 1.010.

42. Hole in salt meadow on tension line between *Juncus Gerardi* (cut for hay) and an association of *Scirpus pungens, Pluchea camphorata, Atriplex hastata* and *Spartina patens* on the other side. Sp. gr. 1.005.

44. Water from bases of plants of *Typha angustifolia* and *Scirpus pungens.* Sp. gr. 1.015.[6]

45. Water at third bridge above Pleasure Bay in the middle of an association of *Spartina stricta maritima, Scirpus pungens, S. robustus.* Sp. gr. 1.005.

46. Above the fourth bridge in middle of a *Spartina stricta maritima* association. Sp. gr. 1.0005.

47. Here a pure association of *Scirpus robustus.* Sp. gr. 1.0005.

48. Association of *Zizania aquatica* and *Scirpus robustus.* Sp. gr. 1.0005.

50. Water from inner edge of an association of *Typha angustifolia* (tall), *Peltandra virginica* and *Cicuta maculata.* Sp. gr. 1.000.

51. Muddy cold water from a hole in an association of *Sagittaria latifolia* (= *S. variabilis*), *Cicuta maculata, Typha angustifolia, Polygonum sagittatum.* Sp. gr. 1.0015.

52. Water from channel under last bridge. Sp. gr. 1.0015.

The fact that such salt marsh species as *Spartina stricta maritima* mingles with fresh-water marsh species under almost fresh-water conditions is to be explained by the occasional inundation of such plants by more strongly saline water at exceptionally high tides, so that the exceptionally high tides enable the salt grass to persist surrounded by fresh-water marsh species. The salt marsh species can

[6] Probably due to evaporation.

withstand fresh water better than the fresh-water species can salt water. These latter plants are able also to withstand an occasional flooding, although normally they are controlled by fresh water. This is probably to be accounted for by the resistance of the leaves that surround the stem, while the roots are in practically fresh water, which saturates the ground and prevents the entrance of salt water into it for some time. The occasional flooding of salt water is not for a sufficiently long time to effect the character of the ground water in which the roots of such plants as *Sagittaria latifolia, Cicuta maculata* grow.

The observations at Belmar began with an estimation of the salinity of the ocean water. The readings from 4–19 are interesting

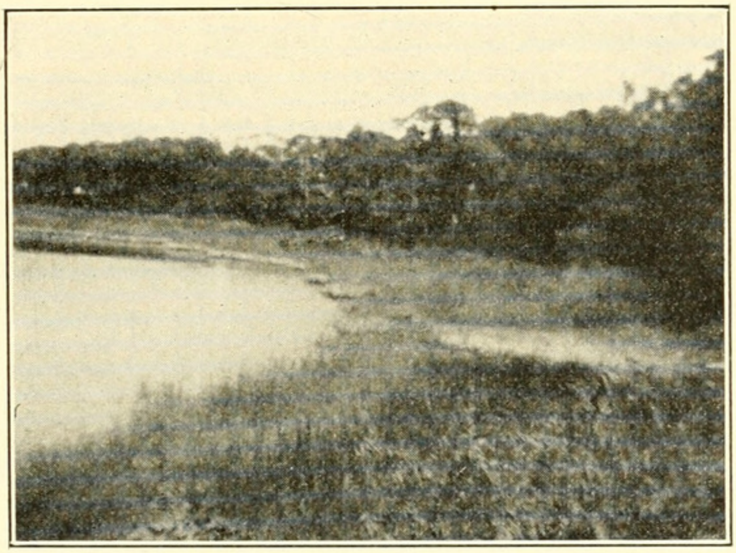

FIG. 2. Basin-like slue along Fifth Avenue, Belmar, N. J., fringed by salt marsh vegetation and backed by forest trees. Several of the stations for hydrometric determinations were chosen along this shore.

because they were made while Shark River Inlet was closed to the sea by a sand bar.

2. Sea water from surf at Belmar. Sp. gr. 1.0215 at 20.6° C. (69° F.); corrected to 15° C. Sp. gr. = 1.0224.

4. Water in Shark River Inlet flooding *Spartina stricta maritima* association. Sp. gr. 1.015.

5. Water from channel opposite B Street, Belmar. Sp. gr. 1.0185.

7. Water from seaward end of marsh island in Shark River. Sp. gr. 1.017. With *Spartina stricta maritima*.

8. Water submerging *Juncus Gerardi*. Sp. gr. 1.016.

9. Water covering *Spartina patens*. Sp. gr. 1.017.

12. Water in large slue along Fifth Avenue, Belmar. Sp. gr. 1.016.

13. Water from bay at Casino Landing, where a rise of eighteen inches was noted after the inlet closed. Sp. gr. 1.0175.

These several readings show the condition of salinity when the inlet through which the tidal salt water enters Shark River is closed and the salt water thus inclosed is diluted by rain and river water until the river shows a perceptible rise of eighteen inches above the level of normal high tide. In such rivers the salt marsh vegetation for considerable periods of time is exposed to fresh water, which would ultimately control, if the inlet would remain permanently closed. But when the inlet is reopened the original conditions of salinity are restored by the tidal flow of sea water in and out of the landlocked bay. This is an interesting corroboration of the recent work of D. W. Johnson,[7] who believes that the indications of apparent subsidence are due to fluctuations in the tidal level due to a change in the configuration of the coast. During the closure of Shark River there was a rise of water level in the river which might account for the rise in the height of the salt marsh layers. After the causal influences had been obliterated, an examination of the layers of salt marsh soil would indicate, according to the older views, a total submergence of the coast line equal to the depth of newly formed marsh peat.

The observations on the salinity of the water at the western end of Newberry (Stockton) Lake, an arm of Manasquan River, are of interest as displaying the edaphic conditions which control the distribution of *Typha angustifolia*. The size of this plant is also directly conditioned by the amount of salinity as measurements later to be presented will show. However, if we begin near the outlet

[7] Johnson, D. W., "The Supposed Recent Subsidence of the Massachusetts and New Jersey Coasts," *Science*, N. S., XXXII., 721–723; Bartlett, H. H., "Botanical Evidence of Coastal Subsidence," *Science*, N. S., XXXIII., 29–31; Johnson, D. W., *Science*, XXXIII., 300–302.

of the lake where the cat-tails occur, the following series of readings are suggestive.

28. (Position I.) Association of *Typha angustifolia*—base of plant covered by water at high tide. Sp. gr. 1.0145.

27. (Position III.) *Typha angustifolia.* Sp. gr. 1.014.

26. (Position V.) *Typha angustifolia.* Sp. gr. 1.014.

25. Position VI.) *Typha angustifolia* with *Atriplex hastata.* Submerging water with sp. gr. 1.012.

24. (Position VII*a.*) Association of *Typha angustifolia, Atriplex hastata, Salicornia herbacea, Spartina stricta maritima.* Sp. gr. 1.0135.

23. (Position VII*b.*) Association of *Typha angustifolia, Scirpus lacustris, S. pungens.* Sp. gr. 1.0125.

22. Outer edge of *Typha angustifolia* association at the head of the lake. Sp. gr. 1.0115.

21. Head of Newberry Lake at inner edge of dense masses of *Typha angustifolia* with *Hibiscus moscheutos* (third lot). Sp. gr. 1.0050.

Influence of Saline Water on Typha angustifolia.—Before beginning a consideration of the data obtained by using the hydrometer and thermometer combined, it is important to consider the influence

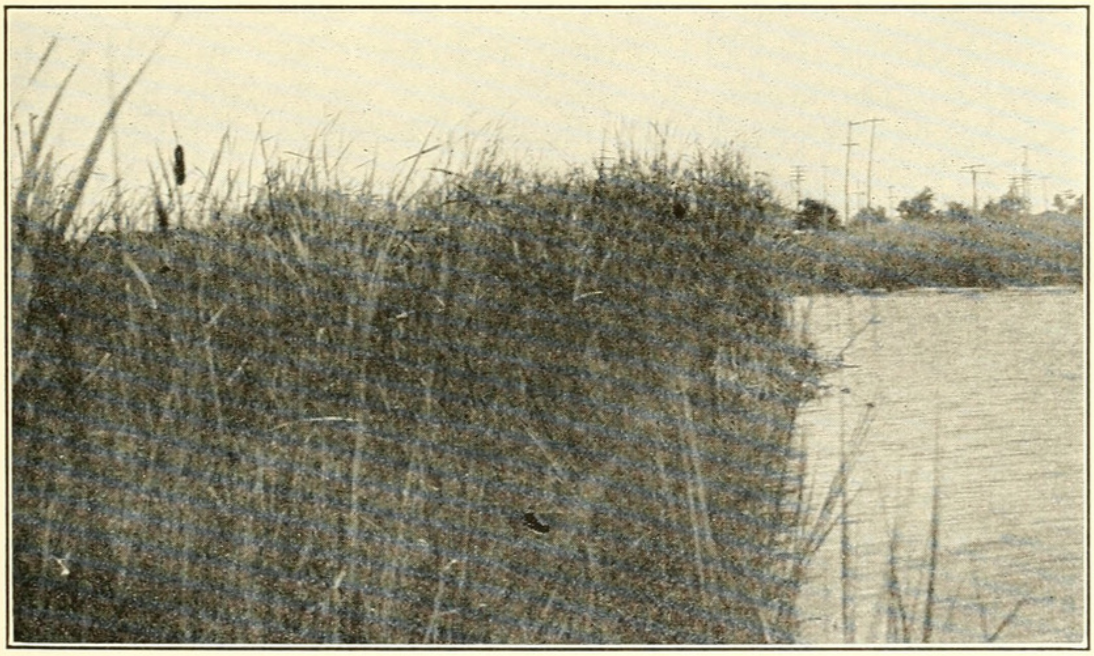

Fig. 3. Cat-tail, *Typha angustifolia,* at the head of Stockton Lake near Sea Girt, N. J. The tall plants are growing at Position III.

of the varying salinity of the water upon the plants which are subjected to the different densities of salt water. For this purpose, I have chosen *Typha angustifolia* because it seems to show in a marked degree the influence of the variation in the saline environment. Six series of measurements were taken at this plant. Three series are based on plants from Stockton Lake and three upon plants from Pleasure Bay.

In all the measurements the height of the plant is measured to the top of the fertile part of the terminal spike. The upper sterile and staminate portion is included, but it is only temporarily present. Measurements are metric.

FIRST SERIES. *Typha angustifolia* FROM STOCKTON LAKE SHORE. (POSITION I.) SP. GR. 1.0145.

No.	Height of Plant.	Length of Spike, ♀.	Breadth of Spike, ♀.	Width of Third Leaf from Top.	No. of Leaves.		Sterile Part.
					Dry.	Green.	
1	.929	.087	.016	.004	6	6	.020
2	1.030	.075	.020	.006	6	5	.025
3	Broken	Broken	Broken	.004	7	5	—
4	1.353	.124	.020	.006	6	6	.015
5	1.015	.080	.019	.006	8	5	.018
6	1.119	.090	.018	.005	7	6	.026
8	1.100	.098	.022	.006	7	5	.022
7	1.124	.c82	.020	.005	9	4	.027
9	1.008	.076	.018	.004	6	6	.020
10	.922	.075	.019	.005	4	6	.021

Series of heights: .922, .929, 1.008, 1.015, 1.030, 1.100, 1.119, 1.124, 1.353. Arithmetic mean = 1.066.

Length of spikes, ♀: .075, .076, .080, .082, .087, .090, .098, .124. Arithmetic mean = .089.

Breadth of spikes, ♀: .016, .018, .019, .020, .022. Arithmetic mean = .019

SECOND SERIES. *Typha angustifolia* FROM STOCKTON LAKE SHORE. (POSITION II.) SP. GR. 1.014.

No.	Height of Plant.	Length of Spike, ♀.	Breadth of Spike, ♀.	Width of Third Leaf from Top.	No. of Leaves.		Sterile Part.
					Dry.	Green.	
1	1.398	.090	.023	.005	7	6	.023
2	1.288	.113	.023	.006	8	5	.015
3	1.430	.091	.021	.006	10	5	.032
4	1.473	.095	.025	.007	13	7	.023
5	1.545	.145	.024	.007	7	5	.013
6	1.293	.087	.022	.006	7	5	.015
7	1.572	.084	.023	.007	9	5	.025
8	1.413	.130	.025	.008	9	5	.024
9	1.300	.126	.023	.008	6	5	.021
10	1.560	.120	.025	.007	12	6	.020

Series of heights: 1.288, 1.293, 1.300, 1.398, 1.413, 1.430, 1.473, 1.545, 1.560, 1.572. Arithmetic mean = 1.427.

Length of spikes, ♀: .084, .087, .090, .091, .095, .113, .120, .126, .130, .145. Arithmetic mean = .108.

Breadth of spikes, ♀: .021, .022, .023, .024, .025. Arithmetic mean = .023.

THIRD SERIES. *Typha angustifolia* FROM STOCKTON LAKE SHORE (POSITION III.) AT HEAD OF LAKE. SP. GR. 1.005.

No.	Height of Plant.	Length of Spike, ♀.	Breadth of Spike, ♀.	Width of Third Leaf from Top.	No. of Leaves.		Sterile Part.
					Dry.	Green.	
1	2.026	.164	.023	.009	8	7	.016
2	2.108	.162	.025	.010	10	7	.024
3	1.862	.154	.018	.011	9	5	.016
4	1.882	.146	.022	.010	7	6	.026
5	1.803	.169	.022	.010	9	7	.031
6	1.789	.141	.025	.011	8	8	.022
7	1.668	.161	.020	.009	8	6	.027
8	1.678	.138	.021	.008	10	6	.c28
9	1.920	.182	.024	.009	7	7	.030
10	1.815	.166	.026	.008	6	6	.012

Series of heights: 1.668, 1.678, 1.789, 1.803, 1.815, 1.862, 1.882, 1.920, 2.026, 2.108. Arithmetic mean = 1.885.

Length of spikes, ♀: .138, .141, .146, .154, .161, .162, .164, .166, .169, .182. Arithmetic mean = .158.

Breadth of spikes, ♀: .018, .020, .021, .022, .023, .024, .025, .026. Arithmetic mean = .022.

If we take the arithmetic means of the plant heights, lengths of pistillate spike portions and breadths of pistillate spike portions of the thirty plants taken from three separate localities along the shores of Stockton Lake, we will appreciate the influence of the saline conditions of the soil upon the relative size of the plants of these three sets.

MEAN DIMENSIONS OF 30 PLANTS.

	Height of Plant.	Length of Spike, ♀.	Breadth of Spike, ♀.	Sp. Gr.
Position I.	1.066	.089	.019	1.0145
Position II.	1.427	.108	.023	1.0140
Position III.	1 855	.158	.022	1.0050

This table clearly shows that the cat-tails in fresh water are much taller than those growing under more saline conditions, and this applies not only to the heights of the plants, but to the other dimensions as well.

The next three series of *Typha angustifolia* were collected along the shores of Pleasure Bay under somewhat similar conditions to those along the shores of Stockton Lake.

FOURTH SERIES. *Typha angustifolia* IN SALT MARSH. SP. GR. 1.015.

No.	Height of Plant.	Length of Spike, ♀.	Breadth of Spike, ♀.	No. of Leaves.		Length of Sterile Part.
				Dry.	Green.	
1	.788	.110	.005	4	7	.025
2	.962	.209	.010	7	2	.035
3	.980	.100	.005	5	6	.040
4	.910	.119	.010	7	4	.035
5	.888	.135	.009	6	3	.020
6	.768	.096	.006	5	4	.063
7	.925	.120	.007	6	5	.100[8]
8	.857	.100	.009	6	4	.100[8]
9	1.005	.119	.006	3	6	.104[8]
10	.904	.130	.006	4	6	.010

Series of heights: .768, .788, .857, .888, .904, .910, .925, .962, .980, 1.005. Arithmetic mean = .898.

Length of spikes, ♀: .096, .100, .110, .119, .120, .130, .135, .209. Arithmetic mean = .127.

Breadth of spikes, ♀: .005, .006, .007, .009, .010. Arithmetic mean = .007.

FIFTH SERIES. *Typha angustifolia* NEAR MIDDLE PART OF UPPER PLEASURE BAY. SP. GR. 1.005.

No.	Height of Plant.	Length of Spike, ♀.	Breadth of Spike, ♀.	No. of Leaves.		Length of Sterile Part.
				Dry.	Green.	
1	.910	.102	.010	5	4	.029
2	1.030	.112	.012	6	4	.046
3	1.130	.128	.014	4	6	.034
4	.879	.090	.011	5	4	.027
5	.877	.089	.010	4	5	.042
6	.833	.087	.007	6	4	.045
7	.932	.081	.009	5	4	.040
8	1.102	.115	.014	5	5	.034
9	1.096	.114	.013	5	6	.030
10	1.180	.133	.015	5	5	.034

Series of heights: .833, .877, .879, .910, .932, 1.030, 1.096, 1.102, 1.130, 1.180. Arithmetic mean = .996.

Length of spikes, ♀: .081, .087, .089, .090, .102, .112, .114, .115, .128, .133. Arithmetic mean = .105.

Breadth of spikes, ♀: .007, .009, .010, .011, .012, .013, .014, .015. Arithmetic mean = .011.

[8] Measurements include sterile and staminate part of the spike.

Sixth Series. *Typha angustifolia* Collected at Head of Pleasure Bay. Sp. gr. 1.000.

No.	Height of Plant.	Length of Spike, ♀.	Breadth of Spike, ♀.	No. of Leaves.		Length of Sterile Part.
				Dry.	Green.	
1	1.564	.145	.015	5	8	.028
2	1.642	.193	.016	5	6	.040
3	1.430	.147	.020	6	5	.032
4	1.688	.117	.018	6	6	.035
5	1.543	.148	.019	6	6	.031
6	1.467	.134	.018	5	5	.052
7	1.615	.144	.019	6	7	.032
8	1.307	.148	.020	5	6	.030
9	1.632	.173	.016	7	6	.021
10	1.657	.182	.015	5	5	.026

Series of heights: 1.307, 1.430, 1.467, 1.543, 1.564, 1.615, 1.632, 1.642, 1.657, 1.688. Arithmetic mean = 1.554.

Length of spikes, ♀: .117, .134, .144, .145, .147, .148, .173, .182, .193. Arithmetic mean = .154.

Breadth of spikes, ♀: .015, .016, .018, .019, .020. Arithmetic mean = .018.

Constructing a table of means of the last three series, we discover that the heights of the cat-tails and the dimensions of the spike increase with the decrease in the salinity of the water.

Mean Dimensions of 30 Plants.

	Height of Plant.	Length of Spike, ♀.	Breadth of Spike, ♀.	Sp. Gr.
Position IV.	.898	.127	.007	1.015
Position V.	.996	.105	.011	1.005
Position IV.	1.554	.154	.018	1.000

Now, if we combine the two tables which demonstrate the mean dimensions of the sixty measured plants collected from six widely diverse positions, we will see at a glance that *Typha angustifolia* when found in soil with saline conditions, as indicated by the specific gravity of the soil water, is reduced in size compared with other plants growing under more, or less, fresh-water conditions. All of the dimensions of the plants are influenced, but not in corresponding proportions, and it is also noteworthy that the cat-tails in a more saline soil are not only smaller in size, but show a more yellowish-green appearance than the taller, darker green plants controlled by fresh water.

Table Showing Influence of Salinity of Water on the Dimensions of Sixty Plants of *Typha angustifolia*. Measurements in Meters.

Habitat.	Position.	Specific Graivty.	Height of Plants.	Mean Height of Plants.	Length of Spikes, ♀.	Mean Length of ♀ Spikes.	Breadth of Spikes, ♀.	Mean Breadth of ♀ Spikes.
Most saline	I.	1.0145	1.066	.982	.089	.108	.019	
	IV.	1.0150	.898		.127		.007	.013
Medium saline.	II.	1.0140	1.427	1.211	.108	.106	.023	
	V.	1.0050	.996		.105		.011	.017
Fresh water.	III.	1.0050	1.855	1.710	.158	.156	.022	
	VI.	1.0000	1.554		.154		.018	.020

Having presented the results obtained by using the hydrometer without the attached thermometer, it next concerns this paper to discuss and tabulate the results obtained by the hydrometer so constructed as to combine with the hydrometer scale a thermometer, whereby density and temperature can be estimated at the same time. This enables us then to reduce all of our specific gravity determinations to the uniform temperature of 15° C., so that the second series of observations are far more accurate as giving the actual salinity of the water which bathes the roots of a number of typic salt marsh plants. In all of the following data, the corrected specific gravity determinations are placed within brackets.

Observations with Hydrometer and Attached Thermometer.

The numbered data given below were collected at three localities convenient to Belmar, N. J., easily reached by trolley, viz., Manasquan Inlet, Wreck Pond and Shark River. The same plan was adopted of working from the most saline conditions of environment to the least saline conditions and the gradual change of the vegetation will be noted, if we follow the sequence of the numbered stations at which hydrometric readings were made.

81. Salt water in north arm Manasquan River. Thoroughfare fringed with *Spartina stricta maritima* and *Salicornia herbacea*. Sp. gr. 1.016; temp. 26°. [Sp. gr. 1.0188.]

71. Salt Creek at bridge back of Manasquan Life Saving Station. Meadow sod is here 45 cm. deep, with sand below. Sp. gr. 1.0155; temp. 23°. [Sp. gr. 1.0174.]

72. Salt Creek, nearer Manasquan Inlet, below the bridge. Here is *Spartina stricta maritima* associated with *Salicornia herbacea*. Sp. gr. 1.0160; temp. 23°. [Sp. gr. 1.0179.]

73. Hole dug in middle of *Spartina patens* association. Water reached at 82 cm. At same level of the marsh, but in a slightly different position were found *Salicornia herbacea* and *Limonium carolinianum*. Sp. gr. 1.018; temp. 21°. [Sp. gr. 1.0194.]

74. Hole dug in the middle of a patch of *Salicornia herbacea*, surrounded by *Distichlis spicata*, *Limonium carolianum*. No free water obtained after digging to a depth of 82 cm.

75. Water from ditch cut through *Spartina stricta maritima*, *Spartina patens*, *Salicornia herbacea*. Sp. gr. 1.017; temp. 20°. [Sp. gr. 1.0182.]

76. Hole 56 cm. deep in association of *Spartina stricta maritima*, *Salicornia herbacea*, *Distichlis spicata*. Sp. gr. 1.0175; temp. 19°. [Sp. gr. 1.0184.]

77. Small marsh pool (7 cm. deep) with *Spartina stricta maritima*, *Salicornia herbacea*, *Spartina patens*. The high specific gravity of the water in this pool due to strong evaporation. Sp. gr. 1.026; temp. 29°. [Sp. gr. 1.02996.]

78. At head of drainage ditch with *Spartina patens*. Sp. gr. 1.015; temp. 22°. [Sp. gr. 1.0166.]

79. Hole in *Juncus Gerardi* association which fringes *Spartina patens* inwardly and touches an association of *Baccharis halimifolia*, *Panicum virgatum*, *Solidago sempervirens*.

80. At head of drainage ditch with *Juncus Gerardi* (as in 79). Sp. gr. 1.0165; temp. 19°. [Sp. gr. 1.0174.]

82. Water from a drainage ditch in *Juncus Gerardi* association. Soil 49 cm. deep. Sp. gr. 1.0105; temp. 21°. [Sp. gr. 1.0117.]

The observations at Wreck Point were made on August 13, 1909, six days after the inlet, which had been closed for some time, was opened. The first three tests were made of the water from the pond proper without relating them to the nearby vegetation.

83. Water at trolley bridge. Sp. gr. 1.0090; temp. 20°. [Sp. gr. 1.0102.]

84. Water at railroad bridge. Sp. gr. 1.0020; temp. 20°. [Sp. gr. 1.0029.]

85. Water at carriage bridge. Sp. gr. 1.0010; temp. 20°. [Sp. gr. 1.0019.]

87. Water in *Spartina stricta maritima* association at high tide, just above the railroad bridge. Sp. gr. 1.0140; temp. 25°. [Sp. gr. 1.0164.]

88. Water in *Spartina stricta maritima* association at high tide, at carriage bridge. Sp. gr. 1.0030; temp. 23°. [Sp. gr. 1.0046.]

86. Stream entering Wreck Pond at tension line between salt marsh and fresh-water marsh at low tide. Here were found *Spartina stricta maritima* in broken patches being gradually replaced by *Scirpus lacustris, Scirpus pungens* and *Spartina polystachya.* Sp. gr. 1.0000; temp. 18°. [Sp. gr. 1.0005.]

89. Water in *Spartina stricta maritima* association along high bank fronted with *Panicum virgatum.* Sp. gr. 1.0000; temp. 22°. [Sp. gr. 1.0014.]

The observations begun on Shark River were delayed by a severe northeast shifting to southeast storm, August 17, 1909, so that the tides were exceptionally high and all of the typic salt marsh plants along Shark River were submerged. Unusual opportunities were presented, therefore, to determine the salinity of the water which flooded the salt marsh species.

93. Frontal association of *Spartina stricta maritima* near opening of the inlet. Sp. gr. 1.0205; temp. 20°. [Sp. gr. 1.0217.]

94. Somewhat back from inlet water covering *Spartina stricta maritima, Solidago sempervirens.* Sp. gr. 1.020; temp. 20°. [Sp. gr. 1.0212.]

95. All of the salt marsh associations of plants on the Belmar side of Shark River, such as *Spartina patens, Juncus Gerardi, Salicornia herbacea,* including *Atriplex hastata* and *Myrica carolinensis,* submerged excepting the tops of *Spartina stricta maritima* and the low sand dunes on which grow *Ammophila arenaria, Baccharis halimifolia, Solidago sempervirens.* Sp. gr. 1.0215; temp. 19°. [Sp. gr. 1.0224.]

97. Some distance back from the inlet along Fifth Avenue, Belmar, the following plants were found submerged: *Scirpus pungens, Cicuta maculata, Hibiscus moscheutos, Panicum virgatum,*

Baccharis halimifolia. Sp. gr. 1.011; temp. 19°. [Sp. gr. 1.0118.]

It will be seen by reference to the above observations that even the least typic of the salt marsh species which usually grow subjected to the influence of fresh water are placed occasionally under more trying conditions during exceptionally severe storms, when they are subjected to the action of almost pure sea water. On August 19, 1909, the storm having subsided, the normal flow of the tide in and

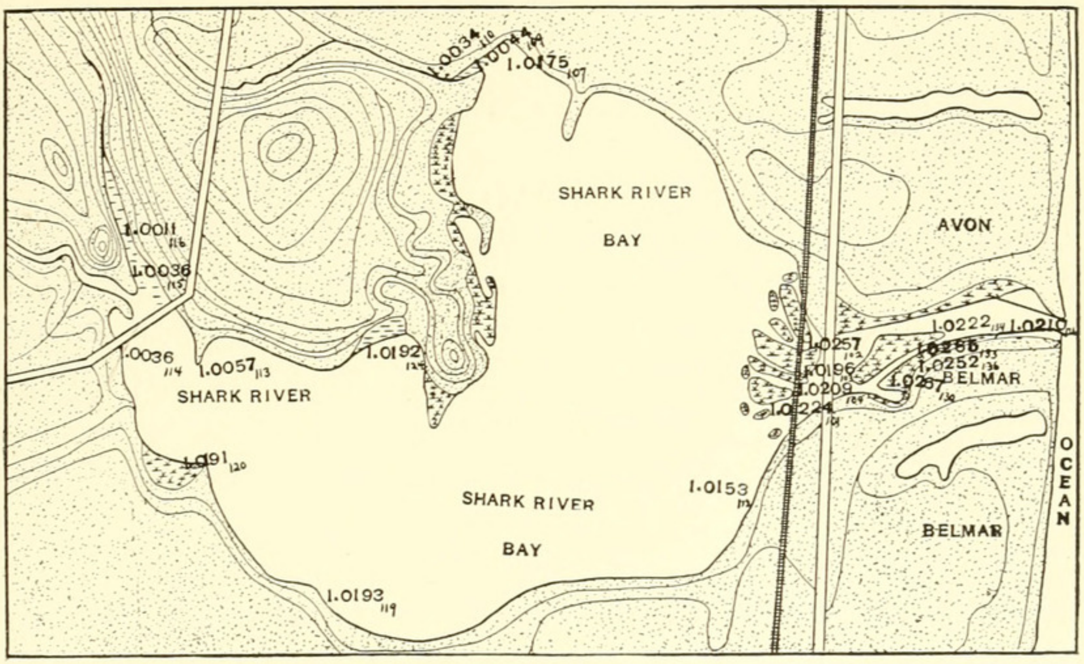

Fig. 4. Map of Shark River and Bay, N. J., showing stations at which hydrometric determinations of the salinity of the water were made. Numbers indicate specific gravities at the points directly under the first figure and the subnumbers indicate the observational stations as noted in the paper and in the original field note-book.

out of the inlet was reëstablished and the following series of observations were then made.

126. Water from lagoon inside jetty at Shark River Inlet at high tide. Sp. gr. 1.0190; temp. 23°. [Sp. gr. 1.0210.]

127. Hole dug 20 cm. deep in an association of *Scirpus pungens, Solidago sempervirens, Spartina patens, Atriplex hastata, Suaeda maritima.* Water rising from a sandy gravel. Sp. gr. 1.0010; temp. 21°. [Sp. gr. 1.0022.]

130. Water from a hole 46 cm. deep in an association of *Juncus*

Gerardi, Limonium carolinianum. Sp. gr. 1.0255; temp. 20°. [Sp. gr. 1.0267.]

131. Water from hole 28 cm. deep in an association of *Distichlis spicata, Salicornia herbacea.* Sp. gr. 1.0065; temp. 20°. [Sp. gr. 1.0075.]

133. Water from a hole 50 cm. deep in a *Spartina stricta maritima* association. At 20 cm. a hard pan of gravel stones was reached, then a layer of sand was passed and at the bottom a hard gravel layer. Sp. gr. 1.025; temp. 21°. [Sp. gr. 1.0265.]

134. Water from Shark River. Sp. gr. 1.0205; temp. 22°. [Sp. gr. 1.0222.]

135. Water from a ditch along back of Shark River marsh, Belmar side, lined with *Spartina stricta maritima, Spartina patens, Salicornia herbacea.* Sp. gr. 1.0015; temp. 20°. [Sp. gr. 1.0024.]

136. Water from hole in marsh 61 cm. deep at the base of a clump of *Baccharis halimifolia* associated with *Distichlis spicata, Aster tenuifolius, Salicornia herbacea, Limonium carolinianum.* Top soil brown and loose, subsoil sandy. Sp. gr. 1.024; temp. 20°. [Sp. gr. 1.0252.]

137. Water covering surface of the marsh in middle of a *Distichlis spicata* association with *Spartina stricta maritima, Salicornia herbacea, Limonium carolinianum.* Sp. gr. 1.0245; temp. 27°. [Sp. gr. 1.0278.]

138. The last test recorded here was to determine if there was any difference in the salinity of the water between ebb and flow. Tide receding rapidly. Sp. gr. 1.0215; temp. 20°. [Sp. gr. 1.0238.]

101. Shark River Bay water in channel through salt marsh bounded by *Spartina stricta maritima* and *Spartina juncea.* Sp. gr. 1.021; temp. 21°. [Sp. gr. 1.0224.]

102. Hole dug in marsh 30 cm. deep in an association of *Spartina stricta maritima, Limonium carolinianum, Salicornia herbacea.* Sp. gr. 1.0245; temp. 20°. [Sp. gr. 1.0257.]

103. Hole dug in marsh 30 cm. deep in an association of *Distichlis spicata* and *Limonium carolinianum.* Sp. gr. 1.0185; temp. 20°. [Sp. gr. 1.0196.]

104. Hole dug 20 cm. deep in a pure association of *Juncus Gerardi.* Sp. gr. 1.0195; temp. 21°. [Sp. gr. 1.0209.]

107. Water at head of north arm of Shark River Bay (see map, Fig. 4) in middle of an association of *Spartina stricta maritima* and *Spartina patens*. Sp. gr. 1.0150; temp. 25°. [Sp. gr. 1.0175.]

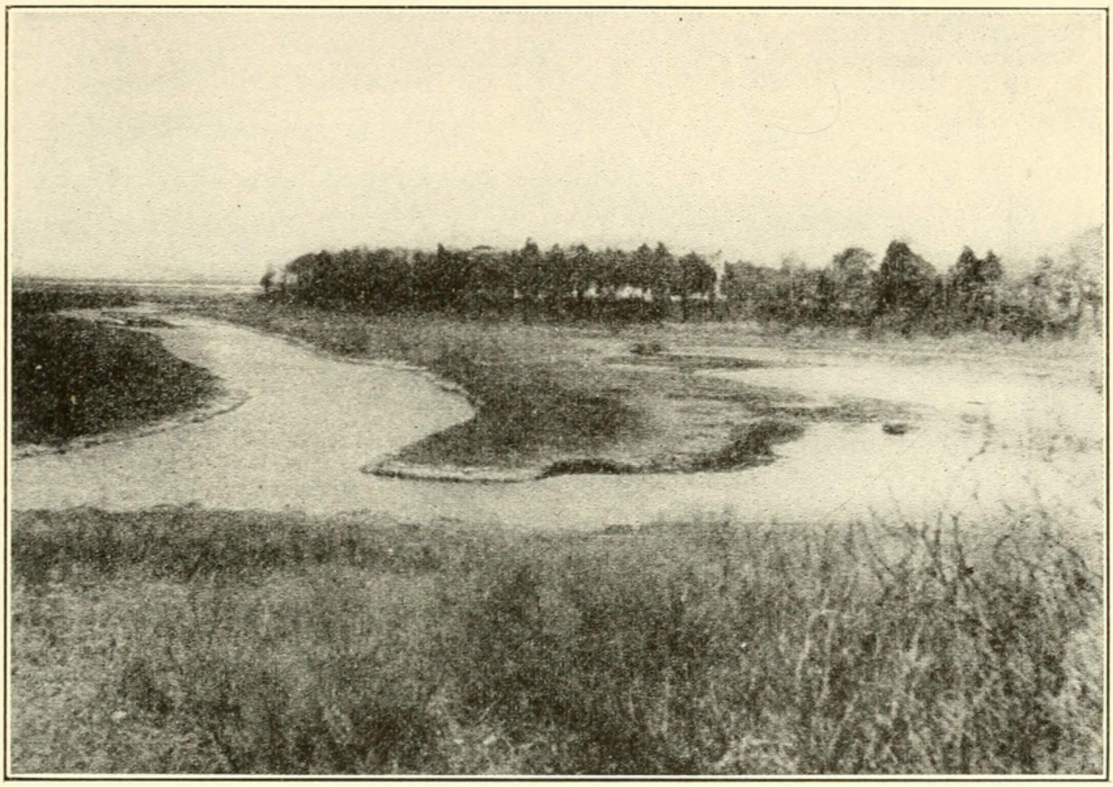

FIG. 5. View of salt marsh island fringed with *Spartina stricta maritima* and covered by associations of *Spartina patens, Juncus Gerardi, Distichlis spicata,* etc. Shark River, New Jersey.

109. Contracted portion of the north arm of Shark River Bay, where *Spartina stricta maritima* breaks up into patches between which grow *Scirpus pungens, Spartina patens* and *Nymphæa odorata*. Sp. gr. 1.0025; temp. 24°. [Sp. gr. 1.0044.]

110. Water at base of a patch of *Spartina polystachya*. Sp. gr. 1.0025; temp. 20°. [Sp. gr. 1.0034.]

112. Water from hole 20 cm. deep at the base of an association of *Phragmites communis* (see Fig. 4). Sp. gr. 1.0010; temp. 28°. [Sp. gr. 1.0153.]

113. Water in upper portion of the south arm of Shark River Bay. Sp. gr. 1.0035; temp. 25°. [Sp. gr. 1.0057.]

114. Water from middle of *Spartina stricta maritima* associa-

tion, south arm of Shark River Bay at carriage bridge. Sp. gr. 1.0015; temp. 25°. [Sp. gr. 1.0036.]

115. Water from last extensive patch of *Spartina stricta maritima* merging with *Typha angustifolia*. Sp. gr. 1.0000; temp. 23°. [Sp. gr. 1.0016.]

116. Water tested at the head of the south arm of Shark River Bay (Fig. 6), where the vegetation becomes continuous and the patches of *Spartina stricta maritima* are divided by narrow lines of *Scirpus fluviatilis, Typha angustifolia, Zizania aquatica*, touching a forest growth of *Nyssa sylvatica, Sassafras variifolium, Pinus*

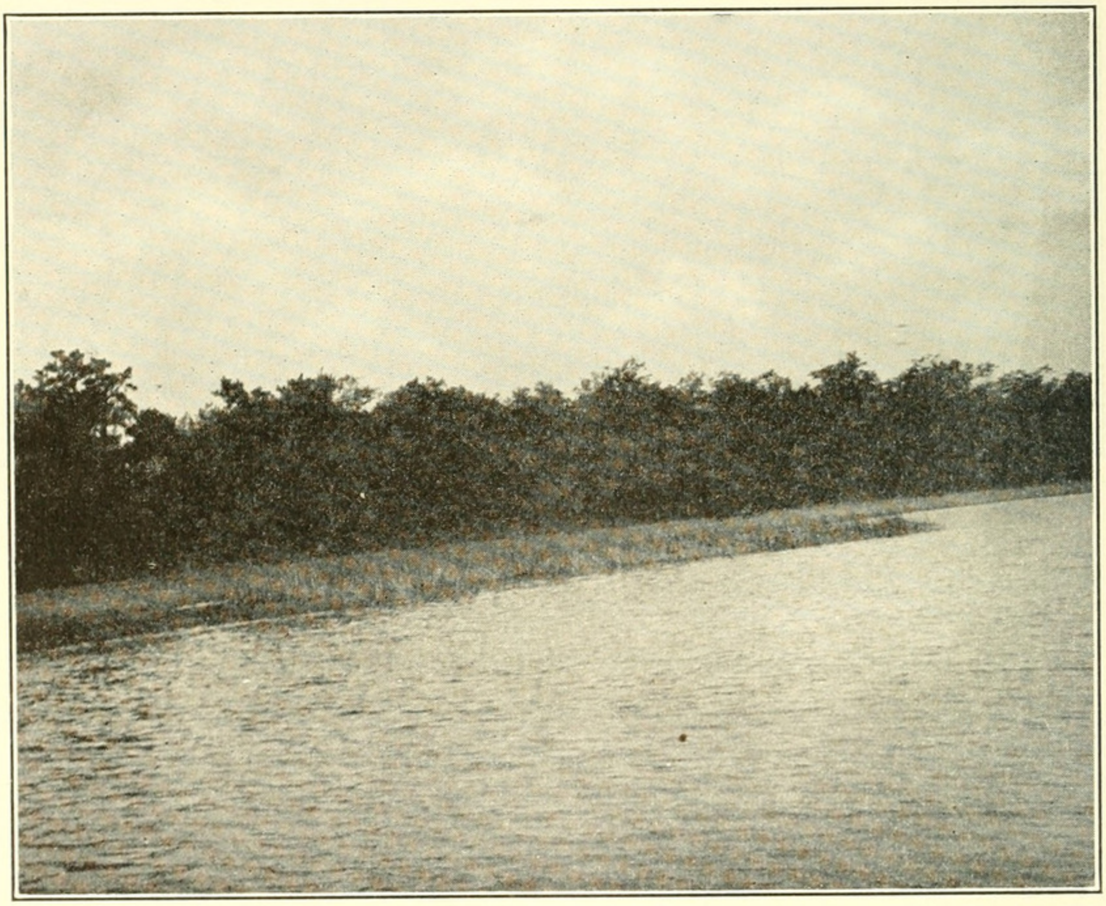

Fig. 6. Association of *Spartina stricta maritima* in upper part of the south arm of Shark River Bay, showing blending and transition of salt-water and fresh-water vegetation.

rigida, Quercus prinus, Q. alba. Sp. gr. 0.9990; temp. 25°. [Sp. gr. 1.0011.]

119. Water 60 cm. deep at a point along south shore of Shark

River Bay with *Vallisneria spiralis* abundant. Sp. gr. 1.0165; temp. 26°. [Sp. gr. 1.0193.]

120. Hole dug in a marsh at base of a clump of *Peltandra virginica*. Sp. gr. 1.016; temp. 27°. [Sp. gr. 1.0191.]

124. Water from a marsh lagoon at base of a steep bluff subjected to evaporation between the daily tides. Lagoon surrounded by *Spartina stricta maritima*. Sp. gr. 1.0155; temp. 29°. [Sp. gr. 1.0192.]

Fig. 7. Clump of *Panicum virgatum* growing along shore of Stockton Lake controlled by fresh water.

The above observations give the geographic data upon which the study of the distribution of the salt marsh species has been based. It will be seen that proceeding from the ocean up the various bays and inlets there is a general decrease in the saltiness of the controlling water as revealed by the use of the hydrometer and the amount of salt which controls in general the habitats of the several species is graphically shown in the sketch map until a point is reached where the salt marsh vegetation mingles with that of the fresh water marshes until it is gradually replaced by vegetation controlled by fresh water (Fig. 7).

Sequence of Hydrometric Readings.

It is important to give now in sequence the various specific gravities corrected to 15° C. to which readings are appended, the name of the plant or the names of the plants subjected to that specific density of salt water. The subnumber indicates in all cases the number of the observation in the series previously given.

1.02996_{77} *Spartina stricta maritima, Spartina patens, Salicornia herbacea.*

1.02780_{137} *Distichlis spicata, Spartina stricta maritima, Salicornia herbacea, Limonium carolinianum.*

1.02670_{130} *Juncus Gerardi, Limonium carolinianum.*

1.02650_{133} *Spartina stricta maritima, Limonium carolinianum.*

1.02570_{102} *Spartina stricta maritima, Limonium carolinianum, Salicornia herbacea.*

1.02520_{136} *Baccharis halimifolia, Aster tenuifolius, Salicornia herbacea, Limonium carolinianum, Atriplex hastata.*

1.0224_{101} *Spartina stricta maritima, Spartina patens,* ocean water from surf at Belmar.

1.0224_{136} water in thoroughfare.

1.02170_{93} water at high tide. Shark River Inlet, covering base of *Spartina stricta maritima.*

1.02090_{104} *Juncus Gerardi.*

1.01960_{103} *Spartina patens, Salicornia herbacea, Limonium carolinianum.*

1.01930_{119} *Vallisneria spiralis.*

1.01920_{124} *Spartina stricta maritima.*

1.01910_{118} *Spartina stricta maritima, Scirpus pungens.*

1.01910_{120} *Peltandra virginica.*

1.01880_{81} water in channel connecting Manasquan River and Stockton Lake fringed with *Spartina stricta maritima, Salicornia herbacea.*

1.01820_{75} *Spartina stricta maritima, Spartina patens, Salicornia herbacea.*

1.01800_{132} *Spartina stricta maritima.*

1.01790_{72} *Spartina stricta maritima, Salicornia herbacea.*

1.01750_{107} *Spartina stricta maritima, Spartina patens, Distichlis spicata.*

1.01740_{80} *Juncus Gerardi.*

1.01660_{78} *Spartina patens.*

1.01640_{87} *Spartina stricta maritima.*

1.01530_{112} *Phragmites communis.*

1.01170_{82} *Juncus Gerardi.*

1.00750_{131} *Distichlis spicata, Salicornia herbacea.*

1.00650_{140} *Scirpus maritima, Pluchea camphorata.*

1.00490_{128} *Spartina stricta maritima, Spartina patens.*

1.00460_{88} *Spartina stricta maritima.*

1.00440_{109} *Spartina stricta maritima, Spartina patens, Scirpus pungens, Nymphæa odorata.*

1.00360_{114} *Spartina stricta maritima.*

1.00340_{110} *Spartina polystachya.*

1.00240_{135} *Spartina stricta maritima, Spartina patens, Salicornia herbacea.*

1.00240_{125} *Spartina stricta maritima.*

1.00220_{127} *Scirpus pungens, Solidago sempervirens, Atriplex hastata, Spartina patens, Suaeda maritima.*

1.00160_{116} *Spartina stricta maritima, Typha angustifolia.*

1.00160_{117} *Phragmites communis.*

1.00140_{89} *Panicum virgatum, Spartina stricta maritima.*

1.00140_{91} *Scirpus lacustris, Scirpus pungens, Spartina polystachya.*

1.0118_{97} *Hibiscus moscheutos.*

1.00110_{116} *Scirpus fluviatilis, Zizania aquatica, Typha angustifolia.*

1.00050_{86} *Spartina polystachya, Scirpus lacustris, Scirpus pungens, Spartina stricta maritima.*

1.00040_{108} iron-sulphur spring water.

Sequence of Salt Marsh Plants Arranged According to Maximum Density of Salt Water.

In order to make what follows more general and intelligible, the specific gravity of saline solutions at 15° C. and the corresponding percentages of sodium chloride in solution is displayed in the following table for converting specific gravities of salt solutions into per cent. of sodium chloride taken from Landolt-Börnstein, "Physikalisch-Chemische Tabellen," p. 322.

Per Cent.	$d\frac{15^\circ}{4^\circ}$	Per Cent.	$d\frac{15^\circ}{4^\circ}$
0.5	1.0034	3.0	1.0209
1.0	1.0064	3.5	1.0246
1.5	1.0100	4.0	1.0282
2.0	1.0137	4.5	1.0319
2.5	1.0173	5.0	1.0355

Now, if we place the salt marsh plants according to their ability to withstand degrees of salinity of water, we can appreciate better the factors which control their distribution in the bays and estuaries of the New Jersey coast. The first figures show the greatest degree of salinity to which the various species are subjected and the second number indicates the limit toward the fresh water end of the series. The range varies in the different species to a marked extent.

Spartina stricta maritima 1.02996–1.00140
Spartina patens 1.02996–1.00220
Salicornia herbacea 1.02996–1.00240
Distichlis spicata 1.02780–1.00750
Limonium carolinianum 1.02780–1.01940
Juncus Gerardi 1.02670–1.01170
Baccharis halimifolia 1.02520–
Aster tenuifolius 1.02520–
Atriplex hastata 1.02520–1.00220
Ocean water, Belmar 1.02240–
**Vallisneria spiralis* 1.01930–1.00000
Scirpus pungens 1.01910–1.00000
**Peltandra virginica* 1.01910–1.00000
**Phragmites communis* 1.01530–1.00160
**Hibiscus moscheutos* 1.01180–1.00500
Pluchea camphorata 1.00650–

Nymphæa odorata 1.00440–1.00000
Spartina polystachya 1.00240–1.00350

Solidago sempervirens	1.00220–
Suaeda maritima	1.00220–
Typha angustifolia	1.00160–1.00110
Panicum virgatum	1.00140–
Scirpus lacustris	1.00140–1.00050
Scirpus fluviatilis	1.00110–
Zizania aquatica	1.00110–1.00000

All of the plants *above the line* are able to withstand a maximum of over 1 per cent. of sodium chloride in the salt water, and may be reckoned as the true salt marsh species, while *Vallisneria spiralis, Hibiscus moscheutos, Phragmites communis,* and *Peltandra virginica* are excluded, because their habitat is frequently an inland, not a salt marsh one. All below the line, according to the accurate data presented for the first time, are not able to grow in salt water the sodium chloride content of which approximates 1 per cent.[9]

By this arrangement we are able to segregate the plants found on the New Jersey salt marshes, for although apparently occupying the same geographic position and growing under similar conditions of environment, yet we can divide them into salt marsh species, those that are adapted to a saline soil with from 1–4 per cent. of sodium chloride, and those less well adapted to a saline soil, but which are to be classed among the plants found in fresh-water swamps. Occasionally, as the list shows, we will meet with such non-saline plants in a typic saline environment. This is to be explained as in the cases of *Vallisneria spiralis, Hibiscus moscheutos, Phragmites communis,* and *Peltandra virginica* by their adaptation to more saline conditions. Again there are fresh-water marsh species found on salt marshes, but their presence is to be explained by the fact revealed by the hydrometer, that while the surface marsh soil may be strongly saline, the subsoil is controlled by fresh water which flows outward from the higher ground under the salt marsh sod. Into the subsoil controlled by fresh water the roots of a number of plants of fresh-water habitat grow, notwithstanding the fact that they are growing in the middle of a salt marsh. Appearances here are deceptive and the peculiar behavior of these plants perplexed me until the hydrometer showed the reason for the presence

[9] See preceding table of percentages and specific gravities with which the above figure may be compared.

of such plants on the salt marsh. The first eleven plants of the preceding list may be looked upon as true saline species, while the other plants of the list are those which are typically found under fresh-water conditions of environment. These plants have accommodated themselves to a soil of some salinity as tested by the hydrometer. On the other hand, the degree of accommodation of the typic salt marsh species is indicated. The following show the widest range of accommodation: *Spartina stricta maritima, Spartina patens, Juncus Gerardi,* while *Salicornia herbacea, Distichlis spicata, Limonium carolinianum* show a small range of accommodation. As a result one is justified perhaps in believing that this difference in the degree of accommodation accounts in part[10] for the general and controlling distribution of *Spartina stricta maritima, Spartina patens* and *Juncus Gerardi,* which are most prevailingly present in the salt marshes of the Atlantic coast, while *Salicornia herbacea, Limonium carolinianum,* with less power of accommodation and smaller size, are rarely controlling, but form small associations, or are intermingled with the other salt marsh species. The salt grass *Distichlis spicata,* although it never grows in areas of great extent, yet is usually found where it grows in nearly exclusive association. This power of accommodation seems to be an inherent property of protoplasm and it varies within wide limits for different kinds of plants. The lower plants seem to have a greater power of accommodation, the higher plants a less degree. Professor G. J. Peirce, of Stanford University, has undertaken to study the behavior of some ponds on the flat shore of San Francisco Bay into which salt water is pumped for the manufacture of salt. The water evaporates during the dry season, leaving an accumulation of salt on the bottom and sides of these ponds, and from a minimum specific gravity of 1.06000 in the rainy season the concentration rises in the course of three or four months until the specific gravity reaches 1.22500. A small crustacean (*Artemia*) and the larvæ of some flies are the only animals living in these brines, but there are unicellular plants, bacteria of various sorts, chromogenic and other kinds, *Chlamydomonas*-like

[10] The vegetative habits of these plants with powerful rootstocks and methods of seed distribution must also be considered as important factors.

algæ, both green and brown, which are found in various stages of their existence at different times in these ponds.[11]

Sections of Salt Marsh Soil.

A detailed study of the various salt marsh soils along the New Jersey coast was begun coincidently with a study of the salt content of the soil by means of the hydrometer, but these observations have not been carried to completion. A few notes on some of the conditions observed may not be out of place. Taking a sample of the muck soil in the middle of an area of the Manasquan salt marsh covered with *Spartina patens*, we find its total depth to be about 104 cm. From this a block of peat was cut 57 cm. thick. The first 21 cm. at the top was of one color, consisting of 12 cm. of a fibrous root material and 9 cm. of a less strongly fibrous layer. The first 12 cm. represent the remains of the cover plant, for this part gave rise to new plants of *Spartina patens* when the soil was laid flat along the side of the cut. Below these upper fibrous layers followed a lighter brown fibrous layer, 14 cm. thick, and then 7 cm. of a black fiberless layer followed by 16 cm. of a brown fibrous layer where the hollow pipe-stem-like remains of the rootstocks of *Spartina stricta maritima* occur. This section of peat clearly indicates a succession of vegetation types. The marsh deposits began in submerging salt water, because the remains of *Spartina stricta maritima* are found in the lower layers. Then sand and clay material was deposited on which *Spartina patens* began to build up successive layers of peat. This was formerly explained by a change of coast line, but the suggestions of Johnson (see *ante*) that it may indicate a change of tidal level seems to be worthy of consideration in a study of the deposits of peat in the salt marshes of New Jersey, where the coast line is under constant change so as to profoundly influence the height of the tides in the rivers and embayments along the shore.

Economic Considerations.

The salinity of the water, which can be determined by the hydrometer, is the determining factor in the distribution of salt marsh

[11] MacDougal, D. T., "Annual Report of the Director," Dept. Bot. Research Carnegie Institution of Washington, 1910, 56.

plants, although the texture of the soil, its aëration and the lines of marsh drainage are influential factors. In the reclaiming of these salt marshes, as has been done so successfully along the Bay of Fundy[12] in Nova Scotia, the hydrometer affords a ready means of determining accurately what amelioration has been secured by ditch drainage. The same method of research can be applied to the study of the alkali soils in many parts of the world, especially in our western states, and the farmer can test the presence or absence of salts and their relative amounts in the soil.

Some years ago Scofield[13] determined the salt-water limits of wild rice, with a view to ascertaining the areas which could be successfully devoted to the cultivation of this valuable but long-neglected food grass. After investigations by means of the electric bridge along Chesapeake Bay and the Potomac River, Scofield assumed that the salt-water limit of wild rice is approximately represented by 0.03 of the normal solution of sodium chloride, while the concentration of the water of Chesapeake Bay is about 0.28 of a normal solution of sodium chloride. So that in establishing cultures of wild rice along the coast streams it is highly important that the concentration of the water covering these areas be determined either by the electric method or by the hydrometer, which is simple and equally applicable. Similarly Fraps[14] determined that 0.3 per cent. of salt is dangerous to the true rice plant where rice farms along the coast are supplied with water pumped from streams occasionally subjected to salt water influences.

The distribution of animals is also profoundly influenced by the salinity of the water. Occasionally extensive oyster beds are ruined by flooding with fresh water, and the oysterman can readily determine the influential density of the water which covers his submerged plantation by means of the hydrometer. Two years ago the following was printed in the Trenton *Evening Times* of Friday, August

[12] Harshberger, John W., "The Reclamation and Cultivation of Salt Marshes and Deserts," *Bulletin Geographical Society of Philadelphia*, July, 1907.

[13] Scofield, Carl S., "The Salt Water Limits of Wild Rice," Bull. 72. U. S. Bureau of Plant Industry, 1905.

[14] Traps, G. S., "The Effect of Salt Water on Rice," Texas Agricultural Experiment Station, Bull. 122, June, 1909.

27, 1909, and this excerpt shows the bearing of this study upon the Delaware River fisheries. I quote in full:

Millions of crabs are moving up the Delaware River from the sea. Their coming is due to the protracted drought, which has reduced the downward strength of the current in the river and caused the saline waters of the Atlantic to reach the harbor of Philadelphia. For the first time in many years the Delaware River is brackish as far as Gloucester, the result of which is that mullet, sea bass and porpoises may be seen every day above Chestei. The crabs which are the kind generally caught off the coast are to be found everywhere from the Delaware Breakwater to Philadelphia. For the first time on record, a big catch was made yesterday off the Point House piers, below Greenwich Point in the lower section of the city. Oldmans Creek, Raccoon Creek on the New Jersey side of the river and other tributaries of the river are alive with fish and crabs, and every day fishermen are bringing to market big hauls made in sight of Dock Street market.

Boilers on river steamboats have to be watched carefully, as the salt in the water causes constant foaming and more than ordinary diligence is required by marine engineers to prevent serious results to vessels for which they are responsible.

In the latter case the use of an hydrometer, or salinometer would indicate the dilution at which the foaming in the boilers no longer took place and thus its use in such emergencies of navigation becomes of great importance.

In the following bibiliography not all of the papers cited deal directly with salt marshes, but they treat of the influence of saline solutions in general upon animals and plants. In this list will be found many important papers which represent the most modern expression of opinion upon the accommodation of organisms to varying degrees of saline concentration.

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EXPLANATION OF PLATES.

Plate XX.

Fig. A. Typic salt marsh near Avalon, N. J., showing prominent growth of salt marsh grass, *Spartina stricta maritima,* fringing open thoroughfare and low sand dunes covered with red cedar, *Juniperus virginiana,* in the distance.

Fig. B. Salt marsh near Avalon, N. J., intersected by tortuous channels at head of a bay blending with the deciduous forest in the center and left.

Plate XXI.

Salt marsh at Somers Point, N. J., with open channel blending with an association, or strip of switch grass, *Panicum virgatum,* which fronts a forest growth of red cedar, *Juniperus virginiana,* holly, *Ilex opaca,* and pitch pine, *Pinus rigida.*