SALINITY DATA ON MARINE AND INLAND WATERS AND PLANT DISTRIBUTION

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In October, 1952, the editor of the Hand Book on Biological Data, Dr. E. C. Albritton, wrote me a letter in which he said ' on the strength of several recommendations I am writing to ask you to prepare certain tabular data which are urgently needed for the Hand Book." The Hand Book, as most biologists know, is a reference work published by the American Institute of Biological Sciences and which is associated with the National Research Council in Washington, D. C.

Dr. Albritton went on to say that these data were needed in connection with studies on the general subject of tolerances of representative water-inhabiting plants to salt concentrations. This request came to me because of certain studies I had made in connection with salinity tolerance in the estuaries of streams entering the Gulf of Mexico and Long Island Sound, Bowman (1916, 1917, 1918). Accordingly, I went over my notes made in those waters almost 40 yrs. ago, and with extensive consultation of more recent work by other investigators, I was able to send the tables requested to the editor in Washington in the spring of 1953 in a preliminary form. In March, 1955, we had corrected the proof of the Condensed Table on Characteristics of Natural Salt Waters, and it is now ready when the new Edition of the Hand Book appears.

Since the tables are so condensed, the explanation of the data might well be enlarged into a short article. In the relationships of certain plants to the bodies of water discussed, this paper is therefore an expansion of the material represented in the table which necessarily could not include reference to plant species and other pertinent facts involved.

As a fundamental statement for this article, it may be observed that the water of the oceans of the world are remarkably constant in their chemical composition. It is the variation in salinity which is the subject discussed here.

Sea water is normally alkaline with a pH between 7.5 and 8.8. In bays where plant life may deplete the carbon dioxide or in enclosed areas of the ocean, as tidal pools where hydrogen sulphide is generated, the pH may fall to neutrality or even become acid. When the pH rises above 9.0, magnesium hydroxide and calcium carbonate are precipitated out of solution. Table 1 gives the average composition of sea water according to Mason (1952).

Salinity is defined as the total weight of dissolved solids in 1 kg. of sea water. Chlorinity is defined as the amount of grams of precipitated halides (Cl, Br, and I) as determined by precipitation with a silver salt from 1 kg. of sea water. Salinity can be calculated from the chlorinity or determined by the density of samples. They are expressed as g./kg. or parts per thousand o/oo.

In the open sea the salinity averages 35 o/oo and in all sea water the relative proportions of the various ions is constant. The standard chlorinity is 19. and all other constituents may be calculated from this constant. There are no significant regional variations in sea water.

The salinity also varies with temperature. As stated by Coleman (1950), temperature of the surface layers of the ocean is 30° F plus and the winter temperature 18° F.; the corresponding salinity 34.32 o/oo to 35 o/oo. Whereas the deeper water of the ocean with a winter temperature 21.5° to 22° F. may be 35 o/oo-37 o/oo. The abysmal depths with very low temperature 4° to 1° F. and pressure may reach a salinity of 40 o/oo–41 o/oo. The coldest and densest water on earth is formed under the Antarctic Ice Cap. It is called Antarctic Bottom Water since due to its weight it sinks and then creeps over the ocean floor. It is the bottom layer of almost all the main ocean basins.

The Arctic Ocean's Bottom Water is not so dense nor so cold as the Antarctic due to greater melting of polar ice in summer and the large volumes of fresh water from the Siberian rivers.

The salinity of the surface waters of the oceans varies with latitude to slight but appreciable degrees. The salinity at the equator is 35. Bordering this, in both hemispheres, is a belt with a salinity of 36. In the N. Hemisphere this belt is between the 20th and 40th parallels of latitude. In the S. Hemisphere it lies between the 10th and 30th parallels. Beyond these belts the salinity gradually decreases so that the 60th parallel N. Lat. it is 31 and at the 60th parallel S. Lat. it is 33. These variations of the surface salinity are due to metorological conditions. In equatorial regions there is less wind, excessive rains and high temperature all causing a moderate salinity. In the belts the fairly high temperature induces evaporation but it is enhanced by strong trade winds and less rain so the

TABLE 1

Composition of average sea water. Ion Cl. 19%

	Salinity	Percent
Cl.	18.980	55.04
Br.	0.065	0.19
SO	2.649	7.68
HCO_3	0.140	0.41
F.	0.001	0.00
H_3BO_3	0.026	0.07
Mg.	1.272	3.69
Ca.	0.400	1.16
Sr.	0.013	0.04
K.	0.380	1.10
Na.	10.556	30.61
Total	34.482	99.99

salinity is highest here. Towards the poles the salinity gradually decreases due to the decrease in evaporation and temperature and to the dilution caused by melting snow which by its low density tends to remain on the surface. Table 2 as published by Marmer, (1930), shows the salinities of special areas of the ocean.

The Red Sea's salinity is due to high temperature, great evaporation and little addition of fresh water. On the other hand the Gulf of Finland is almost fresh water due to the large volume of precipitation and fresh waters poured into it. At the mouth of the Amazon the ocean water is potable for 100 mi. off shore, and off the Siberian Coast the Dwina, Obi, Mezen and other rivers keep the salinity down to 25.

PLANTS IN THE SEA AND THEIR DISTRIBUTION

No plants of the Seed-plant group occur in the deep oceans. However, about 30 genera of Seed-plants live in the oceans fairly close to shores and at depths of 10 to 40 ft. depending upon the light penetration of the water. These genera fall into two families according to Sverdrup (1942); three in the Family Hydrocharitaceae and six in the Family Potamogetonaceae. In the former family I have found *Halophila* of two species in 40 ft. of extremely clear water in the Gulf of Mexico, where the bottom of white coral sand reflects light and gives these delicate green plants sufficient light for photosynthesis, Bowman (1916). In more shallow water, 6 to 10 ft. *Thalassia* and other submerged aquatics thrive, Bowman (1917). *Zostera*, the Sea Grass, is almost world wide in distribution on shallow and muddy shores of oceans. Its close relative, *Phyllospadix*, is abundant on wave washed coasts of Europe and in Denmark it provided almost the sole food for a number of marine animals.

The most conspicious plant life of the sea is, of course, the algae, as I indicated in collections made in Tortugas, Bowman (1918). These live along the continental shelves and are in greatest abundance near the mouths of rivers.

The Myxophyceae or Blue Green Algae are not too well represented in salt water but *Nodularia spumigera* makes the quiet Norwegian fiords slimy with abundant surface growth. *Trichodesmum erythraeum* is a blue-green alga which at certain seasons produces abundant carotene and turns the Red Sea and other marine ocean surfaces a bright red color.

The Chlorophyceae or Green Algae thrive where there is a mixture of fresh and salt water. *Enteromorpha* and *Ulva*, the Sea Lettuce, are common sights in all harbors of the temperate zones, but are restricted to 10 m. in depths. In tropical waters along shallow shores the calcareous algae *Codium*, *Halimeda* and many others abound. But off shore no great quantity of green algae is found in deep water.

TABLE 2

Salinities of certain special ocean areas

	Parts per Thousand
The Baltic Sea and North Sea of Denmark	30
The N. Pacific is uniform at	36
The Gulf of Mexico, West of Australia and Carribean Sea	36
The S. Pacific off the coast of Peru reaches	36.5
The Persian Gulf to the equator	37
The Sargasso Sea in the N. Atlantic	38
Off Brazilian Coast in the S. Atlantic	38
The Red Sea the highest salinity of all oceans	40–41

The Phaeophyceae or Brown Algae are very abundant along all coasts, especially on rocky shores, but more sparsely in brackish water. The Rock weeds *Fucus* and *Ascophyllum* are the common genera. The Kelps of the Atlantic like *Laminaria* and the *Nereocystis* and *Postelsia* or Sea Palm on the Pacific rocky shores are common. Some live at a depth of 15 to 20 m. The Sargasso weed is characteristic of the Central Atlantic where it lives in immense floating masses resembling islands which gives its name to that area called the "Sargasso Sea." Almost all Brown Algae are attached to some stationary object but *Sargassum* can grow vegetatively in floating masses.

The Rhodophyceae or Red Algae, are the only ones that live beyond the continental shelfs. They can live at greater depths than any other marine algae and many forms such as *Corallina* deposit calcium carbonate in their bodies. Their stiff limy remains are of geological significance. Most of the Red Algae are small forms and may live at a depth of 30 m.

Diatoms are minute algae which are universally distributed in all oceans and in fresh water. They constitute the most important item in marine plankton. Square miles of ocean may be covered with diatoms which gives the surface a soupy appearance. Another group of algae are the *Halosphaera*, these also are items of plankton. They are found in the Atlantic, Antarctic and the Mediterranean. The *Coccolithophores* is another group of Yellow-green Flagellates that contribute largely to marine plankton. *Coccolithos pelagicus* is in this class; it has tiny calcareous plates but is small enough to pass through silk nets. It is found in all oceans except the extreme polar seas. In summarizing the algae it may be stated that all algae are located in the upper 100 m. of the open sea due to the lack of light below this depth. In the muds and oozes on the ocean floors only bacteria are found. Here these low plants abound and are relatively less abundant in the upper strata of water. Thus the major forms of plant life in the open sea are microscopic in size, diatoms, Dinoflagellates and Coccolithophores.

SALINITIES OF ENCLOSED OR INLAND BODIES OF WATER

In arid regions with only small precipitation the weathered components of the rocks remain in the soil or are transported to depressions of the terrain, as pointed out by Rankama (1950). The dry air and rapid rate of evaporation do not allow much water accumulate. The great quantity of dissolved minerals finally produces salt lakes or so called "alkali" pools; with further evaporation

TABLE 3

Types of saline lakes

1—Chloride Lakes in which the chief salt is sodium chloride derived possibly from the ocean.
2—Bittern Lakes—rich in magnesium salts.
3—Sulphate Lakes—rich in sulphur compounds.
4—Carbonate and Bicarbonate Lakes—rich in these salts.
5—Alkaline Lakes—which mostly occur in volcanic areas of the earth while the preceding saline lakes occur in areas of sedimentary rocks.

the lakes may turn into dry salt beds. Basins which have rivers flowing into them but which have no outlets become concentrated solutions of salt water but of a very different composition than sea water. The chief salts that can be precipitated from such water are the sulphates of sodium, magnesium and calcium with some bicarbonate. The Caspian Sea is the largest of such salt lakes in the world with salinity 150 o/oo. Others are the Dead Sea, salinity 350 o/oo, Great Salt Lake in Utah, salinity 243 o/oo, and Searles and Owens Lakes in California. These salt or "alkali lakes" are chemically classified in table 3 dependent on their composition.

The Dead Sea is an example of a Bittern Lake. Its water is low in sodium but high in magnesium. Its main feeder is the River Jordan. Its water also contains some bromine which is supposed to be derived from hot springs in the bottom of Lake Galilee—as 2 g. of Br/ton of water occurs in the Jordan River. The salinity of the Dead Sea is ten times that of the ocean *i.e.* about 350 o/oo or about 30 percent of salts.

Searles Lake in the Mohave Desert of California is now almost dry. It represents almost solid lithium phosphate. This lake furnishes nearly half of the world's supply of lithium. Its brine contains 0.085 percent of bromine and the sulphate, carbonate and bromide of sodium, potassium sulphate and borax. Half of the world's total output of borax comes from Lake Searles. Near it is Owens Lake which is fed by Owens River and is much more liquid than Searles Lake. This lake is the source of sodium carbonate and borax.

Great Salt Lake in Utah is the area of a former great inland lake called Lake Bonneville. It is fed by streams flowing over sedimentary rocks and the analyses of these streams show them to be normal river water in which carbonates predominate—but the water of Great Salt Lake is laden with sodium chloride derived from the rocks of its basin. However, compared with sea water, Great Salt Lake has a salinity 7 times greater.

Its general composition is similar to sea water except that it is lower in magnesium and higher in sodium content. Since its brine cannot hold carbonate in solution there are no carbonates in the water of Great Salt Lake. Its composition is given in table 4, according to Rankama (1950).

Flora of the Great Salt Lake was described in 1934 by Flowers. The water of this lake is clear and transparent resembling fresh water. At some places masses of algae in local colonies may give the water a brownish color. There are no emergent plants in the Lake except at bays where fresh water enters. The high salt content is toxic for most plants and the main body of water contains only algae of two groups, four in the Myxophyceae or Blue-Green Algae and two in the Green Algae or Chlorophyceae. The former are *Aphanothece, Microcystis* and two species of *Oscillatoria;* in the latter are *Chlamydomonas* and *Tetraspora.* Only three types of animal life live in the Lake water, a brine shrimp and two species of Salt Fly larva. These feed on the algae. There are no trees

TABLE 4

Salinity of Great Salt Lake

	Percent
Cl.	55.48
SO_4	6.68
CO_3	0.09
Na.	33.17
K.	1.66
Ca.	0.16
Mg.	2.76
Fe_2O_3	—
Al_2O_3	—
SiO_2	—
Salinity	243 o/oo

on the Lake borders and salt flats but a few grasses, weeds and succulent herbs are found here as two species of Salt wort, *Salicornia; Allenrolfea,* the Ink weed; *Suaeda* or Salt Blite and Salt Grass, *Distichlis.* Near fresh water inlets occur numerous marsh plants and other algae, mosses and lichens.

SMALL ALKALI POOLS AND ALKALI SOILS

Like the Salt Lakes and large inland basins these pools or so-called "alkali soils" contain salts of a very different proportion than the ocean. In arid regions with poor drainage the small bodies of water become highly laden with the soluble salts of the native rocks. However, these salts are not always alkaline in the chemical sense. The high concentration of even neutral salts is toxic to plant growth. These salts may be chlorides, sulfates, carbonates or nitrates of sodium, potassium and magnesium and the chlorides and nitrates of calcium. Even sodium nitrate used as a fertilizer may form an "alkali soil," if in excess. Soils full of neutral salts should more properly be termed "saline soils." All of the above salts named are neutral except the carbonates of sodium and potassium.

When the soils full of neutral salts evaporate a white crust appears on the soil or at the edges of pools. This is called White Alkali Soil. The carbonates of sodium and potassium due to their solvent action on organic matter turn the soil dark brown or black. These soils are called Black Alkali Soils. The hydrolysis of this sodium and its reaction with carbon dioxide will form sodium carbonate in the soil and render the soil completely unfit for plant growth.

Plants that will grow in saline soils are *Salicornia* or Salt Wort, *Suaeda* or Salt Blite and *Atriplex* or Orach—where the soil is white encrusted. In 16 states of the western area of the United States, saline soils are hindrances in agriculture. Near Lincoln, Nebraska, the sodium chloride may reach 2.3 to 1 percent of the dry weight of soil in summer. At Great Salt Lake the soil on the shore flats reaches 5.0 to 6.5 percent salt of dry soil weight, according to Weaver (1936).

Black Alkali soils full of carbonates of sodium or potassium form NaOH or KOH which renders the soil basic and prevents all growth but a few halophytes. Alfalfa will tolerate a 300 times greater concentration of magnesium sulphate if a little calcium sulphate is present. In general, calcium seems to mitigate the toxicity of the other ions except in the Black alkali soils. Most plants will tolerate a saturated solution of calcium sulphate but even a very dilute solution of copper sulphate is toxic. Toxicity is believed to be due to the destruction of enzymes in protoplasts when salts are absorbed. In rainy seasons plants can grow in saline soils when the salts are diluted by the rain and carried below the root zones. At White Sands, N. M., the soil is so concentrated in calcium sulphate that only two species of plants can grow there—*Allenrolfea*, the Ink weed and *Abronia* the Sand verbena, as listed by Daubenmire (1947).

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