U. S. COMMISSION OF FISH AND FISHERIES,
GEORGE M. BOWERS, Commissioner.

AN INQUIRY

INTO THE

FEASIBILITY OF INTRODUCING USEFUL MARINE ANIMALS INTO THE WATERS OF GREAT SALT LAKE.

BY

H. F. MOORE.

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From time to time persons interested in the development of the resources of Utah have discussed the possibility of introducing into Great Salt Lake fishes and other animals of economic value which normally have their habitats in the salt and brackish waters of the sea and its estuaries. The matter has been called to the attention of the United States Fish Commission at frequent intervals, and some years ago a provisional promise to investigate the lake was made, but until 1898 the opportunity to make the inquiry did not present itself.

It occurred to the writer, while engaged in experiments in growing oysters in claires, that it might be possible to find places near the mouths of the rivers flowing into Great Salt Lake where the influx of fresh water would mitigate the brininess of the lake sufficiently to make the general conditions favorable for the introduction of that valuable mollusk. It was recognized, of course, that the area which, even under the best conditions, would be found to possess the requisite physical characteristics could not be very extensive, and that there was little hope of introducing marine fishes, for Great Salt Lake holds salt water of a density which could not be endured by ordinary marine organisms. Where fresh water flows into the lake from the rivers there is formed a narrow zone of a density approaching that of the sea, lying between the fresh water on the one hand and the salt on the other. This zone occurs only near the mouths of streams, and its limits are so circumscribed as to allow but small latitude for the wanderings of fish and other marine organisms possessing active powers of locomotion, and they would be restricted therefore in the exercise of one of their most important functions, and would be in constant danger of wandering into the surrounding water where the conditions would be fatal. The oyster, on the other hand, is a sessile organism, and, if its immediate surroundings be favorable, a restricted area does not prohibit oyster culture of a certain character, except in so much as it correspondingly restricts the number of oysters which it is possible to raise.

Influenced by these considerations, inquiry was made of persons interested in the matter and resident in the vicinity of the lake, and the replies indicated that there were certain places near the mouths of the rivers where one might expect to find the fresh and salt waters blending in a manner which would satisfy the requirements so far as the density was concerned.

Preliminary experiments had shown that diatoms, which constitute the chief food of the oyster, would grow in Salt Lake water when it was reduced in density within the limits in which the oyster would thrive, and it was believed that they would be actually found in the lake under the same density conditions. This assumption was afterwards verified by the investigation. Sufficient warrant was then apparent for an investigation which, if it had no other results, would at least set at rest any future agitation and uncertainty concerning the matter.

The scope of the inquiry was enlarged to embrace the question of the feasibility of introducing not only the oyster, but also crabs and fishes, although probably nobody in the Commission had any expectation of favorable results from either, and perhaps with the exception of the writer none had much hope of a favorable report concerning the oyster.

From its configuration, and from the information which it was possible to acquire by correspondence, Bear River Bay was selected as the first and principal point for investigation, although, after the unfavorable result of the examination there, inquiry was directed to all other places which offered any promise of success. About three weeks were consumed in the inquiry.

In order to make the results intelligible considerable attention is given in the report to a résumé of the hydrographic, physical, and chemical features of the lake and its drainage systems, as it is upon these, rather than upon the purely biological conditions, that the unfavorable character of the conclusions is based.

GREAT SALT LAKE DRAINAGE BASIN.

The drainage basin of Great Salt Lake comprises about 54,000 square miles, principally in northern and northwestern Utah, but including also a small part of southwestern Wyoming and southeastern Idaho. Practically all of the water discharged by streams into the lake is derived from the eastern part of its drainage basin, where the high peaks of the Wasatch and Uinta ranges interrupt and cool the moisture-laden winds and cause them to deposit their aqueous contents in the form of snow and rain. During the winter great stores of snow accumulate in the mountains to be released during the spring months, and in some of the higher and more sheltered ravines snow banks persist throughout the year. Owing to the late melting of the snows in the mountains the rivers discharge their maximum amount of water late in spring and the cumulative effect is to bring the lake to its maximum elevation late in June.

There are three principal drainage systems—the Bear, the Weber, and the Jordan—all of which enter the lake on the east side. In addition, there are a number of small streams and creeks, which, in the main, are more heavily charged than the rivers with saline materials. Most of them flow from the Oquirrh and Promontory ranges. On the western side of the lake there are no high mountains, and as there is nothing therefore to abstract the moisture from the winds there is practically no drainage into the lake from the westward.

The land on the west side is, in general, a desert with scattered short mountain ranges of small altitude and the isolated, partly buried buttes and peaks commonly called "lost mountains."

BEAR RIVER.

Bear River rises in the northern part of Utah in a number of small streams which spring from the east slope of the Wasatch Mountains and the north slope of the Uinta Mountains, at an altitude of about 10,000 feet. The course of the stream is at first northerly, several times crossing and recrossing the boundary line between Utah and Wyoming and receiving on its way many small streams from mountain ravines. At Border Station the Bear River finally leaves Wyoming, and entering Idaho is deflected to the northwest as far as Soda Springs, where it circles the end of the Bear River Mountains and takes a southerly course.

Bear Lake, about 22 miles long by 7 miles wide, lies across the boundary line between Idaho and Utah, being contained in about equal parts in each State. North of the lake is an extensive marsh, separated from it by a long, low ridge of sand thrown up by the waves to a height of from 2 to 5 feet above the water level, and pierced in two places by narrow passages, through which the water flows from the lake into the marsh, or from the marsh into the lake, depending upon the relative level of each.

Bear River flows through the northern and eastern part of the marsh, flooding it in times of high water and draining it during dry seasons, and from the conditions stated it follows that the lake to some extent acts as a reservoir, receiving some of the surplus water during flood and relinquishing it again when the river falls. Three million whitefish fry were planted in this lake by the United States Fish Commission in March, 1896, but no evidence has been received that this attempt to introduce the species was successful.

South of Soda Springs the Bear River flows through the fertile Gentile and Cache valleys, the principal tributaries in this region being the Cub River and the several branches of the Logan River on the east and the Malade River on the west bank.

In its lower reaches, below Corinne and the mouth of the Malade River, the river meanders through a low plain used in part for grazing, the width of the stream here measuring between 60 and 75 yards. In the northern part of section 31, township 9 north, range 3 west, it first breaks from its well-defined channel and a large part of its water escapes in two overflows, which spread out into a broad, shallow lake, extending over a large section of what is indicated on the maps as dry land and known to the duck hunters as Bear River Bay.

A few miles lower in its course the river again breaks out in a series of overflows, one of which discharges northward through a shallow lagoon locally called "Section Tom's Bay," and the others flowing southward into South Bay, an equally shallow lake of fresh water lying in the bottom which was covered by the lake during the period of high water between 1865 and 1890. Below the point of efflux of these several "overflows," the main channel of the river, as it existed at the time of the Stansbury survey and the low-water stage of that period, has become almost filled up and reduced to the status of a muddy slough. The course of this channel can still be traced in part by the stumps of the willows which formerly fringed the banks but were killed by the encroaching salt water of the lake and afterwards cut off by the ice that formed on the fresh water above and drifted about under the influence of the wind.

It is evident that during the late period of high water, when the encroachment of the lake upon the land caused the river to discharge farther eastward than is shown upon the map, the silt and sediment brought down by the current were deposited in the old bed and when the lake again subsided the river was forced to seek new channels with the resultant changes in the topography noted above.

Below the upper overflows the country to the northward of the river bank is marshy and overgrown with tules (a species of *Scirpus*), the gathering-place of vast flocks of waterfowl, and below the lower overflows the south side of the river is of the same character. The land map on file at the court-house in Brigham City shows surveyed sections on the north side of the river which are in reality under water (the "Bear River Bay" mentioned above), even at the present low stage of water, while on the south side the recession of the water has exposed a large area of alkali flats and miry clay which was recently part of the lake bed.

The flow of water in Bear River is subject to great seasonal variation, as is shown in the following table recording the discharge as measured at Colinston, Utah, in 1897, according to Professor Fortier:

Date.	Cubic feet per second.	Date.	Cubic feet per second.	Date.	Cubic feet per second.
Jan. 1	1,480	Apr. 20	5,900	Aug. 10	1,100
Jan. 5	1,025	Apr. 25	6,415	Aug. 15	1,100
Jan. 10	1,590	Apr. 30	6,602	Aug. 20	1,025
Jan. 15	1,590	May 5	6,665	Aug. 25	990
Jan. 20	1,275	May 10	7,165	Aug. 30	955
Jan. 25	1,375	May 15	6,665	Sept. 5	1,100
Jan. 30	1,375	May 20	7,295	Sept. 10	1,185
Feb. 5	1,375	May 25	7,665	Sept. 15	1,230
Feb. 10	1,590	May 30	7,295	Sept. 20	1,185
Feb. 15	1,375	June 5	6,540	Sept. 25	1,185
Feb. 20	1,375	June 10	5,500	Sept. 30	1,275
Feb. 25	1,375	June 15	4,805	Oct. 5	1,230
Feb. 28	1,375	June 20	3,990	Oct. 10	1,590
Mar. 5	1,375	June 25	3,035	Oct. 15	1,872
Mar. 10	1,375	June 30	2,570	Oct. 20	1,872
Mar. 15	1,375	July 5	2,445	Oct. 25	1,930
Mar. 20	1,375	July 10	1,930	Oct. 30	1,695
Mar. 25	1,375	July 15	1,590	Dec. 5	1,275
Mar. 30	2,570	July 20	1,375	Dec. 10	1,375
Apr. 5	2,570	July 25	1,375	Dec. 15	1,590
Apr. 10	3,990	July 30	1,142	Dec. 20	1,695
Apr. 15	5,090	Aug. 5	1,100		

The water of Bear River at the head of the upper overflow is turbid, and ordinarily a large portion of the mud would be precipitated in the shallow lagoons which retard the currents near the river's mouth, a part of it being again taken up and carried into the lake during the spring and summer high water. Curiously, however, these lagoons are not permitted to serve as settling reservoirs during the spring and fall, owing to immense flocks of waterfowl which keep the muddy bottom continually stirred up. During a large part of the year, therefore, the river is discharging a heavy volume of sediment into Bear River Bay, which in its upper end, on this account, has become very shallow, with a bottom composed in the main of soft, deep, sticky mud. In a few places the bottom is firm enough to support oysters on the surface, but in most places a person wading will sink to the knees.

The water in the lagoons near the mouth of the river is quite fresh. An analysis by F. W. Clarke of the water, at Evanston, Wyo., showed the following probable constituents in grams per liter: Calcium carbonate, .1080; magnesium carbonate, .0438; sodium sulphate, .0155; sodium chloride, .0081; silica, .0070. The quantities are so small that the salinometer is not appreciably affected even at the mouth of the river, where it must be supposed that the proportions of the several substances, or some of them, are greater, owing to the leaching out of the salt lands near the lake. It was to this locality that some of the preliminary correspondence pointed as a favorable place for the introduction of the oyster, but the observations just noted make it evident that these waters are entirely without the pale of consideration in this connection. It is probable, however, that the cat-fish might be introduced here with considerable hope of success and a fish supply of some commercial importance to the surrounding country might be thus obtained.

JORDAN RIVER.

Utah Lake, which is the reservoir from which the Jordan derives its main supply, lies in Utah Valley about 40 miles south of Great Salt Lake. It is about 20 miles long with a maximum width of about 8 miles, its dimensions being subject to considerable seasonal and non-periodic variations. It derives its main water supply from streams entering the east side of the lake from the Wasatch Mountains. The largest of these is Provo River, which rises in canyons on the west side of the Uinta Mountains and, breaking through the Wasatch Range, empties into the lake near its middle, in the vicinity of Provo City. Four or five other streams enter it from the east and south, but they are very small, except during April, May, and June. Fed as it is by a fluctuating supply, the lake level undergoes great oscillations, in its turn affecting the discharge of the Jordan, through which all of the surplus water is carried.

The Jordan leaves Utah Lake at its northern end and soon after passes through a gap in the Traverse Mountains at a point where the discharge from a former greater Utah Lake has cut a deep channel, now characterized by rapids. North of the "Narrows" the Jordan receives a number of small tributaries from the canyons of the Wasatch, but a large part of the water of these streams is utilized for irrigation purposes in Salt Lake Valley and furnishes the water supply of Salt Lake City. In its lower part the river runs through an alkali plain. It flows in a well-defined channel until it reaches a point west of Woods Cross, where the channel forks, the western fork almost immediately breaking up into a series of tortuous channels in a marsh. The eastern branch maintains its integrity to a greater extent, but the whole country below the forks forms a marshy delta, cut up by sloughs and lagoons, with a bottom of soft mud supporting a growth of sedges and tules. In many of the lagoons a dense growth of watercress forms a mattress rising sometimes as much as 2 feet above the water level.

The only really firm ground in the delta is formed by a sandy tract extending perhaps a mile parallel to the east channel, and destitute of vegetation. This is stated to be the filled channel of the river before the late high-water level in the lake.

As at Bear River, the water in the lagoons is practically fresh, a sample taken in the east channel of the river where it enters the lake having a density of 1.0008. The following is the probable composition of the solid matter in solution in the water at the source of the river in Utah Lake, as deduced from the analyses made by F. W. Clarke, in 1883, the figures representing grams to the liter of water: Calcium carbonate, .0038; magnesium carbonate, .0644; sodium carbonate, .0204; calcium sulphate, .1849; sodium chloride, .0204; silica, .0100. It will be noticed that this water differs from that in Bear River in the much smaller content of calcium carbonate, in the presence of a large proportional amount of calcium sulphate and some sodium carbonate, and in the absence of sodium sulphate. This represents the main supply of the Jordan, but the composition is to some extent modified by the influx of the several creeks entering the river betow Utah Lake, and by the mineral matter leached out of the alkali lands. Its salinity, however, is so low that there is no possibility whatever of introducing marine species, such as crabs, in the lagoons of the delta, and there is no necessity, therefore, to consider the probable physiological effects of the several mineral constituents upon fishes and other aquatic life.

Unfortunately the Jordan River has not been systematically gauged, and its annual oscillation can not be shown, as in the case of Bear and Weber rivers. It undergoes the same variation, however, discharging most water in July and least in early spring. At its maximum it carries much less than the Bear, and at its minimum it has about three-fourths of the flow of that river, its annual oscillation being, therefore, less than in the case of either of the other rivers considered in this report, owing to the fact that its flow is regulated by the reservoir function of Utah Lake. The lake off the mouth of the Jordan River may therefore be considered to have a smaller annual fluctuation in density, so far as the influx of fresh water is concerned, than it has in corresponding relation to either the Bear or the Weber; that is, leaving out of consideration the effects of the wind in directing the flow of the strongly saline water of the lake, there is less liability of a fatal variation due to the influx of fresh water from the river. If, we will say, oysters were put down during the low-water stage of the river, near the outer limit marking the location of the maximum density in which they will live, it is not certain that the water during the flood season would become freshened below the minimum density in which they thrive. But taking into consideration the fact that the outer limits of the zone of favorable density move landward during the prevalence of north winds, owing to the encroachments of the briny water of the lake, it is evident that in so locating our plant as to prevent the one catastrophe we would invite another.

As compared with the Bear River the waters at the mouth of the Jordan are clear and the mud of the lake bottom is harder and not so deep. This is doubtless owing in part to the deposit of a larger proportion of the suspended matter in the sluggish water of the lagoons and sloughs, where it is not stirred up by the waterfowl, as on the Bear River. In many places the bottom on the alluvial fan is quite hard, and covered with a vegetable felting or carpet composed largely of diatoms. This is especially the case in the shoaler, fresher water, to which places, however, the saline waters find frequent access. The zone of mixed water is here broader than at the mouth of the Bear or Weber.

WEBER RIVER.

The Weber River rises in the high ridges of the western part of the Uinta Mountains, between the sources of the Bear River on the north and the Provo River on the south. It receives a number of tributaries on both banks, but none of considerable importance except the Ogden River, which joins it at Ogden.

Below Ogden the Weber runs through low land, and eventually breaks into two branches, one of which flows to the north, the other to the south. The northern branch divides and subdivides, part of it being lost in the swampy flats and part flowing into a shallow bay (not shown on the map), which is connected with the lake north of Mud Island. This bay, which was formed during the recent subsidence of the lake, is about 2 miles long and $\frac{3}{4}$ mile wide, with an average depth of about 4 inches. The southern branch enters the lake 4 or 5 miles west of Hooper, opposite Fremont Island. The channel remains undivided to its mouth, and it carries practically the whole discharge of the river except during the spring floods. In October, 1898, the north channel was almost dry.

The Weber River is subject to greater and more sudden fluctuations than either the Bear or Jordan, doubtless on account of the absence of natural storage reservoirs, such as are found in the lakes on the other rivers.

The discharge as measured at Devil's Gate, Weber Canyon, during 1897 was as follows:

Date.	Cubic feet per second.	Date.	Cubic feet per second.	Date.	Cubic feet per second.
Jan. 1	360	May 5	5,397	Sept. 5	185
Jan. 5	360	May 10	4,557	Sept. 10	220
Jan. 10	360	May 15	4,820	Sept. 15	220
Jan. 15	360	May 20	4,715	Sept. 20	270
Jan. 20	310	May 25	4,400	Sept. 25	270
Jan. 25	360	May 30	3,340	Sept. 30	415
Jan. 30	360	June 5	2,590	Oct. 5	545
Feb. 5	360	June 10	1,615	Oct. 10	545
Feb. 10	360	June 15	1,275	Oct. 15	545
Feb. 15	360	June 20	1,175	Oct. 20	545
Feb. 20	360	June 25	785	Oct. 25	545
Feb. 25	310	June 30	335	Oct. 30	545
Feb. 28	310	July 5	220	Nov. 5	480
Mar. 5	310	July 10	220	Nov. 10	480
Mar. 10	415	July 15	220	Nov. 15	480
Mar. 15	360	July 20	185	Nov. 20	480
Mar. 20	360	July 25	185	Nov. 25	415
Mar. 25	785	July 30	185	Nov. 30	415
Mar. 30	785	Aug. 5	185	Dec. 5	415
Apr. 5	1,275	Aug. 10	185	Dec. 10	415
Apr. 10	2,275	Aug. 15	185	Dec. 15	415
Apr. 15	2,910	Aug. 20	185	Dec. 20	415
Apr. 20	4,610	Aug. 25	185	Dec. 25	415
Apr. 25	2,640	Aug. 30	185	Dec. 30	415
Apr. 30	4,610				

A volume of water, very considerable as compared with the ordinary flow of the stream, is diverted from the Weber River for purposes of irrigation.

The main channel discharges over a well-defined fan, which extends about 1½ miles from the present shore line. The shores here are formed by a part of the delta laid down during a higher stage of water than now obtains, and the slope is so gradual that the position of the water line fluctuates widely under the influence of the winds and slight changes in the lake level, a rise of an inch changing the position of the shore line north of the river mouth by several hundred yards.

The water on the fan is practically fresh, but at its edge, where the slope becomes more abrupt, the density falls rapidly. On October 18, 1898, about 1½ miles from shore the salinometer registered a density of 1.0315 in a depth of 1 foot; 50 yards nearer the shore the depth had decreased to 7 inches and the density to 1.0040; 50 yards farther in the depth was 5 inches and the density 1.0020, and 100 yards farther the readings were 4 inches and 1.0005, respectively. The water on the fan was clear, but the salt water around the rim had a milky appearance, probably due to the imperfect solution of its saline contents on account of its low temperature, 12° C. (53.6° F.). The bottom on the delta is generally firm and there is an abundant growth of diatoms. Both of these conditions are favorable to the growth of oysters, but the density is fatal and the extreme shallowness objectionable.

BRACKISH SPRINGS.

After the completion of the examination of the lake at the mouths of the main streams flowing into it, it appeared desirable to investigate some of the numerous brackish springs which are characteristic of the country bordering on Great Salt Lake. It was thought that perhaps by utilizing some of the ponds to which they give rise, or by constructing artificial ponds or claires and regulating the flow of water, the density might be so regulated as to secure the requisite conditions. The springs selected for examination were those flowing from the end of the Oquirrh Mountains south of Saltaire and Garfield Beach.

At Chambers Station there is a group of springs on the property of Mr. Anderson, most of them in the bottom of a small pond in which carp and trout have been introduced by the owner, both being said to thrive. A small spring on the margin of the pond had a density of 1.0003; about 50 yards below the discharge of the pond the density was 1.0012; about 250 yards below it was 1.0018, and about half a mile from the pond it had risen to 1.0019, all densities being corrected to 15° C. Near the place at which the last reading was taken a sluggish spring rises from a deep hole with abrupt margins, the density there being 1.0014. In the stream forming the discharge of the pond confervoid algæ in abundance and several schools of small fish were seen. There is a copious discharge of water from the pond, and the flow, which was not measured, is said to vary but little with the seasons. In the lower course of this stream the land becomes somewhat boggy and much of the water is lost through evaporation over the increased surface thus produced.

Two springs were next examined on the property of Mr. Spencer, several miles west of Chambers station, on the road to Black Rock. They rise between the highway and the railroad. The east spring has a density of 1.0003 at its source, and the west spring 1.0013 at the railroad and 1.0015 about 200 yards below. Both of them flow through boggy ground, and their courses are much choked with algæ and watercress.

Near Black Rock are two springs just south of the highway and about half a mile from the lake. The eastern one, which is the larger, has a density of 1.0046, the most saline spring examined. The flow from this spring exceeds that of any others except that at Chambers station. The second spring, about one-fourth mile west of the one just described, is much smaller and has a density of 1.0018.

Oysters will live in water of a density or specific gravity between 1.002 and about 1.0024, but near the limits mentioned they are inferior in quality and of but little value as food. In water of low density they become poor, flabby, and tasteless, while near the upper limits of their adaptability they become small and almost worthless, as may be seen in the mangrove oysters in certain parts of the South and in some of the West Indies. To raise oysters of the best quality it is necessary to have the water of such salinity as will give a specific gravity of between 1.010 and 1.020.

It will be observed that none of the springs examined has a density within the limits which experience has indicated as most favorable for the production of sapid oysters, but the eastern or larger spring at Black Rock is saline enough to support adult oysters and to admit of their breeding. In all probability, therefore, provided that the chemical constituents of the water were not such as to prove injurious, self-sustaining oyster beds might be established in the waters flowing from this spring, but their quality would not be sufficiently good to warrant the attempt.

If, however, this water were conducted into shallow ponds the evaporation would tend to raise the density. The evaporation at Salt Lake City is about 75 inches per annum and the rainfall about 50 inches, so that the net loss in fresh water is about 2 feet per year. A pond $2\frac{1}{2}$ feet deep and without an outlet would by solar evaporation alone have its density raised to within the desired limits in less than two years, provided sufficient water from the spring be introduced from time to time to replace that lost by evaporation. If no water be allowed to escape from the pond save by evaporation, there will be speedily reproduced in miniature the conditions prevailing in Great Salt Lake and the density would soon rise to a degree fatal to the oyster. After the pond has reached the desired salinity, however, it may be maintained within the proper limits by regulation of the intake and outlet sluices, the inflowing stream of lower density tending to reduce the salinity of the pond by replacing the denser water which flows from the outlet. By a nice adjustment of the influent and effluent streams it would be possible to regulate the density within comparatively narrow limits with a minimum of personal attention on the part of the operator. Two conditions are imposed by the problem: (*a*) The inflow must equal the amount of water lost by evaporation, plus the quantity flowing out of the pond, minus that which is gained from the rainfall in the pond; (*b*) the smaller amount of dense water flowing out must contain the same amount of salt as the larger amount of less dense water flowing in.

GREAT SALT LAKE.

Great Salt Lake is situated in the northwestern part of Utah, west of the Wasatch Mountains, being embraced within the limits of Box Elder, Weber, Salt Lake, and Toelle counties. Its length is about 80 miles, lying in a northwest-southeast direction, and its greatest width is about 35 miles. In 1869 it had, according to King's survey, an area of 2,170 square miles, this being the maximum area within historic times. At the present time it has decreased to approximately the dimensions shown on the Stansbury map of 1850, when it had an area of about 1,750 square miles, 20 per cent less than in 1869. Its maximum depth, according to Stansbury, was 36 feet; and the King survey, made at the time of highest water within recent years, reports a depth of 49 feet. The shrinkage since 1869 has been approximately 10 feet, so that the maximum depth is not far from 38 or 39 feet at present. The deepest water is west of the Promontory, the water east of that peninsula and Antelope Island being comparatively shoal and gradually becoming shoaler by the deposit of silt from the rivers.

The principal islands are Fremont and Antelope, in line between the

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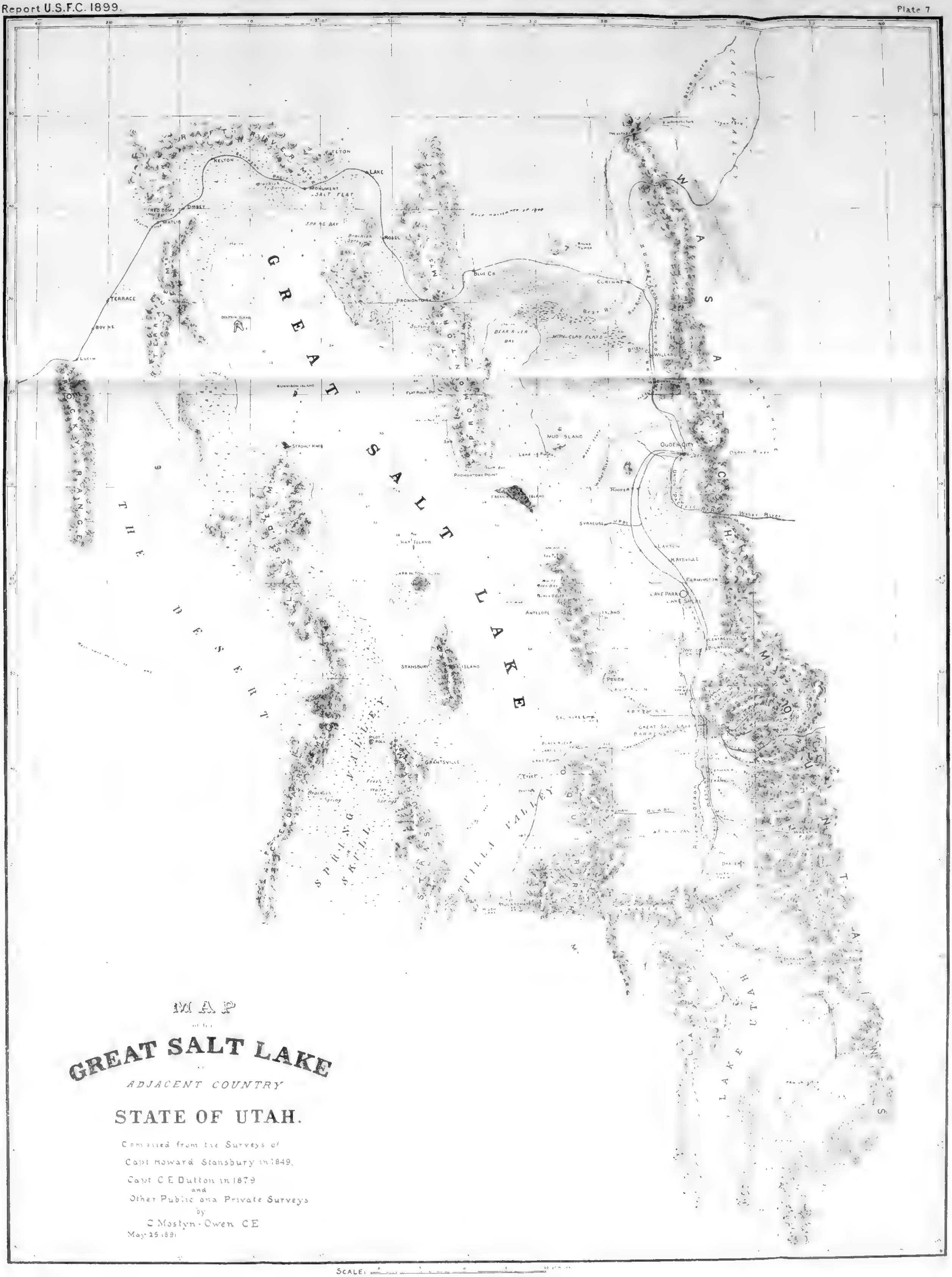
MAP
GREAT SALT LAKE
ADJACENT COUNTRY
STATE OF UTAH.
Compiled from the Surveys of
Capt Howard Stansbury in 1849,
Capt C E Dutton in 1879
and
Other Public and Private Surveys
by
C Mostyn-Owen CE
May 25 1891
GREAT SALT LAKE
THE DESERT
SPRING VALLEY
SKULL VALLEY
TUILLA VALLEY
LAKE UTAH
STANSBURY ISLAND
MUD ISLAND
ANTELOPE
HAT ISLAND
PROMONTORY
PROMONTORY POINT
GUNNISON ISLAND
STRONG'S KNOB
DOLPHIN ISLAND
KELTON
MONUMENT
SALT FLAT
LAKE
TERRACE
LUCIN
BOVINE
CORINNE
WILLARD
OGDEN CITY
HOOPER
SYRACUSE
LAYTON
KAYSVILLE
FARMINGTON
LAKE PARK
LAKE SHORE
GRANTSVILLE
BLUE CR
BEAR RIVER BAY
MUD CLAY FLATS
Weber River
Bear River
CACHE VALLEY
WASATCH MTS
UINTA MTS

SCALE

Promontory and Oquirrh mountains, and Carrington and Stansbury islands, forming a similar chain farther west. At the present stage of water Stansbury Island is connected with the shore, and Antelope Island may be reached with little difficulty by fording. Mud Island, usually known as Little Mountain, now rises from the mud flats north of the Weber, but during the recent high-water stage it was an island in fact.

As is well known, Great Salt Lake is a relic of a great fresh-water or brackish sea, Lake Bonneville, the history of which in geologic times is written in the ancient beaches which terrace the mountain sides which formed its shores. This lake had its fluctuations in level, rising and falling probably in correlation to fluctuations in meteorological conditions, but eventually its surface rose until it stood more than a thousand feet above the present level of Great Salt Lake, when it spilled over the crest of an alluvial dam in Red Rock Pass and discharged in a mighty river into the drainage system of the Columbia. The erosive powers of this discharge over the loosely aggregated alluvial matter soon cut a deep channel and the surface of the lake in a short time fell nearly 400 feet, when further erosion was retarded by the hard rock which was then reached, and the size of the effluent stream thereafter was much diminished and became a factor of the excess of precipitation over evaporation in the Bonneville hydrographic basin, the lake level remaining approximately stationary.

At a later period increasing aridity caused an excess of evaporation over precipitation, the lake fell below the level of its outlet, and its succeeding shrinkage in volume was due to a gradual process of desiccation. In its process of drying up the ancient Lake Bonneville was divided into several portions, three of which, of considerable size, exist as lakes of the present day. Of these, Great Salt Lake and Sevier Lake are strongly saline, while Utah Lake, whose drainage basin receives more water than is carried off by evaporation, has become fresh by the continued discharge of its saline matter into Great Salt Lake via the Jordan River.

Historical knowledge of Great Salt Lake dates practically from the time of the Mormon immigration into the valley, although it had been visited previously by adventurous travelers and trappers. At the time of the settlement of Salt Lake City, in 1847, the lake was at a lower level than it has since reached, and at the time of the first survey, in 1850, its shores bore evidence that it had been at the existing stage for a long time antecedent. Soon after, however, it began to rise, until in 1857 it stood nearly 4 feet above the level of 1850, its surface being at about 6 feet on the Garfield gauge, established at a later period. By 1860 it had fallen again to its former stage, but in 1864 there began a rapid swelling in volume which carried it to its maximum elevation during historic times, in 1868, when it stood at a height of over 13 feet, as referred to the zero of the Garfield gauge. From the high-water stage then reached the lake has fallen in level, with periods of temporary expansion producing secondary maxima in 1876 and 1887, until in the fall of 1898 it stood at about 2½ feet on the Garfield gauge, or barely a foot above the level of the corresponding season of 1850.

In addition to the nonperiodic oscillation described, there is also an annual fluctuation, due to the temperature and precipitation characteristics of the region, the lake reaching its maximum elevation in June and its minimum in November. This is referred to, as follows, by G. K. Gilbert, in his monograph on Lake Bonneville:

The cause of this annual variation is at once apparent. The chief accessions of water to the lake are from the melting of snow on the mountains, and this occurs in the spring, occasioning the rise of the water from March to June. Water escapes from the lake only by evaporation, and evaporation is most rapid in the summer. Before the influx from melting snow has ceased it is antagonized by the rapidly increasing evaporation, and as soon as it ceases the surface is quickly lowered. In autumn the rate of evaporation gradually diminishes; in November it barely equals the tribute of the spring-fed streams, and in winter it is overpowered by such aqueous product of mountain storms as is not stored up in snow banks.

There is still another variation affecting the lake level locally, although its average level is not disturbed. Under the influence of strong winds the water is rolled up on the shelving lee shores to a height of several feet above the normal water line, while on the opposite or windward shores there is a corresponding depression. Even with gentle winds, not exceeding 6 or 8 miles per hour in velocity, the writer has known the water to rise an inch or two on the flats forming the eastern shore of the lake between the deltas of the Bear and Weber rivers.

Each of these variations in the lake's level has an important indirect bearing on the subject of the present investigation, the first two affecting the salinity of the lake both generally and locally, while the third has a purely local effect. It is evident that as the water rises, during either an annual or a nonperiodical elevation, the general density of the lake water must decrease, for the increased volume is due to the addition of fresh water, and the total quantity of salt in the lake remains practically, though not absolutely, the same. During a period of subsidence the contrary is true, although some of the saline matter is left by desiccation upon the shores from which the water has receded, part of this being gradually returned to the lake by leaching and part of it being covered and entrapped in the soil. There are no data available to illustrate the effects of the annual oscillation, but the effects of the nonperiodic fluctuation are shown in the following table:

Date.	Sp. gr.	Locality.	Authority.
1850	1.170		L. D. Dale.
1869 (summer)	1.111		O. D. Allen.
1873 (August)	1.102		H. Bassett.
1885 (December)	1.122		J. E. Talmage.
1889 (August)	1.157		Do.
1892 (August)	1.156		E. Waller.
1897 (November)	1.168	Garfield Beach	H. F. Moore.

It will be observed that the foregoing accords in general with the history of the oscillations of the lake, a low density being coincident with a period of high water, and conversely. For a variety of reasons, principally because of the nonconformity in the location and other conditions of the collection of samples, there is not an absolute agreement.

The density of the lake varies in its different parts, being lowest close to the mouths of the rivers and highest near dry shelving shores. In the latter case the density is raised by evaporation in the shallow water until it sometimes reaches the saturation point and the salt is crystallized out and precipitated on the bottom. The process is aided, of course, by the fact that the lake has no appreciable semidiurnal tides, which would tend to produce a more equable distribution of its saline contents. The circulation, however, in the deeper waters removed from the river mouths is probably sufficient to make the density uniform over large areas.

Near the mouths of the rivers the density is largely conditioned by the volume of fresh water brought down by the stream. When the discharge is heavy the dense water of the lake is pushed back and the zone at which the mingling of the fresh and salt waters occurs is farther from shore than when the discharge is light. If the rivers maintained an approximately even flow during the year this fact could not materially affect the feasibility of introducing marine animals, such as the oyster, for the zone of admixture would remain, other things being constant, at approximately the same position. It happens, however, that the rivers discharging into Great Salt Lake pass through annual oscillations of great magnitude, the maximum and minimum flow of Bear River in 1897, according to the figures published by Professor Fortier, and previously quoted, being about as 15 to 2, and of Weber River in the proportion of about 28 to 1. Data for the Jordan River are not available. It will be seen, therefore, that the fluctuations in the position of what we may call the neutral zone, in which the water has a density of between 1.01 and 1.02, must be very great. Again, during nonperiodic stages of high water—as, for instance, that culminating in 1869—the salt water encroaches on the fresh, and some of the former fresh-water channels of the rivers become converted into more or less saline estuaries.

The annual oscillations would probably affect the local density to a smaller degree, partly because the influence of the higher level of the lake would be masked by the greater inflow of fresh water, as it occurs synchronously, not with the maximum, but still with a high stage of water in the river, and partly by reason of the fact that the rise is not so great as in the nonperiodic oscillations.

Another factor which tends to produce variations in the salinity are the irregular changes in the lake's level, due to the action of the wind. As before stated, winds of even moderate intensity tend to back up the water on flat lee shores, with the result that the denser water moves landward and would inevitably increase the salinity over the areas on which oysters could be planted, and an offshore wind would tend to produce a fall in salinity. In other words, the neutral zone of water, just saline enough to be favorable to oyster life, has no fixed position, but moves shoreward or lakeward in conformity with the direction of the prevailing wind.

The rapidity with which these changes may take place is remarkable, as illustrated by the following observations made from an anchored boat in Bear River Bay on October 10, 1898:

Time.	Density.
3.00	1.0210
3.15	1.0244
3.25	1.0274
3.30	1.031+

In the last reading the density was too great to be read with the salinometers used, but it greatly exceeded 1.031.

A few days later, at the mouth of the Jordan, the density was found to change from 1.009 to 1.0141 within 5 minutes. In both cases there was a lake breeze blowing at a velocity estimated to not exceed 8 miles an hour. The salt water crept into the less salt in long tonguelike streaks, the progress of which could be readily distinguished by their color.

In Bear River Bay, at 12.30 o'clock, on October 10, 1898, the density near the north end of "The Knoll" on the promontory was 1.003, at 5.15 o'clock it was 1.011, and at 8 o'clock next morning it had risen to 1.015. The density was, perhaps, higher during the night, as the wind was southerly at nightfall, when the salinity was increasing; but in the morning it had veered to the north, which would tend to blow the salt water lakeward again.

The "neutral zone" appears to be at all times comparatively narrow. This was best illustrated by observations made at the southern mouth of the Weber River, where the fresh water is discharged over an alluvial fan. At the edge of the delta, where its slope begins to increase in its deflection from the horizontal, the water was found to have a density of 1.031 in a depth of 1 foot; 50 yards nearer the shore, where the depth had decreased to 7 inches, the density had fallen to 1.004; 50 yards farther on it was 1.002, and 100 yards farther it was but 1.0005, or practically fresh. The zone of water of a density suitable for the growth of oysters was certainly not more than 25 yards wide, although it extended around the entire rim of the delta.

At the mouth of Bear River the neutral zone was wider, but the distribution of the salinity was so irregular that it is impossible to state its width. A complication was introduced here by the fact that the density was undergoing rapid change from the effect of the wind, as has been already set forth.

The observations made are recorded in the following table:

Station.	Location.	Density.	Station.	Location.	Density.
1	50 yards off north point of knoll on promontory.	1.003	16	2,100 yards north	∞
2	1,000 yards south	1.010	17	2,200 yards north (point of knoll S. of W.)	∞
3	1,500 yards south	1.005	18	2,500 yards north	∞
4	1,800 yards south	1.012	19	100 yards east	1.021
5	2,100 yards south	1.027	19	Same (15 m. later)	1.024
6	2,400 yards south	∞ *	19	Same (10 m. later)	1.027
7	500 yards east	1.027	19	Same (5 m. later)	1.031+
8	1,000 yards east	1.022	20	300 yards east	∞
9	1,300 yards east	∞	21	400 yards west	1.016
10	1,500 yards east	∞	22	800 yards west	∞
11	400 yards north	∞	23	1,200 yards west	∞
12	900 yards north	∞	24	1,400 yards west	∞
13	1,400 yards north	1.0255	25	1,600 yards west	∞
14	1,700 yards north	1.0215	1	2,100 yards west	1.011
15	1,900 yards north	1.210			

* Much over 1.031, the highest reading on salinometers used.

On the line returning from the promontory to Bear River the density fell from 1.0165 at the promontory to 1.0015 half a mile east-northeast. The entire area of Bear River Bay north of this point, as determined by the investigation, is practically fresh. The fresh water apparently extends farther south near the promontory than on the eastern shore, this being accounted for by the western sweep of the main discharge from the river.

At the mouth of the Jordan the full breadth of the "neutral zone" was not ascertained, as a boat was not available for making the observations. The following is the record:

Station.	Location.	Density.	Depth.
			Inches.
No. 1	Off east mouth of river	1.0008	4
2	300 yards from No. 1	1.0020	2
3	450 yards from No. 1	1.0060	6
4	550 yards from No. 1	1.0110	18
5	650 yards from No. 1	1.0090	20
	Same place 5 minutes later	1.0140	20

It was evident from the last reading and from the change observed in the color of the water that the salinity increased rapidly from station 5 lakeward. It is probably an overestimate to state the width of the zone of water having the salinity 1.010 to 1.020 as 250 to 300 yards.

In the cases of the Jordan and the Weber, the distances were estimated by pacing; in Bear River Bay they were based upon distance per stroke traveled by the boat, and checked by reference to the topography of "The Knoll" on the promontory.

The effects of the general narrowness of the neutral zone and its erratic movement under the influence of the several agents discussed are important in their relation to oyster culture. A narrow body of water of a density between 1.010 and 1.020 could be utilized if its position were fixed, or the middle of a wide zone could be used if its maximum oscillation were less than half its width, as in this case the middle belt would not be encroached upon by water either too salt or too fresh. Unfortunately, however, the amplitude of the oscillations is too wide for the maintenance of this condition, as was proved in the case of

Bear River Bay, and inferred from the data obtained and the testimony of informed persons at the mouths of the Weber and the Jordan.

Even should there be found a limited area where the density conditions were such as could be endured by the adult oyster, it would nevertheless be impossible to establish self-sustaining beds—that is, beds annually replenished by young oysters produced thereon. The young oyster is for the first few days of its independent existence a delicate free-swimming organism, about $\frac{1}{90}$ inch in diameter and extremely sensitive to sudden changes in its environment. A density variation of but a few degrees is sufficient to kill it, and the eggs are not even capable of efficient fertilization in water differing very much in salinity from that in which the parents lived. It can be readily seen that with an organism so fatally responsive to changes of environment there could be practically no hope of securing a successful set of young oysters, and the bed could only be maintained by annual importations from the seacoast.

In Bear River Bay the character of the bottom and the muddiness of the water are also unfavorable to oyster culture. On soft bottom, such as is found over most of this part of the lake, the oyster soon sinks and is stifled, a fate which also befalls it when there is a copious deposit of silt, such as occurs where the muddy water of the river meets the brine of the lake.

At the mouths of the Jordan and Weber rivers the bottom is harder, and the water at the time of the writer's visit was much clearer; but during the high-water stage of spring the rivers deposit large quantities of silt on the delta, just where it would be necessary to plant the oysters if it were attempted at all.

In objection to the introduction of marine organisms into the waters of Great Salt Lake, it was urged that even if the water were diluted to the proper density the composition was so at variance with the composition of sea water that the result would be fatal to marine animals placed in it. The following table shows the relative proportion of the various salts per 100 parts of solid matter in sea water and the water of Great Salt Lake:

Constituents.	Sea water.*	Salt Lake water.†	Salt Lake water.‡
$NaCl$	77.758	83.727	80.5
$MgCl_2$	10.878	6.530	10.3
Na_2SO_4			5.4
$MgSO_4$	4.737	2.264	
$CaSO_4$	3.600	3.576	1.4
K_2SO_4	2.465	3.801	2.4
$MgBr_2$	0.217		
$CaCo_3$	0.345		
$LiSO_4$		0.070	
F_2O_3 and Al_2O_3		.002	
SiO_2		.008	
Surplus SO_3		.022	
	100.000	100.000	100.0

* Dittmar. † Waller, 1892. ‡ Talmage, 1889.

From the foregoing table it will be observed that the sea water and Salt Lake water do not differ so greatly in the relative amounts of their solid constituents as is generally supposed. Both are characterized by the great preponderance of common salt. The principal difference is in the character of the sulphates—magnesium and calcium sulphates predominating in sea water, and sodium sulphate being present in Salt Lake water. It will be noticed that sodium sulphate is not regarded as a probable constituent of Salt Lake water by Waller, although it is a well-known fact that during cold weather it is thrown on the shores in quantities available for economic purposes. Sodium carbonate and sodium bicarbonate, the "soda" which produces the alkalinity of many of the lakes of the arid region, are absent in the waters of both the sea and Great Salt Lake. From an inspection of the analyses there appears to be no warrant for the objection that the divergent composition of marine and Salt Lake waters would render the latter ill adapted or inimical to animals accustomed to life in the former, provided that the same density holds in each case. As has been already mentioned, it was found by laboratory experiment that marine diatoms would flourish in properly diluted Salt Lake water.

A partial experiment with fishes was made with a small quantity of Salt Lake water shipped to Washington through the kindness of a correspondent. The quantity was too small for a conclusive trial, but so far as it went the result was unfavorable, the fish showing distress after a short stay in the water, and dying within two days of the time of their introduction. The density of Salt Lake water was reduced to the same degree (1.016) as the salt water in the aquaria in which the fish had been living, so as to minimize the shock resulting from the transfer from one jar to the other.

The salts in Great Salt Lake are derived from the fresh-water streams and from the fresh and brackish springs flowing into it or discharging in its bottom. The proportion of saline matter in most of the streams is low, although in excess of that usually found in more humid regions, but many springs rising near the rim of the lake are more heavily charged with salts. Some of these have been already discussed and the amount of their salinity indicated, but others of thermal character are much more saline. It is stated that all of the springs arising in the Bonneville beds are brackish. As the lake is without an outlet and all of its surplus water is removed by evaporation, the salts accumulate, and by a process of concentration the waters have reached the condition of a brine. Certain salts of limited solubility and abundant supply have reached the saturation stage and are being precipitated, while others less abundant in the surrounding formations, or more soluble, are still accumulating. The determination of the period of accumulation of salts now in the lake is a complex one, "but we can safely say that the period necessary to charge the lake with common salt by means of the present sources and rate of supply is not more than 25,000 years."*

*Gilbert, Grove Karl. Lake Bonneville. U. S. Geol. Survey. Monograph I, 1890.

During the writer's visit to Great Salt Lake he several times heard the opinion expressed that the extraction of salts from the lake through the several agencies acting in that direction would in time result in a reduction of its density to a degree which would solve the problem of the introduction of marine forms.

Salts are deposited by the lake principally in three ways: (*a*) by desiccation on the flats covered by the water during stages of elevation; (*b*) by supersaturation, especially at reduced temperatures and low stages; (*c*) by human agencies in the process of salt-making.

In times gone by, when the lake was undergoing rapid shrinkage, quantities of salts, great in the aggregate when we consider the area involved, were left upon and in the soil of the exposed bottom, and even during the comparatively small shrinkage between 1869 and 1898 an appreciable quantity of the lake's saline constituents was left upon the flats. In some cases these materials are so entrapped in the soil that they are not again readily dissolved, but a considerable quantity is, under usual circumstances, returned to the lake by leaching. Common salt is also thrown down in places along shore by the concentration of the water on the shallows by evaporation.

Certain of the saline contents of the water are but sparingly soluble, and the addition of the annual increment from the inflowing streams causes supersaturation and consequent precipitation. This is the case with carbonate of lime, which is thrown down as oölitic sand, and sodium sulphate, which is cast upon the shores in winter when the solvent properties of the water are reduced by its low temperature. The sodium sulphate is largely redissolved when the temperature of the water rises, but there is doubtless a constant loss due to the mechanical mixture of some of it with sand and mud thrown up by the waves. It is sometimes collected along shore in winter for commercial purposes. The amount of saline matter annually lost to the lake through the agencies just discussed can not be estimated, and the opinion as to the future adaptability of the lake to marine organisms was not based upon these agencies, but upon the removal of salt for the use of man. Seeing the great quantities of salt at the salt ponds and not appreciating the vast stores of the lake, the mistake is not unnatural. About 50,000 tons of salts are annually taken from the lake for commercial purposes, but less than 84 per cent, or about 42,000 tons, of this is sodium chloride. Basing the calculation upon Gilbert's estimated accumulation period of 25,000 years, the annual influx of salt from the tributaries of the lake is about 16,000 tons, making the net loss about 26,000 tons. The lake at present holds about 400,000,000 tons of common salt, with a water density of 1.168. A greater density than about 1.020 is not favorable to the oyster, and to reduce the lake to that degree of salinity, its volume remaining unaltered, would necessitate the extraction of about 360,000,000 tons of sodium chloride, and at the present rate of loss this would require a period of nearly 14,000 years. It is not considered that the prospect is such as to require very serious attention at present and the niceties of computation have been neglected.

CONCLUSIONS.

The main body of the lake and a large part of its shores are entirely unfit for the introduction of marine animals of economic value, owing to the high salinity of the water. The proportional constitution of the saline contents of the waters of Great Salt Lake is not vastly different from that of salt water. Great Salt Lake is salt and not alkaline. The physiological effect of its waters upon organisms placed therein probably would not seriously differ from that of sea water were it not for its high density, but to attempt to introduce fishes or other marine animals into water having a specific gravity of 1.168 when they have become adapted by nature to a density of but 1.025 would be an utter waste of effort.

In the Deseret Evening News of October 4, 1892, a scientist of Salt Lake City is quoted as follows:

> The fear that scientists have expressed that fish will not live in the lake is entirely groundless. Of course they would have to be introduced gradually, but that can be successfully done. They can be acclimated by degrees.

It is not stated how the fishes are to be "acclimated by degrees," and the speaker apparently bases his opinion upon his repetition with *Artemia gracilis* of the experiments of Schmankewitsch and others upon the European species *Artemia salina*. It is well known that *Artemia* will live either in brine or fresh water, and in a few generations, and sometimes even in one generation, its form will become so changed by an alteration in density that it is referred to a different genus. Other phyllopods exhibit the same adaptability, but that fact does not furnish sufficient basis for a generalization such as has been quoted.

Similar experiments have not been made with fishes nor with the higher crustacea, although the anadromous species like the shad and the Atlantic salmon experience no ill effects from their periodic migration from sea water into the fresh-water rivers, and vice versa. Some years ago the United States Fish Commission made a plant of shad in the Jordan River, but, with the exception of one or two, the fish were never heard from. It is well known that the oyster will not thrive in water of full oceanic density. No oyster beds are found along our coasts at any distance from sources of fresh or brackish water, and in a density of 1.023, a salinity less than one-seventh that of Great Salt Lake, they are small and of very inferior quality, usually growing between tide marks, sometimes on the shores and often on piles, mangroves, and other fixed bodies to which they attach.

The process of evolution has made the oyster an organism adapted to live in brackish or semisalt water, despite the fact that on our coasts there is ample opportunity for it to acclimate itself "by degrees" to water of full oceanic density, or, on the other hand, for it to extend its habitat up the rivers into fresh water.

The optimum density for oyster-culture is between the specific gravities of 1.010 and 1.020, which range in Great Salt Lake is to be found only near the mouths of rivers which flow into the lake on the eastern shore. An inquiry disclosed that the position of the favorable zone fluctuates under the influence of a variety of causes. During the historic period the level of the lake has undergone extensive oscillations, large areas of land being flooded during periods of high water and conversely the bottom of the lake being laid bare at low-water stages. There is an annual oscillation having the same effect in a minor degree, and the seasonal variation in the discharge of the rivers causes a wide range in the density of the lake near their mouths. Finally there are irregular variations due to the influence of the winds in driving the lake water up on sloping lee shores.

If the conditions as found at any given time were constant there would be no difficulty in introducing such sessile marine organisms as the oyster, but the frequent, almost continuous, fluctuations in the density of the water make the attempt entirely unfeasible. It is not improbable that places could be found where a few adult oysters would survive, but the conditions are such as would inevitably prove fatal to the oyster fry which, as a free-swimming organism, would be certain to be wafted by the currents into water, on the one hand too dense, or on the other too fresh, to be withstood by its delicate and sensitive organization. The adverse and unsuitable conditions would also be sure to be reflected in the inferior condition of such adults as might be able to survive.

The writer is convinced from his examination that neither self-sustaining beds, replenished by their own reproductive activity, nor those maintained by annual importations from the coast, as practiced by the planters in San Francisco Bay, can be introduced in Great Salt Lake with any assurance of commercial success.

None of the brackish springs contain sufficient salt to be utilized in their natural condition, but there are reasons to believe, as has been set forth on page 240, that by excavating ponds their waters might be used. The expense would be great, however, and it is doubtful if they would prove to be commercially successful, even if their experimental feasibility should be proved.

The objections to the planting of fish, oysters, etc., in Great Salt Lake are based on physical rather than biological conditions. There is an abundant food supply, the water teeming with brine shrimps and insect larvæ. The available fish food exceeds in quantity that usually found in the sea, its abundance being largely due, no doubt, to the fact that there are no fish to consume it. The lake is also exceedingly rich in minute plants, especially diatoms which constitute the chief food of the oyster, but from a practical point of view this fact has no value when we are confronted by the absolutely prohibitive physical conditions which the present examination disclosed.

There is much greater probability of attaining valuable results by introducing cat-fish into the fresh sloughs near the mouths of the rivers than by attempting the introduction of marine species into the lake.