SOME PHENOMENA IN A DYING LAKE

MELVIN A. BRANNON, PRESIDENT, BELOIT COLLEGE

The purpose of this discussion is to bring to the attention of this Academy some of the salient findings associated with the biological studies of a lake which is rapidly disappearing in the glacial drift regions of North Dakota. The latitude and longitude of this lake are 48° north and 98° west, respectively. The average annual range of temperature is from 35° below zero in winter to 95° above zero in the summer. Ice a meter or more thick forms in the winter. Winds with a velocity of 20 to 35 miles per hour move over the lake during many days in the months of July, August, and September. They cause a rapid lift in vapor pressure on the water surface and consequently evaporation is very high during the summer months.

The territory from which Devils Lake receives its water is an inland drainage basin. There is no outlet from this lake other than that afforded by evaporation. The result is that its specific gravity has now reached a point where the water contains 1½% solution of the salts of lime and magnesium. These salts are chiefly in the form of carbonates and sulphates.

Dr. Warren Upham made a definite study of this inland drainage basin in his work on glacial lake Agassiz. The following quotation from his report is of interest:

"Through the past hundred years maximum and minimum stages of the great Laurentian lakes have alternated in cycles of about a dozen years, during which comparatively scanty average rainfall for several years was followed by an unusually abundant rainfall. These fluctuations are similar to those just noted in the rainfall of North Dakota. Besides such short cycles important secular changes of the mean annual precipitation in this State, occupying considerably longer periods, have caused remarkable changes in the levels of numerous lakes which have no outlet."

"Devils Lake thus shows evidence of having attained, about the year 1830, a level of sixteen feet higher than

its low stage in 1889, reaching at or near the former date to the line that limits the large and the dense timber of its bordering groves. Below that line are only smaller and scattered trees, of which Capt. E. E. Heerman informed me that the largest found by him and cut a few years ago had fifty-seven rings of annual growth. Within the twenty-five years since the building of Fort Totten, this lake has fallen nine or ten feet, and it has fluctuated four feet under the influence of the changes in the average annual precipitation of rain and snow during the past dozen years."

"The high stage reached by this lake about sixty years ago appears to have been limited by an avenue of discharge eastward into Stump Lake, which rose at the same time to within about three feet of this height. The latter and smaller lake, receiving no large tributary and lying in a basin that nowhere extends many miles from the lake, was prevented by evaporation from rising quite so high as Devils Lake, which, during abundant years of rain and snow, receives a large tributary, the Mauvaise Coulee, draining a broad area that stretches sixty miles northwestward to the Turtle mountains. The outlet of Devils Lake into Stump Lake was nearly due eastward from Jerusalem, situated on Lamoreaux Bay at the most eastern portion of the entire lake shore. With an overflow at this point, Devils Lake may many times have been raised to this beach by periodic variations in rainfall during the many centuries since the ice age."

"At the time when the last ice sheet retreated, however, the confluent water of Devils Lake and Stump Lake were raised to a shore line which now has a slight ascent from west to east, lying twenty-one to twenty-five feet above the low stage of Devils Lake in 1889. This shore is traceable around both lakes, passing above the watershed that now divides them."

Our 1922 records now show that the level of the lake has fallen about eighteen feet since June, 1883, when it was 1439.08 feet above sea level, the reading at present being 1421 feet above sea level. The recession of the water during the eighteen-foot vertical drop in thirty-

nine years has greatly diminished the area of the lake. It is not to be inferred that the eighteen food lowering of the surface has been a constantly progressing process. Some years the loss was through the heated summer months and was restored by the melting snows and spring rains. In some cases the low levels have been replaced by higher stages lasting for one or more seasons.

The physical factors which accompany the disappearance or dying process of a lake are numerous. Naturally the most notable features are the lowering of the water level, the emergence of islands, the appearance of land projections and the final separation of the main body of water into lesser basins.

With the continued evaporation of water there is, of course, the attending increase in specific gravity and the lift in osmotic pressure registered by the solutes upon living organisms within the water.

There is a diminution of luminosity and a precipitation of mineral and organic matter as the lake grows older and the dying process advances.

With the development of the shallow basins and the comparative shallowness, even in the deepest part of the Lake, the effect of winds and modification of temperature, distribution of the gases, oxygen, carbon dioxides, and nitrogen are more rapidly modified and adjusted than was the case in the younger and deeper lake.

The chemistry of a dying lake is associated specifically with a concentration in the mineral content and the readjustment in proportion of carbon dioxide and numerous other substances in solution.

The physical and chemical changes incident to the drying up or dying process in Devils Lake are apparently going forward quite rapidly at this time. In 1914 the average collections of water from various parts of Devils Lake showed that it was .94 of 1% saline. During the last eight years, due to the excessive evaporation and the attendant concentration of lake water, the salinity has increased to 1½%. This indicates a rapid concentration of mineral solutes and complicates still further

biological questions which are of particular importance in the investigations of dying lakes.

The chemical composition of the water in Devils Lake has been determined many times during the twelve years that the Biological Laboratory staff has been studying the life of its waters. In 1910 our chemists gave the following report:

TONIC COMPOSITION	Parts per million
Calcium	4.0
Magnesium	603.9
Sodium	2908.8
Bicarbonate Ion	708.0
Carbonic Acid Ion	126.0
Sulphuric Acid Ion	6098.4
Chlorine	1177.0
	11626.1

HYPOTHETICAL COMBINATION	
Calcium Bicarbonate	2.4
Magnesium Bicarbonate	846.9
Magnesium Carbonate	177.1
Magnesium Sulphate	2029.9
Sodium Sulphate	6625.9
Sodium Chloride	1177.0
	10859.2
	12429.0
Total residue	12.2
Silica	4.0
Iron Oxide plus Aluminum Oxide	

Considerable quantities of organic matter and of insoluble matter were present. The water stood for a long time in a warm room. It is quite possible that some of the calcium bicarbonate was decomposed in this way, precipitating out calcium carbonate. This may account to some degree for the small amount of calcium found.

Devils Lake is shallow, twenty feet being its maximum depth. High winds churn the water frequently during the spring, summer, and autumn. Obviously the oxygen, nitrogen, and carbon dioxide would have a continual and rapid vertical distribution during the open season. Analysis of gases at different levels of the lake in 1911 gave the following readings:

1911		Depth	
June 1	Surface 7.49 cc of O_2 per liter of water	13′ level	5.76 cc
June 29	" 5.39	14′ "	4.22 "
July 22	" 5.55	13′ "	3.46 "
July 31	" 5.46	15′ "	4.64 "
Aug. 7	" 5.40	Bottom 18′	2.14 "

For the purpose of this particular discussion, the changes in the physical and chemical factors within a dying lake have particular importance biologically. The student of physiology dealing with plankton, filamentous algae, higher plants, higher animals, and the bacteriological organisms inhabiting the waters of a lake which is gradually disappearing, has an extremely mixed culture, containing many varieties of organisms, all of them undergoing seasonal and periodic change in number of any one form and in the proportional numbers among all forms. This great natural culture solution affords an opportunity for studying permeability, osmotic pressure, and the limits of adaptability of the organisms as well as a study of their reactions upon the medium within which they are contained. An illustration of these points may be had in the reaction of every organism which can live in the waters of a gradually dying lake whose salinity is continually advancing. The reactions of the organisms which survive afford some explanation perhaps for the absence of organisms which cannot survive. Professor Oltmanns made some very interesting studies of the various factors involved when he undertook to transfer certain green algae to water of higher salt concentration.

He says: "Spirogyra and Chara withstand a salt concentration of 0.5%. However, they are unable to withstand a 1% concentration because they cannot take in sufficient salts to raise temporarily the osmotic pressure of their cell sap. In other words, they are unable to bring about proper osmotic alterations rapidly enough to adapt themselves to the saline habitat."

Prior to 1889 the waters of Devils Lake has been populated with vast numbers of great northern pike. Authentic reports state that these fish were taken out in carload lots by those who speared them through the ice. For some reasons unknown to the layman, these food fishes which appeared in actual shoals during the years preceding 1889, suddenly vanished.

The three prevailing explanations of the pseudo-scientists were that the water had become poisonous, that insufficient food was present, and that some disease had caused the fish to die. While any of these might have

been true, a study of the biological situation led to the belief that no one of them had the slightest relation to the sudden disappearance of this important food supply formerly secured from Devils Lake. What really had happened was that due to the isolation of the Devils Lake waters from fresh water lakes to the north having a slightly higher altitude, with the increased dessication during the arid years from 1885 to 1890, the water level in the fresh water lakes and in Devils Lake had fallen below the bottom of the creek or coulee channel which connected them. The great northern pike apparently followed the habits of the ocean salmon and migrated in early spring, passing through the connecting coulee to the sweet water lakes north, where shallow fresh water beds produced large areas of favorable spawning ground, thus insuring the propagation and continuance of the swarming pike. In the autumn, it was reported that the pike migrated from the shallow sweet water lakes to the deeper, and therefore better protected winter habitat of Devils Lake. When the connecting coulee dried up and Devils Lake became segregated from the spawning grounds in the sweet water lakes, reproduction of pike ceased. Obviously, if an organism is prevented from propagating itself, it soon vanishes from the earth, as did the wild pigeon.

Following the studies of the physiographic, physical, and chemical changes, certain experiments were initiated in the adaptation of higher plants and animals to the water of Devils Lake. These organisms were taken from bodies of sweet water within the neighborhood of Devils Lake, or secured from the United States Fish Hatchery. Experiments were tried with yellow perch, rainbow trout, bull heads, and other material available for experimentation. Perhaps the following details of a few experiments may be sufficient for this report of the physical reaction of higher organisms in the water of the dying lake:

Prior to the initiation of our studies at the Biological Station in 1909, many attempts had been made to restock Devils Lake with fish. Much private, municipal, and federal money had been spent in fruitless efforts to secure

this greatly desired result. A study of the experiments which had been made by preceding workers offered small hope of success provided their procedures were closely followed. However, to make quite sure, a duplication of the former experiments was made with the result that those in charge of the Station work became convinced that there was no hope of success in following the lines of procedure formerly instituted. The problem was entirely too complex for any guess work or merely empirical procedure. In other words, it was manifest that successful culture and distribution of fish rested wholly upon ascertaining, first, the physical, chemical, and biological facts which entered into this very complex problem. As already indicated, these facts could be learned only through analyzing many hundreds of collections, carrying forward many experiments, and determining the limiting factors of the life already present in Devils Lake.

After determining that there seemed to be no inhibiting toxic agents present, that there was ample oxygen in the water and thousands of tons of available fish food, an effort was then made to determine whether a successful method of introducing fresh water fish into Devils Lake might be established by following a procedure similar to that which characterized the natural situation in former years. Consequently, a series of tanks was built in the Biological Station and they were supplied with special devices for adding oxygen to the water as it was pumped into the tanks.

Yellow perch and other forms experimented with would frequently show great distress and die within an hour when placed in shallow water at a temperature of 24 degrees C., whereas when the temperature was kept lower, from 17 to 20 degrees C., they appeared to be quite comfortable. In view of this, the water was introduced into the tanks at 17 to 19 degrees C. The aerating devices assured a gas content of 4 to 6 cubic centimeters of oxygen per liter. Yellow perch, steel-head trout, large-mouthed black bass, pike, and some other varieties of fish were used in the experiments conducted during the summers of 1911 and 1912.

It was further found that the fish taken from fresh water lakes and transported 100 miles or even a shorter distance required some time to recover from the effects of transportation. Usually the fish which were weakened or injured through transportation would be eliminated during the first four to six days they were in the experimental tanks. At the expiration of this period, Devils Lake water was mixed with the water from the deep well in the portion of one to three. At intervals of two to three days, the proportion of Devils Lake water entering the tanks was increased until the wholly undiluted Devils Lake water was supplied to the experimental tanks. Under average conditions, with average shipments, it was found that this process of increasing the per cent of Devils Lake water could be completed within ten to twelve days. After the fish had been retained in these experimental tanks for a period of one to three weeks, they were transferred to anchored floating fish pens in order that their condition and behavior might be kept under observation for several weeks. It will be noted that the specific gravity of the Devils Lake water to which they had become adjusted in the acclimatizing experiment was 1.019. It is to be further observed that they were taken from water having an osmotic pressure of .03 to .04 of an atmosphere and they were placed in water having an osmotic pressure of 4.6 atmospheres. As previously stated, it was found necessary to keep the temperature of the tank water within the range of 17 to 19 degrees C., and to maintain an oxygen content not lower than 4 cubic centimeters per liter in order to secure the best results.

The transfer to the floating fish pens in the lake was more successful if it was done in the evening or during cloudy days, presumably because the temperature of the lake water was lower at those times than during periods when it had been subjected to the heat accompanying bright sunshine for some hours. Floating tanks were found to be far more satisfactory than submerged ones. The latter gathered too much floating debris and sand which, of course, would interfere materially with the respiratory apparatus of the fish placed in the submerged pens.

Of the fish used, the yellow perch and steelhead trout proved the most resistant and satisfactory. Excellent results were obtained during the summer of 1911 in the tests with these two varieties. However, it seemed desirable to postpone publication until the experiments could be extended and the results verified by subsequent cultures. Consequently, early in the season of 1912, large reinforced concrete tanks were built and the experiments were conducted out of doors. Yellow perch were gotten again from the nearby lakes and Turtle Mountain region and passed through the control experiments, duplicating those of 1911. When the perch were transported properly and the acclimatizing experiments conducted with care, the percentage of loss was only 10 per cent, including the losses which came from injuries in transportation and failure to recover from the fatigue of the trip. It was found that from 300 perch received on the 19th of July, 246 were vigorous and absolutely normal when examined in the floating fish pens on August 12. The following year we recaptured yellow perch from Devils Lake, proving that they had survived the change one year.

In the latter part of May, 1912, a shipment of rainbow trout was received from the United States Fish Hatchery at Spearfish, South Dakota. They were placed in tanks containing well water on May 22. There were many fatalities during the month of June, due to mechanical troubles with the pumping plant of the station. On July 3, the trout which remained alive from the shipment received six weeks before were transferred to the tanks outside of the building into which there was introduced a mixture of lake and well water. An exceedingly high temperature during the 3d and 4th of July raised the temperature of the upper lake water 10 degrees above that which had been in the indoor tank water. Furthermore, they had been placed in newly built concrete tanks from which soluble salts had not been sufficiently removed by long continued washings with the fresh or well water. The result was that out of 100 placed in the tank at this time, 40% died within 36 hours. There was a lowering of the oxygen content of the water, a great increase in

temperature, and an increase in the soluble materials in the newly built tanks, a combination which was serious for so delicate a fish as the rainbow trout. On July 17, it was deemed that the increase of Devils Lake water had been carried to a point where undiluted lake water might be used. No serious results were noted.

These fish were fed macerated liver. Most of them fed freely and were active, thriving, and growing. Some of them refused to eat from the beginning of the experimental period, and did not grow, but remained in an abnormal condition throughout the entire time they were kept in captivity. On August 14, 48 were transferred to the floating fish pen in the lake. Several of these trout were diminutive and represented the starved, unnourished members which had survived. Two weeks later, on August 29, 34 rainbow trout, after 98 days of experimental work, were turned into the lake. They had grown from 2½ centimeters to 5½ centimeters. They were exceedingly active and vigorous and seemed to be wholly adjusted to their new surroundings. While the experiments with the rainbow trout were attended with far greater losses than was the case in the experiments with the perch, the final results indicated that we were approximating very closely proper methods of acclimatization when we were able to save any of the exceedingly delicate rainbow trout and secure marked growth and great vigor and activity in the stock which were turned loose at the end of the 98 day experiment.

As previously stated, to the plant and animal physiologist it is obvious that biological studies in the waters of a dying lake afford conditions not only for interesting adjustments within the cells of the organisms experimented with, but there is afforded also a remarkable opportunity of investigation for all kinds of cellular biology. This is particularly true in the study of phyto-plankton. The changes in the membrane, the plasmolysis, and the gradual acclimatization in acquiring the "euryhyaline habit", as Professor Oltmanns expresses it, may be studied with the one cell organism in a remarkably successful manner. While one does not attempt to draw general conclusions from a few isolated experiments, nevertheless he is con-

vinced that the rich and rare opportunities for the study of the physiology of multicellular organisms, a study even of such recondite subjects as ductless glands and internal secretions in multicellular organisms, are all of them illuminated, or may be illuminated, by a study of the unicellular and multicellular organisms which inhabit the waters of a dying lake prior to the time when the higher plant and animal life vanished because of the over-concentrated solutes in the water.