KEOKUK DAM AND THE FISHERIES OF THE UPPER MISSISSIPPI RIVER [1]

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INTRODUCTION

With the development of the country there have ensued noteworthy changes in the condition of our streams. Deforestation, clearing of lands, drainage, all have the effect of passing the surface waters quickly into the rivers. The reclamation of swamp lands, leveeing of river banks, and dredging and straightening of river channels make it possible for the water to flow more rapidly through the rivers to the sea. The general effect, therefore, of the natural accompaniments of agriculture and industrial development is to produce extreme flood stages, both high and low, and to shorten the periods of change from one extreme to the other.

[1] Submitted for publication Sept. 28, 1928.

Prepared at the same time and based on observations and collections made during the period covered by this report is a companion paper entitled "Studies of Common Fishes of the Mississippi River at Keokuk" (to appear in the bulletin of the Bureau of Fisheries), in which are presented the known facts of the natural history of the fishes of that region. Such information forms the background of the present study, and the two papers should be consulted together by those interested.

Under primitive conditions the surface waters of a period of heavy rainfall might have required weeks to find its way through forests and over unbroken ground to the river channel,[2] while still further weeks must have been consumed as the swollen stream wound its way to the sea through the dense swamps that bordered the normal channel. A new flood period might, indeed, have begun even before the first had passed and before a stage of extreme subsidence had ensued.

Under modern conditions a similar excess of rainfall finds not only the forests diminished but surface ditches and tile drains carefully laid out to expedite its removal from the lands to the natural channels of the rivers. Once in the rivers, it again finds its way in some measure cleared, so that it may be conveyed to the sea at a more rapid rate. The river, then, rises and overflows with relative dispatch and subsides the more quickly again to a low stage; the fluctuations of level are sharper and more extreme.

The effect of rapid fluctuations upon fish life in the stream is too obvious to require lengthy comment. We know that many of our most valued fishes move out into the shallow waters for the purpose of reproduction, and we see too often that an untimely recession of the floods leaves not only mature fishes of various sizes but also a large proportion of an entire generation of young fishes to perish in isolated overflow ponds, except as they are rescued by artificial means. Furthermore, the conditions for the development and maintenance of a food supply for fish are obviously the less favorable, the greater the degree of fluctuation in level and in expanse of the water.

One would never expect to secure the maximum production of fish in a pond that is to-day 10 acres in expanse and 20 feet deep and next week 3 acres in extent and 8 feet in depth. In any stream the fish and other aquatic animals are subject to natural vicissitudes under the best conditions, but the trend of the changes in our rivers wrought indirectly by man's alteration of the face of the land has been in a direction generally unfavorable to the growth and multiplication of fish.

Some of the changes wrought by man may be in some measure compensatory in effect, however. Of this nature we might expect, generally speaking, to be those developments that tend to control the stream flow or to diminish the degree of fluctuation of level. Among the factors contributing to the control of stream flow are improved methods of agriculture, providing for storage of water in the soil, and the impounding of waters under such conditions as to hold back the surface water in times of excess and to release it gradually in times of deficiency. Such impounded waters we may call reservoirs when the purpose is essentially the temporary storage of excessive rainfall. Another class of impounded water consists of the pools or lakes formed by dams constructed for purposes of power. With these the storage and the liberation of water may be governed largely by power demands, and their effect upon stream flow below the pool may be one thing or another, according to local conditions and according to the mode of operation of the plant. In any case, however, we are likely to find large expanses of water of relatively fixed level and affording favorable breeding and feeding grounds for many species of fish.

In the case of impounded waters classed as reservoirs, where the water is held temporarily, we look for the beneficial effect upon fish life not in the reservoir itself so much as in the stream below, the flow of which is rendered more uniform. In the case of artificial pools and lakes we look for beneficial effects primarily in the lake itself and above it, if fish should thrive in the pool and wander from it.

[2] Rafter (1903) cites important references bearing on this question.

Dams have relation to fish life, however, in other ways than through the creation of regions of impounded waters. They constitute more or less effective barriers or obstructions in the course of the river and thus may interfere with the free passage of migratory fish from one portion of a stream to another. This, in fact, is the effect of dams that is most ever present in the public mind, and it is certainly one of great significance whenever anadromous or broadly migratory fishes are concerned.

Now it is impossible to strike a fair balance in any offhand way between losses and gains to the fishery resulting from the construction of a dam. Except as the conditions may be investigated carefully and the actual facts ascertained, at least in a number of representative cases, broad general statements are unwarranted. For any stream and for the particular location on the stream we must know if there are fishes affected that are of distinctly migratory habit, and if their migrations are of such an extent as to be interrupted seriously by the dam; and we should measure, also, as best we can, the actual compensatory benefits to fish life.

If the principal fishery of a stream is based upon the salmon, and it is known that the salmon must pass in considerable numbers beyond the site of the dam in order to propagate itself, the answer is obvious—the dam is ruinous to the salmon fishery unless the fish can be passed over it by means of proper devices. The effect of the lake in modifying the temperature of the water flowing over the dam is also a factor in this case. (Ward, 1927.) In the case of streams of another region the problem may be more complex, as when the fishery is based not upon one but upon many species, each of which may have its own peculiar habits as regards reproduction and migration.

The investigation now being reported upon was based upon the dam constructed across the Mississippi River between Keokuk, Iowa, and Hamilton, Ill., one of the greatest dams yet constructed for power development exclusively and one that affected one of the principal streams of the United States. Such effects as this dam might have would be felt locally both above and below the dam; they might also be felt at points hundreds of miles away from the dam, above it and, perhaps, below it as well. The investigation was begun in 1913 and was continued, with some interruptions, to 1927. There were several reasons why a period of years was required for the study. In the first place, we knew little regarding the extent of the necessary migrations of the common fishes of the Mississippi River; in the second place, the catches of fish under normal conditions vary widely from year to year, and the conclusions drawn from one year's observation might well be entirely misleading; finally, it was recognized that the effects, both good and bad, might display themselves only after a period of years. The diminution or the increase in abundance of a particular fish might be directly attributable to the dam, although not observable in a practical way until after several years. We do not now assume that all effects of the construction of the dam at Keokuk have yet been realized, but we believe that there is ample warrant for the presentation of a report and for a statement of the conclusions that are drawn.

Circumstances beyond the power of the Bureau of Fisheries to control led to the virtual termination of field observations at Keokuk in 1917 and to delay in completing all the studies necessary for report. A considerable portion of our data, however, was thoroughly organized and put in preliminary report form in 1918. The delay in publication has not been unfortunate, because it is now evident that had conclusions based upon statistical reports been published in 1918 it would have become necessary substantially to revise them in the light of data made available in 1922 and 1927 from the statistical canvass for those years. "Time will tell"—particularly in the case of a substantial alteration of conditions in a natural watercourse.

The conclusions we have reached regarding the effect of the dam at Keokuk upon fish life in the Mississippi must not be held to be applicable to any other dam except as the conditions may be strictly comparable. It is our hope, however, that the observations we have made and the data we have brought together throw some light upon the general question of dams in relation to strictly fresh-water fishes and also contribute something to our knowledge of the habits of fishes of the upper Mississippi River.

We are well aware that there have been other significant changes in the river in recent years besides those associated with the dam. Notable among these are the changes arising from works in aid of navigation, from the development of drainage districts, and from increase in the amounts of sewage and industrial wastes discharged into the stream. It will be seen in our discussion of the changing conditions of the fisheries that we have not lost sight of such factors, and we believe that our data are so presented that it can fairly be judged whether or not our conclusions with regard to results following from the dam are justified.

The report is based upon observations and other data gathered in the manner indicated in the following paragraphs:

While the investigation was under the continuous direction of the author from its beginning in 1913, his personal visits to Keokuk and to other points on the river above and below Fairport, Iowa, were made only at intervals, and most frequently during the first two years of the investigation, when he was stationed at Fairport on the banks of the Mississippi. Emerson Stringham, scientific assistant, who entered the investigation in the second year, made occasional visits to Keokuk and other points during the winters of 1914–15 and 1915–16 and the summer of 1917 and remained on the ground at Keokuk for continuous observation during such portions of the years 1915 and 1916 as the river was not frozen over. Direct observations at Keokuk were discontinued in 1917, when a preliminary report was prepared.[3] An interval of years was then allowed to elapse, during which the reality of seeming trends might be tested by the results of later statistical studies. The last personal observations by the author were made in 1926, when he visited a number of points on the river between Lake City, Minn., and Canton, Mo. The chief object of this last trip was to check, by personal interviews with fishermen, the impressions derived from the study of statistical reports.

Free use has been made of all available published data regarding the distribution and natural history of the fishes considered in this study. The records of collections and observations of fishes made by the various members of the staff of the Fisheries Biological Station at Fairport, Iowa, and its field party on Lake Pepin (Minnesota-Wisconsin), though not brought into this report in detail, have been invaluable.

[3] Soon after the preparation of this report Mr. Stringham left the bureau, and since that time the report has been extended greatly and otherwise modified in the light of new information. The senior investigator proposed to adhere to the original arrangement for joint authorship, but when the completed report was submitted to Mr. Stringham he replied that it would not be right to have his name upon it as joint author. The present author takes this opportunity to say that Mr. Stringham's contributions to the report were very valuable, consisting in observations made on the river (especially at Keokuk), in the discriminating judgment applied to the observations, and in the assembling of literature. In regard to the literature, the present writer has personally examined nearly all of the publications for which references were obtained by Mr. Stringham and has been able to add a good many more. He assumes full responsibility for the conclusions drawn from the study, but it is not out of place to say that the final conclusions differ from those that were formed jointly in 1917 in only a few important particulars, as to which revision of judgment was made inevitable by the accumulation of new data.

The continuity of such collections, made for other purposes summer after summer, have afforded many suggestions and served as a check upon premature generalizations.

A study of the plankton, or minute fish food, of the lake and of the river above and below and an examination of the distribution of aquatic vegetation in the lake were made by A. A. Doolittle in 1914. War conditions prevented a repetition of this survey after a period of two or three years, as was considered necessary for the best use of such data for purposes of deductions.

In the summer of 1921 Dr. Paul S. Galtsoff, of the United States Bureau of Fisheries, studied the composition, amount, and distribution of plankton in various parts of the Mississippi River from Lake Keokuk northward to Hastings, Minn., a few miles above Lake Pepin. His observations and conclusions have already been published by the bureau. (Galtsoff, 1924.)

Statistical canvasses of the fisheries in Lake Pepin and in Keokuk Lake (sometimes called Lake Cooper [4]) were made in 1915 by W. A. Roberts (for the year 1914), in 1918 by Arthur Orr (for the year 1917), in 1923 by various agents (for the year 1922), and in 1928 (for 1927).[5]

Another source of valuable information was found in the regular records of fish stranded on the top of the lock gates during 1915, 1916, and 1917, kept by lock masters William Huele, Timothy Harrington, and Walter Raber by direction of Montgomery Meigs, civil engineer, United States Army.

The officers and employees of the Mississippi River Power Co. have been uniformly considerate and helpful, extending to the investigators free access to all parts of the plant as necessary for the purpose of investigation and furnishing all information requested as well as several of the photographs used in this report. The cooperation of United States Engineer Meigs in allowing the regular use of a trammel net on the top of the lock gate during several months of 1915 and the assistance of lockmen in the operation of the net deserve special mention. Many fish dealers and fishermen (of Keokuk especially and of other places as well) have freely furnished information that has been indispensable to the effective conduct of the investigation, but their names are too numerous to mention.

Grateful acknowledgment is also made for the opportunities and the encouragement extended by former Commissioner of Fisheries Hugh M. Smith and Deputy Commissioner H. F. Moore and, more recently, by Commissioner of Fisheries Henry O'Malley and Elmer Higgins, in charge of scientific inquiry.

KEOKUK DAM AS A POSSIBLE OBSTRUCTION TO FISH

The dam has been described at some length in a previous report,[6] and it is unnecessary to repeat the details in this report. The features of the dam most essential for a correct understanding of its relation to fishes may be stated briefly in the following way:

Its location is across the Mississippi River, 1,435 miles by river from New Orleans (about 1,545 miles from the Gulf of Mexico) and 490 miles by river below

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[4] The name Lake Cooper was originally given to the body of impounded water above the dam and therefore was employed by the bureau in preceding reports. The change in the present report to the use of the name Lake Keokuk is occasioned by the action of the U. S. Board on Geographic Names, which has officially sanctioned the latter designation. To avoid the possibility of confusion, however, it seems advisable to state that our remarks refer in no case to the locally well-known Keokuk Lake of Muscatine County, Iowa.

[5] The results of these canvasses, frequently quoted in this report, are found in full in the following publications: Reports, U. S. Commissioner of Fisheries, for 1916, pp. 58-60; 1918, pp. 75-80; Sette, 1925, pp. 210-212; and Sette and Fiedler, 1929.

[6] Coker, Robert E.: Water-Power Development in Relation to Fishes and Mussels of the Mississippi. Appendix VIII, Report of the U. S. Commissioner of Fisheries for 1913. Bureau of Fisheries Document No. 805, pp. 11-18.

the head of navigation at Minnehaha Falls, near St. Paul, Minn. It is a little above the halfway point between Lake Itaska and the Gulf of Mexico (a distance of 2,553 miles). It is above the greater tributaries—the Missouri (200 miles) and the Ohio (375 miles). In fact, no regularly navigable streams or waters enter the Mississippi above Keokuk except the Rock River and Hennepin Canal, connecting with the river just below Rock Island, Ill., and the St. Croix in Minnesota. The tributary streams of most direct possible effect upon the dam are the Des Moines, about 3 miles below the dam; the Skunk River, entering the lake 35 miles above the dam; the Iowa River, 72 miles above the dam; and the Rock River, 119 miles above.

The site of the dam is just at the foot of the old Des Moines Rapids of the Mississippi, where the valley is comparatively narrow. (Figs. 1 and 2.) "The river at this place, in its natural condition, is about 2,600 feet in width at ordinary low water and about 5,500 feet in width at flood stages." (Clark, 1911, p. 203.) The dam, with its abutments, is nearly 1 mile long, and the fall is 32 feet, more or less, according to the stage of river level above and below. Low water just above the dam, which was formerly about 485 feet, is now 519, referring to the Memphis datum. High water was formerly 505 and is now 525. The pool, or Lake Keokuk, extends to a point a little above Burlington, or about 40 miles above Keokuk. The expanse of the lake is approximately 60 square miles—actually 58 square miles at low water, as compared with 36 square miles of river surface in former times at low water, and 64 square miles at high water as compared with 54 square miles in former times at a corresponding volume flow of the river.[7]

Returning to the dam, we find, beginning from the Iowa shore, the Government shipyard and dry dock, the lock (110 by 400 feet), and a short section of dam connecting the upper end of the lock with the lower end of the power house, which stands in the river 700 or 800 feet from the Iowa shore. Although the lower half of the power house is unfinished, except for its foundation (an integral part of the dam), the entire structure is one-third of a mile long. It extends upstream and nearly parallel with the Iowa shore to connect with the west end of the dam proper, which in turn extends across the river a distance of four-fifths of a mile to the Illinois shore.

We will now examine each of the principal structures constituting the dam (the dam structure, the power house, and the lock), as regards the general relation of each to the movements of fish. Additional details will be found in the companion report, in which the several species of fish are considered separately.

THE DAM PROPER

The dam structure is composed of 119 spans, each consisting of two piers supporting an arch, while the arches uphold a causeway. Between the piers are spillways, over which the water flows. Each of these spans measures 36 feet, center to center, the spillways being 30 feet wide and the piers 6 feet. The height of the spillways is 32 feet; their upstream face is vertical and the downstream face an ogee or compound curve, delivering the water in a horizontal direction down the river. For the protection of the base of the dam from scouring, a broad, low, concrete apron has been constructed.

Between the top of each spillway and the under side of the overhanging causeway is an arched opening about 19 by 30 feet (5.1 by 9.1 meters), which will permit

[7] Information supplied by the Mississippi River Power Co. by letter dated May 19, 1927; high water corresponding to a flow of 300,000 second-feet and low water to a flow of 50,000 second-feet.

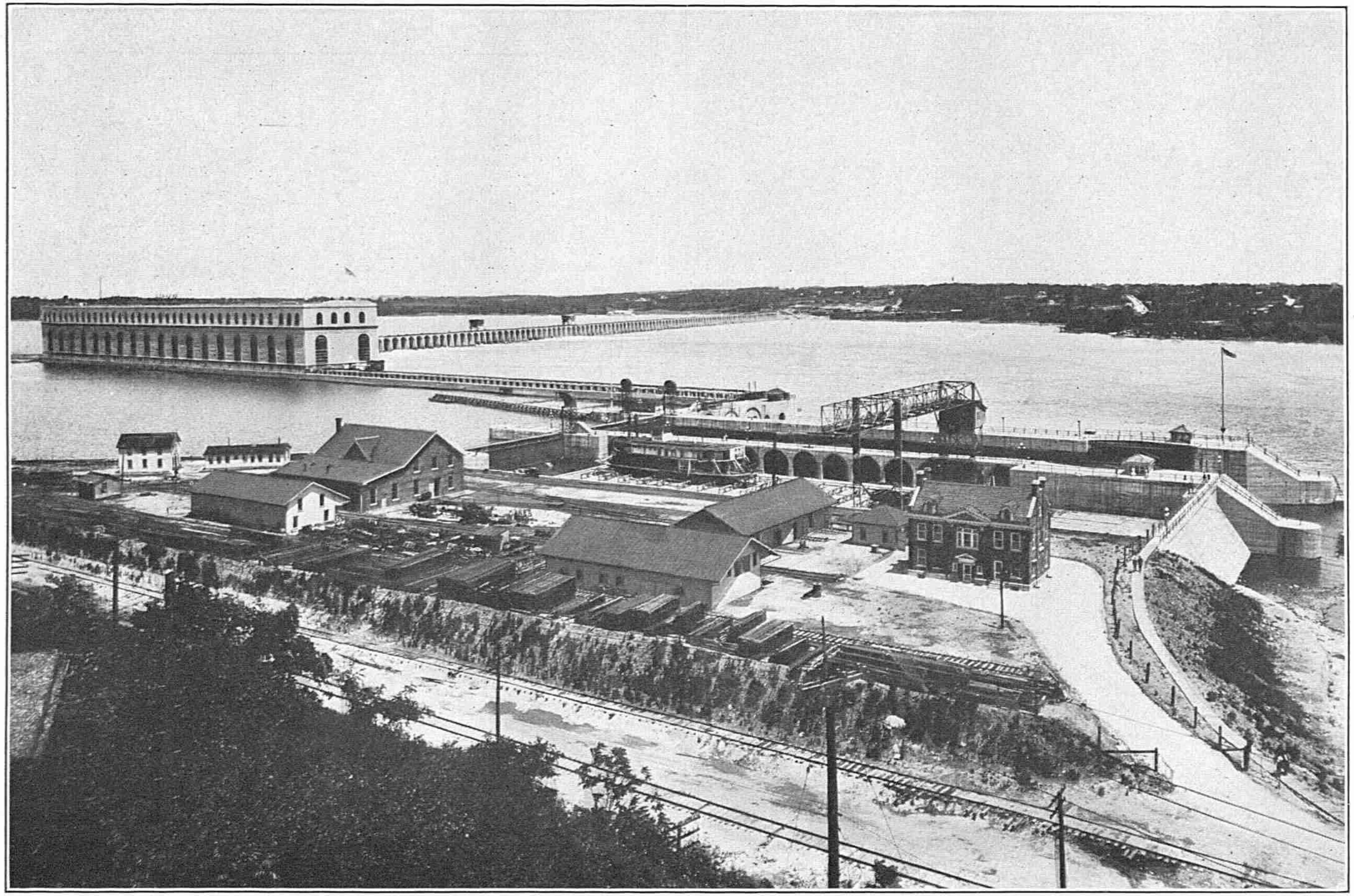

FIGURE 1.—Keokuk Dam and associated structures—dam, power house, lock, dry dock, and U. S. Engineers' offices and buildings

Figure 2.—The river as it appeared before the dam was constructed. Looking eastward over the old "Des Moines Rapids," December, 1910

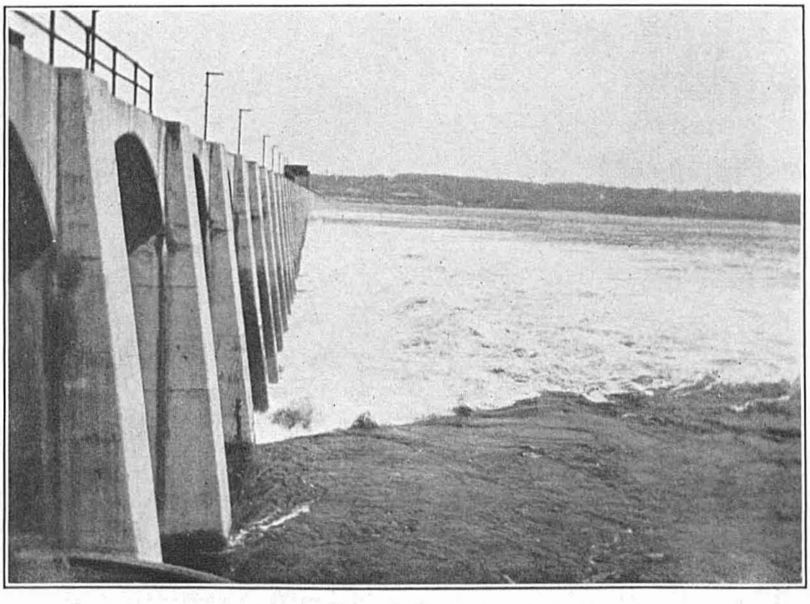

Figure 3.—The surging waters below the open spillways

the passage of ice and drift when the gates are open. The gates are of steel, 11 by 32 feet (3.4 by 9.8 meters), and, working in deep slots in the concrete, may be raised so as to give free passage to the water or may be lowered so as to hold back the water entirely, except such as washes over when the wind is high and such as escapes by leakage. The volume of water passing Keokuk, and therefore the water levels above and below, is regulated by opening and closing these gates. The variations in the number of gates that are open is said to range from none to 100. One hundred and six observations made during the period April 16 to September 15, 1916, each on a separate day, and one or more at nearly or quite every hour of the day and night, showed a range of 2 to 57 and an average of 28+. The average for the whole year, including the period of low water in winter, might well be much less. On June 9, 1915, 74 gates were seen to be open at one time. The gates are raised and lowered by a traveling electric crane, and a complete operation, including the movement of the crane from the adjoining gate, required about 26 minutes previous to 1916; during that year improvements were made, so that a complete operation could be performed in about 6 minutes, and only one crane is needed now.

The head, or difference in water levels, varies considerably, being affected by flood conditions above and below the dam and doubtless by backwater from the Des Moines River prior to July, 1917; according to information supplied by the power company, the head on the turbines had been as low as 21 feet and as high as 37 feet; it was thought that the head at the dam might be as much as 1 foot greater. When a gate is open there flows over the spillway a stream of water about 10 feet deep (at the crest) by 30 feet wide.

We thus have at each spillway in use a waterfall of considerable volume, deflected at the bottom, where the water shoots out with tremendous force in the form of a raging, foaming torrent, which makes a striking spectacle. Only an inadequate idea of it can be gained from Figure 3. The mass of rapid water cuts a deep, sharp trough in the surface of the river, so that the surrounding water is at a considerably higher level than the race water below the open spillways. It may be possible to grasp this from the figure; the dark area in the foreground is the relatively still water, which is always flowing down into the trough made by the water coming over the dam. During most of the year the water makes a terrific commotion when it hurls itself against rocks that extend above the surface of the water. When the stage of the lower river exceeds 11.34 feet (or 495 feet, Memphis datum), all rocks, as they existed in 1916, are submerged. The turbulence of the water is then less spectacular, but the force is still so great that no fish can get to the base of an open spillway. They do, however, come to the dam at a point where spillways are closed, and often work along the base until they are carried by the eddy into the troughlike race, by which they are instantly swept down the river. Sometimes a fish drawn into the edge of the race in this way is tossed high into the air; but in any case its inability to stem the swift current is manifest.

It is evident then that the dam itself (as distinct from the power house and lock) is insurmountable for fish coming from below. Not only can fish not ascend the spillways, but they can not even buffet the current for a distance of several hundred feet below the open spillways.

There are several conditions that might cause fish to approach the base of the dam. In the first place, if there were an upstream movement at the time of the reproductive activity, the fish naturally would be led to follow the swift current as far as it was possible to do so, and as they skirted the main streams from the spillways they would be led in many cases to the base of the dam. In the second place, the aeration of the water would be highest just below the falls, and this condition might be attractive to fish, particularly just before the season of reproduction. Finally, it is not unlikely that a good deal of food is brought over the dam from the pool above, which would serve as bait to draw the fish as near as possible to the dam. Whatever the cause, it seems to be a common observation that fish are found abundantly below dams at certain seasons and particularly in the first years after the construction of a dam. The investigators have, therefore, kept a careful watch for aggregations of fish, of any species at or near the base of the dam. Conspicuous aggregations of fish, however, have rarely been observed at Keokuk, occurring much less frequently than was expected and apparently with no regularity.

While our visits were only occasional during 1913, 1914, and 1917, it must be kept in mind that an observer was in regular attendance during two complete open seasons—1915 and 1916. The first recorded aggregation of fish was reported by Thaddeus Surber in 1913, only a few weeks after the dam was closed. (Coker, 1914, p. 10.) Fish were seen first below the dam on July 10 and 11 in such numbers that local residents captured them not only with hook and line but with dip nets and hayforks. The fish seemed to have been found in the following order of abundance: Buffalo, carp, paddlefish, sheepshead, drum, channel catfish, redhorse, Missouri or blue sucker, toothed herring, and hickory shad. It may be remarked that many of these fish are not particularly migratory.

The next conspicuous aggregation of fish was observed by the writer in the following year on April 29, when only one species, the river herring, was in evidence. The distribution of the herring on this occasion has been described in the following words (Coker, 1914, p. 25):

> The day of my arrival, April 29, was cold, windy, and cloudy, and at first view very few herring were observable. After closer observation, however, they were seen to be present in immense numbers, and congregated in certain locations * * *. A large number were seen just below the short section of dam between the upper end of the lock and the lower end of the power house; many were observed along the outer wall of the tailrace, but in the angle between the power house and the dam and from this point to the nearest open spillway, a short distance away, the herring were fairly massed. Such a close aggregation of fish can rarely be seen in fresh water. They had evidently followed up along the outer edge of the tailrace until they could go no farther. Again, on the outer side of the last spillway in use, which was about 700 feet from the power house, there were considerable numbers of herring. From this point to the Illinois shore, a distance of about two-thirds of a mile, not a single herring was in evidence. It was evident, therefore, that the herring had been guided by the moving water, so that they had in consequence assembled in such remarkable numbers on each flank of the stream below the open spillways, many more being guided to the eastward side by the strong current from the turbines.
>
> Opportunity to observe whether they could breast the strong current was favored by the fact that there were three closed spillways between three open on the east and nine open on the west; thus, there was a triangle of relatively slack water between two strong currents that met a short distance below. To the west of the westward current fish were abundant; to the east of the eastward current they were still more abundant; but in the triangle between not one fish could be seen. It was evident, therefore, that the power of the currents below the spillways proved an effective barrier to the lateral movements of the fish for some distance below the dam, otherwise not all of the fish would have been on the right side of one current and on the left side of the other.
>
> The powerful currents caused slight eddies on each side, so that the dead water at the foot of the dam on either side was continually being drawn into the spillway streams. The fish were also drawn in, and it was easily observed that the velocity of the streams made them perfectly helpless. As soon as they passed into this stream they were thrown up in the foam and spray and often hurled

20 feet or more, back, sides, or underparts up, to be carried off as soon as they fell. Presumably no injuries were received, as no dead or injured fish were observed in the river below. No fish, as previously indicated, were drawn in from the slack water between the easterly spillways and the westerly, although similar eddies prevailed here.

This remarkable aggregation of a fish, presumed to be one of the most migratory in the river, seemed to be especially significant, and we expected that it would be repeated in the following year. However, this expectation was not realized, and it will be seen later that other observations give ground for the belief that the herring is established both above and below the dam. (Coker, 1930.)

In spite of the closest observation in the spring and summer of 1915 and 1916 no extraordinary gatherings of fish other than gar pikes and carp were observed by Stringham. An extraordinary aggregation of carp that occurred near the lock on July 17, 1916, is illustrative. The fish were just below the short section of the dam connecting the lock and the power house, or at the bottom of the chute used for passing over the drift that accumulates in the fore bay above the lock. Thousands of carp were visible at any moment. In this case the occasion of the assemblage of carp was fairly obvious. On July 13 and 14 there had occurred a noteworthy flight of May flies, and millions of them had drowned in the lake. On the 15th the prevailing wind was from the southeast, but on the 16th it was from the north and on the 17th from the northeast. An enormous and noisome mass of May flies, May-fly casts, and duckweed had drifted toward the lock and was flowing in a steady stream through the chute. The carp were snapping up the May flies and duckweed at the surface. Nine of the carp were opened and the stomachs of seven were found to contain principally adult May flies, with some duckweed and the remains of the weed; two were empty. Early the next morning both fish and May flies had disappeared. Later observations on the 19th, 20th, and 21st indicated a recurrence of carp in noticeable numbers associated with a north wind and the presence of the floating food.

While the dam serves as a barrier to upstream movements of fish so far as the dam structure proper is concerned, it is of interest to know if it is in any way a barrier to downstream movements. Observations upon this point are not complete or satisfactory. Fish can and do pass over the spillways, but we do not know that this occurs at all frequently. It is probable that the lake itself operates as a sort of barrier, in that deep still water provides such habitats for fish in downward migration as to inhibit the tendency to move down the river. Certainly, so far as a downward migration is the result of drifting with the current, the relatively slack waters of the lake would serve as an automatic check.

During the latter half of July and August, 1916, when May flies were very abundant immediately above the dam, fish were frequently seen to break the surface, but, on the whole, fish were not often in evidence in the surface waters of the lake near the dam. On August 2, 1915, a number of fish were seen above the western end of the dam, swimming near enough to the surface to make conspicuous wakes. Commonly they swam down near the crest of the dam and then suddenly turned back, but sometimes they were seen to go over the spillways. Such observations could be made only when the fish swam close to the top of the water. It is reasonable to infer that this occasion was not an isolated one and that the fish do go over the spillways from time to time. Several experiments mentioned in another connection show that the goujon (*Leptops olivaris*), the carp, and the paddlefish may go down the spillways and through the turbulent waters below without injury.

So far, then, as regards the dam structure proper, which comprises about three-fourths of the total barrier, we find that no fish can pass upward but that the fish may pass down, particularly those that feed or swim near the surface. The vertical upstream face of the spillways is a factor that must tend to lessen the chance of bottom fish being drawn over with the current. Aggregations of fish at the base of the dam, as if endeavoring to find a way up, have been observed, but with no such regularity as might have been expected. In the few instances, when such conspicuous gatherings of fish came under notice, different species were present each time, and in one case the presence of food brought over the dam was the obvious occasion for the gathering. Such observations do not afford adequate basis for dismissing the possibility that the dam acts detrimentally as a barrier to upstream migrations, and this question will be considered more carefully in later sections of the paper.

POWER HOUSE

The power house, built out in the water and nearly parallel to the Iowa shore, from which it is some 700 or 800 feet distant, forms the eastern boundary of the fore bay. It may be remarked that the fore bay is a semi-inclosed portion of the lake, bounded below by the lock and the dry dock, on two sides by the power house and the Iowa shore, respectively, and above by a long ice fender of concrete, which extends from the upper end of the power house to the Iowa shore, being interrupted by a wide opening of about 300 feet for the passage of boats between fore bay and lake.

The superstructure of the power house is completed for only one-half of the total length as planned (1,718 feet), but the entire foundation walls are in place, being essential to hold back the upper water. The outside wall toward the Iowa shore is not built solidly to the bottom but rests on a series of arches, so that the water from the fore bay has free access to an inner or head bay within the building and extending its entire length. The outer wall of the building, which faces the Illinois shore, rises from the downstream bed of the river and is flanked by the tailrace. (Fig. 4.) The head bay and the tailrace are connected by as many passages as there are turbines, and each main passage consists of four narrow intake passageways; a single large scroll chamber, 38 feet in diameter, around the turbine (fig. 13); the turbine chamber; and the draft tube below. The turbines, of which there are now 15 installed, are arranged in a single linear series from end to end of the house. The tailrace itself is excavated about 25 feet below the bed of the Mississippi; its width is 80 feet at the end, broadening to 230 feet at the lower end of the power house; the precise width below this point does not appear to be known, but the excavation was carried considerably farther down.

The water from the head bay is admitted to each turbine through four gates, each 22 feet high by 7 feet 6 inches wide, consisting of iron gratings, which prevent the passage of large drift but which can exclude only those fish that are of unusually large size, the openings being 6 by 23 inches. The structures within the buildings are more particularly described later in discussing injuries to fish. It is sufficient at this point to state that upward movements of fishes would be stopped absolutely by the turbines. Undoubtedly it would be impossible for a fish to pass upward from the tailrace, through the draft tubes, and beyond the turbines.

To find passage downstream through the power house, a fish must first pass the ice fender, either through the boat channel or through the deeply submerged archways; it must then enter the power house through the arches of the foundation

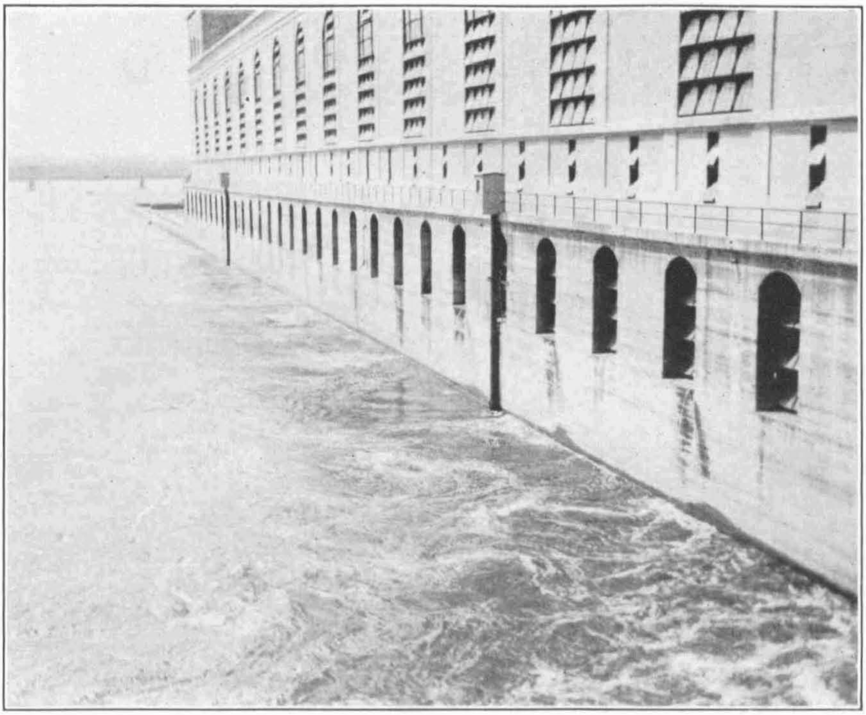

Figure 4.—Turbulent tailrace west of the power house; the outlets from the turbines are beneath the surface on the right

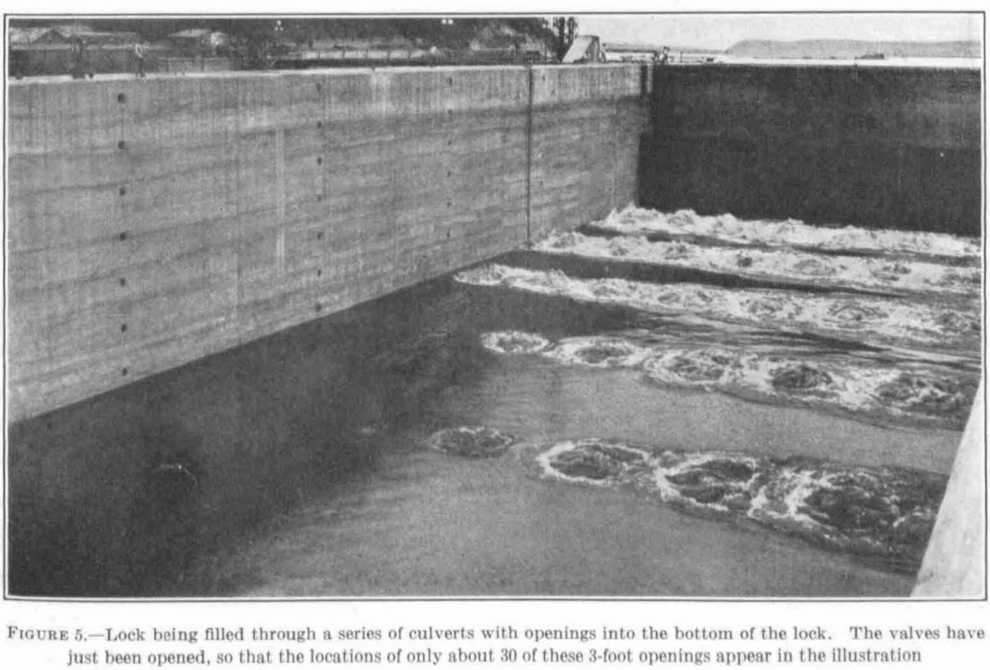

Figure 5.—Lock being filled through a series of culverts with openings into the bottom of the lock. The valves have just been opened, so that the locations of only about 30 of these 3-foot openings appear in the illustration

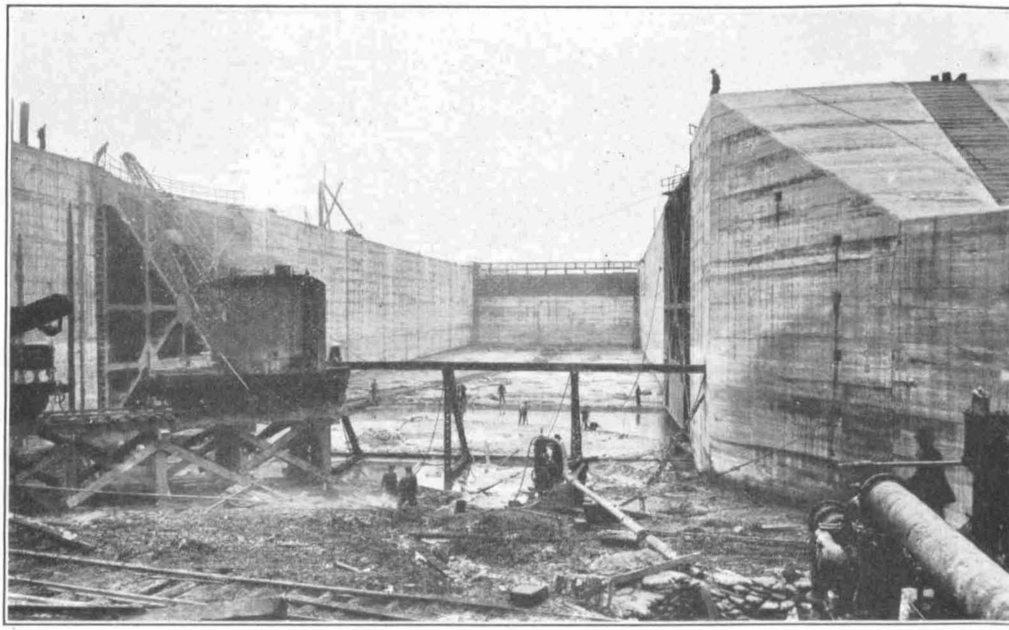

Figure 6.—The lock as it appeared in course of construction. Looking upstream into the lock from below the lower gates which are swung back into recesses in the walls. The head wall and head gate are seen in the background

Figure 7.—Setting a trammel net on the top of the lock gate to determine from which side the fish come

walls. Having passed these partial obstructions, it encounters the screens or gratings at the gates of the intake passages. The openings in the gratings (6 by 23 inches) are wide enough to admit most Mississippi River fishes but so close that a downward-moving fish probably would be deflected just as fish are deflected by the wide-meshed leads of a trap net. The investigators never saw a fish near the screens, except one or two that were put into the water for experimental purposes. The power company's guide, who walked by this head bay several times a day for nearly two years, stated that he never saw a fish here prior to April, 1915; on April 4 he said that a few days before he had seen four or five fish. Obviously, however, only surface-swimming fish would be observable, and it may be that such are deflected more than bottom fish by the ice fender and the arches of the foundations of the power house.

A fish passing into the power house from above, through the screens, would nowhere find a narrower passage than the screen afforded, except in a single unit where the vanes admitting water from the scroll chamber to the turbine have an opening that is only about 5 inches wide, according to information supplied by the power company. Usually the opening between the vanes (fig. 13) is about 9 inches (23 centimeters). It may be remarked that the clearance between the vanes and the blades of the wheel is large enough to pass any fish of the locality. The blades or buckets of the wheel or turbine are 6 to 7 inches apart above, widening downward to 10 or 12 inches. It seems altogether likely that nearly any fish that passed the screens guarding the entrance above could continue with the current of water through the turbine chamber and draft tubes into the tailrace below. Experiments subsequently to be described (p. 112) show the possibility of their going through unharmed.

LOCK

The lock, which serves the uses of navigation, is between the power house and the dry dock. It is of particular interest, as it is the only passageway by which fish may go from the lower river to the upper, and it has been suggested that it might function as a fishway. The inside dimensions are 110 by 400 feet; the lift varies with the head, which is nearly the same as that on the turbines. The lower gates swing open while the upper gates submerge, working up and down in vertical slots. There are, in fact, two gates at the upper end—the ordinary "upper" gate, which is used regularly, and above this an emergency or guard gate, which is normally submerged. Water is admitted to and emptied from the lock through a series of culverts, the main running under the eastern wall of the lock, and having connections with both levels; either or both connections may be closed by valves. Branch culverts from the main run beneath the floor of the lock, and openings in these admit the water into the lock in a series of geysers, as shown in Figure 5, or permit it to run out when the upper valves are closed and the lower ones opened.

It will be inferred from the description that fish would not be likely to enter the lock from below during the process of emptying, as to do so would be to pass through deeply submerging, sharp-angled tunnels, out of which the water is discharging at a velocity that is enormous until the lock is nearly empty. Likewise, they would not gain the upper lake from the lock during the process of filling at a corresponding velocity; furthermore, the intakes are screened by gratings, the openings of which are irregular in size, varying from 1⅞ to 2⅜ inches. So far as it has been possible to learn by inquiry, no fish was ever seen to pass out here, and probably none ever has.

Another significant feature of the lock is the head wall, locally called a "sill," at the upper end of the lock. An examination of Figure 6, from a photograph taken while the lock was unwatered, will give an idea of this particular difficulty to be overcome by a fish using the lock to pass upstream. In the illustration the two swinging lower gates are shown wide open and in their niches in the respective side walls; the wall or sill is in the middle background. A fish entering the lock finds a depth of 10 to 25 feet of still water. The lower swinging gates having been closed, the water is admitted in miniature geysers, as shown in Figure 5, until, after 7 or 8 minutes, it is from 21 to 37 feet (6.5 to 11.3 meters) higher than when the lower gates were closed. The upper gate (black in fig. 6) is submerged until its surface is level with the upper wall, shown light in the background. The fish is now in an inclosure 110 by 400 feet (33.5 by 122 meters) containing about 47 feet of still water. The only exit is the area 110 feet wide and 12 to 14 feet deep over the wall or sill. There is no current to guide the fish to this small opening at the upper edge of one part of a large area of concrete, and, as will be shown hereinafter, this opening exists for only a few minutes, the water being then lowered to the level of the river.

INTERVALS OF FREE PASSAGE

As has already been pointed out, there is no opening by which fish may leave the lock above, except while the upper gate is down. An effort was therefore made to learn during how much of the time this gate is submerged. Since the lock masters' records show the number of lockages, it was necessary only to learn how long, on the average, the gate is down at each lockage.

Without any selection, and just as happened to be convenient, 54 ordinary operations were timed. These operations were made in the usual way for the passage of boats, and, except in a few instances, the persons doing the work did not even know that an observation was being made. The gate remained beneath the water from 1½ to 17½ minutes, and the average for the 54 cases was 4.5 minutes. Of these, there were for the passage of boats northward 29, averaging 3.3 minutes, for the passage of boats southward 22, averaging 6 minutes, and for the simultaneous passage of different boats into and out of the upper end of the lock 3, averaging 4.5 minutes. The longer average time for boats passing downward was due to the fact that for steamboats it was the practice to have the gate ready a few minutes before the boat arrived, so as to run no risk of causing it to stop above the lock. Steamboats passing up out of the lock simply cast off from the wall of the lock and leave, so that there is no corresponding delay. For smaller craft the time of submergence was not affected by the direction in which they are going.

To allow for this difference, and because the observed cases include 7 more "ups" than "downs," we may add 7 imaginary "downs" of 6 minutes each to the 54 observed cases, which gives an average of 4.7 minutes. To simplify the arithmetic involved, 5 minutes will be taken as the average time when there exists a possible passageway for fish during each operation of the lock.

In 1915 the lock was operated from March 1 to November 29, inclusive, or 274 days, and the total number of lockages was 1,489, being an average of 5½ times a day, or almost precisely 38 times a week. Complete records for 1916 are not at hand, but during the 114 days from March 24 to July 15, inclusive (the season of supposed upward migration of fish), there were 477 lockages, an average of 4.2 times a day, or 30 times a week. The actual number per week (excluding fractional weeks at the beginning and end of seasons) during this year and a half varied from 2 to 89; but there were only two weeks with more than 58 lockages. During the first half of 1916 the largest number in one week was 49.

Taking the average of lockages per day as 5 and the average time per lockage as 5 minutes, there was an opening for fish of 25 minutes a day, on the average, or 2¾ hours in a week. The maximum opening in any week during the year and a half in question, excluding two extreme cases, was about 4 hours. Or, to present the figures in one more form and using the same average time per lockage, there was, during the year 1915, an opening for fish for a period of time equivlent to 5⅙ days, and during the first half of the calendar year 1916 (including July 1) 1⅛ days.

EXTENT OF FISH MOVEMENTS DURING INTERVALS OF FREE PASSAGE

The facts already adduced show that there was but little time when a fish had even the slightest chance to pass out of the upper end of the lock. It has also been indicated that the situation was unfavorable during these brief intervals because of the lack of current and the relative smallness of the exit. Certainly, the lock is not entitled to be considered a fishway unless, in spite of these adverse circumstances, there is a dense mass movement of fishes leaving the lock when the upper gate is submerged. The evidence available as to the extent to which fishes move over this upper gate will now be considered.

It will be understood that a trammel net consists of three nets put together, sandwichlike, the middle one, called the "web," being of small mesh and the two on the outside, called the "walls," being of mesh much too large to stop any fish that it is expected to catch. A fish striking the net with appreciable force pushes the web through the opposite wall and thus pockets itself. Figure 7 will perhaps show this more clearly than the description.

A trammel net with web of 2-inch (5-centimeter) mesh between knots and wall of 8-inch (20-centimeter) mesh was supported on the gate by means of three 13-foot (4-meter) pieces of gas pipe, these having the net tied to them and being in turn supported in three holes bored into the respective ends and the middle of the gate. Wedges held the bottom or lead line of the net fast to the gate, and corks kept the other edges at the surface of the water. During part of the first month the cork line would go a little beneath the surface at one end, but this was corrected by doubling the number of corks. When the gate was down the only possible passage was closed by the net, except as hereinafter stated. (Fig. 8.) Operations of the gate were made especially for this work. To give fish an opportunity to enter the lock the lower gates were left open a half hour or more (except on April 3) before closing them and filling the lock. Sometimes they were open 8 or 10 hours; the average was about 2 hours. Leaving the lower gates open for this length of time made the circumstances slightly more favorable than is normally the case; but it would be entirely possible to have the lower gates left open nearly all the time, and the circumstances during the experimental work were, therefore, no more favorable than they might readily be made were it found worth while to do so.

A fish might pass the net at either end through a space between the net and the wall of the lock, possibly 1½ feet (½ meter) wide at the widest part. A trammel net is designed to catch fish on their first contact with the net, and there is probably little passing of the fish along the net toward the ends; however, a few individuals undoubtedly went through at those places. The only other way that a fish too large to go through a 2-inch mesh could get past, with the net on the gate, was by passing downward through one of a series of horizontal openings between the beams of the gate and then under the walk of the gate. These openings are shown in Figure 9. They are not rectilinear; of the eight, six measured about 3 by 8 feet (1 by 2½ meters) and the others were smaller. In order to find these openings a fish would have to descend sharply into a narrow passage without an obstacle to guide him downward. It is possible that some fish of bottom habit might make this sharp descent, but these are the fishes least likely to surmount the wall at the upper end of the lock.

The first operation with the net on the gate was made on March 25, 1915, and the last on August 25 of the same year. Excluding three days, the record for which was lost in a notebook that fell into the water, 94 operations were made—1 in March, 28 in April, 23 in May, 21 in June, 17 in July, and 4 in August. A schedule, conformed to as closely as the exigencies of navigation allowed, provided for different hours on each day of the week—from 3 a. m. to 11 p. m.

In the net itself there were caught about 46 Ohio shad (all but one taken from the lock side), 11 bigmouth buffalo, 2 each of longnose gar and river herring, and 1 each of smallmouth buffalo, river quillback, sauger, mooneye (Alosoides), and bowfin. During these operations many more fish were caught on the surface of the gate than in the net. The net was run diagonally across the gate, bisecting its surface. Except on the first day, note was made as to whether fish lay on the side toward the lock ("below") or on the side toward the lake ("above"). The total of all fish taken in the net and on the gate during the 94 operations was 167 above, 457 below, and 7 not noted. These were distributed among the various species as follows:

TABLE 1

Species	Below	Above	Not noted	Total
Longnose gar	2	2		4
Shortnose gar	21	5		26
Bowfin		1		1
Mooneye (Alosoides)	4			4
Mooneye (Tergisus)	4			4
Mooneye (lost before identified)	1			1
Gizzard shad	23	1		24
River herring	2			2
Ohio shad	45	1		46
Eel	1			1
Bigmouth buffalo fish	20	1		21
Smallmouth buffalo fish	8	2		10
Buffalo fish (lost before identified)			1	1
River quillback	206	87		293
Quillback (Difformis)	3	1		4
Quillback (lost before identified)	1			1
Shorthead redhorse	6	1		7
Quillback or buffalo (lost before identified)	1			1
German carp	6	2		8
Shiner (Atherinoides)	1			1
Spotted cat	52	32		84
White crappie	7	9		16
Black crappie	3	2		5
Bluegill	2	1		3
Walleye	2	1		3
Sauger	5	3		8
White bass		1		1
Yellow bass	1			1
Fresh-water drum	30	14	6	50
Total	457	167	7	631

This is a representative list of the commoner species found about Keokuk during that year, except for the omission of the minnows, goujon, and two species of the current—shovelnose sturgeon and Missouri sucker (blue sucker). Nearly all species were taken more numerously from the lock side than from above. This was due partly, at least, to

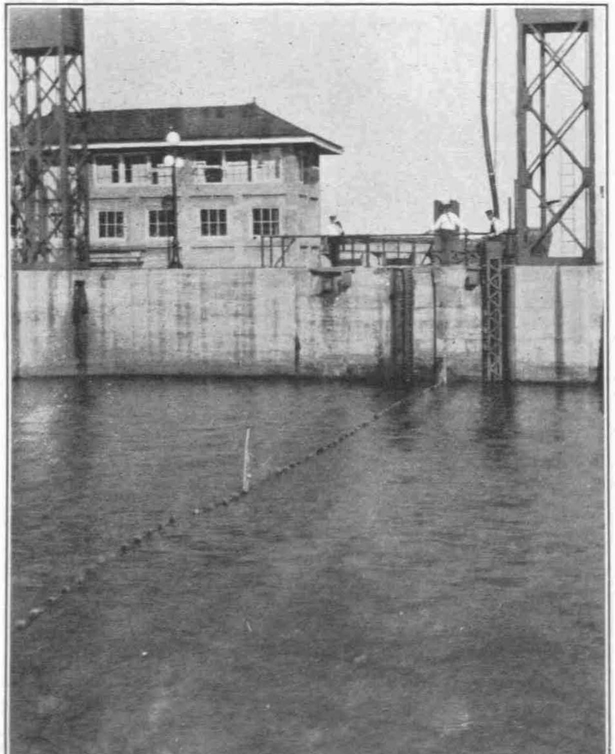

FIGURE 8.—The gate down and the corks keeping the top of the net afloat. Fish passing out of the lock, upstream, and into the lock from the lake, downstream, will be pocketed on different sides of the net

FIGURE 9.—The gate has been rasied, one fish having been caught in the net. Large catches were made on several occasions

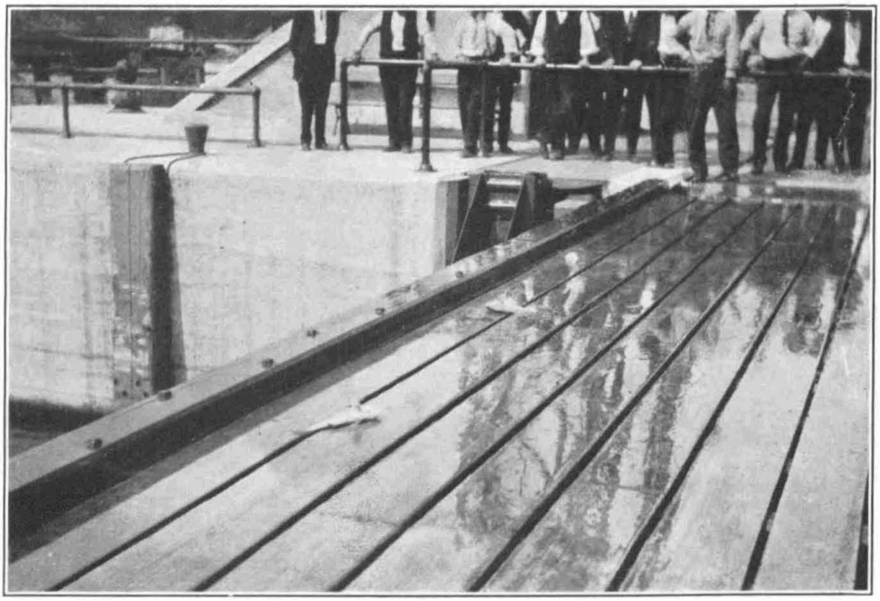

Figure 10.—The head gate of the lock has just been raised and several fish may be seen stranded on its top—a common occurrence

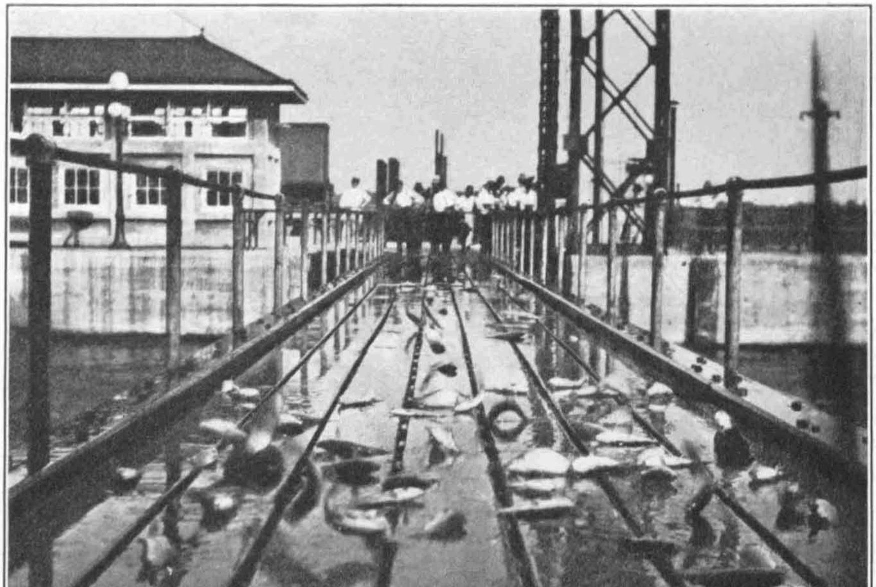

Figure 11.—An unusual catch of fish on the gate (in 1916), chiefly carp

the fact that shortly before the gate is lowered the disturbance incident to the filling of the lock causes the fish here to become very active. However, the taking of 46 Ohio shad, all except one from the lock side, indicates that a few individuals of this species find their way through the lock; from one to five a day were caught on various days from May 4 to July 11. The following may be added as to the species of which more than 25 were taken. The shortnose gar was very abundant about Keokuk and was found everywhere—river, lake, sloughs, and creeks. The same is true of the river quillback, which was, perhaps, the most abundant of all species in the locality that year. The spotted cat taken were nearly all small fish, evidently hatched the same year or the year before. The drum, like the gar, was very abundant, but particularly so in the vicinity of the power house and its accessories. Possibly some of the gar and drum taken were engaged in a migratory movement. The extremely small number taken of every sort of fish shows that there was no such massed movement over the upper gate as would have to occur to make the lock an effective fishway.

CAPTURE OF FISH ON THE UPPER GATE

Nearly or quite the only reason suggested for considering the lock to be a fishway was the fact that fish were often taken on the upper gate when it was raised. (Figs. 10 and 11.) Two stringers, 74 inches (188 centimeters) apart, run the length of the gate near its outer edges; the tops of them are 3⅜ inches (8.5 centimeters) above the surface of the gate. The surface of the gate between the stringers, being 110 feet long, has an area of about 678 square feet (63 square meters); this area consists of timbers laid with spaces between them, through which the water flows. The gate, therefore, is the equivalent of a huge shallow dip net, the stringers restraining the fish at the sides, and the length of the gate, as well as the walls, restraining them at the ends. The stringers are not the most effective possible restraint on fish, but they are high enough to hold some representatives of some species. On July 10, 1915, there occurred an opportunity to see how fish are thus held. The emergency or guard gate was up and held back the water of the lake, while below it the water level was that of the river. The regular upper gate was down and slightly submerged, but not deeply enough to have disappeared even in the muddy water of the Mississippi River. A German carp within the stringers was swimming back and forth along one of them, much like an animal in a zoological park, although by rising slightly it might have escaped.

During 1914, Mr. Huele, the lock master on duty from 8 a. m. to 4 p. m., made notes as to the species found on the gate. These notes contain the names of the same species that were taken commonly in 1915 and 1916 and show that very few fishes were taken when the water was unusually muddy.

During 1915 and 1916 a record was kept by the three lock masters of the number of fishes taken at all lockages. An effort was made at first to determine the species taken, but the gatemen (who reported to lock masters) found that it was impracticable, in the necessarily rapid work, to distinguish closely allied species. Observations made from time to time indicated that species were represented in about the same proportions as when the net was on the gate (see p. 100) except that the Ohio shad and the river herring were rarely, if ever, captured. Tables 2 and 3 were compiled from these special records of fish taken and the regular records of lockages made by the lock masters.

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TABLE 2.—*Record of fish taken on upper gate of lock at Keokuk, Iowa, by weeks, 1915*

Week	Total lockages during week [1]	Gar	Shad, herring, and mooneye	Buffalo fish and quillback	German carp	Spotted catfish	Crappie	Sunfish	Pike perch	Striped bass	Fresh-water drum	Other species	Total fish during week
Feb. 28 to Mar. 6	1										8		8
Mar. 7 to 13	2			2							35		37
Mar. 14 to 20	9		1	4							31		36
Mar. 21 to 27	8								1		1		2
Mar. 28 to Apr. 3	21		1	2							8		11
Apr. 4 to 10	28			12				1			13		26
Apr. 11 to 17	27		1	11			3	2	1	1	12	1	32
Apr. 18 to 24	36	2	4	35	2	3	9	1	4	4	24	1	89
Apr. 25 to May 1	33	6	6	24	5	17	2		4	2	12	2	80
May 2 to 8	40	7	7	35	3	17	4	1	5		26	1	106
May 9 to 15	45	3	4	157	20	67	4	2	7	1	59	1	325
May 16 to 22	22	1	2	74	27	20	4		4	2	41	1	176
May 23 to 29	44	3	2	47	11	50		2	7	2	25	1	150
May 30 to June 5	42	2		5			2						9
June 6 to 12	51	3	1	11		5		1			25	1	47
June 13 to 19	43	11	19	112	6	33	3	1			31	2	218
June 20 to 26	54	8	10	53	4	24				1	33	1	134
June 27 to July 3	68	9	6	66	12	27	2	1			24		147
July 4 to 10	89	11	1	162	48	54	2				147	1	426
July 11 to 17	47	8	1	95	11	18					21		154
July 18 to 24	51	7	1	11		12			1		2		34
July 25 to 31	58	8	4	6		9	1				8		36
Aug. 1 to 7	58	2	1	2	1								6
Aug. 8 to 14	58	4	5	12	3	5						4	33
Aug. 15 to 21	54	6		45	6	14	1	1			61		134
Aug. 22 to 28	53	1	1	34	6	19	1	2		1	10		75
Aug. 29 to Sept. 4	42	2	1	104	29	29	3		1	1	94		264
Sept. 5 to 11	53	2	6	292	205	23			8	1	171		708
Sept. 12 to 18	37	1		8		7	2				8	3	29
Sept. 19 to 25	39	4		4	2	6			1		2		19
Sept. 26 to Oct. 2	45	1		6		13	2				11		33
Oct. 3 to 9	36			2					2		9		13
Oct. 10 to 16	40		1	2		2			7		39	3	54
Oct. 17 to 23	35		2		3	1			3		32	1	42
Oct. 24 to 30	33					2			3		18		23
Oct. 31 to Nov. 6	27			4							13		17
Nov. 7 to 13	19								2		3		5
Nov. 14 to 20	15								2		11		13
Nov. 21 to 27	19												0
Nov. 28 to Dec. 4	7			2							1		3
Total	1,489	112	88	1,441	404	477	45	15	63	16	1,069	24	3,754

[1] These totals of lockages do not include the 97 made as part of this investigation, because the lock masters did not record the fish taken at such lockages.

TABLE 3.—*Record of fish taken on upper gate of lock at Keokuk, Iowa, by weeks, 1916*

Week	Total lockages during week	Gar	Shad, herring, and mooneye	Buffalo fish and quillback	German carp	Spotted catfish	Crappie	Sunfish	Pike perch	Striped bass	Fresh-water drum	Other species	Total fish during week
Mar. 19 to 25	1			1							12		13
Mar. 26 to Apr. 1	5										31		31
Apr. 2 to 8	15			2				1			3		6
Apr. 9 to 15	15		1	17				1			2		21
Apr. 16 to 22	16		1	21							2		24
Apr. 23 to 29	26	3	4	27			4	1	3	2	5		49
Apr. 30 to May 6	26	5	3	36			2	2			7	1	56
May 7 to 13	24	16	10	15		1		1	1	1	3	1	49
May 14 to 20	16	8			1			1			1		11
May 21 to 27	21	17	4	3	1	6							31
May 28 to June 3	26	29	7		2	4						2	44
June 4 to 10	25	34	14	18	2	6						1	75
June 11 to 17	23	32	7	15	3	7							64
June 18 to 24	49	22	6	15	5	14					9	2	73
June 25 to July 1	35	31	3	25	12	14					3		88
July 2 to 8	38	44	18	35	185	5		1				3	291
July 9 to 15	48	34	13	54	664	8	2	2		1		3	781
July 16 to 22	36	34	1	14	498	16	3	27			4	3	600
July 23 to 29	32	10	1	13	202	18	1			1	7		253
July 30 to Aug. 5	46	37	21	15	2,134	16	21	1	1	1	20	3	2,270
Aug. 6 to 12	52	17	14	6	6,666	6	11	2	1		23	3	6,749
Aug. 13 to 19	41	14	20	1	2,972	6	10	2	1		34		3,060
Aug. 20 to 26	55	2	1		2,129	4	12		1		11		2,160
Aug. 27 to Sept. 2	47	3	2	4	1,779	4	11				17		1,820
Sept. 3 to 9	40	7	10	9	558	6	15	2			47		654
Sept. 10 to 16	29	2	10	5	150	5	9	1		1	32		215
Sept. 17 to 23	39	2	8	4	58	8	15		1	1	116		213
Sept. 24 to 30	26		2		28	6	4		2		38	1	81
Oct. 1 to 7	36		7	3	27	2	9		4		68		120
Oct. 8 to 14	28		3		13	3	3		4		29		55
Oct. 15 to 21	32	1	3	1	13	3	3				7		31
Oct. 22 to 28	41		1	1	2		2		1	1	4		12
Oct. 29 to Nov. 4	37		2	2	6		2		7		11		30
Nov. 5 to 11	40		7	5	24		3		4		12	1	56
Nov. 12 to 18	30						2		1	1			4
Nov. 19 to 25	35		2				1		5		2		10
Nov. 26 to Dec. 2	11		1	4									5
Dec. 3 to 9 [1]	11												
Dec. 10 to 16 [1]	1												
Total	1,152	404	207	371	18,134		145	45	37	10	560	24	20,105

[1] No fish.

During 1915 the average catch per lift of the gate was 2½ fish. During 1916 the German carp was remarkably abundant in the vicinity of Keokuk, and this abundance was represented in the catch on the gate but at a later time than the spawning season. (Coker, 1930.) The average number of carp taken per lockage was 15.7; the average number of fish of all other species was 1.7. The records seem to show that the number of fish taken on the gate is no more than should be expected of such a device, particularly when it is recalled that the water in the lock is set into violent turmoil just before the gate is lowered. Evidently the lock transfers a few fish one way or the other, generally irrespective of the migratory movements of the fish. It is possible, however, that certain migratory movements are faintly reflected in the catch on the gate.

In 1926 lock masters Heule and Harrington informed the author that very few fish were now seen on the gate as compared with conditions in former years. Seven lockages were witnessed by the author or a member of his party on August 23, 1926, the total catch being 1 sheepshead, 5 fiddlers, and 4 sunfish, or 1.4 fish per lockage. While this seems a very low figure, it will be observed that it compares very closely with the record for 1916, excluding carp; furthermore, identically the same figure is obtained when the catches of the week of August 22 to 28, 1916, are averaged—75 fish in 52 lockages, or 1.4 fish per lockage.

One other feature of the lock must be considered in connection with the possible function of the lock as a fishway, and that is its location about one-half mile downstream from the dam proper, close to the Iowa shore and out of the main currents from the spillways and from the power house. Such a location, of course, is highly favorable to its use for purposes of navigation.

It is an obvious conclusion that fish engaged in an active upstream migration are guided by the direction of flow of the strong current. At Keokuk this would lead them past the lock and up toward the base of the dam from a region of generally slack water. There is nothing about the lock itself, with its large pool of still water, and the entrance to the lock apart from the main current to "suggest to the fish" that this is the best avenue of passage to the upper reaches of the river. It is not surprising that a large proportion of fishes taken in the lock are such as we associate with still waters or as are taken in shore nets—carp, drum, buffalo fishes, etc.

In regard to the lock, then, the evidence indicates that it does not function as an effective fishway. It is located apart from the main streams, and no current passes through it. Although it is frequented by a variety of species and many fish are stranded upon the upper gate when raised, the observation and experiments fail to reveal any evidence of a practical migration of fish through it. Systematic trials with a net closing the upper opening of the lock show that there is no considerable movement of fish there. The upper gate of the lock takes a few common fish because it operates like a dip net—with a very large surface but low sides. The number of fish caught thereon is what might be expected of such a device and is not indicative of any appreciable migratory movement, although it is possible that migratory movements of species are faintly reflected in the catch. Even if its location and structure were more favorable to its functioning as a passageway for fish, it could not do so effectively, because it is open above only for brief periods of a few minutes at a time, and the sum of all its open periods during the spring and early summer (when upstream migrations are expected) amounts to scarcely more than a single day.

CONCLUSIONS REGARDING THE DAM AS A BARRIER

We have seen that the dam must serve as a practically effective barrier to the upstream movements of fish. They can not pass up the spillways or even buffet the current below an open spillway. Undoubtedly they can not pass up through the turbine chambers. The lock, the only remaining means of passage, does not witness any distinct migratory movements through it. It is possible for fish to pass downward, perhaps through various passages, but especially over the spillways. We have no observations to indicate that any considerable number of fish pass from upper to lower river over the dam, and it is reasonable at least to suspect that fish engaged in a downstream movement would find in the large lake above the dam, with its deep and relatively still waters, the conditions ordinarily sought farther downstream, or that the slacking of the current in the lake would inhibit a further downstream migration. This would not of course, be the case if there were distinctly anadromous fishes (other than the Ohio shad—see Coker, 1930) in the Mississippi—that is, those that live in the sea or ascend rivers to spawn—or if certain species must avoid the cold waters of a northern climate.

The actual effect of the dam upon the several common species, as far as our data reveal it, will be treated in another place; but it remains in this connection to inquire into the general significance of the barrier in the light of observations of migrations of fishes at Keokuk.

SIGNIFICANCE OF THE BARRIER

TYPES OF MIGRATORY MOVEMENTS

The term "barrier," as applied to any fixture in the course of a stream, implies a necessity for some sort of movement of fishes from place to place. If any group of fishes were found to live continuously in the same place with no necessity or habit of removing therefrom, a structure of any kind placed above or below that place could not be termed a barrier for that group. No matter if the structure be impassable, it is not an obstruction to movement if there be no necessity or inclination for the fish to pass.

If another group of fishes is accustomed to range indiscriminately back and forth over an extended region, then a construction that checks these movements at a certain point becomes in a definite sense a barrier, but perhaps not a significant one.

If, again, some fishes are habituated to spend certain periods of their lives below a given point in a stream and other periods above that point, an impassable obstruction becomes a barrier of a significance that is greater or less according as the periodic migrations are essential for the continued existence and abundance of the species on one side or the other of the barrier.

The significance of the Keokuk Dam as a barrier depends, then, upon what species of fish may inhabit the Mississippi River at Keokuk in any season and what may be the migratory movements habitual or essential to those species. These are questions into which we must inquire as closely as possible.

The most familiar, because the most extreme and the most conspicuous, instances of a migratory tendency in fishes are those of the Atlantic shad, the alewives or river herring, and the salmons, all of which at certain definite seasons leave their accustomed waters to pass in definite migration up the courses of the rivers to spawning grounds that may be hundreds of miles from the point of departure in the sea. Such fishes are termed "anadromous," a word of Greek derivation meaning "uprunning." While none of the familiar species mentioned are found at Keokuk, it does not follow that there may not be other species there that are also of anadromous habit.

Another type of migratory habit equally pronounced, though less conspicuous and familiar, is just the reverse of the anadromous habit and is called "catadromous." This is manifested by the common eel, which spends the greater part of its life in rivers and lakes but which, on the approach of sexual maturity, abandons the fresh waters and journeys down to the sea to give rise to a new generation in the depths of the ocean. The young eels born in the sea find their way into the mouths of the rivers, which they ascend gradually and adopt as their home until they, in turn, must return to the sea to accomplish the ultimate end of their existence.

A third and very familiar form of migration is that characterizing the majority of the common fresh-water fishes, which at the time of spawning find their way into the shallower waters along the shores, in the outspreading water of spring floods, or in the upper portions of the smaller tributary streams. Very few of the common fishes are known to form nests or deposit eggs in the deeper waters of the rivers and lakes.

There are yet other manifestations of a migratory habit, which may be less regular or definite in character. Such are the movements governed by the search for food, the seeking of protection from extreme temperatures, the avoidance of enemies, or the perhaps involuntary drift with the current.

These, then, are the types of migratory movements that we must have in mind in our consideration of the fishes of the Mississippi as they may be affected by the dam in question, and if our knowledge of the movements of fishes were complete it would be possible to answer in brief and definite terms the question of the significance of the dam as a barrier. That knowledge is as yet too incomplete, but, before listing and discussing the species of fish collected in the vicinity of Keokuk in the light of what we know of their movements (Coker, 1930), we may present in summary form the results of our inquiry as to whether or not there is evidence that any considerable migration of fish past Keokuk had existed and been checked by the dam and whether or not such interference with the movements of fish, if it exists, is of economic consequence.

EVIDENCE OF MIGRATION

On the whole, there has been discovered much less evidence of extensive migration passing or attempting to pass Keokuk than had been expected. The degree of abundance of fishes at Keokuk after the completion of the dam (see p. 94) indicated some sort of migration of paddlefish, river herring, Ohio shad, and possibly buffalo fishes, and subsequent observations have tended to confirm this indication.

Persistent watching for the gathering of fish about the dam, power house, and lock during 1915 and 1916, and evidence of various sorts accumulated in those years, made it appear that the structures also stopped some upstream movements of shortnose gar, carp, drum, and perhaps shovelnose sturgeon and three species of catfishes. Movements of the sauger may, perhaps, be checked in winter. We may well expect a decline in abundance of the eel above Keokuk. All of these species are of economic value, but the desirable characteristics of the gar are offset by other traits, and some reduction in its abundance will not be generally deplored. From what we know of the life histories of fishes it is believed that only the river herring and Ohio shad will have their spawning seriously interfered with, and this could be a matter of distinct economic importance in the case of the herring for reasons stated in the companion report. (Coker, 1930.) If the eel, one species of catfish, and possibly the paddlefish are substantially excluded from the upper river, there will result a loss of fishery products valued at a few thousand dollars annually. The checking of migratory movements by buffalo fishes and carp is not believed to be of economic significance, and probably the same is true in the case of the shovelnose sturgeon, two species of catfishes, the sauger, and the drum.

A very simple explanation may be offered for the upstream migratory tendency on the part of all of the species just mentioned (except the herring and Ohio shad) and doubtless for many other fishes.

It might be safely assumed that most fishes have periods of inactivity or of reduced activity. In aquaria it has been observed that such periods occur with yellow perch and black bass (Townsend, 1916); the carp hibernates (Hessel, 1878, p. 869), and observations elsewhere reported (Coker, 1930) indicate clearly that the same is true of the drum. Very probably they seek still places in which to spend their quiescent intervals, but nevertheless, they must be swept downward frequently, and even when not hibernating they must often be carried downstream.

If fish drift down with the current at any season, they must work upward or against the current at another, unless the upper parts of streams are to be entirely depleted. From this aspect it is a matter of indifference what the cause of the movement may be—necessity to find breeding grounds, to secure food, to encounter different temperatures, or something else. In such case an obstruction midway of a stream, which checks downward movement as well as upward migration, has no material effect upon the abundance of fish above and below the obstruction, although local and seasonal distribution of fish may be modified somewhat. Stoppage of current, as in a pool, must check downward drift independently of a structural barrier.

In some cases these upward and downward movements extend for such a short distance that the species may exist above a dam placed close to the headwaters of a stream. However, we would expect to find fewer species above than below such a barrier, because those engaging in more extended migrations would not have a sufficiently extended range above.

Hankinson (1910) made an interesting study of the fishes in a small creek near Charleston, Ill. Seventeen species were collected, of which seven were common and permanent and three others were common at times. Even within the limits of this creek there appeared to be upward and downward movements, for during one spring a minnow (*Campostoma anomalum*) was abundant below but not above a temporary barrier until the barrier was washed out, and thereafter it was abundant farther up the stream. The author did not find any relation between temperature and the presence of fish (species not stated); the largest aggregation was seen on January 28, when, with the water a few degrees above freezing, examples of the minnow just mentioned were feeding. This is particularly interesting in its bearing on the hypothesis that has been suggested. If, as indicated by the observations of Hankinson, some species are active throughout the year, it is evident that they might maintain themselves in the headwaters of a stream without engaging in any considerable migratory movements. Further study may show that there is some relation between the extent to which river fish migrate and the extent to which they hibernate or æstivate, and that one habit is associated with the other in the case of species inhabiting running water.

Parenthetically, it should be stated that the hibernation or æstivation of fishes is probably less profound than that of mammals, the organs of locomotion, for instance, being used moderately. (Townsend, 1916.)

The migration of our inland fishes appears, for the most part, to be of the character that has been outlined. Obviously, movements of this sort might be checked at the middle of the range of a species without any result more serious than a limited seasonal gathering of fish below the dam and either a slight depletion of the upper river, by fish dropping down and being carried over the dam, or, where there is a lake above, the temporary accumulation of drifted fish above. If the barrier occurs near the limit of the range of a species that engages in this relatively slight sort of migration, that species might well be excluded from the upper side of the dam, and this probably has happened at Keokuk with the Fulton catfish.

Fishes that engage in extensive migrations to spawning grounds above the point where the dam is located would be affected more seriously because reproduction would be diminished or altogether prevented. Examples of this class are the Ohio shad and probably the river herring. The catadromous eel may be excluded from the upper river, thus having its range diminished though its spawning is not interfered with.

ALLEGED DIVERSION OF FISH UP THE DES MOINES RIVER

The Des Moines River enters the Mississippi about 3 miles below the dam, and the suggestion has naturally occurred to some that the dam would divert fish up this tributary. In September, 1913, shortly after the completion of the dam, reports reached the author that the Des Moines River at Ottumwa was filled with fish alleged to have been deflected up that river by the dam at Keokuk. He proceeded at once to Ottumwa and Eldon to ascertain the facts more directly. Nineteen persons in all were interviewed, and the information gained served to throw rather more light upon human psychology than upon the actual effects of the dam. (See also, Coker, 1914, p. 24.) At Ottumwa, of nine persons engaged in fishing, eight said positively that there were no more fish than ordinarily, while one thought that there were more "Government shad" every year; five asserted that fishing was worse than usual; three of these fishermen said the dam was bound to have an effect, although it could not be seen. Of two persons who never fished, one had "heard" that there were more and one thought there "must" be more.[8]

At Eldon three fishermen reported the fishing poorer than last year, but one said there were more fish, although they did not catch more; two dealers said fish were distinctly less plentiful than last year; two nonfishermen said fish were more plentiful. Another person from Keosauqua said there were few fish this year at that place. Several persons at both places visited spoke of there being in evidence an unusual number of very small carp and channel catfish, not compensating, however, for the usually greater abundance of fish of commercial size. It was noteworthy that many of the fishermen suggested explanations for the unusual scarcity of commercial fish, attributing the cause to pollution or to gars.

It is certain that the rumors that led to the inquiries were based not upon facts but altogether upon expectation, and that the expectations were not realized in 1913. The expectation evidently was founded upon the common impression that there is a mass migration of fish in general up the stream courses, and that if this mass movement is checked in one stream it must be deflected into the nearest available tributary. Certainly the information gained does not offer substantiation for such an impression.

In July, 1916, Mr. Stringham spent two days at Ottumwa, Iowa, and found that there had been no remarkable abundance of fish in recent years; a few carp were then being caught on set lines, and it was said that catfish were taken occasionally. One or two fishermen believed that the Keokuk Dam diverted fish up the Des Moines River, but that they did not get above Bonaparte, Iowa, because of wastes from a gas plant at Ottumwa. One day was spent at Bonaparte, and careful inquiries were made of the one man who depended largely on fishing for a livelihood and the three others who did considerable fishing. They testified that the gar was the only fish taken in unusual numbers and that fishing was better when there had been a dam at the location. The dam referred to was washed out about 1903 (Lincoln, 1904, p. 11), 10 years before the completion of the Keokuk Dam. However, it was definitely learned at Keokuk in October, 1915, that commercial fishermen from that place were then making some large catches of spotted catfish on the lower Des Moines River. Inquiry of three of the older fishermen showed that the Des Moines had long been a good place to catch this species, particularly in autumn, and the literature shows that the fish was very common many years before the Keokuk Dam was built. (Jordan and Meek, 1885, p. 2; Call, 1892, p. 45.) It is possible that the runs of spotted cat in the Des Moines River in 1913 and 1915 may have been increased by fish from the Mississippi, which, but for having encountered an obstruction at Keokuk, would have continued up the main stream; but there is no evidence to that effect.

[8] A Mr. Bryant at Ottumwa told of the capture of a single specimen of paddlefish in the Des Moines River at Ottumwa in 1911 (before the dam was built). The fish was unknown locally. There is, I believe, no other record of the capture of this species in that river.

INJURING AND DESTRUCTION OF FISH

EXTENT AND CHARACTER OF INJURY

From the time the plant was completed there have been complaints by the fishermen that fish were being maimed and killed. These injuries are variously attributed to the turbines and rock piles at the base of the dam; some think they occur while fish are trying to ascend and others while they are moving downstream. Although no conclusion has been arrived at, the evidence is presented in full so as to be readily available for future investigation.

The observations by Surber (Coker, 1914, p. 15), and by Stringham during 1915 and the first half of 1916 failed to throw light upon the matter, though a few dead and injured fish were noted.

In August, 1914, the author observed several examples of the paddlefish taken in a floating gill net in swift water below the dam, the snouts of which had been broken off entirely. During June and July, 1915, there were usually some dead fish floating in an eddy at the south end of the finished half of the power house, and in the course of the same months reports from four independent sources told of dead catfish floating down the river.

On May 26, 1916, a goujon, 84 centimeters (33 inches) over all, was found floating past the lock with the left half of the head to the shoulder girdle cut off; the fish was fresh, and the flesh was used by one of the men working at the lock. A German carp about 1 meter long was found in the eddy below the power house on June 9 with a gash near the dorsal edge just behind the collar bone. Another fish of about the same size and probably the same species was seen on July 15 floating down the tailrace with its head cut off to the shoulder girdle. One or two more large and some smaller fish were seen floating, but the character of their injuries was not ascertained.

From the beginning the complaints had centered largely on the paddlefish, but very few representatives of this species were taken during 1915 or the first half of 1916. On July 31, of the latter year one was picked up off Main Street in Keokuk, having the bill or snout broken off and the operculum hanging loose. Up to August 23 one other example (a very small one) was seen at Keokuk, and this likewise had the snout broken. On alternate days, beginning August 23 and ending August 31, seine hauls were witnessed in which 53 paddlefish were taken, being more than were seen in the course of the rest of two seasons' work. Of these 36 fish, constituting 66 per cent, had the snouts broken. Included in these 36 were about half a dozen with the bones cracked but the snout not lost nor bent, and approximately as many with part of the snout gone. The usual type of injury was a fairly clean cut, there being no general mashing of the snout. The body was otherwise unhurt.

With a view to learning whether paddlefish suffer this way in other localities some inquiries were made. On August 24, 1916, Earl Bauter, then at Montrose, Iowa, mentioned that they had taken one on the Illinois River the preceding fall with its snout broken. In reply to a question he said that they had caught altogether 75 to 100, and the rest were sound; most of them were caught in a seine and a few in hoop or fyke nets. Of half a dozen large ones taken in Keokuk Lake that summer, all were uninjured. Dr. George Wagner, who in 1904 examined about 1,500 at Lake Pepin (Wagner, 1908), wrote on September 13, 1916, that all were taken in seines, and that while he kept no record of injuries he is very sure that none of them showed any sign of broken bones. On September 18, 1916, Austin F. Shira, director of the Fisheries Biological Station, Fairport, Iowa, said he had seen about 500 taken in seines at Lake Pepin but none with the snouts broken. On October 1, 1916, Franz Schrader wrote that he examined about 40 captured by seine at Lake Pepin that year. About half of these were examined closely for microscopic parasites; some had slight abrasions, but none had any serious injuries. Stockard (1907) evidently examined many fish during two springs in Louisiana, but the number is not indicated; he found three whose snouts had been broken and the wound healed over.

It will be noted that the injuries received about Keokuk were almost exclusively to the heads of the fishes. To secure testimony as to the part of the body that was usually hurt, the question was put to a number of fishermen and dealers, care being taken to make it general in form so as not to indicate the answer expected. The dates of inquiry, names of men, residences, and the substance of the replies are as follows:

August 29, 1916

Ed. McGee, West Keokuk. Spoonbill (paddlefish) injured only on snout; buffalofish sometimes have scales off and are sometimes hurt on mouth.

September 4, 1916

Joe McAdams, Keokuk. Generally on head or behind shoulder girdle; hardly ever elsewhere.

William Stanton and Mr. Wilson, Keokuk. Mostly on head, but occasionally a hole is punched in them anywhere.

Trumer Jackson, Warsaw. Spoonbill and carp, mostly on head, some nearly cut in two. No injury to any other part noticed.

Luthur McAdams, Alexandria. On head only.

September 15, 1916

Jack Job, Canton. Mostly on head, sometimes on tail.

Joseph Winkler, Canton. No injured fish found.

STRUCTURES CONSIDERED

The rock piles at the base of the dam and the turbines are the two instrumentalities that had been suspected of being responsible for injuries to fish. The rock piles have been mentioned in connection with the description of the dam on page 93. (See, also, fig. 12.) During the spring of 1915 the power company was making some observations on the turbines, and this gave an opportunity to inspect the structures in question; the descent to the turbine was made on April 1. If a fish should get to the head bay and through the screens or grating as already suggested (p. 97), it would then be in the intake or scroll chamber; this is normally full of water even when not in operation. As shown in Figure 13 it is dry. The flow of water is regulated by opening or closing the gates or vanes, which appear in the upper middle of the illustration behind slender columns; they open and close by partially revolving on their long axes. These vanes are the first obstacle that a fish would meet after passing the screens. On the day of observation the vanes stood with openings between them about 9 inches (23 centimeters) wide. When a unit is generating electricity these are slightly but constantly oscillating, so as to regulate precisely the pressure on the turbine; but the size of the opening remains substantially the same as when it was measured, except that one unit, used for electricity sold locally, has a smaller opening, being, about 5 inches wide, according to information supplied by the power company.

Inside the vanes is the turbine, more commonly called "wheel." Between the vanes and the blades or buckets of the wheel there is a large space. The wheels are

Figure 12.—Looking eastward over the dam in July, 1913. Exposed rocks may be seen below the spillways. (This photograph was taken soon after the dam was completed)

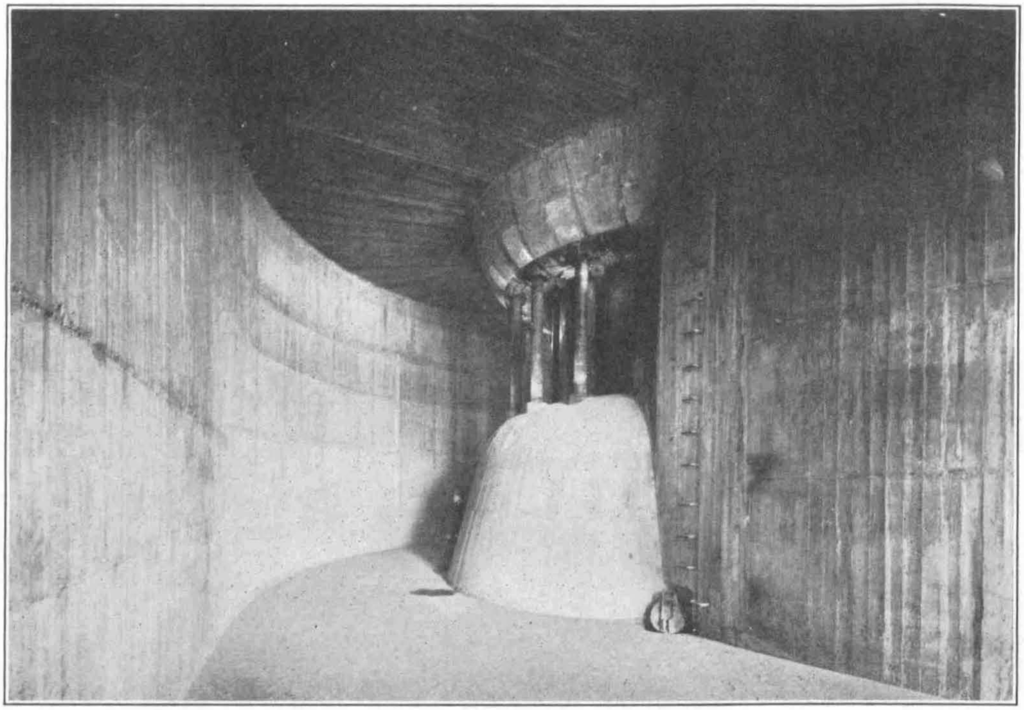

Figure 13.—Intake or scroll chamber leading to one of the turbines. Note the man in the shadow in the center of the picture

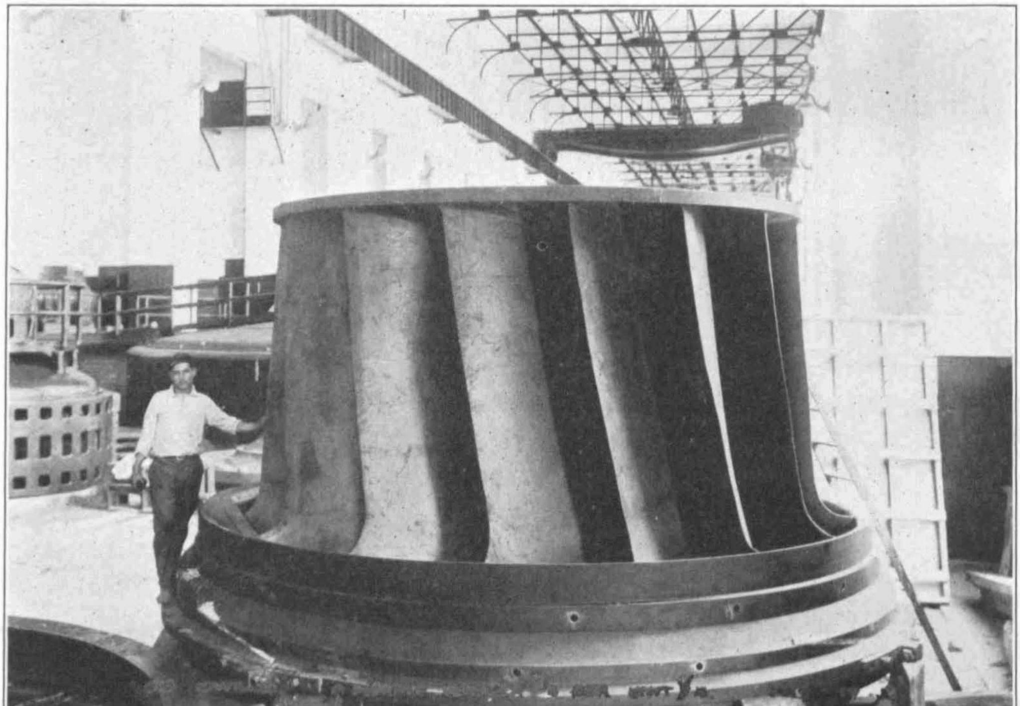

Figure 14.—Rotor or wheel of a turbine in process of installation

of two types. The type shown in Figure 14 gives a clearance of about 0.5 to 0.8 foot (15 to 23 centimeters) less than the other, but still large enough for any fish of the locality. It should be understood that the water passes smoothly and without commotion through the turbines, so that a fish passing with the water would move rapidly but without being subject to any violent churning action.

The wheel itself was examined as closely as possible. The blades or buckets appeared to come closest together at the top of the inner edge, where the aperture, as estimated, is 6 to 7 inches (15 to 18 centimeters) wide; this widens downward to about 10 or 12 inches; below is the river.

After passing the screens in the head bay, a fish would nowhere find a narrower passage than the screens afford, except in one unit, where the vanes stand about 5 inches apart. Probably a fish is trapped here occasionally, but it seems doubtful whether many fish go down through the turbines (p. 97); and the percentage, small enough to pass the 6-inch screen but too big for the 5-inch vanes, that chances to enter this particular unit must be negligible.

EXPERIMENTS

In an effort to learn whether fish are hurt at the base of the dam or elsewhere, Stringham allowed several fish to pass over the dam and others to go through turbine chambers. Three attempts in May and June, 1916, with paddlefish, goujon, and carp, respectively, were made by tying a line to the fish and attempting to draw it back, but in spite of modifications of method each time the three fish were lost because the line broke. The goujon was seen swimming before the line broke.

On June 18 a carp 53 centimeters (21 inches) long and weighing 2 kilos (4½ pounds) was dropped on the crest of the water of operative spillway 104, with a long line tied through its caudal peduncle, played out, and drawn back at another part of the dam; it was entirely uninjured and lively. On August 2 a carp 51 centimeters (20 inches) long and weighing 1.5 kilos (3⅓ pounds) was similarly dropped through spillway 105, a twisted cotton line (No. 90 or thereabouts) 116 meters (380 feet) long being used. The fish was drawn back alive but with scales scratched off each side of the back before the dorsal fin, the left opercle broken into four pieces, and the shoulder girdle partly severed from the body.

On August 3 two carp, the smaller 56 centimeters (22 inches) long and weighing 2 kilos (4½ pounds) and the larger 81 centimeters (32 inches) long but not weighed, were fastened to ½-gallon buoys by lines each about 3 meters long, tied through the lower lips. They were dropped through spillway 106. The smaller was picked up below entirely uninjured. The larger was slightly scratched on the right opercle, and there was a little blood on each side under the base of the dorsal fin, but there was no abrasion.

On August 24 three paddlefish, measuring 63 to 84 centimeters (25, 28, and 33 inches), respectively, were dropped through spillway 42, similarly attached to buoys but with the line tied through the caudal peduncle. One became fast among the rocks but later floated free. The smallest was picked up dead but bore no marks. The other was uninjured, though there was a slight scratch at the base of the caudal fin, which may have been overlooked before the fish was dropped in.

On August 27 several paddlefish, with pieces of cork from a life preserver tied to their snouts, were dropped into a whirlpool in the head bay of the power house, inside the screens; and, after passing through a turbine, one was picked up in the river below. On the first one dropped into the head bay, too much cork had been tied and it did not submerge. Two others disappeared, and it is not known whether they went down. Two more evidently went down because the corks were found below. A sixth fish was put through and picked up below entirely uninjured and lively. This one was 72 centimeters (28½ inches) over all, and the piece of cork tied to its snout was 7½ by 4½ by 2½ centimeters; it had been dropped into the head bay above unit 8 and carried down by a strong whirlpool.

On August 29 two more paddlefish of about the same size and with slightly larger pieces of cork were put through in the same manner and picked up swimming and uninjured.

With little hope of success, two attempts were made to test whether fish are hurt while trying to ascend the draft tubes. Paddlefish were staked out in the tailrace by means of a long line tied to the tail; but the line repeatedly became entangled in something at the bottom of the tailrace, and the effort was abandoned.

DISCUSSION OF EVIDENCE AND CONCLUSION

The net results of the experimentation and observation are negative. The fishes dropped over the dam and put through the turbines escaped remarkably well, considering how they were hampered, particularly as the worst-looking places were selected purposely. Furthermore, the injuries received were to various parts of the bodies instead of being confined to the heads. It seems entirely possible that fish should ascend the draft tubes to the turbines, the velocity of the water being only about 9 miles immediately under the wheel and considerably less than 3 miles at the outlet. (Mississippi River Power Co., 1913, p. 32.) But, though the wheels move at a considerable velocity, the portions of them that would strike an ascending fish are broadly rounded, and it seems improbable that the injuries received could be inflicted by such a surface. In spite of these negative indications it is possible that further work would show that fish are sometimes hurt in one of the ways suggested. Paddlefish, at least, are damaged in substantial numbers, and it is desirable that the cause be ascertained. There remains the possibility that the fish are injured in attempting to pass between some of the old pilings that, for a long time, at least, remained submerged about the raceway below the power house. If, while swimming abreast of the current, a fish should attempt to pass between two closely approximated piles, it is conceivable that the force of the current against the body of the fish would wrench the bill off as readily as one could break the bill by inserting it between two posts and moving the fish sharply to one side.

EFFECTS OF THE DAM UPON CONDITIONS IN THE RIVER BELOW

BOTTOM CONDITIONS

The bottom material at and near Keokuk, below the site of the dam, as shown by Chart No. 136 of the Mississippi River Commission, was rock and sand with a little gravel and clay near the banks. These conditions were not changed by the dam, except that some sand may have been washed out right at its base. Places reported to have a bottom of mud were found by dredging (in April and May, 1916) to have sand, with occasionally molluscan remains and sometimes clay pellets. The changes in the character of bottoms above the dam must be pronounced and significant, but opportunity has not occurred for the investigation of such conditions. Before the dam was built the bottom in the rapids was described by Clark (1911) as "solid rock bottom all the way across." He said, furthermore:

The waters at Keokuk can not accurately be called turbulent. They are not hurled over hidden boulders and irregular rocks with the speed of a Niagara. The river has much the same velocity and presents the smooth appearance of water running down an inclined surface.

While under such conditions the bottom might be expected to be swept fairly clean, there were enough loose rocks and gravel to support very abundant fresh-water mussels. No doubt under lake conditions there must occur a gradual accumulation of silt over the former bottom of the rapids. (See remarks on silting in section entitled "Fresh-water mussels" in Coker, 1930.

ICE

One striking change has occurred in river conditions. For a distance below the plant the river no longer freezes over, because the obstruction breaks up the ice. Sheet ice forms in the coves, and a couple of miles south it extends from the banks well out into the river. At Warsaw (5 miles south of the dam), in 1915, the frozen area extended nearly to the channel from each shore; but, according to information supplied by the fishermen, the river was not entirely frozen for another mile down. The next year the river probably did not freeze over anywhere south of Keokuk, although some informants asserted that it froze entirely across for a short distance somewhere between Canton, Mo., and Warsaw, Ill. Local informants report conditions in 1916–17 that were similar to those of 1914–15. Prior to the construction of the dam the river usually froze sufficiently so that teams could be driven across along the whole region from Canton northward and for some distance southward.

The open condition of the river has been a boon to fishermen, facilitating operations in the winter. Men who used fyke nets reported that anchor ice formed on their nets and hampered them. The formation of such ice at the bottom of a river, where the current is rapid and the surface open, is a phenomenon that has long been known but is not very well understood. (Barnes, 1906, Ch. VII.)

OXYGEN CONTENT

No observations have been made on the extent to which the water is oxygenated by the Keokuk Dam, but this must be great. The early conditions in the lake above, with decaying vegetation, active animal life, and deficient plant life, may have caused diminution in the percentage of oxygen below the average for the river. So far as the lower river is concerned, this loss probably is fully compensated for by the dam. On the Illinois River, Forbes and Richardson (1913, pp. 542 and 549) found that polluted water had its dissolved oxygen substantially restored and its carbon dioxid diminished by falling over a 10-foot dam. The authors added that the difference in oxygen doubtless had its effect upon the abundance of fishes, but that the fish population below the dam was small as far as indicated by limited observations. The present conditions on the lake are likely to be followed by others that will tend to give a higher percentage of oxygen to the water. Since the conditions have not been investigated, they can be referred to here only as suggestive of a significant factor in the influence of the dam upon fish life in the river.

FLUCTUATION OF RIVER STAGE

To determine as nearly as possible the effect of the dam in respect to increased or lessened stability of river stage below Keokuk, the reports of the United States Weather Bureau (Frankenfield, 1911, p. 235; Henry, 1913, p. 219; Henry, 1915, p. 231; Henry, 1916, p. 89) and later reports have been examined, and, from the daily stages given therein, certain computations have been made, and these are embodied in Table 3. Although there are differences each year, the records prior to 1913 cover approximately the months of March to December, inclusive, but all observations given for those years are included in the computations. The stages of 1914 and subsequent years are recorded complete, but the computations are based on records from March to December, inclusive.

TABLE 4.—*Oscillations of river stage, in feet, at Keokuk, Iowa, 1910–1912 and 1914–1919 (including, for comparison, yearly fluctuation at Davenport, Iowa)*

Year	Davenport, Iowa	Keokuk, Iowa									
	Difference between highest and lowest in year	Difference between highest and lowest in year	Difference between first of month and first of month following, maximum and minimum			Difference between Sunday and following Sunday, maximum and minimum			Difference between morning and following morning, maximum and minimum		
			Least	Most	Average	Least	Most	Average	Least	Most	Average
1910	7.8	12.0	0.9	8.4	2.86		2.9	0.63		3.0	0.16
1911	10.6	12.3	1.8	11.8	4.76		10.4	1.83		2.9	.29
1912	11.3	17.7	.1	5.8	[1] 1.7		5.6	1.31		6.4	.31
Average	9.9	14	1.33	10.23	3.98		6.30	1.07		4.1	.25
1914	8.9	13.3	1.4	7	3.97		5.8	1.10		3.6	.33
1915	8.1	15	2.7	10.2	6.19		5.2	1.81		5.2	.43
1916	13.9	17.6	.2	8.6	2.75		9	1.30		4.87	.37
Average	10.3	15.3	1.43	8.6	4.3		6.67	1.40		4.56	.377
1917	11.1	16.6	.1	12.8	2.66	0.5	5.9	1.36		6.5	.33
1918	9.3	16.6	.3	7.2	3.32		4.5	1.01		2.8	.36
1919	13.3	18.1	.4	8.7	3.15	.3	8.7	1.95		4	.43
Average	11.2	17.1	.27	9.57	3.04	.27	6.37	1.44		4.43	.373

[1] 9 months.

It will be observed that the average annual fluctuation of river stage at Keokuk was more marked during the 3-year period (1914–1916) immediately following the construction of the dam (15.3 feet) than during the 3-year period (1910–1912) preceding its construction (14 feet), and even more so during a following 3-year period (1917–1919)—17.1 feet. It was urged by the power company that the differences indicated by these figures were due to climatic causes rather than the dam. They claimed that the daily combined flow of water through the power house and over the dam was equal to the natural flow that would occur here, except that they occasionally raised or lowered the lake very gradually and except that the wind made a slight difference. According to their computations the variation resulting from the raising or lowering of the lake amounted to only two or three-tenths of a foot a day.[9] Whether or not this would make enough difference to account for the instability shown by the foregoing table may be doubted.

Certainly, some corroboration of the view of the power company is derivable from a comparison of the fluctuations of stage at Davenport, Iowa, during corresponding periods. Davenport is far enough above the dam (120 miles by river) to be beyond the possibility of effect from the dam. Nevertheless, the fluctuations during corresponding 3-year periods have displayed a somewhat similar history. The average yearly range for the period 1910–1912 was 9.9; for the period 1914–1916 it was 10.3; and for the period 1917 to 1919 it was 11.2. The years of greatest fluctuation were the same as for Keokuk, namely, 1912, 1916, and 1919. Evidently,

[9] Based upon verbal statements of an officer of the company to Emerson Stringham in 1916.

then, either climatic or other conditions in that part of the Mississippi Basin above Davenport have caused greater fluctuations of river stage in years subsequent to the construction of the dam than in years immediately preceding. The facts coincide with the suggestion made on page 88, above, that under modern conditions fluctuations of river level are tending to become sharper and more extreme. There seems to be further support for that suggestion in information communicated to the author by the Mississippi River Commission in a letter of April 4, 1927, referring primarily to another matter:

> The records of this office cover only 15 low waters at Keokuk, 10 of which were below zero. The lowest was 2.8 feet below zero (481.86 feet above Memphis datum) on December 18, 1922.

The creation of a constantly higher level for some miles northward of Keokuk may have reduced the capacity of this portion of the river to take up floods; in other words, the floods become largely concentrated at Keokuk. Conversely, it is necessary, when the river is falling, to hold back water to maintain the constant level of the lake, and this, of course, occasions a more rapid fall below. Earnest efforts, it is believed, are being made by the company to maintain as stable conditions as possible below, and their records showed improvement in 1916. These efforts are made with the object of avoiding the infliction of damage to steamboats, but the results are of advantage to the fishery, for violent and excessive changes would result in the stranding of fishes, as actually occurred at the beginning through inexperience. (Coker, 1914, p. 10.)

LAKE KEOKUK

CREATION OF A RIVER LAKE

The Keokuk Dam has changed the Des Moines Rapids and a part of the river above them into a large area of relatively still water. (Figs. 2 and 17.) From the biological as well as from some other standpoints this is a matter of great interest. For this body of water the name Lake Cooper was commonly used and will be found in the literature, but the United States Geographic Board (1916) has decided upon the name "Keokuk Lake."

Stockard (1907, p. 758) remarks upon waters of this intermediate character as follows:

> Other such lakes still retain a direct connection with the river and are termed by the fishermen "river lakes." In these there is a current, which often becomes very strong during the spring freshets, when the water of the Mississippi River rises.

The present author (Coker, 1914, p. 9, footnote) defined the term as meaning "such a body of relatively still water as would ordinarily be called a lake, which is yet intimately connected with a river, either as interpolated in the course of the river or as an arm of a river."

It is scarcely necessary to add that there exist waters intermediate between river-lakes and rivers, on the one hand, and between river-lakes and lakes on the other. The distinction is one of degree but none the less valuable for that reason.

The biological conditions of the lake in 1914 were studied by A. A. Doolittle, and a summary of his observations is presented in another section of this report (p. 118). A more exhaustive and continued investigation of the lake would have been of great practical importance, but, unfortunately, it could not be arranged to continue or to report upon the survey until the observations of Doctor Galtsoff were made in 1921 (p. 119). It is necessary for our present purpose, before discussing the several species of fish, to present a general account of the physical and biological conditions of the lake based primarily upon observations of Mr. Stringham.

AREA

The effects of the dam are said to extend as far as Oquawka, Ill., 41 miles (66 kilometers) northeastward from Keokuk and 54 miles (87 kilometers) along the course of the lake and river; but the influence as far away as this is scarcely perceptible, and the upper end of the lake may, for convenience, be taken as at Burlington, Iowa, 31 miles (50 kilometers) northeastward from Keokuk and 42 miles (68 kilometers) along the course of the lake (fig. 15). The general form between these two points is that of a drawn-out letter S or a compound curve, the outer edges of the curves being at Dallas City, Ill., and just north of Montrose, Iowa, respectively. The width varies from about ½ to 2½ miles (0.8 to 4 kilometers), as appears from a map prepared by the power company in 1913 or 1914. Subsequent raising of the water level may have increased this maximum width, and even on the map the width is greater where slender fingerlike projections extend out from the general border of the lake.

The area of the lake, as roughly determined by applying a planimeter to the same map, was about 53.3 square miles (138 square kilometers), but this map does not include all backwaters. The records of the power company show that from the greatest level in 1914 (occurring January 29) to the greatest level in 1916 prior to September (occurring January 15) an additional 3.6 square miles (9.3 square kilometers) was overflowed. Part of this additional overflow would be above Burlington, which has been assumed to be, practically speaking, the upper end of the lake. Including all lateral backwaters, the total area of the lake in 1916 was probably in the neighborhood of 60 square miles (about 150 square kilometers). According to information supplied by the power company, the lake was to be raised an additional foot, and the total area would then be nearly 70 square miles. Of course, there has been a large increase in volume of impounded water, and, by calculations made at the office of the company in June, 1917, this would amount to somewhere in the neighborhood of 14,000 million cubic feet, when the lake had been raised to the stage of 525 feet, Memphis datum. Unfortunately, from the viewpoint of the fisheries, the area of the lake has now been reduced substantially by the construction of levees and the reclamation of submerged lands for use in agriculture. The principal drainage district (covering the Green Bay region and lying between Fort Madison and the Skunk River) was drained during the winter of 1918–19; this reduced the area of the lake by 10 to 15 square miles. Under present conditions the area of the lake varies between 58 and 64 square miles, depending upon the stage of the water.

DEPTH

The water depths for this region as it was are shown on Charts Nos. 136 to 140 of the survey made by the Mississippi River Commission in 1891. These soundings were made at low stages of the river, those for the rapids (Keokuk to Montrose, Iowa) being made while the river was at 1.5 feet on the Keokuk gage, or at 486 Memphis datum. The greatest depth on the rapids was 15 feet (4.6 meters), and the depth along most of the channel was about 6 or 7 feet (about 2 meters). From Montrose north to Burlington there were some soundings of 26 feet (7.9 meters), but the depth of the channel did not average over 12 to 15 feet (3.7 to 4.6 meters).

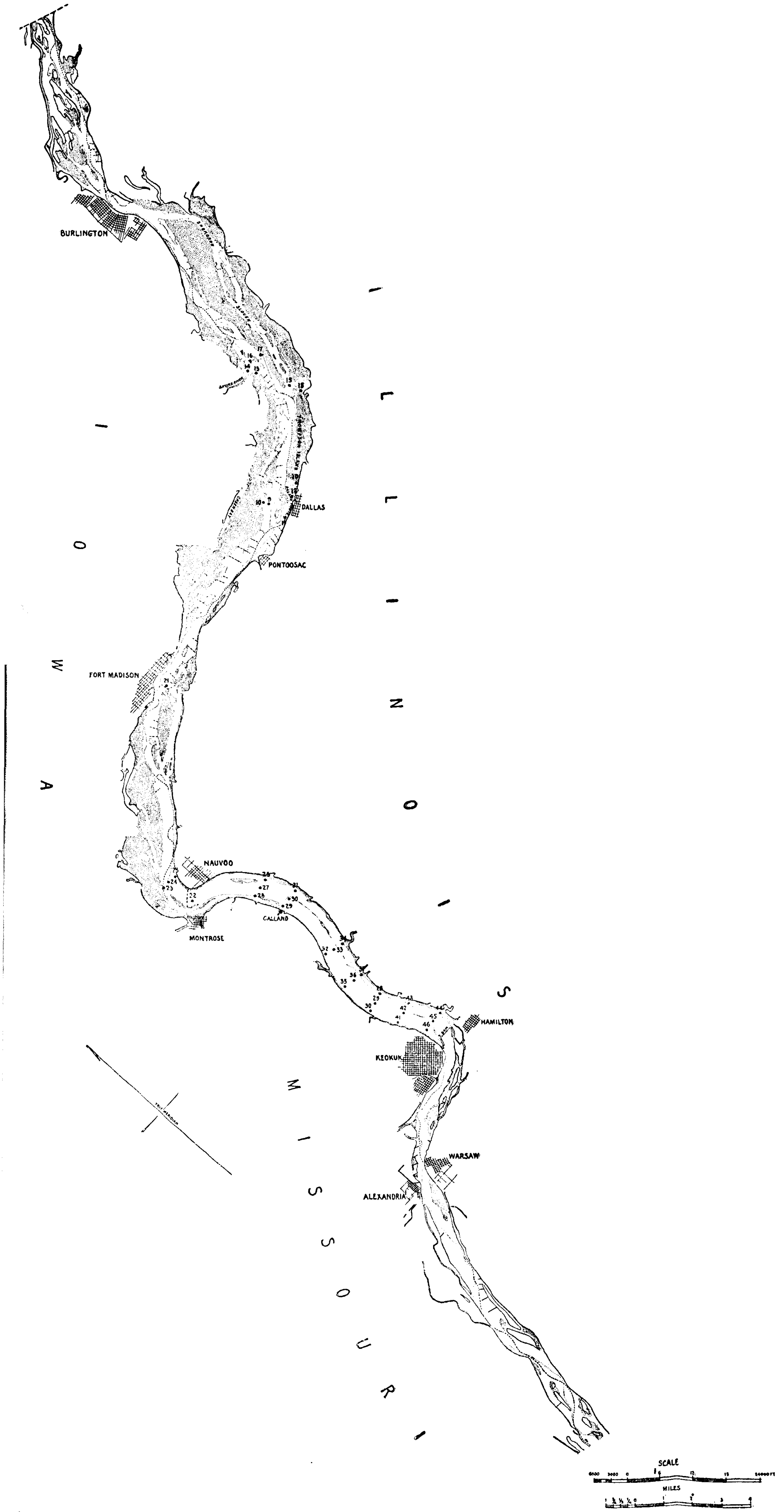

Figure 15.—Lake Keokuk and the adjacent parts of the Mississippi River. (Above dam areas formerly submerged, but shallow, are defined by dotted outlines; are as formerly above water but now submerged and relatively shallow are indicated by close stippling. Below dam shallow areas are indicated by stippling. Boat channels, 1901, indicated thus, ...; 1904, thus, — — — —; old wing dams indicated ———. Reduced from blue print furnished by Chief of Engineers, War Department.)

The surface level of the new lake at Keokuk, according to the records of the power company, did not fall below 520.8 Memphis datum during 1916, or nearly 35 feet (10½ meters) higher than at the time of taking the soundings just mentioned. This would give a depth of 40 to 50 feet (12 to 15 meters) on the old rapids, were there no filling in by sediment. On July 23, 1916, soundings were made at three points in the fore bay just above the lock. These showed depths of 36½ to 40 feet (11 to 12 meters); on this day the lake stage at the lock was 523 feet, Memphis datum. The place where these soundings were made is below the dam and power house, and evidently there has been little filling in here.

On July 4, 1917, when the lake stage, according to the lock master's record, was 523.5, soundings were made at intervals of 100 meters, first crossing the lake beginning at the point of the power-house portion of the ice fenders and proceeding to the Illinois shore, and then recrossing the lake at a distance of ½ to 1 kilometer above the first line. The depth to within 300 meters from the banks varied from 7.3 to 11.1 meters (24 to 36½ feet), being for the most part between 9 and 10 meters, deeper above the power house and shallower near the Illinois side.

For much of the distance from Keokuk to Burlington, on the Iowa bank, the bottom rises rather abruptly; but there are large areas of shallow water, particularly in the vicinity of Fort Madison and below. On the Illinois side the bottom slopes up more gradually at most points.

TURBIDITY AND TEMPERATURE

There are probably no existing data as to the turbidity of the old river where Keokuk Lake now exists. The lessened velocity of the water would tend to reduce this, because of settling, but the accumuated silt on the bottom may be stirred up from time to time by irregular movements of the water.

In the fore bay, where the water is rushing to the power house, turbidity was observed on 71 days during 1915—from April 12 to August 13. A rectangular piece of wood with an area of about 1 square centimeter (16 square inches), painted white, disappeared at depths of 9 to 47 centimeters (3½ to 18 inches), the average being 21½ centimeters (8½ inches). As a substantial part of the matter carried in suspension probably has been deposited before the water gets to the fore bay, it is reasonable to suppose that the turbidity of the lake would usually be greater toward Burlington.

Water temperature was observed at the same place in the fore bay. Observations were made on 75 days in 1915, beginning April 9 and ending August 14. During this period the temperature ranged from 50½° to 79° F. (11° to 26° C.). The season of 1915 was cooler than that of 1916; on July 14 of the latter year, at 11 a. m., a temperature of 86½° F. (30° C.) was recorded just above Montrose, Iowa, where the lake is shallow. While the depth of Keokuk Lake is not sufficient to justify expectation of any considerable difference between bottom and surface temperatures, Doolittle (MS.), in 1914, found that the bottom of the lake at Keokuk always registered 2° F. lower than the surface. The bottom temperature is probably about the same as in the old river, or possibly a little cooler in midsummer and fall; the surface may be a little warmer, as the water from the north now remains here longer than it did in the day of the rapids.

VELOCITY OF CURRENT

The rate of the current on the old rapids is given in a report to the Secretary of War (Hains, 1867, p. 277), as follows: "Its mean surface velocity is 2.88 feet per second, and its mean velocity deduced therefrom is 2.304 feet per second" (a little more than 1½ miles per hour). A study of the former current at Burlington was made with much refinement by Mackenzie (1884) in the month of October. He found it to vary from 1.2 feet per second (0.82 m. p. h.) on October 7 at a depth of 16 feet to 2.9 feet per second (1.98 m. p. h.) on October 14 at a depth of 1.7 feet. Doolittle (MS.), in the summer of 1914, made three observations each near Keokuk and Nauvoo and two near Burlington; these were presumably at or near the surface. Table 7, based upon these records, shows roughly the difference between the old and the new conditions. At Burlington the current has been scarcely checked; right above the dam it has been almost stopped. The velocity on the old rapids must have been much greater at times than these figures show. In 1910 (Frankenfield, 1911, p. 234) the stage at Galland rose 3.9 feet (1.2 meters) from December 21 to 22 and had fallen 4.3 feet (1.3 meters) the next day. On the second of these two days the velocity at and below Galland must have been very great.

TABLE 5.—*Velocity of former river, in miles per hour, compared with present lake*

Place	Old river	Present lake
Old rapids, now lower end of lake	1.58	0.0–0.4
Nauvoo, Ill., 12 miles north of dam		.64–1.2
Burlington, Iowa, now the upper end of lake	0.82–2.0	1.13–1.8

BOTTOM MATERIAL

The bed of the old rapids was described by Hains (1867, p. 277) as "a broad, smooth rock, seamed by a narrow, crooked channel, or in some places several of them, alternately widening and narrowing, shoaling and deepening * * *. The rapids are, therefore, not broken and noisy, but, the descent being gradual, the water flows over its bed in a broad, smooth, unbroken sheet, with nothing but the faintest ripples on its surface * * *." Keys (1895, p. 316) states that the bed of the rapids was chert (a quartz similar to feldspar) lying at the top of the Burlington limestone. Charts Nos. 136 to 140 of the survey by the Mississippi River Commission show patches of sand and gravel at the upper end of the rapids; from here to Burlington the bottom was nearly all sand, with some rock and gravel and scarcely any mud. Writing of the conditions in 1914, Doolittle (MS.) states that the bottom of the lake where sounded or dragged was a fine bluish-gray mud, but that a sand bar had formed off Nauvoo, Ill. On July 4, 1917, many soundings were made within about one-half mile above the dam, and only mud was found, except close to the banks. Reference may be made here to the remarks concerning the silting in of the area of the former rapids, made in the section of the companion report (Coker, 1930) entitled "Fresh-water mussels."

PLANKTON OF THE LAKE IN 1914

In the second season of the lake, Dr. A. A. Doolittle made for the bureau a series of studies of the plankton of Lake Keokuk. It was expected that the survey would be repeated after the lake had aged two or three years, and that the results of the two surveys in comparative form would be prepared for publication. Doctor Doolittle was unavoidably prevented from continuing the investigation, and the data that he obtained in 1914 have remained unpublished. It is desirable to include here an abstract of his observations as prepared by him (next three following sections). The later study of the plankton of the upper Mississippi in 1921 by Doctor Galtsoff (1924) included Lake Keokuk, although he could not, in the circumstances, work this region intensively. In comparing the results of the two studies it must be remembered that there is much reason for believing that a new lake is richest in its first years.

ENTOMOSTRACA

1. In the earlier portion of the season (July) the Entomostraca in the main channel of the Mississippi River and in Lake Keokuk increases in numbers with approach to the dam at Keokuk, as illustrated by the following figures showing the approximate number of Entomostraca per cubic yard of water: At Oquawka, 55 miles from the dam and above its influence, 50; at Burlington, 52 miles from the dam, 100; at Nauvoo, 12 miles from the dam, 150 (over submerged land, 250, and in the protection of weeds, 450); at Keokuk, 2 miles from the dam, 1,500. The increase is attributed to the more favorable conditions accompanying the slackening current, such as the partial loss of sediment in suspension and the greater time allowed both for development of food materials and the multiplication of the Entomostraca. In weeds these favorable conditions are increased and, in addition, there is furnished shelter and fundamental food.

2. The tributaries of Lake Keokuk and the Mississippi River in July show an Entomostracan population greatly exceeding that of the main river and lake at this time. The numbers apparently vary with conditions and somewhat as follows: (*a*) The larger tributaries or arms, without current and with relatively small openings upon the river or lake, may have 50,000 Entomostraca per cubic yard; (*b*) tributaries or arms without current, whose openings upon the river or lake are relatively larger, yield about 2,500 per cubic yard; (*c*) tributaries through which there is current, though scarcely appreciable, possessed Entomostraca at the upper limit of backwater in the number of about 5,000, increasing downstream to about 20,000 until coming within the direct influence of water from the main channel.

3. The river and lake in August showed the following changes in Entomostracan content, generally in the direction of substantial increase in population, as may be seen by comparing the following approximate figures for August with those previously given for July: Above the prism of the dam (Oquawka), in the low water then prevailing, 35; within the prism of the dam at Burlington, 100; at Nauvoo, 1,500 in the main channel (20,000 to 30,000 over submerged land and 150,000 among weeds); at Keokuk, 25,000. The increases are attributed to the same factors that operated in July.

4. In August the tributaries showed differences, but not the same kind of differences as in July: (*a*) In tributaries without current and shut off from the lake by relatively narrow openings or having little means of preventing stagnation the Entomostraca had decreased to 25,000 per cubic yard; (*b*) in tributaries or arms of the lake not subject to stagnation the Entomostracan population had held its own or increased to 50,000 and 100,000 per cubic yard; (*c*) in the river and the tributaries with current the Entomostraca maintained or increased their abundance, the numbers running from 5,000 to 30,000 per yard but being always less in the upper limit of backwater.

5. The Entomostracan population of the lake itself passed its maximum by late August or very early September, though still showing about 5,000 per cubic yard at the latter time.

6. The river and the lake are enriched by the run-off from tributaries, and the river itself below the dam is enriched by the run-off from the lake. The enrichment from the tributaries holds both as to numbers and species, but the species distinctive of a tributary do not survive long in the main channel. Such local enrichment may be 100 per cent. The run-off from Lake Keokuk enriches the river below, so that, at a point 5 miles below, the plankton Entomostraca were found to be from thirty to fifty times as abundant as in the river above the influence of the dam. This was in early August, the season of maximum production of Entomostraca in the lake.

OTHER PLANKTON ANIMALS

Zooplankton other than Entomostraca came under observation as the collections were studied. Chief among these plankton elements were rotifers, which belonged mostly to two genera, Asplanchna and Anuræa. The latter genus was represented by several species and varieties, chiefly *A. aculeata*. There were occasionally present *A. cochlearis*, *A. tecta*, *Polyarthra platyptera*, *Conochilus volvox*, *Triarthra longiseta*, and *Pedalion miron*. Rotifers were seldom absent from the plankton. Until the latter part of the summer they were practically a negligible quantity in the main body of water. In the tributaries they were frequently abundant, and in places they constituted the whole of the plankton. In July and in most of August Asplanchna might be regarded as the more important on account of its size and because it was at times the dominant factor of the plankton; later in the season it became rare. *Anuræa aculeata* was more consistently present than Asplanchna and, while usually occurring in greater numbers, its smaller size prevented its contributing much to the bulk of the plankton. As the season progressed other species of Anuræa were encountered, *A. cochlearis* and *A. tecta* more than others, the latter occasionally being the dominant rotifer. Still other species or varieties of Anuræa and other genera, some of them mentioned above, were found in the plankton after the dominance of Asplanchna had passed. In the latter part of the season—that is, in late August and early September—the lower part of the lake reached a stage of maturity as to succession of plankton forms such as was attained much earlier in the tributaries; then Asplanchna was found and *Anuræa aculeata* became abundant.

Few Protozoa were recognized, yet a species of Euglena formed a very dense bloom upon Skunk River, Flint Creek, and Prairie Slough. Associated sometimes with this Euglena were two species of Ceratium.

Insect larvæ were not found in abundance in the plankton of the lake or of its communicating waters. *Corethra* sp. did enter into the catches once in Lake Keokuk, sparsely in Skunk River, Spring Slough, Green Bay, and more abundantly in Sullivans Slough and Devil Creek.

PHYTOPLANKTON

Algæ rarely occurred in the plankton in measurable quantities until August. Traces of green algæ were, possibly, present from the beginning. Blue-green algæ though more easily detected, were not seen until July 28. The algæ, once having made their appearance, increased as to frequency and amount till near the end of the season of observation in early September. The following general considerations as to the occurrence of algæ stand out clearly from the detailed record.

Green algæ.—(*a*) The volume of green algæ increased with the season. This was especially to be noted in the main body of water and with the approach to the dam at Keokuk. (*b*) In chutes with running water and over submerged land there was an increase of green algæ. (*c*) In the tributaries without current and filled only with back water from the lake the amount of green algæ decreased with distance from the lake. (*d*) In tributaries with running water there were no green algæ except within the immediate influence of the lake. The species of green algæ in the main channel were *Converva* sp., or convervoid forms, with very slight admixture of Pediastrum and Polyedrium. With the passing of the river water over submerged lands and into dead-water tributaries or arms species of green algæ characteristic of stagnant conditions were found. Thus, *Pediastrum boryanum* and Eudorina would appear with considerable regularity, and at times Scenedesmus, Volvox, Glosterium, and Staurastrum.

Blue-green algæ.—Blue-green algæ made their first appearance in late July but were consistently present thereafter in the main channel and in chutes with running water derived from the river or lake. In "dead-water" arms of the lake, blue-green algæ were not encountered. They were likewise absent from tributaries with running water. Apparently food conditions are so changed by chemical action or by the metabolism of green or blue-green algæ that, when not kept constant by renewal of river water, blue-green algæ can not exist. The species of blue-green algæ were few. *Anabaena circinalis* and *A. flos-aquæ* were present and prevailed as the dominant blue-green algæ until mid-August; while encountered once thereafter, they had virtually disappeared by August 20. Clathrocystis was likewise present from the beginning in small amounts, equaled Anabæna by mid-August, and thereafter, with one or two exceptions, was the sole blue-green alga recognized. Nostoc was found over submerged land in the region above Montrose from August 10 to 21. Considerable amounts of Lyngbia were found in water with weedy and stagnant conditions, but these localities were very limited in area. An increase in this and similar forms may be expected in the regions where water Persicaria becomes thickly established.

FISH FOOD

As has been seen, the old rock bed of the river is now covered with silt, but the present lake extends over what was formerly land, and here there must have been, and must still be, much decomposition of land vegetation with consequent depletion of the oxygen supply. On the other hand, one of the chief effects of winds and waves and of the growth of aquatic plants is the reoxygenation of the water. It is quite certain, too, that much of the submerged organic matter has been utilized as food by fishes and by other organisms, notably May-fly nymphs, which in turn serve as food for fish.

The most conspicuous form of acquatic vegetation that appeared in the early years was duckweed (including several species), which was sometimes thick enough in 1915 and 1916 to give a green appearance to large areas of the surface of the lake. Of the larger sorts of exclusively aquatic vegetation the only other kind noticed was the hornweed (Ceratophyllum), which the fishermen found on their lines, and of which thick masses attached themselves to structures immediately above the lock. The simpler single-celled plants, both floating and attached, were noted, but casual observation did not show these to be present in any remarkable abundance. It is worth noting that the only large aquatic plants occurring abundantly away from the shores were forms that do not strike roots into the soil and therefore do not bring into the biological economy of the lake the fertilizing elements of the bottom soil. (Pond, 1905.) The virtual absence of rooted aquatic plants in the lake proper (noted also by Doolittle) was doubtless characteristic of the immature phase of the lake. As the bottom becomes stabler it is probable that rooted forms will appear. The hornweed is considered a good oxygen producer, but the duckweed is not (Titcomb, 1909, pp. 11, 16; Barney and Anson, 1921); and oxygen may be a matter of importance on the lake, for there were times in 1916 when portions of the open lake near Montrose appeared stagnant.

The author made observations of plants in the vicinity of Dallas City, Ill., and Fort Madison, Iowa, in September, 1917. In the lake·principally great masses of duckweed were observed, Spriodela predominating about Fort Madison, and Lemna occurring in great rafts about Dallas City and in Peales Lake, so called. The masses of Lemna seemed to originate over submerged woodlands, whence they floated out into the open lake. No other true aquatic plant (excluding algæ) than Lemna was observed in Peales Lake, but in Green Bay, on the Iowa side (fig. 16), there were in different places acres of smartweed, *Polygonum emersum*, cat-tails, *Typha latifolia*, price cut-grass, *Homalocenchrus* (*oryzoides*?), and tall tick-seed sunflower, *Bidens trichosperma*, all characteristic of swampy rather than lake conditions. Of plants not growing high above the water, there were observed only floating duckweed, Lemna and Spirodela; some pondweed, *Potamogeton* (*natans*?); and the lotus, *Nelumbo lutea*. Within two years after this visit the Green Bay region and adjacent territory of shallow water from a point about 5 miles above Fort Madison to the Skunk River had been inclosed with levees and drained.

The Potamogetons are generally very desirable plants in lakes, but it was observed in Green Bay that the duckweed accumulated in close drift among the floating leaves of the pondweed, making large floating islands, forming a dense shade, preventing the growth of submerged leaves, and, no doubt, when the masses are too large, checking the growth of algæ and other aquatics in the waters beneath. The submerged leaves of the pondweed in such cases were either very small or rotted off. The excessively abundant duckweed in the middle portion of Lake Keokuk at that time was undoubtedly a pest from the point of view of the welfare of fish.

The various species of emergent vegetation mentioned above seemed to serve useful, purposes, both in that their submerged stems gave attachment for algæ (not present to excess) and protection for small aquatic animals, and in that their emergent stems and leaves attracted quantities of grasshoppers and crickets, many of which must have found their way into the stomachs of fish while flying from plant to plant. The floating leaves of the lotus served as temporary lodging places for such insects, while the stems were bored by the larvæ of a moth, probably *Bellura gortynides*.

May flies were enormously abundant on the lake in 1916. (Needham, 1920.) Scattered observations made during the present investigation showed that these are of great importance as fish food, and Forbes (1888, p. 488) found that nearly a fifth of all the food consumed by all adult fishes examined by him consisted of "neuropterous" insect larvæ, the greater part of them being May flies. Their abundance in the lake may be related to a great quantity of decaying land vegetation, for at least some species of May flies eat such food. (Needham, 1905, p. 40; Needham, 1908, p. 262.) Possibly this particular kind of insect will be less abundant when the old terrestrial vegetation becomes exhausted and there develops a more normal aquatic environment with living water plants.

Among the small floating animals and plants (the plankton) the minute Crustacea of many species, grouped together as Entomostraca, are known to constitute an important item and are, perhaps, the principal item in the diet of very young striped bass, sunfishes, black basses, crappies, gizzard shad, minnows, suckers, buffalo fishes, and catfishes; among full-grown fishes they are especially important to the paddlefish, crappies, minnows, quillbacks, and buffalo fishes. (Forbes, 1888, pp. 487, 496.) As the minnows and gizzard shad constitute, in their turn, the chief food of game fishes and others, it is apparent that these tiny animals are very important to the fishery. Doolittle found, in July, 1914, that the entomostracan plankton in the river and lake proper increased in numbers with approach to the dam in notable degree, the number of these small food elements rising from about 50 per cubic yard at the upper end of the lake to 150 at Nauvoo and 1,500 at the extreme lower end of the lake. Later in the season he observed a similar and even more striking contrast between the food supplies under river and lake conditions, respectively, the number of Entomostraca per cubic yard rising from 35 at Oquawka (in the river above the lake) and 100 at Burlington (in the extreme upper end of the lake) to 1,500 at Nauvoo and 25,000 at Keokuk. The increase was attributed to more favorable conditions accompanying the slackening of the current, such as the partial loss of sediment in suspension and the greater time allowed for multiplication of the Entomostraca. A similar difference between the amount of life in rivers and quiet waters occurs in and near the Illinois River. (Kofoid, 1903.) The investigation of this river was very thorough and extended over several years; wide variations were found in different localities and in different months, but the general result showed the quiet waters to be about three and one-half times as rich as the channel; and Kofoid concluded (p. 545) that the small organisms of the river have their source, to a large degree, in impounded backwaters and are maintained to a considerable extent by the run-off of the latter. The bearing of this on the situation in Keokuk Lake is obvious and is indicated further by Doolittle's observations in the waters tributary to this lake (p. 119).

The observations and conclusions of Galtsoff (1924) are most pertinent:

> When the water becomes stagnant, or at least flows slowly, the plankton crustaceans grow more numerous. This has been observed in both Lake Pepin and Lake Keokuk. The increase of Copepoda and Cladocera is especially noticeable in the backwaters of Lake Keokuk, where the crustacean population progressively increases from the upper part of the lake to the dam (p. 414).
>
> The productive capacity of such river-lakes as Lake Keokuk is lessened by the instability of the hydrographic conditions. Nevertheless, the increase of plankton in Lake Keokuk during low stages of water indicates the increase of its general productive capacity (p. 419).

Until the point has been determined for Keokuk Lake by a sufficiently extended investigation, it is perhaps worth while to consider some of the reasons for expecting the lake to have a richer food content that the ordinary channel of the Mississippi. In the first place, it should be kept in mind that the mere motion of the water, by itself, is almost certainly of no importance to small floating animals. Terrestrial man thinks of moving water with reference to fixed bottom or shore. However, the movement of the medium in which they live is of great importance to aquatic creatures as the movement of the earth in space is to man, not because of the motion itself but because it changes the relation to other things. In other words, the motion of the water is significant to plankton organisms only because it is relative—it tends to change the position of the animal with reference to bottom, shores, atmosphere, sunlight, sources of supply, injurious objects, the sea, etc. A suggestive paper on this point has been published by Lyon (1904).

It is well to recall that most fresh-water organisms can utilize the water only after it has fallen as rain and before it is washed into the sea or evaporated. To illustrate the point about to be made, we may take an extreme and hypothetical case. It is obvious that a coastal creek from which the water ran into the ocean within a coup'e of days of its fall could not have much fresh-water floating life because there would be no time for it to develop. Any retardation of this process of carrying rain to the ocean increases the chance for these animals to reproduce their kind. Accordingly, any checking of river currents should be desirable from this standpoint, although, if carried too far, new and unfavorable factors might appear. It is probable that this checking of progress to the ocean is the chief reason why lakes are richer than rivers. The river is fed constantly, both directly and indirectly, by newly fallen water. The waters of lakes have had a longer history from the time when they were in the form of falling raindrops.

Another reason for expecting lakes to possess more organic life is that they usually have substantial amounts of rooted vegetation, whereas rivers have but little of this (Kofoid, 1903, pp. 236–252); and it is rooted plants rather than drifting plants that enrich the water from the soil (Pond, 1905, pp. 522–525). Evaporation may be of some importance because it replaces, to the extent to which it occurs, run-off to the sea, and thus reduces by that amount the sweeping into salt water of river life; evaporation is greater on lakes (Rafter, 1903, pp. 23 and 39ff) probably because the water is exposed longer and because of the freer action of wind on the water.

One other point is worth noting. The water of a river does not move forward in a simple column but is retarded by the sides and bottom and usually by the air. This retardation of the whole perimeter of a cross section of a river causes extreme irregularity in the character of the movement. The result is complicated by many factors, but it may be said that in a general way a river rolls forward like a wheel, or rather like two sets of wheels (Gilbert, 1914, pp. 248–249), and any given particle of water must be now and again swept from the surface to the bed and up again. It is necessary to diverge a little and recall that green plants are the ultimate food of all creatures, and that they can grow only in sunlight. In the water these plants are represented by (among other things) minute algæ, which constitute an important and perhaps the principal ultimate food of aquatic life. As they can grow only in sunlight, it is probably exceedingly difficult for them to carry on life processes while they are whirled frequently from sunlit areas to the deeper and almost sunless regions of the Mississippi River. Whether or not the interruptions as such are harmful, the reduction of sunlight certainly is.

As the result both of observation and of inference, it has been the conclusion of some investigators that the plankton of a river is produced largely in the tributary waters and is carried into the river, a conclusion that links well with the observation that currents are unfavorable to the production of plankton.[10] Allen, for example, after extensive studies of the plankton of the San Joaquin River in California, says that "water currents above a very moderate speed are distinctly inimical to plankton development." [11] (Allen, 1920, p. 124.) Galtsoff (1924, pp. 412 and 413) gives some observations to show that there is pronounced plankton development in places in the Mississippi River, independent of the contribution of tributaries. It is evi-

[10] For a discussion of this question, see Galtsoff, 1924, pp. 411–415.

[11] A similar conclusion was stated by Schröder in 1899, after studies of phytoplankton on the Oder River, Germany, as mentioned by Galtsoff (1924, p. 413) and adopted by Steuer as Schröder's law.

dent that the question of the direct productivity of the moving waters of large streams merits further investigation.

After many years of investigation of the Illinois River, Richardson (1921, p. 374) concludes that: "Speaking generally, the richest sections of the river floor are those with the least average slope and the slowest current, and therefore with the most abundant sediments." Again he says (p. 376): "In our opinion, and that of the most intelligent and observant fishermen, the lakes are the favorite feeding grounds of the larger and more common fishes, and this opinion is supported by the fact that the lakes have a more abundant food supply per acre and that the heaviest fish yields come from sections where the ratio of lake areas to river is greatest." Richardson estimates the productivity of the lakes and backwaters, as compared with the river, at about 2 to 1 (289 pounds of fish per acre in lakes and backwaters, and 141 pounds per acre in rivers, p. 469).

Whatever may be the general superiority of slack waters over flowing waters in respect of biological productivity, it seems, from the studies of Galtsoff, that Lake Keokuk, although possessing something of the character and the advantages of a lake, is nevertheless not now to be given high rank as a lake. A similar inference may be made from the study of the commercial fisheries treated in the companion report. (Coker, 1930). Lake Keokuk, of course, is still immature as a biological plantation, and its final state can not be foretold, but in any case it is not in high degree free from many of the vicissitudes of river areas.

It has been assumed that an increase of organisms constituting fish food would mean an increase of fish, but even this conclusion has been questioned by the authority who has devoted the most study to the ecology of the fishes of the interior waters of the United States. Forbes and Richardson (1914, p. 494), referring to an increase of organic life in the Illinois River, state:

> The fisheries of the stream should feel the effects of this greater abundance of this important element of fish food; provided, it must be added, that the plankton supply is really at any time a limiting element in the production of fishes, such that we may amend the aphorism, given on another page, to the form: "The more plankton, the more fish." It will, however, be a long time, in the writers' judgment, before the whole economy of fish production in our streams is so thoroughly understood that such a statement will be warranted.

Going even further than this, Juday and Wagner (1909, p. 21) have suggested that an unusually large amount of plankton in a lake might be detrimental to fishes because of the reduction of oxygen resulting from decay. It is evident that more knowledge on the questions involved is needed, but it is probable that rivers, at least, are improved as fish habitats by an increase in their content of food for fish.

SPAWNING GROUNDS

The fresh-water fishes, in general, are believed to spawn in shallow water. Examination of virtually all of the literature on the breeding habits of fishes occurring in the Mississippi River confirms this view for the species that have been observed at spawning time.[12] A great proportion of the newly submerged areas of Keokuk Lake are mostly shallow, and it is a reasonable expectation that these areas will make the lake a nursery for fish, which will help to stock not only the lake but to some extent the section of river above and possibly that below, also. The question may be raised whether or not the lake would have been biologically more pro-

[12] The breeding habits of the river herring of the Mississippi, the paddlefish, and the drum are not known.

ductive had the submerged woodlands been more generally cleared before the lake was filled. One might have the impression that land such as is represented in Figure 16, had it been cleared of vegetation and left to form spaces of open water, would have produced more useful plankton (drifting microorganisms, both plant and animal), would have supported more rooted aquatic plants to serve as food producers and oxygenators, would have contributed less to the deoxygenation of the lake, and would have afforded better breeding places for fish. One might have this impression, but the precise observational and experimental data to substantiate or to contradict such an inference are now lacking. It might be suggested that refuge is a primary need of young fish, and that this is afforded by the submerged brush and fallen trees; but refuge can also be offered by rooted aquatics, which at the same time serve other useful purposes to aquatic animal life. Since the question is continually arising as to the propriety of fully clearing lands that are to be submerged by the formation of lakes and fish ponds, there is obviously a very practical sort of problem in this that awaits critical study.

The preceding paragraphs were written prior to the author's last visit to the lake in 1926, when it was found that the aspect of the lake had changed greatly in respect to the submerged islands and shores. Where forests of dead trees had stood on submerged lands (fig. 16) there were now chiefly stumps and a dense growth of Sagitaria and other aquatic plants (fig. 17). Doubtless some of the trees had rotted at the base and fallen, but it was said that many of them had been cut away during the winter, when residents of the shores could work on the ice and haul the wood away for use as fuel. Where the lake in 1917 had presented the aspect of winding passages amongst heavily wooded areas, there was in 1926 uninterrupted view in all directions. Shallows still prevailed over submerged islands and shore lands, but the water in such places was subject to more severe wave action. (Coker, 1930.) The Green Bay region and adjacent territory, as has been mentioned previously, had been removed from the lake entirely and converted into agricultural lands, thus eliminating some of the best breeding and nursery grounds for fish.

ABUNDANCE OF FISH

During 1914, 1915, and 1916 several visits were made by Stringham to the markets at Burlington, Iowa; during 1915 and 1916 to those at Fort Madison, Iowa, and to fisheries at Nauvoo, Ill.; and during 1916 to newly established fisheries at Montrose, Iowa. There was a tendency at first to complain that fish were less abundant than theretofore; in 1915 this was substantially confined to two species—the Missouri sucker, a southern species never common here, and the shovelnose sturgeon. By 1916 the complaints had about ceased. It seemed clear, however, that the sturgeon fishery was ended for the southern end of the lake, and that it had probably diminished above. Against this, there had been gains in carp, catfishes, and drum, and possibly in buffalo fishes and black bass. As to game fishes, little or no complaint was heard at any time. There was observable a distinct development of the commercial fishery with the use of more and larger apparatus. The statistics of the commercial fishery for 1922, to be discussed later, will show that the gains had been maintained for black bass, catfish, and drum, but not for carp and buffalo fishes. The sturgeon fishery apparently had disappeared in that year.

In 1917 the author interviewed fishermen and dealers at Fort Madison, Dallas City, and Burlington and on Green Bay. The general purport of the information

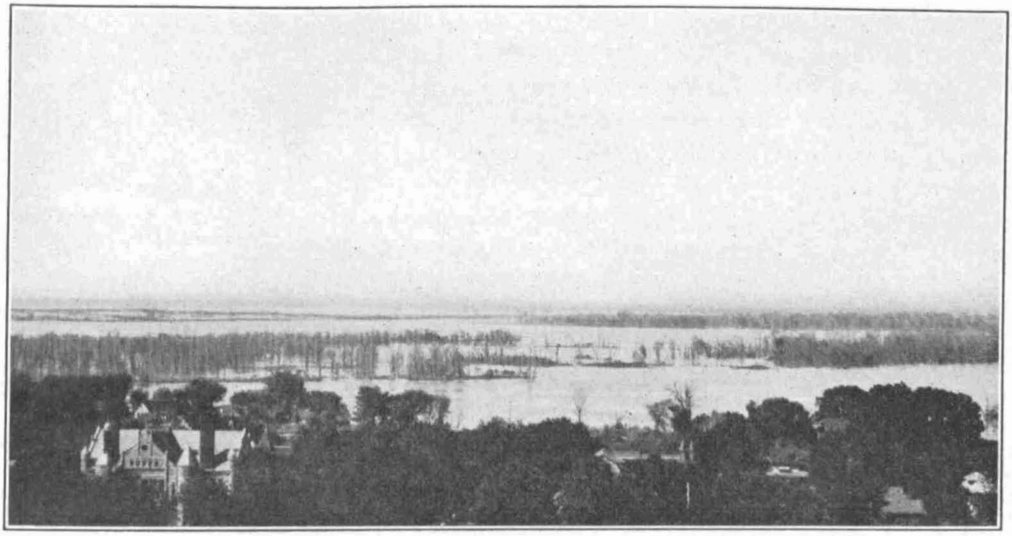

FIGURE 16.—Overflowed islands opposite Dallas City as they appeared in 1917

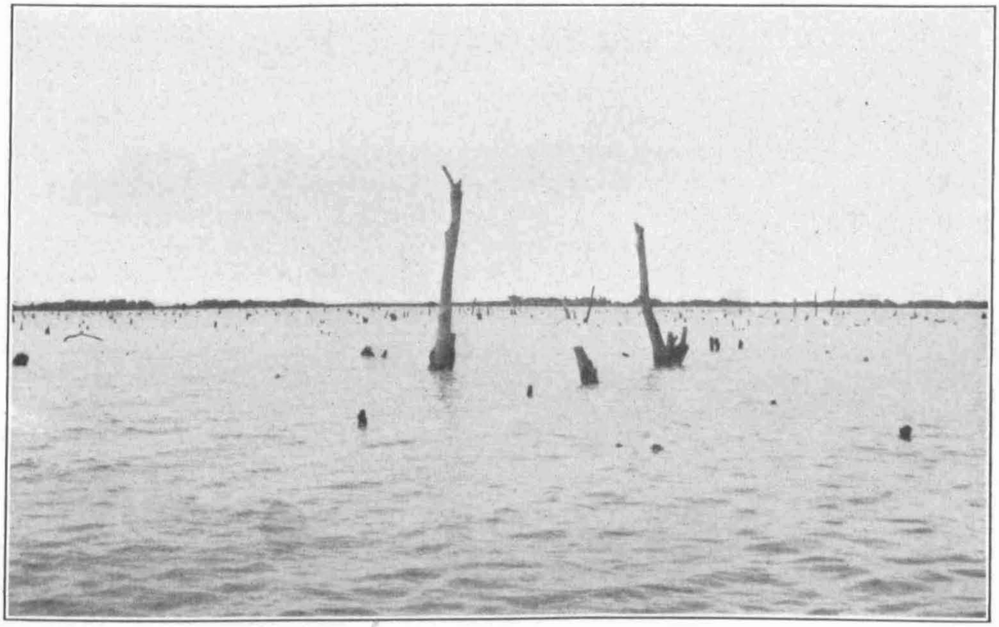

FIGURE 17.—The same region in 1926

received was that "hackleback" (sturgeon), spoonbill cat (paddlefish), and suckers were disappearing, but that carp, buffalo fishes, bass, sunfish, and crappie had greatly increased. There was a marked difference of opinion in regard to catfish, and one dealer stated that catfish, while fewer, were larger. It was also said that whereas there were three commercial fishermen at Dallas City in 1917 there were 35 in 1920. More definite information in regard to the commercial fishery is found in the following section, and the individual species of fish are treated in a later paper. (Coker, 1930.)

SUMMARY OF OBSERVATIONS

Keokuk Lake, formed by the dam at Keokuk, Iowa, extends 42 miles to Burlington, Iowa. The width varies from about ½ to 2½ miles or more, and the total area is about 60 square miles. The greatest depth is about 36 feet. The increase in volume will ultimately be about 14,000,000,000 cubic feet, less the reduction due to filling in by sediment and to reclamation by levees and drainage. The stage, and therefore the area, presumably fluctuates substantially less than that of the river before the construction of the dam. The turbidity and temperature probably are not greatly different from what they were under former conditions, but the velocity of the current has been reduced, the reduction near the dam being very great. The old rock bottom has been covered deeply with silt. The lake, while supporting few rooted aquatic plants, up to 1916 gave evidence of an enriched fish-food content, and there were reasons for expecting that this condition would continue to improve. Land submerged by the widening of the water area should supply favorable spawning beds for game and food fish, but a very large portion of the most favorable areas has been reclaimed for agricultural uses by the construction of levees and by drainage.

DEDUCTIONS FROM THE COMMERCIAL FISHERIES OF LAKE KEOKUK AND LAKE PEPIN

One of the most practical means of determining the effect of the dam upon the fishes of the river would be the comparison of the conditions of the commercial fisheries before and after the construction of the dam. Unfortunately, we have no comparable surveys of the fisheries of the river for such times. This lack has been partly compensated for by surveys of two of the most important regions of fishery above the dam, made soon after the construction of the dam and after periods of 3, 8, and 13 years, respectively. Since the report was first submitted for publication another survey (for 1927) has been completed, and we are enabled to include comments based upon statistical data in manuscript offered by the division of fishery industries. We have not reorganized the section, but we have added a column to each of Tables 6 and 7 and have inserted references to the results of the survey for 1927 wherever pertinent.

It is evident that the dam could not have exerted its full effect upon the fish life of the upper river within a year and that whatever effect may have followed a year after the obstruction was completed should have been more conspicuous in subsequent years. Accordingly, a comparison of the fisheries in Lake Keokuk for 1914, 1917, and 1922 (the dam having been completed in 1913) should give a fair indication of what was happening in that part of the river most immediately affected by the dam. Furthermore, if the dam was far-reaching in its effect by shutting off migratory fishes from the upper river, then a comparison of the fisheries in Lake Pepin, 400 miles (by river) to the north, for the same years should give some indications of the changes. Under any circumstances, of course, reasonable allowances must be made for such fluctuations as occur from year to year without the intervention of artificial obstructions or improvements, and for such as might result from developments other than the dam.

The full reports of the statistical surveys of the fisheries of the lakes for the years 1914, 1917, 1922, and 1927, respectively, are found in the reports of the Commissioner of Fisheries for the fiscal years 1916 (pp. 58–60), 1918 (pp. 77–80), 1924 (Appendix IV, Fisheries Industries of the United States by Oscar E. Sette), and 1928 (pp. 544–546). The results of the surveys are summarized in Tables 6 and 7.

Attention should be directed first to the fact that between the years 1914 and 1917 prices of fishery products had risen substantially under the influence of war conditions, the average price per pound for all fish being more than 40 per cent higher in the latter year than in the former. The higher price obtainable no doubt proved a stimulus to the fisheries, for the coarser fishes particularly. Again, prices had declined by 1922, and this might be supposed to have an effect. However, since, the returns from all other forms of labor had risen and then fallen in a somewhat corresponding manner, it does not appear at all probable that the stimulation due to price could have had so pronounced an effect as to create an appearance of abundance where actual scarcity prevailed. All comparisons in the text will be made, not on the basis of value but with reference to quantities in pounds of catch.

TABLE 6.—*Fisheries of Lake Keokuk, 1914, 1917, 1922, and 1927*

Items	1914	1917	1922	1927
OPERATING UNITS	*Number*	*Number*	*Number*	*Number*
Fishermen	105	118	122	102
Boats:				
Motor	36	52	58	70
Other	94	80	111	82
Fishing apparatus: [1]				
Seines		1	2	3
Anchored gill nets		12	235	26
Trammel nets	14	17	17	
Fyke nets	1,378	1,368	1,301	1,594
Fish traps		81		815
Dip nets			1	
PRODUCTS	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Black bass	15	4,163	6,200	
Bowfin		26,000		14,055
Buffalo fish	249,900	696,543	113,946	67,872
Carp, German	302,365	762,259	276,431	291,199
Catfish and bullheads	71,535	109,904	183,919	140,343
Crappie	70	17,560	13,770	
Eels	3,800	2,087		
Fresh-water drum or sheepshead	26,860	160,554	65,040	27,538
Pike		20		
Pike perch, sauger			2,280	
Quillback or American carp		5,936		9,880
Spoonbill cat, or paddlefish		927	27,405	1,249
Sturgeon, sand [2]	1,900	454		
Sturgeon, shovelnose			600	
Suckers	4,640	700		
Sunfish	50	13,879	11,590	13,563
Turtles				385
Total	661,135	1,800,986	701,181	566,084

[1] Trot and hand lines are omitted from this statement because data on the quantity in use are not available.
[2] Reported as lake sturgeon in 1914.

TABLE 7.—*Fisheries of Lake Pepin, 1914, 1917, 1922, and 1927*

Items	1914	1917	1922	1927
OPERATING UNITS	*Number*	*Number*	*Number*	*Number*
Fishermen	135	126	219	139
Boats:				
Motor	28	35	109	39
Other	54	55	136	105
Fishing apparatus: [1]				
Seines	14	17	33	23
Anchored gill nets	664	371	351	152
Fyke nets	295	262	95	280
Fish traps	8	14		
Spears			7	4
PRODUCTS	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Bowfin	1,534	24,021	16,136	3,334
Buffalo fish	261,250	300,808	340,309	33,449
Carp, German	237,517	467,588	2,578,916	615,242
Catfish and bullheads	26,830	254,249	127,384	53,076
Eels			541	318
Fresh-water drum or sheepshead	131,785	118,304	395,592	113,793
Mooneye, fresh	9,300	7,656		8,976
Mooneye, smoked	1,465	7,250		
Pike	50			
Quillback or American carp	60,605	14,238	47,377	4,835
Spoonbill cat, or paddlefish	8,877	2,923	15,971	1,191
Sturgeon, lake	1,067	512	5,253	
Sturgeon, shovelnose			1,080	
Suckers	18,340	15,260	43,466	31,911
Sunfish	50			
Turtles			442	
Total	758,670	1,212,809	3,572,467	866,125

[1] Trot and hand lines are omitted from this statement because data on the quantity in use are not available.

In the first place, it is observed that the total catch of fish in Lake Pepin in 1917 was 60 per cent greater than in 1914, due in part, no doubt, to increased prices and the war-time demand for fish as a substitute for meats, while the catch in Lake Keokuk had increased 172 per cent; this means that the catch in the lake created by the dam was nearly three times as great in the fifth year of the lake (1917) as in the second year (1914). By 1922 the catch of fish in Lake Pepin was nearly three times as great as in 1917, or nearly five times the yield of 1914; this remarkable change was due in considerable measure, but not wholly, to the increased catch of carp. On the other hand, the catch in Lake Keokuk in 1922 was 61 per cent less than in 1917, although somewhat greater than in 1914. In 1927 the catch in Lake Pepin was comparable to that in 1914, but somewhat larger, while the catch in Lake Keokuk, continuing to decline, was less than in 1914.

The fishes taken in respective quantities of 25,000 pounds, or more, in either lake in any one of the years of report were as follows: Buffalo fish, catfish, fresh-water drum, carp, quillback, suckers, and bowfin. We will consider these severally.

The catch of buffalo fish in Lake Pepin was 15 per cent greater and in Lake Keokuk 179 per cent greater in 1917 than in 1914. The increase in the northern lake is not material, but in the southern lake it appeared in 1917 that the new conditions had afforded opportunity for a substantial development of the buffalo fishes as a natural resource, and this coincided with the statements of fishermen at Dallas City, Ill., a principal fishery point on the lake. The remarkable decline in the yield of buffalo fish reflected by the canvass of 1922 seems at present inexplicable on the ground of any known change in conditions from 1917 to 1922 other than the substantial reduction of area of the lake by reclamation of submerged lowlands. (Coker, 1930.) It may be remarked that buffalo fish was the most valuable fish product of both lakes until 1922, when carp took the lead in Lake Pepin and catfish in Lake Keokuk. Nevertheless, the take of buffalo fish in the upper lake in 1922 showed a further increase over that of 1917. The surveys for 1914, 1917, and 1922 suggested a steady upward trend in the abundance of buffalo fish in the region of Lake Pepin, but in 1927 buffalo fish were found in extremely small numbers.

The changes apparent in the catches of bowfin (1,466 per cent increase) and catfish (848 per cent increase) in Lake Pepin are not explicable on the basis of any conditions possible of association with the dam. In the case of the bowfin the increase is most probably attributable to the propaganda conducted by the Bureau of Fisheries in 1917 for the greater utilization of this fish in smoked form; thus, from Lake Keokuk 26,000 [13] pounds were marketed in 1917, whereas none had been sold in 1914; and again, none were reported in 1922, but a significant catch appears in 1927. There is no dependable market, apparently, for this much condemned fish, and the fishery goes by vagary.

The large catch of catfish and bullheads from Lake Pepin in 1917 may also have been associated with the "eat more fish" campaign of war times, but it will be noted that even in 1922 the catch was more than four times as great as in 1914 (but only twice as great in 1927). Lake Keokuk shows a steady increase in pounds of catfish taken up to 1922, the yields for the three years of survey being, respectively, 72,000, 110,000, and 184,000 pounds (140,000 in 1927). These figures seem consistent with the expectation that impounded waters of increased area would be favorable to the multiplication and growth of several species of bottom-feeding habit.

A decline in the catch of drum in Lake Pepin had been observed in the seine collections made by the bureau in connection with the propagation of fresh-water mussels, and it had been suspected that this might be attributable to the dam; but the decline of 10 per cent in commercial catch in that lake from 1914 to 1917 was matched by an increase of 498 per cent in Lake Keokuk, which is also above the dam. When we examine the figures for 1922 we find a great increase for Lake Pepin (234 per cent) but a decline of 59 per cent for Lake Keokuk; the catch of drum in Lake Keokuk was still, however, more than twice as great in 1922 as in 1914. In both lakes the figures for yield of drum in 1927 are not notably different from those of 1914.

While the capture of "German" carp, the chief product of fishery (in quantity) in both lakes had virtually doubled in Lake Pepin in 1917, the increase in Lake Keokuk was substantially higher, an increment of 152 per cent being observed. In 1922 the remarkable increase of 452 per cent may be noted for Lake Pepin, while the catch in Lake Keokuk fell 64 per cent, having been even smaller than in 1914. Regarding the latter lake, reference may be made to previous remarks concerning the buffalo fish. The great catch of carp in Lake Pepin in 1922 undoubtedly was due to a notable natural phenomenon, which is discussed in another place. (Coker, 1930). The catch in 1927, while much smaller than in the years about 1922, was still much larger than in 1914 or 1917. In Lake Keokuk the change from 1922 to 1927, as regards the carp, was not significant. The large catch of 1917, for reasons to be mentioned later (Coker, 1930), was due, perhaps, to special conditions.

The quillback or "white carp," on the other hand, shows first a marked decline in Lake Pepin, the catch in 1917 (14,000 pounds) being about one-fourth the catch of 1914 (61,000 pounds), with a partial recovery in 1922 (47,000 pounds) and an ex-

[13] In the text, figures are given in round numbers in nearly all cases. Exact figures may be found in the tables.

treme decline in 1927. A beginning of a fishery for quillback was seen in Lake Keokuk in 1917, but the quantity yielded was not significant; the fishery did not show in the 1922 canvass but appears again in 1927.

Among the most esteemed of commercial fishes that seem to have declined in abundance in recent years are the paddlefish, or so-called spoonbill cat, and the sturgeons. For both of these there was substantial diminution in the returns from commercial fisheries of Lake Pepin from 1914 to 1917 (67 and 52 per cent, respectively); both seemed to show recovery in 1922 (increase over 1917 of 446 and 926 per cent, respectively), but in 1927 appeared insignificantly or not at all. In Lake Keokuk the paddlefish fishery, not appearing in 1914 and insignificant in 1917 (927 pounds), showed more signs of life in 1922 (27,000 pounds). In 1927, however, the reported yield was only about 1,200 pounds.

The lake-sturgeon fishery is now insignificant, unfortunately, and the figures are too small to be used safely for inference. The sand-sturgeon fishery of Lake Keokuk, of little importance in 1914 (1,900 pounds), dwindled to virtually nothing in 1917 (454 pounds); in 1922 it was represented by a small catch (600 pounds) of shovelnose sturgeon (another name for the same species) but did not appear at all in the report for 1927.

In the case of suckers there was observed a decline of 17 per cent in Lake Pepin from 1914 to 1922 but a great increase in 1922, the figures for the respective years being 18,000, 15,000, and 43,000 pounds (32,000 pounds in 1927). In Lake Keokuk a decline of 85 per cent appeared in 1917, and none were reported for 1922 or 1927.

Eels have never been sufficiently abundant in the extreme upper portion of the Mississippi River to enter substantially into the commercial fishery. They have been more plentiful farther south, as in the region of Keokuk. From 1914 to 1917 there was noted a decline of 45 per cent in the take of eels in Lake Keokuk, and none was reported for 1922 or 1927.

While the statistics of the capture of game fish (black bass, crappie, pike, pike perch, and sunfish) in Lake Keokuk for 1917 and 1922 are suggestive of an increased abundance of such fishes, as would be expected, the figures can not be used safely for purposes of strict comparisons. The laws of both Iowa and Illinois have imposed limitations upon the capture of game fishes and attach conditions to their shipment for sale from certain waters. (Stringham, 1919, pp. 10, 11, and 19.) It is unlikely, therefore, that full and correct information regarding the capture and sale of such fishes is obtainable by statistical agents from the fishermen.

Had we no other canvasses than those of 1914 and 1917, we might draw rather definite conclusions; but the data for 1922 would upset them seriously. Some fish that at first rose quickly in yield failed later fully to maintain the rise; others that seemed distinctly on the decline are found to have come back into prominence. If we should now draw any such conclusions they must be tentative. Certain facts may first be recalled.

1. The canvasses of 1914, 1917, and 1922 reveal a steadily increasing commercial catch in Lake Pepin—in round numbers the successive yields are 759,000, 1,213,-000, and 3,572,000 pounds. While the trend showed an interruption in 1927, when 866,000 pounds were taken, it would be difficult to relate this to a delayed effect of the dam.

2. Considering Lake Pepin and the three surveys during a period of 9 years after the construction of the dam: (*a*) Two kinds of fish show increasing yield each

time—buffalo and carp. (*b*) Five kinds show, first, moderate decline, then increase—drumfish, quillback, paddlefish, lake sturgeon, and suckers—and all but the quillback were taken more abundantly in 1922 than in 1914. (*c*) Three kinds of fishes show, first, material increase, then decline—bowfin, catfish, and mooneye—but the catches of bowfin and catfish were still much greater in 1922 than in 1914, while the mooneye was not represented at all in 1922.

3. Lake Keokuk offers a different story: (*a*) Two kinds of fish, at least, show a progressive increase in yield from 1914, through 1917, to 1922—catfish and paddlefish. This is true, also, of the leading gamefish—black bass, crappie, and sunfish—if the figures are to be accepted as correct. (*b*) Three kinds gave greatly increased yields in 1917 but reduced yields in 1922—buffalo, carp, and drum—the yield of drumfish being reduced only as compared with 1917, since it was still as great as in 1914. (*c*) Three kinds show steady decline, the catches being small even in the first year and not appearing in the last year—eels, sand sturgeon, and suckers. (*d*) Two fishes figured only in the products of 1917—bowfin and quillback.

From the statistics of the commercial fisheries we can derive no impression of diminution of fishes in Lake Pepin following the construction of the dam. The quillback and possibly the mooneye offer the only possible exceptions. It must be said, however, that at least two species of buffalo fish play a part in the fishery but are not distinguished by statisticians, and, therefore, there remains the possibility that one has diminished while the other has increased, although there is no evidence to that effect. A similar statement may be made in regard to catfish.

As regards Lake Keokuk, the only kinds of fish of commercial importance in 1914 that were taken in less abundance in 1922 were buffalo fish and carp, fishes that showed increasing yield in Lake Pepin. Eels, sturgeon, and suckers also declined or disappeared; while commercially unimportant in the locality, these fishes are to be regarded as potentially important. However, since lake sturgeon and suckers maintained their place in Lake Pepin, it is evident that they were not excluded from the upper river. The sturgeon of Lake Keokuk (the shovelnose) presents another question.

The statistics for 1927 offer a picture distinct from those of the preceding years of report but do not seem to necessitate substantial modification of the statements made in the two preceding paragraphs. We have to do possibly with one of those occasional years of very poor conditions for the fishery.

The relatively very large catches of buffalo fish, carp, and drum from Lake Keokuk in 1917 offer a nice problem. Possibly we have here another illustration of an apparently common rule of development of newly formed lakes. According to this rule, if it may be so called, there occurs, first, an increase of the smaller animals and plants that constitute the food supply of larger fish; second, a great multiplication and growth of the larger feeders (fish) until the crest of a wave of fish population is attained; third, a depletion of food supply as a result of overabundance of feeders; fourth, depletion in numbers or diminution in average size of fish until the fish population is at the trough of the wave; and finally, an approximate biological balance when fish are less abundant than they were at the crest of the wave and perhaps more abundant than at the trough of the wave. If this explanation applies, later surveys may show improvement. If the reclamation of submerged lands is the cause of the fall of the catches, no material improvement is to be expected. It is important that further surveys should be made. (No improvement, but the reverse, is shown by the survey of 1927.)

It may be thought that more detailed consideration should be given to the matter of changes from year to year in the amounts of the several kinds of gear in use. Undoubtedly such changes have some effect on the returns, particularly in the cases of fishes of minor importance. As regards the fishes of major importance, shifts in the use of gear are likely to be the result rather than the cause of variable yields of particular fishes. On the whole, after studying that question with some care, we doubt if the changes of gear reported could have had such an effect as to modify significantly the general aspect of the returns. It must be said, however, that for strictly accurate comparisons of the catches of different years it would be necessary to consider not only the numbers of each kind of apparatus used in each year but also the number of days and hours that each piece of apparatus was employed. It must never be forgotten that the "margin of error" in the use of such statistics is very broad at the best; we can only say that we do not believe it is wide enough to make fish appear abundant when they are scarce or rare when they are actually abundant.

NOTES OF A. S. PEARSE ON CHANGES IN FISH FAUNA IN LAKE PEPIN

Before leaving the subject of fisheries in Lake Pepin, reference should be made to two systematic examinations of fishes in that lake conducted, respectively, by Dr. George Wagner, of the University of Wisconsin in 1903 and 1904 (Wagner, 1908), and by Dr. A. S. Pearse, of the same institution, in 1920 (Pearse, 1921). Doctor Pearse makes the following comparison of conditions existing in 1903–4 and 1920, respectively, as regards the more important species of fish:

> Marked changes have evidently occurred in the fish fauna of the lake since Wagner (1908) made his observations in 1903 and 1904. The lamprey eel is no longer common, probably because its usual host, the spoonbill, has decreased in numbers. Wagner says (p. 27) "The spoonbill (paddlefish) is one of the most abundant forms in Lake Pepin throughout the summer." In 1920 this species was rather uncommon. Again Wagner says that the rock sturgeon is "not uncommon" and that the hackleback is rare. In 1920 (Table 2) the hackleback was abundant and the rock sturgeon (not seen by the writer) very rare. Wagner took no bullheads except the tadpole cat. Three species were common in 1920. The buffalo (*Ictiobus cyprinella*) was "very abundant" and is now rather uncommon. It has been replaced by the carp, which in 1920 led all other species in commercial value. Wagner found the skipjack (river herring) "very common," and in 1920 it was quite rare. He found the rock bass very common, and the young "extraordinarily numerous alongshore." In 1920 no rock bass were caught, although special efforts were made. The local fishermen all agreed that it was an exceedingly rare fish. The perch was rare in 1904, and in 1920 was rather common. Small largemouth black bass are no longer so abundant alongshore as to be a "nuisance in fishing with a minnow seine."
>
> The spoonbill, rock sturgeon (lake sturgeon), and buffalo have evidently been more or less "fished out" during the past 15 years, and the last has been replaced by the carp, which has similar habits. Wagner probably took no bullheads because he did not fish with trot-lines. The writer sees no apparent reason for the marked decrease of the skipjack and rock bass.[14]

[14] Neither of these last-mentioned fishes plays a part in the commercial fishery. The rock bass, however, is important as a game fish and local food fish, and the "skipjack," or river herring, is of great economic importance as a carrier of the larval stage of one of the most valuable commercial mussels.

CONCLUSIONS

It remains to give our special observations regarding the fishes of commercial importance possibly affected by the dam and to consider each in the light of all available information concerning them. For reasons of practical convenience this is made the subject of a special report to follow, entitled "Studies of common fishes of the Mississippi River at Keokuk." (Coker, 1930.) However, it is appropriate here to give our conclusions in full, and this is done with the understanding that the data supporting many of the conclusions presented are to be found in considerable part in the other report.

The dam acts as an effective barrier to upstream movements of fishes, being impassable in that direction for any kind of fish except in so far as they may pass through the lock. The evidence indicates that there is no distinct migratory movement of fish through the lock. The location of the lock with reference to the currents and the manner and extent of its operations preclude its functioning as an effective fishway.

Little evidence was found to indicate that free migration past any one given point in the river as far north as Keokuk is of vital importance to any species of fish of the region except the eel, river herring ("skipjack"), Ohio shad, blue sucker (probably), and possibly the rock sturgeon. Each of these fish is mentioned severally in the following paragraphs.

Fish may pass over the dam in a downstream direction, but we could find no evidence that this occurred to a detrimental degree for any kind of fish, excluding the eel.

Reports that fish in upstream migration were deflected in quantity up the Des Moines River, a tributary entering the Mississippi River just below the dam, were carefully investigated on two occasions in different years and were found to be manifestly without foundation in fact on these occasions.

Injured fish, chiefly paddlefish, frequently are seen floating in the swift current just below the dam and near the western shore. Many experiments were made, but the cause of the injuries could not be determined. It was learned by experiment that carp and goujon could pass over the dam without evident injury, and that it was possible for paddlefish to pass downward through the turbine chambers without observable injury. It does not follow, of course, that fish could not receive injury in making such passages. There is the possibility that the injuries resulted from encounters with submerged piling in the extremely swift waters of the tailrace.

Studies of the records of river level for both Davenport (above the lake) and Keokuk (below the lake) for the years 1910 to 1919, inclusive, show that the fluctuations tended to become more marked in the later years at both places.

While a lake of considerable expanse and depth now covers the site of the former Des Moines Rapids and adjacent sections of the river and its bordering lowlands, typical lakelike conditions have not developed and probably never will develop to an extent comparable to the conditions in Lake Pepin. Both lakes represent impounded portions of the river—the one artificially impounded, the other naturally impounded. The differences between the two are attributable to the greater volume of the inflowing river relative to the area of Lake Keokuk, the greater amount of sediment carried by the river in its lower course, and the reclamation of a very valuable portion of the lower lake for agricultural uses. The increase of plankton in Lake Keokuk suggests the increase of its general productiveness, but the plankton development in that lake has not been found comparable to the development in Lake Pepin. Lake Keokuk is subject to more of the vicissitudes of ordinary sections of the river.

The statistical surveys of fisheries in Lake Pepin for 1922, when compared with surveys of 1914 and 1917, indicate an increasing catch of paddlefish, but oral reports in 1926 and the survey of 1927 indicate a recent scarcity of this and other commercial fishes. The surveys made for Lake Keokuk show increasing yields in 1922, with a corresponding drop in 1927, and this is in accord with the reports of commercial fishermen. The evidence indicates that the species finds in Lake Keokuk favorable conditions for reproduction and growth. The effect of the power development, if any, on the paddlefish fishery of the upper river is favorable. However, somewhere in connection with the dam a noticeable number of paddlefish receive serious injuries, the cause of which we have been unable to ascertain.

The decline of the rock sturgeon in the upper river can not be associated with the the presence of the dam, as that fish had been virtually lost to the upper part of the river before the dam was built. The shovelnose sturgeon, small but very valuable, may be declining in importance in the river above the dam, but the evidence is not very clear. Further inquiries should be made during a season of good flow of water, such as had not prevailed for several years before 1926. The lake offers no advantages for it. Since the fish seems to be holding its own better below the dam, it is possible that breeding conditions are better there and that the fish would be more abundant in the upper river were the dam not an obstruction to its upward range. Some breeding evidently occurs above the dam.

Gar pikes are undiminished in numbers, if not increasing, but that condition can not well be associated with the dam. The yellow sandshell, the most valuable of all mussels, which propagate with the aid of gar pikes, is greatly increasing in abundance in the upper river, a condition very desirable in itself but probably due to the increasing numbers of wing dams built in aid of navigation and serving as protection to areas of relatively still and shallow waters along the shores, where the sandshells may thrive.

The bowfin (or dogfish), formerly despised generally, is now in some demand, but is not found in the upper Mississippi in such abundance as would be expected. Its extremely predacious habit makes it an undesirable element.

The mooneyes appear to have been unaffected by the dam. The gizzard shad, very valuable as food for other fishes, might be expected to multiply abundantly in the lake, but we have no evidence yet of its notable increase.

The river herring, while still abundant below the dam, does not now appear in the upper river in anything like the numbers observable in former times. Undoubtedly it breeds above the dam as well as below, but we are led to the conclusion that the upper river formerly was stocked largely by migration from more southern waters, and that the effect of some comparatively recent change has been to cause a great reduction in the abundance of river herring in the upper river. That the dam was the effective factor in this change is strongly evidenced by the fact that diminution in numbers of river herring was observable immediately after the dam was built and was most pronounced at that time. Apparently there has been a partial recovery, but river herring are found now in far less abundance than formerly. The valuable niggerhead mussel, dependent in nature upon the river herring for its early development, is gradually declining in importance in the upper Mississippi. We can not, of course, say to what extent the decline is due to the intensive fishery for a mussel of very slow growth or to what extent it is attributable to the reduction in numbers of the fish upon which the mussel is dependent.

The Ohio shad in upstream migration at the season of spawning is stopped by the dam. Unfortunately this fish has been so little known that we have no information whatever regarding its occurrence in the river before the dam was built.

Eels bred in the sea are virtually estopped from passing into the upper river. Small eels are reported to occur at times in substantial numbers at the base of the dam. The eel may be expected to become quite rare in the Mississippi and tributaries entering it above Keokuk unless young eels can be planted above the dam.

Of the catfishes, only the Fulton cat is affected adversely by the dam. It is there stopped in northward migration, but it probably never ascended the river far above the site of the dam. It seems certain that they were once seasonally abundant in the Des Moines Rapids, which are now submerged by the water of the lake.

There has occurred a notable increase in the local abundance of the channel catfish and niggerlip catfish in Lake Keokuk, due undoubtedly to the favorable conditions provided by the lake for breeding and growth of catfishes.

Excluding the blue sucker, none of the "suckers" seems to have been unfavorably affected by the dam except in so far as the lake, with its still waters, has made that particular locality unfavorable for such species as are addicted to swiftly flowing water.

The blue sucker presents a problem. Up to about the time the dam was built the blue sucker was very abundant in swift water for a limited season in each year. Since that time it has almost disappeared from the river above the dam and, seemingly, below it as well. As the indications are that the fish was strongly migratory in habit, there is the probability that the dam has shut it off from its best breeding grounds and that the sucker stock of the river above and below the dam has suffered in consequence. We do not know of a type of fishway that could have been used to obviate the difficulty.

There is found no reason to believe that the dam, acting as an obstruction, has had any significant effect upon the abundance of the buffalo fishes in any parts of the river unless, perhaps, quite locally. It has been said by one experienced fishery manager that "southern" buffalo were greatly diminished in Lake Pepin after the dam; but to suppose that Lake Pepin is contingent upon the river 500 miles below for its stock of any species of buffalo fish involves assumptions regarding the natural history of buffalo fishes that are not justified by any body of evidence.

The favorableness of conditions for reproduction of buffalo fishes and carp in Lake Keokuk unfortunately has been reduced by the drainage of large areas of overflow lands since the dam was built.

The dam as a barrier has had no significant effect upon the basses, crappies, and sunfishes. The lake offered favorable conditions for the multiplication and growth of such fishes, but its advantages have been lessened by the drainage of the Green Bay district.

As regards the pike perches, it is not probable that the dam has any significant effect upon the abundance of the fishes unless it be comparatively local. Too little is yet known in reference to the migratory habits of the sauger, the only species that could be affected seriously by the dam.

There is no evidence of effects, one way or the other, upon the white bass or the yellow bass.

The indications are that the dam has had no marked effect upon the general abundance of drumfish in the river either above or below Keokuk, although it may interfere with local nomadic movements.

Fishes that seem not to be affected significantly by the power plant (except locally) include nearly all the commercial and game fishes. Fishes that it seems likely have suffered real detriment are the river herring (and with it the niggerhead mussel), the Ohio shad, the eel, and the blue sucker. It is possible that the shovelnose sturgeon also has been affected unfavorably. The Fulton catfish has been shut off from the upper 50 or 100 miles of its former range. Fishes that have derived benefit from the development of the lake are the paddlefish, catfishes, buffalo fishes, carp, black bass, crappie, and bluegill (?). The benefit to the paddlefish may extend far up the river; the benefits in the other causes are probably localized, and they were far more notable before the Green Bay district was drained.

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