18.—THE AQUARIUM OF THE UNITED STATES FISH COMMISSION AT THE WORLD'S COLUMBIAN EXPOSITION.

REPORT OF THE DIRECTOR.

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The aquarium of the United States Fish Commission was universally regarded as one of the most attractive features of the World's Columbian Exposition, having been a source of wonder and delight for months to several millions of people.* Its early readiness for the visitors, at a time when most of the exhibition areas were cheerless wastes of seemingly hopeless disorder, gave it a prompt popularity, which neither the inspirations of the Art Gallery, the diversions of the Plaisance, nor the glories of the Court of Honor served at any time materially to lessen. It was a place of marvels for the populace, and especially for the native of the Mississippi Valley, who, although an industrious fisherman, may rarely have seen a fish distinctly in the muddy waters of his streams and lakes, and to whom the forms and actions of many of the most abundant animals of the sea were as novel as if the contents of our tanks had been made to order for our special use.

A brief account of the means and methods by which these results were reached in the space of a few months; of the difficulties inherent in the plan and in the situation; of the failures and successes of the enterprise—both sufficiently numerous to make the administration of it a decidedly interesting task; and especially of the new facts and experiences resulting, may perhaps be profitable to others in kindred fields, and even deserving of some attention from a larger public.

An aquarium is intended to be a bit of aquatic nature brought within the easy reach of man, with as little disturbance of natural conditions and relations as the circumstances will permit, and with the most faithful representation possible of such conditions and circumstances as it is nevertheless necessary to disturb or destroy. Its only worthy dependence for sources of interest is on that love of nature, and especially of living nature, common among unspoiled men, and often the redeeming trait of those otherwise quite sophisticated. To present and represent living nature faithfully, without unworthy tricks to catch attention, and especially without falsehood or any other kind of deception, but still to do this by means and in a way which will justify

NOTE.—This article, intended originally for the Fisheries Congress held in October, 1893, has been revised in part, to include results reached during the closing days of the exposition season.

* For some hours each day, during a large part of the season, entrances to the aquarium averaged from 100 to 150 per minute, packing the corridors to the limit of their capacity. Many thousands daily were turned back at the doors by the overcrowded condition of the building, or forced to content themselves with a hurried and distant glance at the exhibit.

and heighten one's delight in the natural world by recalling pleasing experiences, by introducing novel objects, and by conveying agreeable or important information, is the task of the aquarium manager, as it is that of the director of the zoological garden and that of the curator of the natural-history museum. To use aquarium material merely for display and not mainly for instruction is as silly as to attempt to make butterflies more beautiful by arranging them in the form of a star; and to put into the water with an imprisoned living animal anything which misrepresents it to an ordinary observer is not only mischievous, but base.

These are high principles, and in an exposition aquarium as large as ours, repaired, finished, furnished, and stocked in three months of almost unexampled winter and one of stormy spring, it was not, of course, always as easy to live up to them as if one could have had the advantage of some years of leisurely preparation. But we did as well as we could, more conscious than anyone else could be of the distance between ideal and realization, and glad all along that we had so much for our visitors to look at that they rarely thought of the things which we could not get.

January 1, 1893, the Aquarium annex of the Fisheries Building was as cold as an ice-house, its tanks all unfinished, black caverns of asphalt dimly seen through dirty glass, most of them leaky (as we found when it became warm enough to permit us to let water into them) and the water-pipes burst by freezing all over the building—a discouraging wreck, much of which had finally to be taken down and replaced.

The principal things to be done with the least possible delay were to test the sufficiency of the aquarium tanks and to make such changes and repairs as this test should show the need of; to finish suitably the interior of these tanks with such naturalistic and decorative work as would make them a fit home for the various aquatic forms they were to contain; to get the earliest possible start of aquatic vegetation as a further naturalistic decoration; to repair the burst and broken water-pipes for the conveyance of water, salt and fresh, to the tanks and away again; to get the heating plant enlarged so that water might be admitted to the building without danger of freezing;* to provide a pool or inclosure for the reception of fishes as brought in, that suitable selection might be made of uninjured and vigorous specimens for the aquarium, and that a good stock might be kept in hand from which the aquarium tanks could be replenished as disease or accident should make this needful; to introduce filters for the salt and fresh water, neither of which had as yet been provided; to plan and manufacture apparatus for the warming of the water in spring and fall and for its cooling in midsummer; to complete and test the electric pumping outfit for the circulation of the salt water; to bring, nearly a thousand miles from the sea, a supply of salt water sufficient to fill aquaria of a capacity of 40,000 gallons, together with a pumping supply in the huge cisterns of the sea-water system; and, most difficult and responsible task of all, to accomplish the object for which all the rest was planned, namely, to assemble collections in extraordinary number and in the largest possible variety from the Great Lakes, from the rivers and smaller streams of the interior, from both oceans, and from the Gulf, such as should illustrate the aquatic fauna of the country properly and in a way to justify the large expenditures already made and and those still needed for the completion of the exhibit.

* The temperature in the aquarium annex fell at one time to 11° F. while the heaters were carrying all the steam allowed.

The weather of the winter and spring was an almost uninterrupted succession of storms, which embarrassed and delayed preparations in Chicago and practically broke up again and again our field operations on the Great Lakes and on the Illinois and Mississippi rivers; nevertheless, May 1, "opening day," the aquarium was in good working order throughout, with the interior decoration of the tanks completed; nearly all were stocked fairly well—some profusely—with a good variety of marine animals and fresh-water fishes; and the machinery of maintenance and further supply was thoroughly organized and at work on a scale to insure an abundance of material throughout the season. By June 1 we had probably the largest collection of fresh-water fishes in number and variety ever brought together in the world, and a marine exhibit which, considering the great distance from the sea, reflected the highest credit on the officers and men of the Commission whose energy and resources had brought it together.

Without entering into unprofitable detail of our experience, I have thought it desirable to give here such a description of our plant and equipment and of certain special features of our work as may be supposed to have a value for the guidance of others similarly engaged, together with such contributions to biological knowledge as we were able to make under the peculiarly disadvantageous circumstances surrounding us in the midst of the rush and turmoil of a great exposition season.

The Fisheries Building was erected and equipped by the Exposition Company substantially according to plans made by the architect, Henry Ives Cobb, the aquarian management having had nothing to do with plans or construction previous to January 1, 1893, at which date the aquarium annex was transferred to the control of the U. S. Commissioner of Fisheries, and by him placed in charge of the writer. This annex or wing, connected with the main building by an open corridor, had the form of a circle 131 feet inside diameter. The outer walls were comparatively low and the roof conical, the interior part of the cone being elevated above the outer part upon a low wall with many windows. The aquarium tanks were arranged in two concentric circles: an outer circle of smaller tanks with glass fronts within lighted by windows in the outer wall of the building and by heavy glass in the roof above; and an inner circle with both outer and inner faces glass and lighted only from the roof, the two being separated by a passageway 15 feet wide. This aisle was so shut in above by a vaulted ceiling that the only light admitted to it, except that from the general entrances to the building, reached the spectator through the glass fronts of the aquaria.

Between the outer circle of aquarium tanks and the wall of the annex was a narrow passage for the attendants, who were of course thus behind the scenes when at work. The inner tanks were reached by ladders going from this passage over the vaulted ceiling of the aisle above mentioned and thus also concealed from view. Above both sets of aquaria were panels of darkened glass (covered by us with heavy felt), some of which were hinged to permit the introduction of specimens to the tanks. The central portion of the room was occupied by a circular pool 26 feet across, separated from the inner circle of tanks by a corridor or aisle about 15 feet wide and lighted by windows in the vertical part of the roof.

The entire glass frontage of the aquaria amounted to 665 linear feet, approximately 3,000 square feet in all, the total capacity of the 50 tanks being 140,000 gallons, of which about 40,000, in 15 tanks, were devoted to the marine exhibit. The central pool contained about 6,000 gallons of fresh water additional. The tanks of the outer series were in two sizes, all rectangular in shape, the smaller (24 in number) with a frontage of 5½ feet and a width from before backwards of 3¾ feet at bottom and 5½ feet at top; the larger size (16 in number) of twice the above length, but of the same dimensions otherwise. The inner tanks were in three sizes, the 8 smallest with a frontage of 15 feet outside and 11½ inside, the next (a single tank) of double these dimensions, and the third (likewise a single tank) 56 feet long on the middle line, with glass frontage of 60 feet and 46 feet linear, on the outer and inner faces respectively. All the tanks of the inner circle were 8¾ feet from front to back.

The fresh water was derived from Lake Michigan through the general water supply of the park and passed through pressure filters* of a nominal capacity of about 10,000 gallons an hour, but sometimes worked by us at three times this rate. In order to secure the perfect clearness of water indispensable to a proper display of our material it was found necessary to introduce an alum tank into the circulation, provided with an automatic regulator by which a fixed proportion of alum in solution was mingled with the water before it passed through the filters. The flocculent precipitate thus formed by the union of the alum with the mineral matters of the lake water so entangled all minute suspended particles that they were taken out by the fine quartz sand of the filters, leaving the water beautifully clear and also chemically free from any surplus of alum. Provisions were likewise made for warming this water, when necessary, after it emerged from the filters, by passing it through a coil of brass tubing encased in a large piece of heavy iron pipe filled with steam from the boiler used in heating the building.

A receiving pool, in three divisions, was made in the lagoon by inclosing and subdividing an area along shore, adjacent to the aquarium, with a fence of wire netting fastened to heavy wooden posts. As the water level varied greatly with the direction of the wind, a seine with numerous floats was attached to the upper border of this fence. The extremely unfavorable character of the weather early in the season prevented the rapid accumulation of large quantities of specimens for which we had planned and prepared, and this pool was consequently but little used. But for this unforeseen and unavoidable delay we should have escaped many of the subsequent difficulties of aquarium maintenance. It was a part of our original plan to store our field fresh-water collections—especially those brought from considerable distances—in this pool, leaving them there until those injured in transit or diseased had either died or recovered, selecting then from the remainder, from time to time, what were needed for the aquaria. Pressure of time and a determination to be "ready May 1" usually compelled us to add the fresh material to the exhibit as fast as it came in.

The first installment of salt water—to the amount of 42,000 gallons—was transported from the sea at Beaufort, N. C., in seven tank cars loaned to the Commission by the Standard Oil Company, and hauled by the Chesapeake and Ohio Railroad free of charge. The salt water circulating system† consisted of an underground cistern 46¾ feet long, 18¾ feet wide, and 8½ feet deep, a pressure tank in the roof of the main Fisheries Building 30¼ feet in circumference and 5 feet deep, supply pipes of hard rubber leading from the latter tank to the aquaria, return pipes of the same

* Furnished, put in place, and maintained gratuitously by the O. H. Jewell Filter Company, of Chicago.

† A technical description of the circulating plant of the aquarium, prepared by Passed Assistant Engineer I. S. K. Reeves, chief engineer of the Commission, is appended to this article.

material conveying the water from the aquaria to the underground cistern, and hard-rubber electric pumps of a capacity of 3,000 gallons per hour, by which the water was lifted from the underground cistern to the tank in the roof. Between the aquaria and the cistern was inserted a sand and gravel filter, and between the roof tank and the aquaria a heating apparatus like that provided for the fresh water. This heater was used, however, chiefly as a cooler by passing a current of lake water through the inner coil. The pumps were in duplicate, only one being in service at a time. These and the rubber tubing connected with them were made to order by the Rubber Comb Company of Rochester, N. Y.

The fresh water entered the tanks by means of numerous jets, from which it escaped with sufficient force to carry the air well towards the bottom. We found it desirable, however, to maintain a more efficient bottom circulation by attaching rubber tubes to some of these jets. In the marine aquaria the salt water was similarly introduced to the tanks, but an additional aërating apparatus was provided in the form of an automatic air-pump working by water pressure obtained from one of the fresh-water supply pipes. From this pump air was distributed to all the salt-water tanks, at the bottom of which it escaped in the form of clouds of minute bubbles forced through plugs of basswood inserted in the sides of rubber tubes. This highly successful device for the subdivision of the air is the result of a series of experiments made by Mr. Harron, of the U. S. Fish Commission, under the instruction of the Commissioner.

The tanks were decorated internally with great skill and ingenuity by Mr. J. B. Mora, of Chicago. For the salt-water aquaria a calcareous tufa had been obtained, at a cost of about $30 a carload, at Toledo, Ohio, where large deposits of it are quarried for use in the manufacture of paper. It came in selected shapes admirably adapted to decorative work. As we could not foresee the kinds of marine animals which it would be possible to secure, no especial naturalistic effects were attempted in the decoration of the marine aquaria, but generalized grotto-like and other ornamental designs were worked out with charming result. This same material was used for a massive central rockwork in the pool, from the summit of which the water fell in cascades and trickling streams.

The interior finish of the fresh-water tanks was carefully planned in advance with reference to the favorite haunts and native surroundings of the principal classes of fishes which we might expect to obtain. Muddy river banks, bluffs, and islets of stratified rock, ponds with sunken logs, pebbly lake shores, margins of pools, submerged trees and stumps, the water-logged rubbish of an old boat landing, fallen brushwood and the like, and rocky beds of streams with mossy incrustations were all admirably reproduced, in the only manner practicable with the time at our disposal, in cement, sand, and gravel. For the purely ornamental fish, like golden ides, goldfish, and the more brilliant minnows, aquaria were decorated in a purely fantastic manner, with a view simply to heightening the artistic attractiveness of the collections.

Most of our internal decorations were originally designed in expectation of adding to them effects to be derived from aquatic vegetation appropriate to the habits and environment of the various kinds of fish. For the purpose of getting an earlier start of aquatic plants than could be had from the vicinity, collections were made throughout January and February at Eustis, Fla., and shipped to the aquarium early in March. This part of our preparations failed, however, in part because of the unseasonable weather which froze or severely chilled the plants in transit, and partly because of the long delay in the manufacture of the heating apparatus for the fresh-water circulation, which was, in fact, not ready for use until all need of it had long passed by. As the water of the lake was but a few degrees above freezing when our southern collections arrived, they could not be made to grow in place, and presently perished. Experiments were made by the gardener, engaged for this purpose, at starting these plants in water warmed by the direct introduction of steam, and also in the conservatories of the city parks, but all practically failed, and it is evident that the shock of the transfer and change of condition was too great. After the season opened at the North a new embarrassment arose, due to repeated attacks of fungous fish disease, with the germs of which we found the Lake Michigan water supply to be continuously loaded. As the only practical method of combating this disease required the frequent use of salt in the aquarium tanks our water plants perished almost as fast as they were introduced, and we were finally obliged to give up all attempt at plant decoration.

Our organization for fieldwork was completed by the assignment of cars and men for collections at Quincy on the Mississippi and at Meredosia on the Illinois; at Put-in Bay on Lake Erie; at Beaufort, N. C.; and, later, at Woods Holl, at Tampa Bay, Fla., and at Monterey, San Francisco, and Puget Sound on the Pacific coast. The Fish Commission stations at Leadville, Colo.; Neosho, Mo.; Northville, Mich.; Green Lake, Me., and the Central station at Washington, were also repeatedly laid under contribution during the season. A lot of magnificent specimens of bred trout was sent us from the New York Fish Commission station at Caledonia, N. Y., and large and valuable contributions of superb aquarium material were accumulated for us from time to time at Spirit Lake, Iowa, by Mr. T. J. Griggs, fish commissioner of Iowa. The three regular cars of the U.S. Commission were placed under the orders of Dr. S. P. Bartlett, at Quincy, and of Mr. J. J. Stranahan, at Put-in Bay, and a new car, intended for transporting marine material, was bought by the Commissioner and equipped with large tanks and an aërating apparatus.

Our special purpose in making our marine collections was somewhat different from that governing our fresh-water work. For the former we sought objects of popular interest; examples of well-known food-fishes (as the salmon, red snapper, sheepshead, and pompano); animals especially attractive because of their size, their extraordinary forms and actions, their beauty, or their peculiar habits and modes of life (sharks, sea-anemones, starfishes, hermit crabs, and remoras, for example); finally, the oddities and monsters (skates, flounders, toadfishes, burrfishes, sea-robins, and the like). We wanted, in short, the food-fishes, the beauties, and the wonders of the sea.

The fresh-water collections, on the other hand, were planned primarily to give to the uninstructed visitor a fair general idea of the fish fauna of our interior waters, not preferring any class or kind over another, but reproducing, as nearly as practicable under our conditions, a symmetrical picture of the fish life of the lakes, rivers, and smaller streams of the interior United States. A few specially brilliant exotic species were introduced to relieve the otherwise too somber effect of the fresh-water exhibit; and as an accessory object we undertook also to illustrate, to some extent, the results of scientific fish-culture, as carried on at the stations of the U. S. Fish Commission.

In the assignment of tanks the smaller ones were used as a rule to display species and varieties so grouped and labeled that the observer could distinguish kinds and learn their names; the larger ones to exhibit groups, either natural families or mere assemblages living together in the same waters. The 60-foot tank, for example, showed the fishes of the Mississippi River and its larger tributaries; the sunfish family were displayed in another 13 feet long; numerous examples of the minnow family and other smaller species were thrown together in still another aquarium of intermediate size.

The central pool was used for a time as a receiving tank in which cars of live fish were unloaded as they came, kept until adjusted to their new conditions, and then transferred to their proper aquaria. It usually contained, consequently, a miscellaneous assemblage of material from all sources, and was made the permanent home of several of our largest fresh-water specimens.

The pioneer inmates of the new aquarium, a lot of 6,000 young lake trout, yearlings and two-years old, came from the Northville station March 21, and remained for many weeks a principal ornament of our exhibit. Next followed a large load from Washington, mostly carp and ornamental fish. Then, April 10, another car came in, the first from the field, containing a thousand specimens, representing 26 river species.

Storms blew from every quarter, driving our crews out of the lake again and again, and floods arose until rivers were miles wide on our principal collecting-grounds. But what we could not do in one way and place we usually managed to do in some other, and by May 1, 11 carloads had arrived, large and small, 5 of them fresh-water collections, 4 of bred fish from the stations of the Commission, and 2 from the Atlantic on the Carolina coast. Thus, on "opening day," we had in our tanks numerous representatives of 60 species from rivers and lakes, and of 42 from the sea.

Field collections were continued throughout the summer, as required to maintain and improve the exhibit, and especially to make good our heavy losses from disease. Not less than 50 carloads of specimens were received from all sources between March 21 and October 9. Of these, 7 came from the Great Lakes; 5 from smaller lakes, mostly from Spirit Lake, Iowa; 15 from the Mississippi and Illinois Rivers, and 4 from smaller rivers and streams, including the grayling streams of northern Michigan—31 in all from fresh-water situations. To this number may be added 6 carloads of fresh-water species from the stations of the U. S. Fish Commission, and 1 from the New York Fish Commission station at Caledonia in that State. Twelve carloads came in from the sea, 5 of them from Woods Holl, 4 from the North Carolina coast, 2 from the Pacific (California and Washington), and 1 from the Gulf at Tampa Bay, Fla. The total number of species and well-known varieties represented in the aquarium during the season by living specimens was 208; 93 of these were marine and 115 were fresh-water forms; 102 of the latter and 54 of the former were fishes; the remaining 39 of the marine species were miscellaneous invertebrates.

The force in charge consisted of a director, whose duties were mainly administrative; two superintendents, one for the fresh-water aquaria and one for the marine; two attendants for the latter, both engaged the greater part of the time in policing the tanks, feeding, and otherwise caring for the fish, and, at intervals of a day, in emptying, washing, and repacking the sand and gravel filter. On the fresh-water side five attendants were required, their time being so divided that three were usually present at once. The care of the aquarium at night required the attendance always of one and sometimes of two of the above force. In the pump-room were three engineers, and the services of a fireman were needed when heat was wanted in the building. One additional employé collected minnows as food for species which could not be fed otherwise, attended to the reception and transfer of fresh collections, and made himself generally serviceable within and without the aquarium.

I have neither time nor inclination to enter into a systematic history of our operations during the season, but will only select from the items of our experience some of those which seem to me the most interesting or the most profitable for future guidance.

First, with reference to the planning and arrangement of the aquaria. Impressive and pleasing as is the general effect of the circular disposition of our tanks, I would not now plan a circular building like ours for an aquarium in which great crowds of visitors were to be received. Something is lost in the fact that few of the aquaria can be seen at once, but the lack of sufficient provision for a free movement of the air through the corridors is a much greater defect. The two double-doored entrances were distant from each other only a little over a fourth of the circumference of the building, and the radiating passages leading inward from them cut the circular corridors between the rows of tanks into two very unequal segments, one approximately 75 feet long and the other 190 feet. In this longer passageway the air was practically stagnant much of the time, and often so offensive with the emanations of the crowd that sensitive persons could not stay in it. A rectangular building with opposite entrances at ends and sides would have permitted a much freer movement of both air and people. Still better, perhaps, would have been a structure in the form of a Greek cross, with a low central dome and entrances at the ends of the arms.

My summer's experience fully convinces me that in the large fresh-water aquarium the deep glass-fronted tank should be in great measure replaced by shallow basins or pools or basin-like tanks borne on raised foundations, or with sunken walks between, and left freely open above to both air and light. These basins should not be set so low as to give a distorted view of the fish when looked down upon from above, nor so high that a person of average height might not readily see to the bottom while standing a little distance away. If the bottom were saucer-shaped, with shallow water at the edges, minnows and larger fish might well be kept together with charming effect, and suitable plant decorations could be introduced without obscuring unduly the view of the interior. Among my reasons for a preference of the open pool is the advantage thus gained in the inevitable struggle with parasitic fungi infesting fresh-water fish. As the salt-water species are free from this difficulty, there is no objection, so far as they are concerned, to the closed tank now in general use. It is clearly a great error, however, to plan any large aquarium without provision for small open tanks in which the smaller animal forms may be shown to good advantage, and especially those which may best be seen from above. This is as true of fresh-water animals as of ocean forms. Many of the oddest and most interesting aquatic creatures are too small to be commonly noticed, even if extremely abundant; but are large enough, nevertheless, to arouse great interest and repay careful observation if put in small, readily accessible tanks.

The comparative advantages of the open-pool system were continuously illustrated throughout the season by the history of our collections in the large central pool. In this basin, 2½ feet deep, with a surface area of 530 square feet and a bottom of white sand, trouble with fungous disease was at all times practically insignificant; while in the deep, narrow tanks adjacent constant and often unmanageable difficulty was experienced. This contrast is the more remarkable if we consider that the central pool was used as a receiving tank, and consequently often contained many specimens injured in transit. The shallow basin was also much more easily kept clean.

These conclusions are still further reinforced by the experience of the Illinois commissioners in a live-fish exhibit maintained in the Illinois State Building. Here still shallower pools with white enameled bottoms were used, supplied, as in our own central basin, by a dripping, splashing inflow of water falling from a considerable height. The miscellaneous collections in these pools were almost free from parasitic fungus attacks throughout the entire season.

The interior decoration of tanks of all descriptions with rock work and other naturalistic material is a matter of especial practical importance. These decorative materials should cover the interior surfaces, especially the backs and ends, but should not be so constructed as to occupy the interior of the tanks and thus obstruct a view of the contents. Especial care should be taken that no holes or crevices are left in which dead fish or other noxious objects may remain concealed. The best materials for naturalistic decoration are native rock, clean sand and gravel, and Portland cement. With proper cleaning down, repeated soaking, and thorough washing out, no contamination of the water need be feared, even with a closed circulation. Mud and clay, water-soaked wood, and the like, are of course inadmissible, and cement must be used for the imitation of these materials.

I need hardly add that in any well-constructed aquarium suitable storage and work rooms and offices of administration will be provided. It would, of course, be a great error in a permanent establisment to omit ample provision of laboratory rooms and appliances for systematic scientific study and experiment. These could be furnished at a slight addition to the first cost and could be maintained at a comparatively trifling expense. They would greatly increase the usefulness of any aquarium by making its resources available for the advancement of knowledge, thus enlisting the sympathy, aid, and support of scientific men and of the educated classes generally.

Our circulating apparatus for the salt water was, when supplemented and completed according to the plans of Engineer Reeves and the Commissioner, in every way satisfactory for summer maintenance, with the single exception of a lack of sufficient means for temperature control—a difficulty due to the character of the building and not to the circulating plant.* It is possible that a better plan of securing pressure might be devised than that of the use of the elevated tank. A closed underground cistern of air-tight construction, into which the water should be forced by the pump, depending upon air pressure within the cistern to send the water up to the aquarium

*The temperature of the salt water, beginning May 1 at 50°, reached 70° F.—regarded by us as the danger point for susceptible marine species—on June 19, but the second day afterwards fell off a degree. The 7th of July it came up to that point again, and remained between 70° and 74°, with only an occasional drop to 69½°, until August 12; 70° and 70½° were again repeatedly reached during the latter half of August, but the month closed with a temperature record of 67°. In September, 71½° was reached at the middle of the month, but the record fell to 61° and 62° for September 30. During October the thermometer readings varied from 67° on October 12 to 57° on the last day of the month, when the exposition closed. The highest temperature noted (74°) was reached July 25, with an average air temperature in the aquarium for the day (6 a. m. to 6 p. m.) of only 83°. These temperatures were reached notwithstanding the constant use of the cooler, the shading of the windows in the wall by cheese-cloth curtains, and the covering of the roof lights with an outside canvass screen.

The fresh-water record runs from May 1 to September 30, three daily observations being taken for the air and water. May 1 the lake water, as received in the aquarium tanks, stood without variation at 42° F., the air averaging 46°. The rise in temperature for May was gradual and steady, reaching 46° May 15, 50° on the 21st, and 55° on the 30th. It remained practically at this point until June 13, when it began to rise again, going somewhat irregularly to 65° on June 30. This rise continued to 70°, first reached July 11, and to our maximum record of 74°, made July 24, 31, and August 1. The fall from this highest point was gradual and very slow, the last observation (September 30) being 59°

tanks, has many features to recommend it for practical use. Steam, instead of electric pumps, would also have this especial advantage, that the power would be under the immediate control of the aquarium management, and not liable to possibly fatal interruptions through failure of connections, especially at night—an accident which we barely escaped several times.

The fresh-water system, it will be remembered, was constructed for a continuous inflow of lake water, which ran away again after passing through the tanks. By this system an enormous quantity of water was required, amounting in our aquarium, during the warmest weather, to no less than 40,000 gallons an hour. Even at this rate it took nearly three hours to renew the water in the tanks, and a much greater supply would have saved us some heavy losses consequent upon trouble with a protozoan parasite presently to be described. In a permanent aquarium the cost of so large a quantity of water and the expense of filtration would be an important item in the maintenance.

By this method, also, everything depends upon the continuous integrity of the filter. We found the lake water to be heavily infected all the seasons through with the germs of fungous fish-disease. These fungous spores were largely removed by our alum filter, even when worked at two or three times its normal capacity; but, on the other hand, even a few hours disability of the filter not only resulted in an offensive clouding of the water, but was invariably followed by an outbreak of fungous disease all along the line of our tanks. It has consequently seemed to me possible that a closed circulation like that on the salt-water side might have given us a more perfect command of the aquarium and its contents, and possibly at even less expense than was involved in the system we used. If it had proven possible, under our conditions, to establish water plants generally in our tanks, this would, of course, have assisted in aëration, and a much smaller flow of water would have sufficed. It would have been necessary, however, even with "balanced" aquaria, to keep up a considerable movement of water through tanks carrying as heavy loads as ours, especially at night, when oxygen comes off slowly or scarcely at all from water plants, and fishes are consequently more liable to death from suffocation. For the *Salmonidæ*, especially in summer, a rapid and abundant flow is necessary; and for fish affected with the trout parasite, presently to be described, the water should run through the tanks in torrents day and night.

The great success of the aquarium season was the transportation and maintenance of our excellent collection of marine animals in their normal state of health and comfort. Ocean forms were never before carried alive over distances approaching those from Chicago to Florida and the Pacific coast, and, although many specimens fell by the way, the ratio of the lost to those delivered in good condition rapidly diminished with the experience of the car captains and their crews. The most successful trip of the summer, in fact, was that made by Capt. Lamson with a small load from Puget Sound.

The original supply of sea water was gradually increased by additional amounts brought in by the cars as they came with their loads, and by pouring into the filter from time to time a few hundred gallons of a simple solution of Turk's Island salt. The fixed density maintained was 24° by scale. *

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* The total amount of salt water received from the sea was approximately 50,000 gallons. To this 8,820 gallons of salt solution were added from May 3 to September 21, the largest amount at any one time being 1,080 gallons. Five hundred gallons of fresh water were used from October 1 to 9 to make good losses by evaporation and to maintain the proper density.

Fed with chopped clams and minced liver and beef, most of our specimens ate freely, became hearty and fat, healed their bruises and grew new tails when injured, and several species laid their eggs or reared their young as if still in their native haunts.* The smaller Atlantic sea-anemones only (*Metridium marginatum*) slowly dwindled with the advance of the season, not dying, but diminishing in size to a third or a fourth their original proportions. In the large, deep tank, which was the only one available for them, they could only be fed by mixing minced meat with the water, and this could not be supplied them in sufficient quantity without fouling the water to an injurious extent.

It was a great surprise to all concerned to find that a collection of marine animals in large variety and of the most interesting character could be maintained on the shore of Lake Michigan nearly a thousand miles from the seas, as easily and almost as cheaply as at Woods Holl, on the Atlantic coast—far more easily, in fact, than could a similar collection of the animals of the lake itself; yet this was the common and emphatic judgment of the whole aquarium force. Losses were generally heavy for a few days after the arrival of a consignment from the coast, but when those badly bruised and greatly weakened had died, the remainder usually lived surprisingly well. In the middle of the season, for example, during the three weeks from July 18 to August 8, only thirteen specimens died of the several hundreds in our salt-water collections at the time, *viz:* a sea-robin, six sheepshead, a small skate, a tautog, a flounder, a filefish, and two Pacific anemones; and a week of this period passed with the loss of only a single fish.

In this connection it should be remembered that the end toward which we were working, and the forced and hurried character of our operations, made it impossible for us to experiment with the various species coming to our nets, or to select to any considerable extent those known to be hardy in the aquarium. We were compelled to take our chances with everything not notoriously unfit for even temporary maintenance. With time, experience, and opportunity for methodical procedure, a marine aquarium collection could be gradually brought together in the interior which would far surpass in numbers, variety, and cheapness of maintenance that which we were able to hurry in pell-mell for a brief exposition season.

It seems not especially remarkable that the salt-water aquarium should prove, in the present state of our knowledge, much easier of maintenance than the fresh-water, since it has heretofore received by far the greater share of attention. Most of the great aquaria of the world have been either on the coast or in easy reach of the sea, and have contained marine animals chiefly, since these are, on the whole, much more varied, curious and beautiful, and also of greater scientific interest than those of fresh-

* Two viviparous perch (*Micrometrus aggregatus*) of the Pacific coast, brought from Monterey June 20, gave birth July 9 to 17 young, which grew rapidly and were alive at the close of the exposition. A toadfish (*Batrachus tau*) spawned July 9, but the eggs did not hatch, probably for lack of fertilization. Mummichogs (*Fundulus heteroclitus*) and stickle-backs (*Apeltes quadracus*) also spawned in July, and a number of young hatched from their eggs were alive November 1. August 27, a skate's egg containing a young skate, still alive, was found in an aquarium tank with adult female skates. In September 5 whelks (*Sycotypus canaliculatus*) spawned, each requiring from 2 to 5 days to extrude its long string of large, tough egg-cases. Young anemones (*Metridium marginatum*), hatched after the arrival of the lot from Wood's Holl, were abundant in the anemone tank all summer, covering the rocks in hundreds. The fresh-water species spawning were the common sucker (May 4 to 20), golden ide (May), goldfish (June 16), pike perch (April 1 to 30), yellow perch (April 29 to May 9), rainbow trout (May 30), Von Behr trout (November 5), Mississippi catfish and blue sunfish (*Lepomis pallidus*).

water habit. Our own fresh-water collection, which usually contained over a hundred species, represented by two or three thousand specimens, was probably the largest ever maintained, and the previous experience of our aquarium superintendents having been chiefly with salt-water forms, the difficulties impending were not fully appreciated in advance. Our determination to be visibly ready May 1* forced us to do some things which would not have been admissible under other circumstances.

The great obstacle to the successful and economic maintenance of a fresh-water aquarium is the liability of many species to parasitic disease, either that due to saprolegniaceous fungi (with which we were already very well acquainted) † or to that caused by a protozoan parasite not hitherto reported for this country, and but little known in the Old World.

Fungous parasitism began with especial virulence very early in the season—a fact to be attributed partly to the enforced hurry of our preparations, which made it impracticable to assort or quarantine our specimens as they came in, and partly to a delay in placing the filters, on which account we were obliged to keep our material for some weeks in unfiltered water.

The plant parasite causing this disease was carefully investigated at my instance by Mr. G. P. Clinton, assistant in the botanical department of the University of Illinois.‡ Only one fungous form was found attacking the fish—probably the well-known *Saprolegnia ferax.* It was not, at the time of his visit, in a stage of development favorable to the precise determination of the species, and there is consequently some uncertainty with respect to its specific name. There is no doubt, however, that it belongs to the genus *Saprolegnia.* It appears in patches, large or small, either in the form of a grayish or whitish film (sometimes half fluid and sometimes resembling a thickish felt), or as a growth of delicate threads an eighth to half an inch in length, springing from the surface of the affected fish either in tufts or irregularly distributed. It takes its origin in every case in microscopic spores each provided with minute swimming hairs (flagella) by which they move freely through the water. These spores, matured by myriads in growing fungous threads, settle on excrement or dead animal matter in the tank, and may grow and multiply there as freely as on the fish.

Dead flies furnish an excellent nidus for the cultivation of this fungus, and the presence of the spores in the water may be very easily determined by simply dropping a dead fly into a bottle filled with the water to be tested. In this way we demonstrated the general infection of all the waters in and out of the aquarium. Every

* All the tanks but two were occupied on "opening day," many of them to the limit of their capacity.

† In our efforts to control this fish-parasite, and in matters of aquarium management generally, I enjoyed the great advantage of the aid and advice of Dr. T. H. Bean, representative of the U. S. Fish Commission on the Government Board of Control. His long connection with the Commission in capacities which made him thoroughly acquainted with its aquarium methods, and his own experience while in charge of the aquarium exhibit of the Commission at the Cincinnati Exposition in 1888, made him an invaluable adviser in every emergency, and much of our success was due to his unfailing kindness and to his warm personal and official interest in aquarium affairs.

I take this occasion also to express my obligations to Mr. W. de C. Ravenel, chief special agent of the Commission, in general charge of its exhibit, for much valuable assistance and advice given in his capacity of administrative officer.

The aquarium was in immediate charge of Messrs. L. G. Harron and Alexander Jones, without whose expert skill and faithful service success would have been utterly impossible.

‡ Mr. Clinton's report is presented as an appendix to this paper.

experiment tried with water from the lake, from the lagoon, and from the central pool in the aquarium building, and a large proportion also of those tried with vials of water from the aquaria and from the supply pipes inside, yielded cultures of this *Saprolegnia.*

The principal safeguards and remedial measures against this fungous disease are (1) the original discrimination of susceptible from hardy species of fish, that each may receive its appropriate care and treatment; (2) the utmost care in the capture, handling, and transportation of fish intended for the aquarium, that they may arrive without bruises or loss of scales, and (even more important than this) without unnecessary weakening of their vitality; (3) the use of a large shallow pool as a temporary receptacle for new arrivals, where they may be kept under surveillance and under the most favorable conditions until any tendency to fungous disease may have declared itself; (4) the rejection, or at least the separate maintenance, of all injured specimens until death or complete recovery; (5) the maintenance of a hospital tank to which all individuals may be immediately removed for special care and treatment on the first appearance of fungous parasitism in any tank; (6) the use of open shallow tanks (in place of deep aquaria) with light-colored bottoms, freely exposed to sun and air, and the maintenance of a free and rapid flow of water through them; (7) the association in the same tank of fishes of different habit, but especially the distribution everywhere of suckers, buffalo, or other bottom feeders, which continually police the tanks by working over the bottom for particles of food; (8) the most scrupulous cleanliness in the management of the tanks, and care not to introduce a superabundance of food; (9) the thorough filtering of the water, preferably with the aid of alum so added that there shall be no excess remaining; (10) the prompt and thorough disinfection, by washing and soaking with a solution of carbolic acid, of every tank in which the fungus appears; (11) the use of a solution of salt or carbolic acid as a remedy for moderate cases of disease; and finally (12) an abundant food supply and expert care generally in the maintenance of the health and vigor of the fish. For this last purpose I am inclined to suggest the establishment of an exercise pool for the larger and more active species, especially the game fishes, which might thus be released occasionally from their cramped quarters in the aquarium and permitted to stretch their muscles in a good straight swim.

I hardly need say that in handling diseased specimens special nets should be used, which should then be considered as infected and should never be allowed to touch healthy fish or be put into the water with them until soaked in some disinfectant solution. I may add that the source of the water supply may easily have an important bearing on the liability to fungous disease. If derived from clean springs or wells, or perhaps even from clear running streams, the water will contain few or none of the spores of *Saprolegnia,* since this fungus grows normally and most abundantly on decaying organic substances. It would further seem a good general practice in establishing a fresh-water aquarium, to select only young or half-grown specimens as representatives of the more susceptible species, since these commonly resist the fungus far better than adults, and might be expected to become in time much better adapted to aquarium life.

Although there is a general impression that this fungous disease will not attack healthy fishes unless offered a starting-point in some surface injury, it is now certain that this is not true. The general current of our observation during the season leads to this conclusion, which has been amply confirmed by a special experiment arranged to test the possibility of protecting the more susceptible kinds by the nicest aquarium management. October 1 an expert botanist and bacteriologist, already mentioned, Mr. G. P. Clinton, of the University of Illinois, thoroughly disinfected, with a strong carbolic acid solution, an aquarium tank completely isolated with respect to water supply and overflow. In this tank was placed a collection of small-mouthed black bass which had been brought to the aquarium especially for this experiment. They had been taken in the seine, landed with the utmost care, borne in the hands to avoid surface injury, transported in an abundance of water, and were when put in the tank in perfect condition in every way. They received the best of care and treatment, but within two weeks the *Saprolegnia* appeared upon them, and before another week the whole lot was practically gone with fungous disease. It should be said that the aquarium filter was working badly at the time, and that more than the usual number of spores doubtless entered this tank.

As the most general result of our season's work and observations with respect to the relative susceptibility of the various species of fishes handled by us during the summer, it appeared that native vigor of constitution and adaptation to a life of confinement were the most important elements of a capacity to resist fungous attack. The spores sprout abundantly in the surface slime of fishes of every description, but their filaments seem to penetrate the skin of certain species only, and of many of these only under special conditions. The most susceptible fishes on the whole were the active game fishes, whose imprisonment in our small aquarium tanks seemed to work too great a change in their habit of life to keep them in perfect health. Among these it was not an uncommon thing for a considerable group to remain in a tank by themselves for a long time without the appearance of any fungous disease, but later to go almost all at once, as if they had finally succumbed through a gradual weakening of their vitality under their prison life. On the other hand, many kinds susceptible at first, and even seriously attacked, would rally presently, after they had become accustomed to confinement, and especially after they had begun to feed.

Among the most susceptible fishes were the large-mouthed black bass, crappies (both species, but especially the paler), the white bass, the yellow bass, the pike-perch, the yellow perch, and the tooth herring. The sand pike or so-called jack salmon was scarcely less liable to the disease, and the warmouth sunfish was also frequently attacked with fatal effect. The lake trout and grayling were occasionally killed by this fungus; the common pike became liable to it if left long in confinement; and the common species of redhorse, and the stone-roller, though lasting frequently for weeks, would eventually drop off one by one. The common sucker and the buffalo were rarely infested after they had begun to eat. The forked-tail cat, the mud cat, the common bullheads, and the marbled cat, rarely suffered at all; on the other hand, the yellow catfish (*Ameiurus natalis*) was often severely attacked. The sheepshead or white perch appeared usually somewhat delicate; but three specimens, among the earliest of our fishes to arrive, lived the whole season through. The spoonbill (*Polyodon*)—never before kept in an aquarium for any length of time—lived with us for months with an occasional appearance of saprolegniaceous fungus on bruised surfaces, especially at the tip of the snout, but perished, if at all, from lack of its native food, which is of a character not to be supplied to it in our tanks. Rock bass, trout, bream, and the sunfish species generally, except those already mentioned, were not often infested, although the bream and other sunfishes were likely to go one at a time, as they weakened individually. The European carp and the common ornamental fishes (golden ide, goldfish, and tench), thoroughly accustomed as they are to aquarium life, were scarcely affected at all; and the dogfish, the gars, the sturgeons, the striped sucker, the native species of carp, the burbot, the eel, and the lamprey were also practically free from disease. Whitefish, although living but a short time in the aquarium, were not particularly liable to the fungous disease, but seemingly died because they would not eat.

April 28, eighty-seven young catfish (*Ameiurus albidus*) about 6 inches long, just received from the Potomac River, were placed in an aquarium together. Their interesting habit of massing in the center of the tank, each one swimming slowly back and forth and in and out through the school, attracted common attention to them. About six weeks later it was noticed, however, that their habit had changed completely, and that they now scattered everywhere, swimming restlessly about day and night, as if eager to escape. At this time it was also observed that the skin of these fish was covered with minute white specks, that they had ceased to feed, and were beginning to die. The usual aquarium treatment for fungous disease was tried without special result, and as other species near them in the aquarium had become similarly affected, I began, July 10, a preliminary microscopic and experimental study of their disease. The minute pimple-like specks on the skin, on the gills, and within the mouth were found to contain large, spherical, densely ciliate protozoa. These were contained in little cavities in the epidermal layer of the skin or mucous membrane, within which they kept up an incessant rolling motion. If freed from their confinement they swam about rapidly through the water, where they could be readily seen with the naked eye.

I soon ascertained that this parasite belonged to the genus *Ichthyophthirius* of Fouquet,* first described in Europe in 1869, and recorded there as an aquarium parasite especially destructive to young trout, but infesting a number of other species also. As the practical problem pressed upon us much more urgently than the scientific one, we began without delay a series of experiments with vinegar, salt water, copperas, carbolic acid, and other like substances, hoping to find some disinfectant solution in which the infested fish might be dipped with the effect of killing the parasite without injuring the fish. Time failing for the active and continuous work which the subject demanded, I had the good fortune to secure the assistance of Dr. Charles W. Stiles, of the Department of Agriculture, who was at the Exposition at the time. By courtesy of Hon. J. Sterling Morton, Secretary of the Department of Agriculture, Dr. Stiles was given leave of absence, and July 17 entered on a systematic experimental investigation of the subject. The report which he has filed for publication with this paper makes unnecessary any further account of the matter here.

I will only add that no disinfectant substances were found practically useful. Salt was the only one even recommended to us as the result of Dr. Stiles's experiments, and if this were employed to the extent necessary to destroy the parasite, it commonly affected the fish more injuriously than did the parasite itself.

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* See *Infusionsthiere als Hautparasiten bei Süsswasserfischen*, by F. Hilgendorf and A. Paulicki, (Centralbl. f. d. med. Wissensch. 1869, p. 33); *Note sur une espèce d'infusoires, parasites des poissons d'eau douce*, by D. Fouquet (Arch. zool. exper., t. v, 1876, p. 159); *Chromatophagus parasiticus n. g. et n. sp. Ein Beitrag zur Parasitenlehre*, by C. Kerbert (Nederl. Tijdschr. v. d. Dierk. Jahrg., v., 1884, p. 44); "Manual of Infusoria," p. 530, by W. S. Kent; Bronn's "Thier-Reichs" Bd. I, III. Abth., p. 1678; and *Ein infusorieller Hauptparasit bei Süsswasserfischen*, by O. Zacharias (Biol. Cent. 1893, p. 23).

The diseased fish could not eat, but rejected their food as if their mouths were sore, and their respiration was seriously affected by the inflammation of the mucous membrane of the gills. These difficulties, added to a general irritation of the skin, shown by the restlessness of the fish and by their disposition to scratch themselves in the sand, seem quite sufficient to account for our heavy losses among infested fish. The trout exhibit was very nearly destroyed for a time, and several other species were almost equally infested, but with quite various effect. The season's experience confirmed the conclusions of Kerbert that this is a hot-weather parasite, since it disappeared almost entirely from the aquarium during the month of September, as the temperature of the water fell off. It is thus very likely to affect most injuriously species which are most sensitive to the heat. The thickness of the skin seemed also to modify greatly the effects of an attack; and this is perhaps the reason why young fish are much more likely to succumb than old. Young catfish died like sheep with the murrain,* but adults of the same species would become gray with pimples without apparent suffering, and presently become clear again. Wild brook trout, brought in from the streams, proved much more hardy under this disease than tame-bred specimens, but all recovered as the weather cooled.

We have no reason to suppose that this parasite is common under natural conditions, and do not know, in fact, that it was brought into the aquarium more than once. It would seem, therefore, that its ravages might be held in check by a prompt recognition of it on its first appearance, and the complete isolation, or perhaps the immediate destruction, of infested fish. Certainly nothing should be allowed to go into an uninfested tank which has been in any sort of contact with an infested one. The best remedial measure known to us is a constant and very abundant flow of the clearest water obtainable. This seems not only to check the development of the parasite, but also sweeps off those which escape from the tissues of the infested fish previous to reproduction, and so reduces the probability of repeated infection.

If I were again to experiment with remedies for this disease, I would construct a hospital tank with hard bottom and smooth vertical sides, and with a second bottom, say, 6 inches above the other, made of wire netting with meshes just small enough to prevent the passage of fish. In this tank I would put salt so freely as to keep a layer of dense salt water in the bottom of the tank the greater part of the time, but not so freely as to render the water above the screen injurious to fresh-water fish. As the parasite leaves the fish and sinks to the bottom, losing its power of locomotion before dividing to give origin to young, and as when naked it is very readily killed by salt, I should thus expect to prevent its multiplication in the tank, and should hope that the fish infested might presently clear themselves spontaneously. An occasional dip of the fish in a salt-water bath would probably be an aid to recovery.

From the foregoing it will be seen that the greatest present problems of aquarium management are those connected with the maintenance in confinement of fresh-water fish. I have only to hope that this frank statement of my experience with the exposition aquarium of the U. S. Fish Commission may contribute to the solution of these problems, and help to make more easily possible to the American public a real knowledge of the aquatic life of this country.

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*One hundred and fourteen young spotted catfish, 5 or 6 inches long, were taken out of a single tank July 28, dead over night with this disease.