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Feasibility of introducing coldwater fish into Lake Sharpe, South Dakota

John Harris Grover

Iowa State University

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FEASIBILITY OF INTRODUCING COLDWATER FISH INTO LAKE SHARPE, SOUTH DAKOTA.

Iowa State University, Ph.D., 1969
Zoology

University Microfilms, Inc., Ann Arbor, Michigan
FEASIBILITY OF INTRODUCING COLDWATER FISH
INTO LAKE SHARPE, SOUTH DAKOTA

by

John Harris Grover

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
DOCTOR OF PHILOSOPHY

Major Subject: Zoology

Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

Head of Major Department

Signature was redacted for privacy.

Dean of Graduate College

Iowa State University
Ames, Iowa
1969
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Lake Sharpe, the newest main stem Missouri River reservoir, was evaluated for possible introduction of coldwater fish species. Data have been collected on the reservoir from 1966 to 1968. Summer water temperatures reached a minimum of 19°C. Dissolved oxygen levels were only once observed below 6.8 mg/l. Specific conductance had a mean value of 760 micro ohms/cm. Secchi disk depths of 2 to 5 m were common in Oahe tailwaters and the lower reservoir. Water level was stable in the main reservoir but usually fluctuated 2 m or more daily in Oahe tailwaters. Tributaries had intermittent flow and the Bad River, especially, has brought in considerable silt during peak discharges. Mud covered most of the reservoir bottom except in the tailwaters where sand, bank gravel and shale were more prevalent. Forty-two fish species are listed for Lake Sharpe. Gizzard shad, Dorosoma cepedianum, and yellow perch, Perca flavescens, composed 85 percent of the young of the year fish in 1968. Walleye, Stizostedion vitreum, were the most abundant adult fish in gill net catches in 1968. Benthic invertebrates, consisting of 91 percent Chironomid larvae by number, were most numerous in shallow areas. Standing crop was estimated at 1.15 g wet weight/m². Zooplankton mean standing crop was estimated at 3.6 kg dry weight/ha. Scattered populations of higher aquatic plants were noted.

Literature on temperature limits and other requirements for nine coldwater fish species was reviewed. The fish considered were coho salmon, Oncorhynchus kisutch; kokanee salmon, Oncorhynchus nerka, cutthroat trout, Salmo clarki; rainbow trout, Salmo gairdneri; landlocked salmon, Salmo
salar; brown trout, *Salmo trutta*; brook trout, *Salvelinus fontinalis*; lake trout, *Salvelinus namaycush*; and the hybrid splake, *Salvelinus fontinalis* X *S. namaycush*. It was concluded that temperature conditions in Lake Sharpe would favor the more temperature tolerant types like rainbow trout, brown trout and coho salmon. Salmonids would have to compete with existing fish populations for food and space, an ability that is usually lacking in salmonids. Predation by other fish, particularly northern pike, can be expected to take a heavy toll of any salmonid stocking. Stocking of larger fish would reduce predation by most species. Successful reproduction of salmonid fish in Lake Sharpe is doubtful because of the lack of suitable spawning sites and anticipated predation on young fish. Stocking of salmonid fish into Lake Sharpe is not recommended. If stocking is attempted, a put-and-take program of stocking rainbow trout offers the best chance for creating a coldwater sport fishery.
INTRODUCTION

The Missouri River forms the upper part of the world's longest river system. Once considered the "Big Muddy", the Missouri River has undergone drastic changes in recent years with the creation of huge reservoirs along its course. The newest of these reservoirs is Lake Sharpe, located in central South Dakota. Preliminary studies on Lake Sharpe indicated that it might be suitable as a trout or coldwater-fish lake. This investigation was initiated in 1967 to explore such a possibility.

To answer the question of the feasibility of introducing coldwater fish into Lake Sharpe, two objectives were set. One was to obtain an adequate description of conditions existing in the reservoir including information about temperature, dissolved oxygen, available food, water flow, bottom types and competitors. The second objective was to review the known information about the ecological requirements of desirable coldwater fish species. Information such as temperature tolerances, oxygen requirements, food demands, reproductive needs and competitive tolerances has been sought.

I was employed by North Central Reservoir Investigations (NCRI), U.S. Fish and Wildlife Service from June 1967 through August 1968 to assist in their Lake Sharpe investigations and to collect supplementary information for use in evaluating the reservoir for coldwater fish introductions. When this study was initiated, NCRI was collecting information about water temperature, dissolved oxygen, plankton, turbidity, light transmission and fish populations. While employed I helped with this on-going work and added sampling of benthic invertebrates, bottom material
and water movement. Methods and results of these investigations that bear on the feasibility of introducing coldwater species are presented in this thesis. A comprehensive limnological report on Lake Sharpe is being prepared by NCRI.

The six main stem reservoirs on the Missouri River were authorized by Congress in the Flood Control Act of 1944 as part of what has been known as the Pick-Sloan plan. The main purposes of the reservoirs are flood control, generation of hydroelectric power, control of water for navigation, recreation and water storage. The U.S. Army Corps of Engineers constructed and maintains the dams, regulates the flow through the system and maintains most of the recreational facilities along the shores. Fish and wildlife management is the responsibility of the states, but the U.S. Fish and Wildlife Service is conducting research to assist in such management.

Lake Sharpe is formed by Big Bend Dam near Fort Thompson, South Dakota, and extends 143 km (89 miles) along the course of the old river to the tailwaters of Oahe Dam near Pierre, South Dakota (Figure 1). The reservoir started filling in December 1963 and reached stable operating level by December 1966. The lake has a surface area of 22,582 ha (55,800 acres) and a maximum depth of 24 m (78 ft). Average width is 1.6 km (1 mile). Storage capacity (maximum pool) is $2.34 \times 10^9 \text{ m}^3$ (1.9 million acre feet). Average discharge from Oahe Dam in the year from June 1, 1967 to June 1, 1968 was $652 \text{ m}^3/\text{sec}$. At this rate it would take about 41 days to replace the water in the reservoir provided there was a complete exchange.
Figure 1. Map of Missouri River and main stem reservoirs in North and South Dakota.
LAKE SHARPE DESCRIPTION

Temperature

Temperature measurements were made with thermometers, thermisters and a bathythermograph. Thermal patterns of the main reservoir water mass for the year from November 1967 to October 1968 are depicted in Figure 2. Temperatures below the ice near Big Bend Dam in January and February 1968 were a homogeneous 0.5 to 1.0 C surface to bottom. Summer temperatures of 22 to 25 C were common near the shore and in shallow protected areas in 1967 and 1968.

According to powerhouse records, maximum temperature of water entering Lake Sharpe through Oahe Dam was 20 C in both 1967 and 1968. Maximum temperature of water leaving Lake Sharpe through Big Bend Dam was 22.2 C in 1967 and 23.3 C in 1968. All peak temperatures were reached in August. Water leaving Lake Sharpe in the summers of 1967 and 1968 was 1 to 4 C warmer than water entering (Figure 3).

Dissolved Oxygen

Since May 1966, monthly oxygen readings have been taken by NCRI at seven hydrographic stations (Figure 8) along the reservoir. Water samples for oxygen analysis were obtained with a Van Dorn water bottle and determinations were made using corrected readings from a Precision Scientific Co. galvanic cell oxygen analyser. Samples were taken from 1 m below the surface, 1 m above the bottom and, at deeper stations, from mid-depth.
Figure 2. Horizontal temperature profiles (°C) in Lake Sharpe, South Dakota, on varying dates from November 1967 to October 1968
FIGURE 2 (CONT.)
FIGURE 2 (CONT.)
FIGURE 2 (CONT.)
Figure 3. Tailwater temperature below Oahe and Big Bend Dams on the Missouri River in South Dakota, June 1967 to August 1968
The water entering the reservoir had sufficiently mixed with air to become saturated with oxygen. Oxygen determinations for the tailwaters varied from 8.6 to 13.7 mg/l, with the higher readings at lower temperatures. The data showed little reduction in oxygen content as the water passed through the system. The lowest oxygen reading of 4.4 mg/l was taken from the deepest part of the reservoir near Big Bend Dam on July 22, 1966. No other determination was less than 6.8 mg/l.

Conductivity

Conductivity, reported as specific conductance, was measured with a Solu Bridge manufactured by Industrial Instruments, Inc. Values ranged from 650 to 900 with a mean of 760 micro mhos/cm (Figure 4). Oahe tailwaters had a mean of 746 while means at the downstream stations ranged from 760 to 764 micro ohms/cm. Samples from the surface and near the bottom had essentially the same specific conductance.

Light Penetration

Light penetration was measured with a standard black and white 20-cm diameter Secchi disk. Related measurements on water clarity were made with a transmissometer (Model 410, Hydro Products Div., Oceanographic Engineering Corp.) and a turbidimeter (Model 1860, Hach Chemical Co.).

Light transmission readings were often taken at the same time as Secchi disk readings (Figure 5). The relationship of 306 paired observations, fitted by least squares regression, had the formula:

\[
\log \text{Secchi depth} = 0.0116 \times (\% \text{ transmission}) - 0.7004
\]
Figure 4. Mean and range in specific conductance of water samples from Lake Sharpe, South Dakota, 1966 to 1968
Figure 5. Relationship of Secchi disk depths to light transmission at 1 m as determined by 306 paired readings from Lake Sharpe, South Dakota, in 1967 and 1968
Secchi depth was in meters and percent light transmission was at 1 m depth. The logarithmic transformation was used to produce a straight line. The two variables had a correlation (r) of 0.93.

Water entering Lake Sharpe through Oahe Dam is relatively clear. Secchi disk readings of 3 to 5 m and light transmissions of 90 to 100 percent were common in the tailwaters. Tailwater turbidities had a range of 1.5 to 5.2 Jackson Turbidity Units (JTU), with a mean of 2.7 JTU.

As water moved away from Oahe Dam it became less clear. Current and wind action undoubtedly mixed mud into the water and at times considerable silt was brought in by the Bad River. When the Bad River was running high, water just below its mouth had enough silt to give Secchi values of less than 0.2 m, light transmissions of 0 percent and turbidities great enough to cause "blinding" in the turbidimeter (suggesting values over 1,000 JTU).

Water clarity increased again further downstream as the reservoir widened and deepened. Secchi readings of 2 to 5 m were common at West Bend and near Big Bend Dam and light transmission values were correspondingly high. Average surface turbidity readings during the open season of 1967 and 1968 were 19 JTU at Medicine Knoll Creek, 15.3 JTU at Chapelle Creek, 7.5 JTU at Joe Creek, 5.6 JTU at West Bend and 4.4 JTU near Big Bend Dam.

Current

Current was measured by a Price-type current meter and with modified sea bed drifters. The U.S. Geological Survey has also measured current and flow at the Pierre highway bridge with a Price-type current meter and
their results have been made available. In the lower reservoir currents were measured through the ice.

The current meter used was only accurate down to 0.17 m/sec. Current velocity below Joe Creek (69 km upstream from Big Bend Dam) was less than 0.17 m/sec. Readings at Joe Creek in the main channel were 0.2 m/sec.

Sea bed drifters were used to determine surface currents. The drifters were weighted to make them just heavy enough to sink and suspended by a 1 m line to a cork float (Harvey and Gould, 1966). The lines were attached to the wide end of the drifters. The drifters were released on windless days and recovered after a known time interval, usually 0.5 to 2 hours. Rate of travel was determined by dividing the straight line distance from release to recovery site by time of travel. Usually a straight line series of drifters was set out perpendicular to shore. The pattern of movement reflected the different rates of flow across the reservoir.

Releases in the tailwaters region, at Chapelle Creek and at West Bend indicated that current was swiftest in the old river channel which was the deepest area. Slowest flow was always near the shores. The fastest drifters moved 0.13 m/sec at West Bend and 0.44 m/sec at Chapelle Creek which are 42 and 113 km above Big Bend Dam, respectively. In Oahe tailwaters the drifters moved 0.91 m/sec during a slightly above average discharge of 906 m³/sec. Drifters did not move in a half hour in mid Hippie Lake.

Personnel of the U.S. Geological Survey made readings at the Pierre
highway bridge on September 18, 1968, when the flow was at a maximum since closure of Oahe Dam. They reported a flow of 1929 m$^3$/sec with a mean velocity of 1.07 m/sec. The place where the bridge crosses the river probably represents an area with near maximum velocity for Lake Sharpe.

Water Level

The general policy of the Corps of Engineers has been to maintain a year-round stable water level on Lake Sharpe. Records show that water level in the main reservoir has seldom varied more than 0.3 m from the set figure of 433.1 m above sea level. However, there has been considerable fluctuation of water level in the tailwaters of Oahe Dam because of varying discharge rates. Daily fluctuations of 2 m or more have been common just below the dam although these fluctuations have been reduced to about 0.7 m by the time the water has passed 20 km downstream to the gauge on Farm Island. Discharge pattern has been quite variable (Figure 6) though it has usually followed power demand which has been lowest on weekends and holidays and peaks during the noon and supper hours. When there has been no discharge from Oahe Dam, water level in the tailwaters has dropped to the same as the main reservoir leaving about 2 m water in the main channel below the dam but exposing adjacent shore and shallow areas. High discharges have brought water levels up over 3 m from the base level in the tailwaters.
Figure 6. Daily mean and extremes of discharge from Oahe Dam, South Dakota, March 1968
Tributaries

No continuously flowing tributary enters the Lake Sharpe portion of the Missouri River. Streams entering Lake Sharpe discharge water during spring runoffs and after heavy rains but otherwise have little or no flow.

The largest tributary is the Bad River which enters Lake Sharpe at Fort Pierre. Mean discharge of the Bad River since gauging began in 1928 has been 4.6 m$^3$/sec. The recorded peak discharge of 1240 m$^3$/sec was reached on June 18, 1967. Flow has dropped to zero for long periods in each year since records have been kept (U.S. Geological Survey).

Bottom Types

Bottom composition was determined concurrently with benthos sampling. Material brought up in the dredge was visually classified:

- Mud - fine material that would pass through the No. 60 soil screen.
- Sand - coarser material up to about 5 mm diameter particle size.
- Bank gravel - mixture of small rocks and sand.
- Shale - soft rocks of consolidated mud.

Additional notes were made on color, texture and gross organic content of the bottom material.

The greatest variability in bottom material occurred in the area from Oahe Dam to Farm Island (Figure 7). The bottom of the tailrace consisted of bank gravel with the shore protected by rock riprap. Below the tailrace most of the main channel was sand. A 20 to 30 m belt of shale was noted along the east shore from Oahe Dam to Pierre. A small area of boulders was observed just below the east boat ramp near the dam (in the
Figure 7. Approximate bottom composition in Lake Sharpe, South Dakota, from Oahe Dam to Pierre, Summer 1968
spring fishermen have found walleye congregated near these boulders where the fish have presumably sought a place to spawn). Places out of the main current like Oahe Marina, the stilling basin and behind the several islands had mud bottoms.

Below Farm Island most of the bottom was covered with mud washed in from tributary streams. Following the record discharge of the Bad River in June 1967, soundings by the Corps of Engineers and NCRI showed that almost 2 m of new silt had been deposited between Farm Island and Chapelle Creek. Bottom material in this area of high deposition was very fine and soft with a light chalky-brown color reflecting its origin in the Badlands of central South Dakota.

Further downstream the bottom muds were darker in color and contained more detritus. Sediments in the Big Bend Dam area were typically dark gray or black in color and frequently contained old sticks and weed stalks. Bottom samples taken in areas of inundated trees usually had a darker color and more organic material than samples from surrounding areas.

Cursory examination of the exposed shoreline area during a brief 1.6 m water level drop in September 1967 indicated much of the shore area is lined with rock rubble from the adjacent banks. The banks are either of the Pierre shale formation or glacial till.

Another shoreline type is a shallow shelf of flooded prairie. Bottom muds on this shelf were usually firm and still had patches of old prairie sod. The shelf was most apparent just up river from West Bend recreation area on the inside of the bend in the reservoir.
Fish

An initial fish survey was conducted by the South Dakota Department of Game, Fish and Parks in 1965. Since 1965, NCRI has continued sampling and is attempting to monitor fish stocks through an extensive program of gill netting, seining, trawling and trap netting. An annotated list of fishes collected from Lake Sharpe is presented in Table 1.

Table 1. Annotated list of fishes collected from Lake Sharpe, South Dakota, 1965 to 1968

<table>
<thead>
<tr>
<th>Fish</th>
<th>Occurrence</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pallid sturgeon, <em>Scaphirhynchus albus</em> (Forbes and Richardson)</td>
<td>Occasional</td>
<td>Only a few specimens collected in recent years. No evidence of reproduction since impoundment.</td>
</tr>
<tr>
<td>Shovelnose sturgeon, <em>Scaphirhynchus platorynchus</em> (Rafinesque)</td>
<td>Common</td>
<td>Found especially in channel areas. No evidence of reproduction since impoundment.</td>
</tr>
<tr>
<td>Paddlefish, <em>Polyodon spathula</em> (Walbaum)</td>
<td>Occasional</td>
<td>Only a few specimens collected in recent years. No evidence of reproduction since impoundment.</td>
</tr>
<tr>
<td>Shortnose gar, <em>Lepisosteus platostomus</em> Rafinesque</td>
<td>Occasional</td>
<td></td>
</tr>
<tr>
<td>Gizzard shad, <em>Dorosoma cepedianum</em> (LeSueur)</td>
<td>Abundant</td>
<td>Numbers reduced by harsh winters but reproduction restores populations in summers.</td>
</tr>
<tr>
<td>Goldeye, <em>Hiodon alosoides</em> (Rafinesque)</td>
<td>Common</td>
<td></td>
</tr>
</tbody>
</table>
Table 1. (Continued)

<table>
<thead>
<tr>
<th>Species</th>
<th>Common/Occasional</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carp, <em>Cyprinus carpio</em> Linnaeus</td>
<td>Common. Reproduction less in recent years.</td>
<td></td>
</tr>
<tr>
<td>Silvery minnow, <em>Hybognathus nuchalis</em> Agassiz</td>
<td>Common.</td>
<td></td>
</tr>
<tr>
<td>Flathead chub, <em>Hybopsis gracilis</em> (Richardson)</td>
<td>Occasional.</td>
<td></td>
</tr>
<tr>
<td>Fathead minnow, <em>Pimephales promelas</em> Rafinesque</td>
<td>Common. Frequently used bait fish.</td>
<td></td>
</tr>
<tr>
<td>White sucker, <em>Catostomus commersoni</em> (Lacepede)</td>
<td>Occasional. Frequently used bait fish.</td>
<td></td>
</tr>
<tr>
<td>Blue sucker, <em>Cycleptus elongatus</em> (LeSueur)</td>
<td>Occasional. Prefers swifter water. Little evidence of reproduction since impoundment.</td>
<td></td>
</tr>
</tbody>
</table>
Table 1. (Continued)

Northern redhorse, *Moxostoma macrolepidotum* (LeSueur)  
Common.

Black bullhead, *Ictalurus melas* (Rafinesque)  
Abundant in first year or two. Has decreased drastically in recent years.

Channel catfish, *Ictalurus punctatus* (Rafinesque)  
Common.

Stonecat, *Noturus flavus* Rafinesque  
Occasional.

Flathead catfish, *Pylodictis olivaris* (Rafinesque)  
Occasional.

Burbot, *Lota lota* (Linnaeus)  
Common.

White bass, *Roccus chrysops* (Rafinesque)  
Common.

Green sunfish, *Lepomis cyanellus* Rafinesque  
Occasional.

Orangespotted sunfish, *Lepomis humilis* (Girard)  
Occasional.

Bluegill, *Lepomis macrochirus* Rafinesque  
Occasional. Frequently put in farm ponds and may escape into lake.

Largemouth bass, *Micropterus salmoides* (Lacepede)  
Common.

White crappie, *Pomoxis annularis* Rafinesque  
Common. Young mostly in the Hipple Lake area.

Black crappie, *Pomoxis nigromaculatis* (LeSueur)  
Common. Young mostly in the Hipple Lake area.

Johnny darter, *Etheostoma nigrum* Rafinesque  
Common.

Iowa darter, *Etheostoma exile* (Girard)  
Occasional.
Table 1. (Continued)

Yellow perch, *Perca flavescens* (Mitchill)
Abundant. Poor survival beyond first year.

Sauger, *Stizostedion canadense* (Smith)
Common.

Walleye, *Stizostedion vitreum* (Mitchill)
Abundant. Recent reproduction high.

Freshwater drum, *Aplodinotus grunniens* Rafinesque
Common.

Combined seining and trawling operations for young of the year fish took 314 fish/effort in 1967 and 723 fish/effort in 1968. Yellow perch and gizzard shad accounted for 85 percent of the catch in 1968. Over 30 walleye young of the year were taken in a single seine sample in several areas, primarily the mid-reservoir in 1968. Juvenile fish of all species were most abundant in the mid-reservoir catches and least abundant in tailwater catches.

The order of abundance (number of fish) taken in gill netting operations at seven stations along the reservoir from June to September 1968 was: walleye (821), carp (489), yellow perch (455), shovelnose sturgeon (302), channel catfish (299), river carpsucker (164), sauger (146), goldeye (112), northern redhorse (89), northern pike (56), bigmouth buffalo (51), white crappie (36), freshwater drum (21), blue sucker (18), smallmouth buffalo (8), shorthnose gar (7), gizzard shad (6), pallid sturgeon (4), white bass (3) flathead catfish (3), burbot (1) and stonecat (1). The middle and lower reservoir had greater numbers of
yellow perch, carp, and walleye in the summer with numbers increasing from Farm Island towards Big Bend Dam. No area produced more than two northern pike per gill net set in 1968.

Gill net sampling for adult fish in Oahe tailwaters indicated seasonal migrations by most species. Catch was lowest in summer, increased in October and remained at a high level through May. Walleye and river carpsucker dominated catches during the high season. Northern redhorse contributed important numbers during the spring. Burbot entered the catch from November to May.

Benthos

Methods

Benthos sampling was conducted from June 1967 to August 1968 on six base transects established along the reservoir (Figure 8). Three to eight samples, stratified by depth and distance from shore, were taken biweekly on each transect during the open water period and when practicable during the winter months. Supplementary random sampling was conducted in diverse habitats, including tree and plant areas, shores with riprap and several embayments.

An orange-peel dredge was used to take benthos samples. The dredge had an inside diameter of 26 cm and a maximum sampling area of 0.053 m². Bottom material from each dredge haul was washed in a No. 60 soil screen (0.250 mm openings). Material retained by the screen was preserved in formalin. Organisms were picked from the preserved material using a sugar flotation technique (Anderson, 1959).
Figure 8. Map showing NCRI hydrographic stations and benthos sampling transects on Lake Sharpe, South Dakota
Contingency chi square tests were used to test differences between sample groups. The number of samples, classified according to the number of organisms in each sample (0-50, 51-100, 100+ organisms per sample), was used as the treatment. Differences were judged significant at the 1 percent level.

Results

Over the 14-month sampling period, 1,268 samples were taken. The mean number of organisms was 1052 per m². Chironomid larvae accounted for 91 percent of the organisms. Other important types included Oligochaetes, Chaoborus spp., Ceratopogonid larvae, Nematodes and Ephemeroptera nymphs (Table 2). A few individuals were also recovered in the following groups, listed in order of abundance: unidentified Diptera pupae, Trichoptera, Odonata, Arachnida, Amphipoda, Hemiptera, Mollusca and Hirudinea.

Mean benthic numbers in different habitat types of the upper, mid and lower reservoir were compared (Table 3). There were significant differences between habitats within each region but no significant differences between regions were found. Shoreline and protected areas had more benthic organisms than current swept and deep areas.

Samples from the first 4 m had more organisms than samples from greater depths (Table 4). The difference in the number of organisms was significant. Significant differences were also apparent between benthos numbers in different substrata types (Table 5).

Rocks in the riprap areas of the upper reservoir had negligible benthos which was attributed to their frequent exposure during periods of
Table 2. Composition of 1,268 benthos samples from Lake Sharpe, South Dakota, June 1967 to August 1968

<table>
<thead>
<tr>
<th>Organism type</th>
<th>Mean no. per sample</th>
<th>Percent of total</th>
<th>No./m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chironomidae larvae</td>
<td>50.8</td>
<td>91</td>
<td>955</td>
</tr>
<tr>
<td>Oligochaeta</td>
<td>1.9</td>
<td>3</td>
<td>36</td>
</tr>
<tr>
<td>Unidentified and misc.</td>
<td>1.0</td>
<td>2</td>
<td>19</td>
</tr>
<tr>
<td>Ephemeroptera nympha</td>
<td>0.7</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>Chaoborus larvae</td>
<td>0.7</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>Ceratopogonidae larvae</td>
<td>0.5</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>Nematoda</td>
<td>0.4</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>56.0</td>
<td>100</td>
<td>1052</td>
</tr>
</tbody>
</table>

Table 3. The mean number of benthic organisms in different regions of Lake Sharpe, South Dakota

<table>
<thead>
<tr>
<th>Area and habitat</th>
<th>No. samples</th>
<th>Mean no. per sample</th>
<th>No./m²</th>
<th>Percent reservoir area</th>
</tr>
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<tbody>
<tr>
<td>Upper reservoir</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main channel areas</td>
<td>226</td>
<td>35</td>
<td>658</td>
<td>5</td>
</tr>
<tr>
<td>Backwaters</td>
<td>236</td>
<td>71</td>
<td>1335</td>
<td>11</td>
</tr>
<tr>
<td>Backwaters</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle reservoir</td>
<td>229</td>
<td>27</td>
<td>508</td>
<td>19</td>
</tr>
<tr>
<td>Main channel areas a</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shallows: outshore</td>
<td>123</td>
<td>57</td>
<td>1072</td>
<td>22</td>
</tr>
<tr>
<td>Shallows: inshore</td>
<td>270</td>
<td>84</td>
<td>1579</td>
<td>8</td>
</tr>
<tr>
<td>Lower reservoir</td>
<td>113</td>
<td>25</td>
<td>470</td>
<td>31</td>
</tr>
<tr>
<td>Deep areas</td>
<td>71</td>
<td>107</td>
<td>2212</td>
<td>4</td>
</tr>
<tr>
<td>Shore areas</td>
<td>1268</td>
<td>56</td>
<td>1052</td>
<td>100</td>
</tr>
</tbody>
</table>

a Over 50 m from shore.
Table 4. The mean number of benthic organisms at different depths in Lake Sharpe, South Dakota

<table>
<thead>
<tr>
<th>Depth</th>
<th>No. samples</th>
<th>Mean no. per sample</th>
<th>No./m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 - 4.0 m</td>
<td>822</td>
<td>67</td>
<td>1254</td>
</tr>
<tr>
<td>4.1 - 8.0 m</td>
<td>155</td>
<td>47</td>
<td>880</td>
</tr>
<tr>
<td>8.1 - 12.0 m</td>
<td>102</td>
<td>40</td>
<td>756</td>
</tr>
<tr>
<td>12.1 - 16.0 m</td>
<td>60</td>
<td>28</td>
<td>517</td>
</tr>
<tr>
<td>16.1 - 20.0 m</td>
<td>103</td>
<td>23</td>
<td>438</td>
</tr>
<tr>
<td>20.1 - 24.0 m</td>
<td>26</td>
<td>28</td>
<td>525</td>
</tr>
<tr>
<td></td>
<td>1268</td>
<td>56</td>
<td>1052</td>
</tr>
</tbody>
</table>

Table 5. The mean number of benthic organisms found in different bottom types of Lake Sharpe, South Dakota

<table>
<thead>
<tr>
<th>Material</th>
<th>No. samples</th>
<th>Mean no. per sample</th>
<th>No./m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mud</td>
<td>958</td>
<td>58</td>
<td>1087</td>
</tr>
<tr>
<td>Mud and sand</td>
<td>133</td>
<td>67</td>
<td>1277</td>
</tr>
<tr>
<td>Sand</td>
<td>85</td>
<td>7</td>
<td>126</td>
</tr>
<tr>
<td>Bank gravel</td>
<td>59</td>
<td>50</td>
<td>944</td>
</tr>
<tr>
<td>Shale rocks</td>
<td>33</td>
<td>92</td>
<td>1722</td>
</tr>
<tr>
<td></td>
<td>1268</td>
<td>56</td>
<td>1052</td>
</tr>
</tbody>
</table>
low water.

Two stations with submersed vegetation where sampling was repeated over the study period averaged 106 and 161 organisms per sample which was relatively high. Two stations located in emerging dead trees near Chapelle creek averaged 33 organisms per sample. A station in trees under 13 m water at West Bend averaged only 5 organisms per sample.

Larval phantom midges, Chaoborus spp., questionably included in the benthos because of their nighttime planktonic activity, were repeatedly common only in one spot in the reservoir, Hippie Lake, a large backwater behind Farm Island. Mayfly nymphs, including the burrowing Hexagenia and the climbing Caenis, were more prevalent along the shore in the lower two thirds of the reservoir. Nematodes were found more in the Oahe tailwaters region and appeared to be parasitic or predaceous on Chironomid larvae.

Over the sampling period, organism numbers increased slightly during the late winter and then decreased to the same levels in the summer of 1968 as the summer of 1967 (Figure 9). A winter increase in benthos is normal (Welch, 1952).

The heaviest sample had a wet weight of 0.93 g. A random subsample of 100 samples taken from the first 1,000 samples had a mean wet weight of 0.06 g. Extrapolated, this would give a benthic standing crop of 1.15 g wet weight/m². This standing crop estimate is well below any of the regional averages for standing crop given by Hayes (1957). Moyle (1961) presented a long list of standing crop estimates from different lakes, none of which were as low as the Lake Sharpe estimate. Low benthos has been reported on the lower Missouri River by Berner (1951) and Morris et
Figure 9. Mean number of benthic organisms/m² by month from Lake Sharpe, South Dakota, July 1967 to August 1968
Special factors which may account for low benthos are newness of the reservoir, high cropping by fish, siltation, low temperatures and water current with its associated shifting bottom. Lewis and Clark Lake, the lowest of the main stem Missouri reservoirs, appears to have had an increase in benthos, especially of the mayfly Hexagenia, since impoundment in 1955 (Swanson, 1967). Similar increase in Hexagenia or other organisms may take place in Lake Sharpe though future sampling will be needed to determine this.

**Plankton**

Another part of the NCRI hydrographic survey has been plankton sampling. Oblique tows were made with a high speed Miller plankton sampler (No. 10 nylon mesh) during monthly survey cruises. Organisms in the plankton collections have been identified, counted and weighed by Mr. Ron Rada, a graduate student at the University of South Dakota at Vermillion.

*Cyclops*, *Diaptomous*, *Daphnia* and Copepod nauplii were the chief zooplankters in Lake Sharpe. Density estimates from the different tows ranged from 0.0 to 40.6 zooplankters/l, with a mean of 7.0 zooplankters/l. Dry weights ranged from 0.0 to 0.289 mg/l, with a mean of 0.036 mg/l.

A rough conversion of mean weight to standing crop, based on a mean depth of 10 m, gives an estimate of 3.6 kg dry weight/ha. Taking the mean weights for the peak period in the most productive area, the June and July samples from West Bend sampling station, the standing crop estimate is
Figure 10. Mean zooplankton dry weights from Lake Sharpe, South Dakota, 1966 to 1968
Figure 11. Mean zooplankton numbers and dry weights from Lake Sharpe, South Dakota, 1966 to 1968
Higher Aquatic Plants

Observations on higher aquatic plants were made in the summers of 1967 and 1968. Identification of plant samples has been confirmed by Dr. Jean W. Wooten of Iowa State University.

Occasional small populations of emersed plants are found along the shore of the reservoir. More extensive growths are located on the lower end of Farm Island and the adjacent shore, on Antelope Island, and just below Oahe Dam to the west of the main channel. Types identified from these areas include American bulrush, *Scirpus americanus* Pers.; hardstem bulrush, *Scirpus acutus* Muhl.; cattail, *Typha* L. spp.; and willow, *Salix* L. spp. The swampy area below Oahe Dam is fed by seepage through the dam and parts of it remain ice free throughout the winter. The sand islands between the dam and Pierre and the west side of LaFramboise Island have extensive growths of willows which are partly submerged during periods of high water discharge. Areas of emersed vegetation are used extensively by water fowl especially as a resting place during fall migration. The stable water level from Farm Island downstream would appear to favor further development of emersed shoreline vegetation provided light penetration is sufficient and substrate is suitable.

Submersed higher vegetation has become established in parts of the reservoir and new populations have developed during the observation period. Plants usually grow in small patches or beds located near the shore or in shallow water from 1 to 3 m deep. Plant beds are most
abundant on the shallow shelf just up river from the West Bend recreation area where American pondweed, *Potomogetonnodosus* Poir, and sago pondweed, *Potamogetonpectinatus* L., have been identified. Additional beds of pondweeds have been noted along the east shore near Big Bend Dam and in the stilling basin below Oahe Dam. There is a small population of flatstem pondweed, *Potamogetonzosteriformes* Fern., just below the east boat ramp near Oahe Dam.

**Summary of Conditions**

**Temperature**

All water in the system reached a summer minimum of at least 19 C. Shallow standing water has occasionally exceeded 25 C. Some summer thermal stratification occurred in the lower reservoir.

**Dissolved oxygen**

Oxygen levels were usually near saturation and only once observed below 6.8 mg/l.

**Conductivity**

Specific conductance has ranged from 650 to 900 micro mhos/cm.

**Light penetration**

Secchi disk readings were highest in the tailwaters and lower reservoir, commonly 2 to 5 m. Lowest water clarity has been below the mouth of the Bad River during high runoff when silt has decreased light penetration to practically zero.
Water level

The Corps of Engineers have maintained a stable water level in the main reservoir but fluctuations of 2 m or more have occurred almost daily in Oahe tailwaters because of discharge variations.

Current

Flow in the lower reservoir was less than 0.17 m/sec. Water movement was fastest in the old river channel. During a peak discharge average velocity at Pierre was 1.07 m/sec.

Tributaries

Tributaries to Lake Sharpe have intermittent flow.

Bottom types

Most of the bottom of Lake Sharpe is mud except in Oahe tailwaters where sand, bank gravel, and shale predominate. Rock rubble and riprap line parts of the reservoir shore.

Fish

Forty-two species are listed for Lake Sharpe. Young of the year fish were most abundant in the mid-reservoir and were mostly yellow perch and gizzard shad in 1968. Walleye also produced good numbers. Gill netting showed seasonal migrations of most species into the tailwaters, especially during the colder months. Northern pike catch declined to less than 2 per gill net set in 1968. Walleye was the most abundant species in the 1968 summer gill net catches.
Benthos

Benthic invertebrates, 91 percent chironomid larvae, averaged 1052 organisms/m². Numbers were greatest along shore and least in mid-channel. The standing crop, estimated at 1.15 g/m², is comparatively low.

Plankton

Zooplankton was composed chiefly of Cyclops, Diaptomus, Daphnia and nauplii. Dry weights reached summer peaks near the first of July and were greatest in the lower reservoir.

Higher aquatic plants

Scattered populations of emersed and submersed plants were noted.
CONSIDERATIONS ABOUT INTRODUCTIONS

Objectives

The main reason for introducing coldwater fish into Lake Sharpe would be to improve the sport fishing. Discussion of the recreational and economic advantages of "trout fishing" is beyond the scope of this study, but it is generally recognized that coldwater fishing is desirable. If quality trout fishing could be established in Lake Sharpe, it would certainly be a resource that would attract fishermen from a wide area.

Any species introduced for sport fishing should possess qualities of high demand, sportiness, palatability, ease of capture, etc. The species should be able to survive and grow under the existing conditions and ideally be able to reproduce and maintain a natural population. If natural reproduction were unlikely or limited, the species must be readily propagated artificially and be available for stocking. The anticipated creel returns should be sufficient to justify the costs of stocking.

Other reasons for introducing fishes into Lake Sharpe would be to improve the forage base and to utilize unused food or niches. Some species might even have potential commercial value. The danger of introductions is that an undesirable situation might develop as in the case of the carp, for example.

Species Considered

According to Wilkins, Kirkland and Hulsey (1967) species of coldwater fishes currently being used in state programs within the United States
include coho salmon, *Oncorhynchus kisutch* (Walbaum); kokanee salmon, *Oncorhynchus nerka* (Walbaum); cutthroat trout, *Salmo clarki* Richardson; rainbow trout; landlocked salmon, *Salmo salar* L.; brown trout; brook trout, *Salvelinus fontinalis* (Mitchill); lake trout, *Salvelinus namaycush* (Walbaum) and the hybrid splake. This list of fish formed the basis of the types to be considered for possible introduction into Lake Sharpe.

**Coho salmon**

Coho, one of the anadromous Pacific salmon, have recently been introduced into Lake Michigan and are apparently successful in the freshwater environment. Their success has stimulated considerable interest in their introduction elsewhere.

Brett (1952) stated the lethal temperature limits as 0.2 and 25.0 C. Coho are most active and able to withstand fatigue at 17 to 21 C (Brett et al. 1958). Davison et al. (1959) reported coho fed well during the winter when held at 18 C with 2.9 mg/l dissolved oxygen. Less oxygen made behavior sluggish. At 20 C feeding dropped off when oxygen levels went down to 4.0 mg/l (Herriman et al. 1962). Phillips and Campbell (1962) found that 8 mg/l dissolved oxygen was needed for embryo survival.

Cohos usually spawn high in tributary streams though Dvinin (1959) noted a case of lake spawners. Eggs are deposited in autumn or early winter and hatch in the spring. Young usually spend at least their first year in the stream before migrating. Young fish feed on invertebrates. Larger individuals eat small fish, a characteristic which helped coho develop in Lake Michigan where alewives were abundant and predaceous fish
are few because of the sea lamprey. Coho grow rapidly, usually maturing at three years of age when they return to their parent stream to spawn and die (Tody and Tanner, 1966). Juveniles of coho and other normally anadromous forms have a tendency to move downstream. High mortalities have been reported for coho and other species passing through or over dams by Hamilton (1955), Regenthal (1957), Finnell and Klein (1966), etc.

**Kokanee salmon**

Kokanee are the landlocked form of the anadromous sockeye or red salmon so well known from the Pacific coast. The literature concerning sockeye is abundant though not all applies to the kokanee form. Foerster's recent book (1968) is the most complete work on the species. A discussion about introducing kokanee into the Great Lakes has been prepared by Maher (1964).

Kokanee are native to a few western lakes and have been successfully introduced elsewhere. They are somewhat smaller than their anadromous relatives. Sigler and Miller (1963) indicate that a typical adult in the intermountain region would be 30.5 cm long and weigh 340 g. Kokanee may be taken by anglers and support a limited commercial fishery in Lake Pend Orielle, Idaho and Christina Lake, British Columbia.

Brett (1952) reported the upper lethal temperature as 24.4 C and found that young in a vertical temperature gradient showed little preference though the greatest concentrations were at 12 to 14 C. Young fish were unable to survive 4 days at 0 C. Brett (1956) reported another upper lethal temperature at 24.8 C with fish acclimated to 20 C. Young fish died when held more than a few days at 25.6 C (Donaldson and Foster, 1941).
At 22.8 C the young lost weight and at 21.1 C they were just able to maintain themselves. Best growth was obtained in the 11.7 to 17.2 C range. From 3.9 to 7.2 C growth was poor and food conversion low. Brett et al. (1958) found young had an optimum sustained swimming speed (1 hr) of 30-45 cm/sec. They found sockeye more active at lower temperatures and less active at higher temperatures than coho salmon.

Brett (1950) felt that oxygen levels over 30 percent saturation (e.g. 3.5 mg/l at 10 C) would be adequate for any species including sockeye in Lakelse Lake, B.C.

Food of the kokanee consists almost entirely of planktonic crustacea. Fish feed mostly at twilight when they move from deep water to near the surface. Because of their food habits, kokanee are not usually deemed competitors with other sport fish. Kokanee are often considered a forage fish, however, and are planted partly to provide food for other salmonids like rainbow trout and lake trout (Sigler and Miller, 1963). Beckman (1952) recommends planting only where adequate food supply is available. Kokanee disappeared in Shasta Lake, California, coincident with a threadfin shad boom (Borgeson, 1966).

Maturity is reached after 3 to 5 years when the fish stop feeding and seek a place to spawn. This occurs in autumn. Gravel in a small stream is the preferred pace to make redds. Delisle (1962) found that spawning took place in water moving 0 to .66 m/sec. Faster water was avoided. Narver (1965) reported the apparent success of an artificial spawning channel for kokanee. They are also known to spawn in lakes if no tributaries are accessible. Eggs are usually deposited as water
temperature approaches 10 C. Held at a constant 6.1 C eggs hatch in about 110 days (Sigler and Miller, 1963). Temperatures less than 6 C caused high mortality in green eggs (Bosley, 1960).

**Cutthroat trout**

Cutthroat trout are native to western North America. Cutthroat have been successfully introduced into many western waters and are widely acknowledged as a fine sport fish. Their range includes the upper Missouri River though Bailey and Allum (1962) did not report them in South Dakota.

Temperature and oxygen limits have not been accurately set for cutthroats though it may be assumed that limits do not exceed those of other trout. Irving (1955) found in Henny's Lake, Idaho, that the growing season was limited to the open water period and felt that an August decline in feeding was caused by high temperature (up to 20 C) and low oxygen (down to 5.9 mg/l). Purkett (1951) found that cutthroat grew best in the lower, warmer part of the Gallatin River, Montana, which had a July temperature of 12.8 C compared to 7.7 C in the upper river.

Food habits of cutthroats have been reviewed by Hazzard and Madsen (1933), Idyll (1942) and others. It is apparent that the diet varies in different circumstances. Small fish feed on invertebrates, usually taking those organisms which are most available. Larger fish usually add fish to their diet if available, though Calhoun (1944) found that cutthroats did not take minnows even when the latter were abundant in a California lake. Fleener (1952) suggested that the small size of cutthroat in the Logan River, Utah, resulted from the lack of a forage fish species. Echo (1955),
on the other hand, felt that the forage fish, yellow perch, in a Montana lake should be reduced or removed because the young perch competed with the cutthroat for food and thus slowed trout growth.

Cutthroat spawn in the spring depositing eggs in shallow riffles of small streams. Spawning usually takes place as the water temperature nears 10 C (Sigler and Miller, 1963). In summarizing the life history of cutthroat in Yellowstone Lake, Wyoming, Benson and Bulkley (1963) reported that fry, on the average, emerge from the gravel 30 days after eggs have been deposited. Merriman (1935) was able to incubate eggs at 11.3, 8.25 and 6.35 C. Cope (1955) indicated that the building of dams across streams reduced spawning habitat and depleted the species in Utah.

Although they have been established in new waters, cutthroat trout populations are generally on the decline. Sigler and Miller (1963) have attributed the decline to the introduction of other fish species with which the cutthroat is unable to compete successfully, to the inability to withstand heavy fishing pressure, tendency to hybridize, and difficulty and expense of rearing in hatcheries. Cutthroat have declined in Montana streams where other trout species have been introduced (Hanzel, 1960). There has been recent interest in maintaining cutthroats because some races appear to have been eliminated and others are endangered.

**Rainbow trout**

The rainbow trout is the most widely introduced and propagated of the salmonid fishes. Rainbow are prized by fishermen and receive the brunt of the trout fishing effort. Stocks originally came from the Pacific coast where they exist in both the freshwater and anadromous (steelhead) forms.
Rainbow have similar spawning habits to cutthroat trout, usually spawning during the spring in small gravel-covered streams.

It is generally accepted that rainbow do not do well in waters that exceed 21.1 C (70 F). However, there is ample evidence to show that they will survive at warmer temperatures. Temperature tolerance is affected by oxygen levels and previous temperature acclimation. Black (1953) found that fingerlings acclimated to 11 C survived 22.4 C, 50 percent died at 24.0 C and all died at 25.7 C. Eddy and Surber (1947) reported that rainbow have been taken from well aerated waters with summer maximums as high as 29.4 C. Growth is best at 12.2 to 21.1 C and may be restricted by colder temperatures (Hazzard, 1933). Mantelman (1960) gave the selected temperature in the range 13 to 19 C depending on acclimation temperature. Garside and Taite (1958) reported 13 C as the rainbow's temperature preferendum.

Oxygen levels of 2.47 mg/l were lethal to rainbow at 22 C in a hatchery (Burdick et al., 1954). The Water Pollution Research Board (1957) reported the minimum oxygen level that rainbow trout were able to survive for 84 hours at 10 C as 1.89 mg/l. At 16 C it was 3.00 mg/l and at 20 C it was 2.64 mg/l. Baker and Mathis (1967) and others have generally used 3.0 mg/l dissolved oxygen minimum and 21.1 C maximum as the criteria to decide if reservoirs in the southeastern part of the United States would support trout.

Some of these southeastern reservoirs have been able to support trout because of summer thermal stratification which traps cooler water in the deeper areas. Baker and Mathis (1967) found good growth and survival of
rainbow in Bull Shoals, Arkansas. Trout stocked at 20 cm length were large enough to escape heavy predation and also were able to eat the abundant threadfin shad.

A number of dam tailwaters in the Southeast have also provided excellent trout fishing (Pfitzer, 1954; Parsons, 1957). Rainbow have survived better than brook or brown trout and there is even some evidence of reproduction though most of the redds were exposed or washed out during peaking operation. These tailwaters generally did not have large populations of other fish when trout were stocked. Threadfin shad were introduced below Dale Hollow Dam in Tennessee to provide forage for trout. The shad have become established and rainbow trout are eating them.

A 1968 experimental stocking of fingerling trout in Lake Francis Case, the next reservoir below Lake Sharpe on the Missouri River, has not produced the results desired. Examination of fish stomachs showed that northern pike, walleye and goldeye preyed heavily on the stocked trout. Up to 30 trout were found in a single northern pike stomach. Small trout were also stocked into Lake Sharpe in 1964 but failed to survive which was attributed to adverse conditions following the stocking (Fogle, 1965).

**Landlocked salmon**

Atlantic salmon in the landlocked form are highly prized game fish in their native New England area. Attempts at establishing stocks elsewhere have met with only limited success.

Landlocked salmon require relatively cool water. Bishai (1960) felt 23 C was the upper limit for *S. salar* young raised in colder water. Huntsman (1942) observed heat death in a river where the water temperature
was recorded at 29.5°C. Atlantic salmon grew better in a hatchery at 15 to 18°C than at 13°C, the usual optimum temperature for raising trout (Markus, 1962). Javaid and Anderson (1967) reported a final temperature preferendum of 17°C. Allen (1940) found in the River Eden (North England) that young fed slowly and did not grow when water temperature was below 7°C.

Young fish feed mostly on insects. Larger fish do best if forage fish are available.

Landlocked salmon spawn in the fall of the year when they move from lakes into inflowing or outlet streams. Fish usually mature at age III or IV and may live through more than one spawning period.

Successful establishment of new populations seems to be partly dependent upon having a suitable stream for spawning and early life. Newly hatched young usually remain in streams for at least one year. Stocking into lakes should be done with at least 12.7 cm fish which take one to three years to produce in a hatchery (Greeley, 1954).

Warner et al. (1968) found newly stocked landlock salmon were preyed upon by chain pickerel and other predaceous fish in Maine lakes.

Brown trout

Brown trout, native to Europe, have been widely introduced in North America. Both cool streams and lakes are suitable habitat. Brown trout are highly regarded by anglers and have the reputation of being most difficult of the trout to capture by angling.

Brown trout spawn during the fall in streams or on rocky reefs of lakes. Eggs hatch in 57 days at 8°C (Embody, 1934). The young and small
fish eat invertebrates while the larger individuals prefer fish. Feeding occurs mostly at dawn and dusk and not at night (Swift, 1962). Browns feed all year around but their growth is less at extremes of temperature. Maximum feeding takes place at 10 to 19 °C and maximum activity is at 10 to 12 °C (Brown, 1952). Frost and Brown (1967) reported 25.3 °C as the upper lethal temperature. Davis (1961) reported survival has been observed in waters up to 29.4 °C.

Brown trout seem to withstand heavy fishing pressure better than other trout because of the difficulty in catching them. This quality makes them less desirable where high returns from put-and-take fishing are a goal (Staley, 1966).

Brook trout

Brook trout are native to cool waters of eastern North America. The species has been widely introduced and is frequently raised in hatcheries. Brook trout are highly sought by fishermen and are known as one of the easiest trout to catch.

Brook trout prefer temperatures between 8 and 12 °C (Sullivan and Fisher, 1953) and generally restrict themselves to water 19 °C or below (Creaser, 1930; Burton and Odum, 1945). Eddy and Surber (1947) indicated that brook trout seldom thrive in streams with a summer mean temperature over 10 °C. Upper lethal temperatures range from 24 to 26 °C depending on acclimation (Brett, 1941). The upper lethal temperature for fully acclimated brook trout is 25.3 °C though some fish may survive for short periods to 28.3 °C (Fry, 1951). Ricker (1934) suggested that 24 °C be considered the practical upper limit. Huntsman (1942) reported mortali-
ties of brook trout in Moser River, Nova Scotia, when the water temperature reached 29.5 C. Belding (1928) felt that higher temperatures may make the fish more susceptible to other harsh environmental factors. Baldwin (1957) found that brook trout ate best at 13 C. Above this temperature their utilization of food for growth declined with increasing temperature. Hoar (1942) noted that feeding was stopped by extremely high temperature.

Water where brook trout are found is usually well aerated. Creaser (1930) felt that critical oxygen levels were seldom encountered by brook trout in water below 20.0 C. Shepard (1955) produced 50 percent mortality in young brook trout at 1.75 mg/l oxygen. The fish were unacclimated to low oxygen and the temperature was 9 to 10 C.

Brook trout are fall spawners and normally choose streams for spawning. They have been reported to spawn in ponds and lakes (Foye, 1956; Eipper, 1964), a characteristic which has made them especially recommended for stocking in lakes with no tributaries (McAfee, 1966).

Preferred food is insects and planktonic crustaceans although larger fish may eat fish or crayfish. Insufficient food and overcrowding may produce stunted populations. Most studies indicate that brook trout seldom live over 4 years. Slow growth may produce greater longevity (McAfee, 1966).

Brook trout do not compete well in mixed populations of fish. Wilkins et al. (1967, p. 447), reporting on the success of trout in the reservoirs of the Southeast, said, "Brook trout are generally unable to compete when superimposed on established populations of either warm- or cold-water fishes." Pfitzer (1954) reported that brook trout were not
successful in the tailwater fisheries of Tennessee. McAfee (1966) noted that populations are low in California waters where nongame fish are abundant.

**Lake trout**

Lake trout have appeal because of their large size which frequently exceeds 9 kg.

Gibson and Fry (1954) listed the upper lethal temperature of young lake trout as 23.5°C which is comparatively low. Eddy and Surber (1947) claimed that lake trout do not thrive in water over 18.3°C. McAfee (1966) recommended stocking only in California lakes which have a year-round supply of well-oxygenated water below 13°C.

Small lake trout feed on invertebrates but will quickly switch to fish as they attain size if fish are available.

Nolting in McAfee (1966) found that lake trout did best in Colorado lakes deeper than 15 m. Eddy and Surber (1947) believed that a lake should be 30.5 or more meters deep to be suitable. Specialized fishing is required to catch lake trout in the deep waters where they usually go to avoid warmer temperatures.

Lake trout spawning takes place in the fall when fish release their eggs over lake shoals. Egg deposition may take place at a variety of depths and over a wide variety of substrate. Silt-free angular rocks provide the best protection and survival of the spawn (Prevost, 1957).

McAfee (1966) points out that lake trout populations are usually sparse which he attributes to slow maturation, high vulnerability to fishing and low productivity in the lake trout's usual environment.
Sigler and Miller (1963, p. 51) say, "The stocking of lake trout is complicated by the fact that eggs are difficult to obtain and the young fish have more than their share of trouble when they are being reared to a size of more than four or five inches."

**Splake**

The splake is a hybrid cross between the male brook trout and the female lake trout. They have the advantages of the larger size and greater longevity of lake trout and the shallow water habits of brook trout. Splake fecundity is less than parental species though survival of $F_2$ progeny is still fairly high (McAfee, 1966). Sowards (1959) obtained only 38.5 percent hatching success with splake eggs and cites other reports of 28 and 75 percent.

Martin and Baldwin (1960) reported splake were doing well in Algonquin Park, Ontario, where they resembled brook trout in angling, depth distribution, food, maturity, fecundity, and time and duration of spawning. The hybrid resembled lake trout more in length-weight characteristics and place of successful spawning. Several generations have been naturally produced in the Park waters.

Eipper (1964) felt that splake are less suited to New York farm ponds than brook trout because of their lower temperature tolerance. Fry (1953) found warm acclimated (20 C) hybrids had thermal tolerances closer to brook trout than lake trout. Klein (1966) found that splake moved from warm summer lake water to a cooler inflowing stream. Splake were in colder water than rainbow in a Colorado lake during the summer (Leik, 1960).
Other species

A number of other species could be discussed but they would offer little advantage over the ones already considered. For example, other American species of Pacific salmon, genus *Oncorhynchus*, are if anything less adaptable to an entire life in freshwater than the species discussed (Tody and Tanner, 1966). Other *Salvelinus* species like the dolly varden, *S. malma* (Walbaum), are less highly thought of as sporting fish. The grayling, *Thymallus* spp., has not been able to hold its own against other fish and is mostly an invertebrate feeder. Whitefish (subfamily Coregoninae) generally have little sport fishing appeal. The inconnu, *Stenodus leucichthys* (Guldenstadt), has been experimentally raised in a hatchery in North Dakota for possible introduction into reservoirs. The current information about inconnus was summarized by Scott (1961) but more needs to be known about their potential impact in the reservoirs before introduction could be advised. Stock from the ohrid trout, *Salmo lethica*, from Yugoslavia is now being started in the United States (Prog. Fish-Cult., 1965). This species is supposed to offer the advantage of being a lake spawner. However, I am skeptical that it could better survive in Lake Sharpe than the other species of trout that are already proven in America.
Table 6. Summary of characteristics of nine coldwater fishes

<table>
<thead>
<tr>
<th>Species</th>
<th>Preferred habitat</th>
<th>Spawning place</th>
<th>Best temp. for growth °C</th>
<th>Max. temp. °C</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coho salmon</td>
<td>First year in ocean or large lakes</td>
<td>High in streams</td>
<td>To 25.0</td>
<td>21</td>
<td>Normally anadromous. 3-yr life cycle</td>
</tr>
<tr>
<td>Kokanee salmon</td>
<td>Lakes</td>
<td>Gravel bottomed streams</td>
<td>11.7 to 17.2</td>
<td>24.8</td>
<td>Landlocked sockeye, plankton feeder</td>
</tr>
<tr>
<td>Cutthroat trout</td>
<td>Lakes and streams</td>
<td>Shallow stream riffles</td>
<td>-- to --</td>
<td>--</td>
<td>Suffers in competition with other trout</td>
</tr>
<tr>
<td>Rainbow trout</td>
<td>Lakes and streams</td>
<td>Gravel bottomed streams</td>
<td>12.2 to 21.1</td>
<td>24</td>
<td>Widely introduced</td>
</tr>
<tr>
<td>Landlocked salmon</td>
<td>First year at least in large lakes</td>
<td>Gravel bottomed streams</td>
<td>To 18</td>
<td>23</td>
<td>Difficult to establish</td>
</tr>
<tr>
<td>Brown trout</td>
<td>Lakes and streams</td>
<td>Usually streams</td>
<td>7 to 25.3</td>
<td>19</td>
<td>Difficult to catch</td>
</tr>
<tr>
<td>Brook trout</td>
<td>Streams and small lakes</td>
<td>Streams, ponds or lakes</td>
<td>8 to 25.3</td>
<td>19</td>
<td>Short longevity</td>
</tr>
<tr>
<td>Lake trout</td>
<td>Deep cold lakes</td>
<td>Rocky lake bottom</td>
<td>To 23.5</td>
<td>18.3</td>
<td>Attains large size</td>
</tr>
<tr>
<td>&quot;Splake&quot;</td>
<td>Lakes</td>
<td>Rocky lake bottom</td>
<td>To 25</td>
<td>19</td>
<td>Reduced fecundity</td>
</tr>
</tbody>
</table>
DISCUSSION

The fact that many fish are now surviving in Lake Sharpe stands as prima facia proof that conditions are suitable for fish life. The question is whether the high demands of coldwater fish will fit the limits imposed by Lake Sharpe.

Summer water temperatures have been slightly above optimum though usually within maximum tolerance limits for most of the species considered. The tailwaters of Oahe Dam and hypolimnetic waters of the lower reservoir have had the coolest summer temperatures and it is to these areas that coldwater fish would be expected to move during warmer periods. The warm temperatures would disfavor the less tolerant types like Salvelinus species so a more tolerant type like rainbow trout, brown trout and coho salmon would be a better choice for Lake Sharpe.

There is no evidence of oxygen deficiency. Oxygen levels never dropped near what could be construed as a critical level for any fish species. Specific conductance was in the normal range and turbidity was not excessive for fish existence.

Suitable types of food for coldwater fish are present. Benthic organisms, though not abundant, include common salmonid food types like midge larvae and mayfly nymphs. High temperatures may keep fish out of the more productive shallow areas in the summers which would have a detrimental effect on growth as was the case with splake in Colorado (Leik, 1960). Zooplankton standing crops were comparable to those found in western lakes which have sustained favorable salmonid growth (Foerster, 1968). The increase in zooplankton weight near the first of
July would come at a favorable time for salmonid utilization. The large numbers of yellow perch and gizzard shad should provide a good forage base for larger, fish eating salmonids, although these and other species in the lake would be competing with salmonids for available invertebrate food.

Fish are notably plastic in their food and habitat selection and able to take advantage of opportune conditions (Larkin, 1956). The numerous fish already in Lake Sharpe have had time to fill the available niches so it is unlikely that newly introduced fish would find an appreciable void waiting to be filled. If introductions were successful, it would be because the new fish were able to displace other fish, an ability that is usually lacking in salmonid species. The inability of trout to compete with other fish has been demonstrated many times (e.g. White, 1924; Rawson, 1948; Zilliox, 1954) and most management recommendations concur that trout do best where other fish are not abundant.

Besides competing for food and space, other fish affect salmonids through predation. Northern pike, walleye, burbot, yellow perch, goldeye and largemouth bass, all species established in Lake Sharpe, are known trout predators. The recovery of the many trout in fish stomachs following the recent stocking in Lake Francis Case demonstrated the fate that would await small salmonids in Lake Sharpe. Northern pike, especially, pose a threat to salmonid introduction because of their voracious feeding habits and ability to take larger fish. Northern pike have not reproduced significantly in the past few years but at least some should persist for several years because of the species' longevity. Frost and Brown (1967) pointed out that pike have a food preference for trout and that large pike
selected trout of catchable size. They also noted that where trout and pike existed in the same waters, trout fishing is improved by pike removal. They cited one estimate from an Irish lough where 1,170 pike were believed to have eaten 41,768 kg (46 tons) of trout in one year. Trout were a major part of northern pike diet in a Wisconsin stream (Hunt, 1965) and soft-rayed fish were preferred over spiny-rayed fish as pike food in an aquarium experiment (Beyerle and Williams, 1968). The favorable growth of northern pike in Lake Sharpe suggests that young pike might be stocked into the reservoir as an alternative to coldwater fish.

Trout populations in some waters receive a degree of protection by their distribution as in the "two story" thermally stratified southeastern reservoirs and the deep northern lakes where temperature preferences segregate trout from some of the other fish types. Such protection is unlikely in Lake Sharpe because the reservoir is not especially deep and has not stratified strongly. Also, predaceous fish like northern pike and walleye are found in all parts of the reservoir.

Most of the species of salmonids prefer streams with gravel beds for spawning. Such streams are clearly not available to Lake Sharpe, though a suitable substitute might be provided in the form of an artificial spawning channel. Gravel bottom, rock rubble or riprap could provide spawning sites in the tailwaters although success is doubtful because of changing water levels, strong current and numerous fish capable of eating eggs or newly hatched fish. Unsuitable bottom type and high siltation would make reproduction in the middle stretches of the reservoir unlikely. Rocky banks in the lower reservoir might provide a suitable spawning place
for lake spawning species. However, it is unlikely that any of the stream spawning fish would remain in the lower reservoir in the spawning season as the fish usually migrate upstream. Other species might be forced out of the lower reservoir by high temperatures. Even if hatching were successful, survival would be tenuous because of predation. For these reasons successful salmonid reproduction is unlikely and populations would need to be sustained by continued stocking, preferably of larger fish which would reduce susceptibility to predation by all species except northern pike.

The established fish populations in Lake Sharpe already support a valuable sport fishery. Thus, poisoning or removal of these fish to make room for trout would be ill-advised. The introduction of new species may increase the total standing crop of fish but could also reduce populations of individual species (Carlander, 1955). Hence, if trout were successful, it might cause some reduction in other valuable game species like walleye.

Though salmonid stocking is not recommended, consideration of all factors indicates that rainbow trout are the coldwater fish most likely to succeed in Lake Sharpe if any were stocked. Rainbow have provided the best angling in other areas similar to Lake Sharpe and are readily available from hatcheries. Brown trout would be less suitable because they are harder to catch. Cutthroat trout are difficult to raise in hatcheries and are poor competitors. Coho salmon are too short lived and might migrate out of the reservoir. Kokanee are so small they would likely be preyed upon by other fish. Lake Sharpe is too warm and shallow to be good lake trout habitat. Landlocked salmon have a poor success record elsewhere.
Rainbow are more tolerant of warm water than brook trout or splake.

If rainbow were stocked in Lake Sharpe, they should be of catchable size to minimize predation, which will still be considerable especially if northern pike continue to exist in the reservoir. Reproduction of rainbow is unlikely so that stocking would have to be on a put-and-take basis. Stocking during a cold water period usually provides better survival. Publicity following stocking would help maximize the return. Rainbow trout are so universally accepted it is unlikely they would be unpopular in Lake Sharpe. If problems did occur, stocking could be discontinued.
LITERATURE CITED

Allen, K. R.

Anderson, R. O.

Bailey, R. M., and O. Allum

Baker, R. F., and W. P. Mathis

Baldwin, N. S.
1957 Food consumption and growth of brook trout at different temperatures. Amer. Fish. Soc., Trans. 86: 323-328.

Beckman, W. C.

Belding, D. L.

Benson, N. G., and R. V. Bulkley

Berner, L. M.

Beyerle, G. B., and J. E. Williams

Bishai, H. M.
Black, E. C.  

Borgeson, D. P.  

Bosley, C. E.  

Brett, J. R.  
1941 Tempering versus acclimation in the planting of speckled trout. Amer. Fish. Soc., Trans. 70: 397-403.

Brett, J. R.  

Brett, J. R.  

Brett, J. R.  

Brett, J. R., M. Hollands, and D. F. Alderdice  

Brown, M. E.  

Burdick, G. E., M. Lipschultz, G. Dean, and E. J. Harris  
1954 Lethal oxygen concentrations for trout and smallmouth bass. N.Y. Fish Game J. 1: 84-97.

Burton, G. W., and E. P. Odum  

Calhoun, A. J.  
Carlander, K. D. 
12: 543-570.

Cope, O. B. 
1955 The future of the cutthroat in Utah. Ut. Acad. Sci., Arts 
Letters, Proc. 32: 89-93.

Creaser, C. W. 
1930 Relative importance of hydrogen-ion concentration, temperature, 
dissolved oxygen, and carbon-dioxide tension, on habitat 

Davis, H. S. 
1961 Culture and diseases of game fish. Univ. Calif. Press, 
Berkeley. 332 p.

Davison, R. C., W. P. Breese, C. E. Warren and P. Doudoroff 
1959 Some experiments on the dissolved oxygen requirements of 

Delisle, G. E. 
1962 Water velocity tolerated by spawning kokanee salmon. Calif. 
Fish Game 48: 77-78.

Donaldson, L. R., and F. J. Foster 
1941 Experimental study of the effect of various water temperatures 
on the growth, food utilization, and mortality rates of 
fingerling sockeye salmon. Amer. Fish. Soc., Trans. 70: 339- 
346.

Dvinin, P. A. 
1959 Lake coho, Oncorhynchus kisutch (Walbaum) morpha relictus nova. 

Echo, J. B. 
1955 Some ecological relationships between yellow perch and cutthroat 
trout in Thompson Lakes, Montana. Amer. Fish. Soc., Trans. 84: 
239-248.

Eipper, A. W. 
1964 Growth, mortality rates, and standing crops of trout in New 

Eddy, S., and T. Surber 
1947 Northern fishes with special references to the upper 
276 p.
Embody, G. C.
1934  Relation of temperature to the incubation periods of eggs of four species of trout. Amer. Fish. Soc., Trans. 64: 281-292.

Finnell, L., and W. D. Klein

Fleener, G. G.

Foerster, R. E.

Fogie, N. E.

Foye, R. E.

Frost, W. E., and M. E. Brown

Fry, F. E. J.

Fry, F. E. J.
1953  Lethal temperature experiments with speckled trout X lake trout hybrids. J. Hered. 44: 56-57.

Garside, E. T., and J. S. Taite

Gibson, E. S., and F. E. J. Fry

Greeley, J. R.
Hamilton, J. A. R.  

Hanzel, D. A.  

Harvey, J. G., and W. J. Gould  

Hayes, F. R.  

Hazzard, A. S.  
1933 Low water temperature, a limiting factor in the successful production of trout in natural waters. Amer. Fish. Soc., Trans. 63: 204-207.

Hazzard, A. S., and M. J. Madsen  

Herriman, R. B., C. E. Warren, and P. Doudoroff  

Hoar, W. S.  

Hunt, R. L.  

Huntsman, A. G.  

Idyll, C.  

Irving, R. B.  
Javaid, M. Y., and J. M. Anderson  

Klein, W. D.  
1966 The summer movement of hybrid and brook trout into an inlet stream. 
Prog. Fish-Cult. 28: 146-151.

Larkin, P. A.  
1956 Interspecific competition and population control in freshwater fish. 

Leik, T. H.  

Maher, F. P.  
1964 On the feasibility of introducing kokanee, the landlocked sockeye salmon, *Oncorhynchus nerka kennerlyi*, to the Great Lakes. 

Mantelman, I. I.  
1960 Distribution of the young of certain species of fish in temperature gradients. 

Markus, H. C.  
1962 Hatchery-reared Atlantic salmon smolts in ten months. 
Prog. Fish-Cult. 24: 127-130.

Martin, N. V., and N. S. Baldwin  

McAfee, W. R.  

Merriman, D.  
1935 The effect of temperature on the development of the eggs and larvae of the cut-throat trout (*Salmo clarkii clarkii* Richardson). 


Progressive Fish-Culturist 1965 A trout from Yugoslavia. Prog. Fish-Cult. 27: 164.


Rawson, D. S. 1948 The failure of rainbow trout and initial success with the introduction of lake trout in Clear Lake, Riding Mountain Park, Manitoba. Amer. Fish. Soc., Trans. 75: 323-335.


Scott, W. B.  
1961  Summaries of current information on kiyi, bloater and inconnu.  
No. 10.  9 p.

Shepard, M. P.  
1955  Resistance and tolerance of young speckled trout (Salvelinus  
fontinalis) to oxygen lack, with special reference to low  

Sigler, W. F. and R. R. Miller  
203 p.

Sowards, C. L.  
1959  Experiments in hybridizing several species of trout.  Prog.  
Fish-Cult. 21: 147-150.

Staley, J.  

Sullivan, C. M., and K. C. Fisher  
1953  Seasonal fluctuations in selected temperature of speckled trout,  
187-195.

Swanson, G. A.  
1967  Factors influencing the distribution and abundance of  
Hexagenia nymphs (Ephemeroptera) in a Missouri River reservoir.  

Swift, D. R.  
1962  Activity cycles in the brown trout (Salmo trutta Lin.).  I.  

Tody, W. H., and H. A. Tanner  

U.S. Geological Survey  

Warner, K., R. AuClair, S. Roche, K. Havey, and C. Ritzi  
1968  Fish predation on newly stocked landlocked salmon.  J. Wildl.  
Manage. 32: 712-717.
Water Pollution Research Board

Welch, P. S.

White, H. C.

Wilkins, P., L. Kirkland, and A. Hulsey

Zilliox, R. G.
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