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Fishes of the Big Sioux River

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BY

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FISHES OF THE BIG SIOUX RIVER

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser Date

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INTRODUCTION

An understanding of the fishes and limnology of a river is essential to the effective management of the river. The climate, soils, and agricultural practices in eastern South Dakota create unusual characteristics in rivers draining that area. One of the principal rivers of the area is the Big Sioux River.

Fishes of this river were first studied about 1900 by Meek and by Everman and Cox (Bailey and Allum, 1962). A later survey by Churchill and Over (1933) apparently included the Big Sioux River, but collection data were inadequate for detailed comparisons. Since that time collections of fishes were made on the river by the Iowa Conservation Commission (Harlan and Speaker, 1956). The most recent collections of fishes were made by Bailey and Allum (op. cit.) who had only three sampling stations, the southernmost being at the south edge of Brookings, County.

In 1966 this study was undertaken to survey the fishes and water quality of the river to provide a basis for estimating its recreational potential. Some problems of sampling fish populations in such a river and of interpreting the data obtained were also studied.

STUDY AREA

The Big Sioux River lies in extreme eastern South Dakota and drains the southern part of the Coteau des Prairie. The character of this river is due in part to the glacial origin of the soil. The entire drainage is in glacial till, mostly 50 to 400 feet thick, overlying igneous bedrock. Most of this till was deposited by the Kansan ice sheet and had weathered to deep valleys before the Wisconsin ice sheets again covered the eastern part of the Coteau. The Wisconsin ice sheets deposited thinner layers of till over the Kansan till (Rothrock, 1943). The river bed lies largely in alluvial soils that were probably deposited during the retreat of the last ice sheet, but the rest of the drainage lies in soils with a limey glacial till underlayment (Westin, Puhr, and Buntley, 1959). The river bed consists mainly of shifting sand and small gravel. Silt beds are found in quiet backwaters or above dams. Large rock and gravel are uncommon except at Dell Rapids and Sioux Falls where the bedrock of Sioux Quartzite outcrops. The outcrop at Sioux Falls forms a natural falls which is probably an effective barrier to the passage of fish.

Headwaters of the Big Sioux River are in Grant County from which the river flows southward through Coddington, Hamlin, Brookings, Moody, Minnehaha, Lincoln, and Union counties to the Missouri River at Sioux City, Iowa. During the study, the flow of the river was highly variable, and the section from the headwaters to approximately Watertown was intermittent with flow occurring only during spring runoff and after heavy rains. While only scattered pools remained in this area during periods when there was no flow, the level of the pools did not change appreciably once flow had ceased, indicating that the aquifer in this area is near the surface.

The flowing portion of the river varies from 20 feet in width below Watertown to over 200 feet in some areas near the mouth. There are no major tributaries in South Dakota and only one, the Rock River, enters from Iowa. Except where old impoundments slow the flow, the river is generally broken into long riffles and pools with appreciable current. There is a variable margin of trees along the lower part of the river, and many trees have fallen into the river due to undercutting of the banks. The upper part of the river (approximately that part north of Brookings) flows through open pasture or cultivated fields. The average depth of the river is from 1 to 5 feet except for the southern 10 miles which is deeper.

The city of Sioux Falls, with a population of approximately 85,000, contributes a large amount of heat, dissolved organic matter, salts, and apparently some particulate organic matter to the river. During the winter when the flow of the river is at its lowest level, the outflow from the Sioux Falls sewage treatment plant may be greater than the flow of the river itself (Herreid, 1967). The city of Sioux Falls draws its water from the Big Sioux River aquifer above Sioux Falls. This probably has the effect of reducing the surface flow through the city. Most of this water is returned to the river as partially treated sewage below Sioux Falls.

The entire Big Sioux drainage is extensively farmed, and evidences of agricultural pollution were found throughout the entire length of the river. These included such things as cattle breaking down the banks of the river and standing in the river, improper planting of row crops resulting in heavy erosion, dumping of trash and junked machinery into the river, and the inflow of wastes from feedlots.

METHODS AND MATERIALS

Fish sampling was conducted when conditions were favorable during 1966 and 1967 at 14 stations from the headwaters to near Akron, Iowa. Because of the long distances to the lowermost sections of the river and because Iowa is at present doing work on the fish of the lower Big Sioux River, efforts were concentrated on the upper portion of the river.

The types of nets employed to sample fish were seines, trap nets, hoop nets, and gill nets. The seines ranged from a 40-foot bag seine to a 10-foot seine. Mesh of all seines was 0.25-inch square measure and depths were at least 4 feet.

In 1966 one trap net with hoops 2 feet in diameter, 0.5-inch square mesh, and 30 feet of lead of the same size mesh and 3 feet deep was used. In 1967 three trap nets with hoops 3 feet in diameter, 0.75-inch square mesh, and 80 to 90-foot leads of the same size mesh and 5 or 6 feet deep were used. Trap nets were fished both in areas of fast current and in areas where the current was almost undetectable. They were fished without leads and with the throats downstream in most fast current situations. In stillwater situations, fishing was usually done with leads. The leads were placed either across the stream or aligned with the stream. Usually both methods were tried at each location. These nets were usually fished for more than 24 hours at one location, but they were inspected every 24 hours with few exceptions.

By late summer of 1967, it was difficult to find sufficient water to cover the throats of the trap nets. Since smaller trap nets were not available, several hoop nets with 18 to 24-inch hoop diameters were obtained and used in August and September 1967. These nets were baited with cheese and fished with their mouths downstream in fast current. Again these nets were checked every 24 hours.

Two gill nets were used during the summer of 1967. One was an experimental gill net 200 feet long with mesh ranging from 0.75 to 2.5 inches. A shorter section of gill net approximately 50 feet long and with only 1.0-inch mesh was used in several areas too small for the larger net. Both nets were 8 feet deep and were fished at the surface, though the lead line was usually on the bottom. Most trials with gill nets were above dams where the water was relatively still and deep. These nets were fished along or across the channel of the river. No attempts were made to fish gill nets in water with any appreciable amount of current.

An electric shocker was used during the late summer of 1967. It consisted of a variable voltage rectifier unit with a stepped transformer to vary the voltage and a 1500 watt gasoline generator which provided 115 volts of 60 cycle a-c to the rectifier unit. The output of the shocker was 100 or 160 volts d-c as measured with a 10,000 ohm per volt multimeter at no load and using the two transformer taps that were used in the field. Currents ranged from 1 to 4 amperes depending on the conductivity of the water and the amount of anode immersed in the water. The voltage under load was not measured. The shocker assemble was placed in a small flat-bottomed aluminum boat and either propelled by a small outboard motor or pushed by hand as dictated by the depth. The positive electrode was mounted on a small boom 9 feet in front of the boat and the boat itself was used as the cathode.

Explosives were tried in an effort to take fish in areas not fishable by other means. At first a product known as "Atlas Seal Control", essentially a large firecracker with a weighted end to cause it to sink, was tried. While this item was originally intended to frighten seals, it has proven quite useful in spot sampling in the smaller streams of South Dakota (A.C. Fox, personal communication). Numerous trials in the Big Sioux River, however, indicated that "Seal Control" was not powerful enough, probably because the river is larger than the small streams where the "Seal Control" was effective and often has a soft sand bottom which absorbs the concussion of the explosion. At this time a larger and more powerful explosive was developed. "Primacord" detonating fuse produced by the Ensign-Bickford Company was cut to various lengths, folded up and fitted into a small paper cup about 1.5 inches in diameter and 2.0 inches in height, and this was filled with patching plaster and allowed to harden. In sampling an area with these explosives, a dynamite cap was fused with about a 20-second fuse and then taped to the end of the "Primacord" with plastic electrical tape. Lengths of "Primacord" from 18 to 36 inches proved to be effective in most situations. If a still more powerful charge was necessary, a 1.0-inch section of 50 per cent ditching dynamite was used instead of the "Primacord". This was rarely necessary however.

In 1966, rotenone was tried in the vicinity of Fairview in a joint effort with the Iowa Conservation Commission's river biologist for that area. After several attempts were foiled by high water, a last partially successful attempt was made in September while the water was still higher than desirable. In 1967, sodium cyanide in briquette form was used extensively. The required quantity of cyanide was deposited in the upper end of a riffle after first blocking off the lower end of the section to be sampled with a 0.25-inch square mesh block net. Sections sampled were usually about 200 yards long. At the levels used, fish affected by the poison and not collected in the sample usually did not die from the poison. In some instances small fishes and minnows were killed, however. Dosage was determined empirically at first, but later samples were obtained using estimated quantities of cyanide. In areas where there appeared to be a greater than usual amount of suspended organic matter, it was sometimes necessary to supplement the dosage.

Fish were collected by dip nets as they surfaced and were also collected in the block net.

For very small fish (under approximately 8 cm) only counts of numbers by species were made. Usually a representative sample of minnows and small fishes was brought back to the laboratory to confirm identifications made in the field. In some cases where the catch of minnows and small fishes was very large and the weather was especially hot, only a representative sample of the minnows and small fishes was counted by species. This sample was weighed. Then the rest of the small fishes and minnows were weighed, and the numbers of each species were approximated on the basis of the proportions of each species in the weighed and counted portion of the sample. This was necessary since, under these conditions, the fish decomposed so fast that species became indistinguishable before all the fish could be counted.

The species described as quillback (*Carpiodes cyprinnus*) was keyed out to *Carpiodes forbesi* with the key by Moore (1957) and also with the key in Bailey (1956). Bailey and Allum (1962) only list *C. carpio* and *C. cyprinnus* as present in the Big Sioux and discuss the possible taxonomic difficulties involved. The American Fisheries Society, however, now lists four species of *Carpiodes*, the two accepted by Bailey and Allum, and in addition, the two that they considered only ecological variants. Bailey and Allum is used as the final authority since theirs is the only recent work done in this geographical area.

In all types of sampling, the captured fish (except the small fishes and minnows) were weighed and measured, and scales were taken from a representative sample of the scaled fish.

Water samples were taken approximately every month during 1966 and early 1967. Samples were sometimes taken more often if it appeared that conditions had changed; for example, during runoff from a heavy rain. If conditions were essentially constant, as in the fall and early winter of 1966, water sampling was occasionally ommitted. In 1967, water samples were taken at various times from several sites from the headwaters to below Flandreau.

Because the water was often shallow, the use of the Kemmerer water sampler was often impossible. Thus, whenever open water was available for sampling, water was allowed to flow gently into a standard 300 ml oxygen bottle. Trials showed that this method of collection introduced no measurable amount of oxygen. In all cases, two samples were collected at each site in oxygen bottles, and an additional sample of approximately 2 liters was collected in a plastic bag for later analysis in the laboratory. One of the samples in the oxygen bottles was analyzed for dissolved oxygen using the azide modification of the Winkler method. The other sample in an oxygen bottle was used for alkalinity and pH determinations. Alkalinity was determined by titration with 0.0500$\underline{N}$ H_2SO_4 and pH was determined with a Beckman Model N pH meter. These analyses were done in the field except during extremely cold weather. On these occasions, the oxygen samples were fixed and then the rest of the analyses were conducted immediately upon returning to the laboratory.

The samples in plastic bags were refrigerated in the field until they could be frozen for later analyses. Laboratory analyses were made for conductivity, total hardness, sulfate, chloride, nitrite, nitrate, ammonia, total phosphate, sodium, and potassium. At first, Hach methods and chemicals were used almost exclusively in conjunction with a Bausch and Lomb Spectronic 20 colorimeter (Hach Chemical Co., Cat. N. 9). When these procedures were tested against standards prepared according to methods in Standard Methods for the Examination of Water and Wastewater (Am. Pub. Health Assoc., 1965), several tests were found to be quite unreliable. This was due largely to the charts supplied with the colorimeter. At this time analysis methods outlined in Standard Methods were used for all colorimetric tests. The method used for sulfate was the titrimetric method described by Fritz and Yamamura (1955). Sodium and potassium were determined using flame photometry with a Coleman Junior and a Coleman Model 21 flame photometry attachment.

Water temperatures were measured with a pocket thermometer that had been calibrated against a laboratory thermometer. Temperature was measured in flowing water only.

Turbidity measurements were made when possible using a Secchi disc. Attempts to bring water samples back to the laboratory and measure the turbidity on a colorimeter did not produce consistent results within a sample.

Attempts to sample bottom organisms with an Eckman dredge and a Surber sampler were unsuccessful due to the scattered nature of bottom organisms. Samples collected either had no organisms or were rich in organisms; there were no intermediate collections even from the same station. Most samples had no organisms at all. This gave very misleading results with the limited amount of sampling which was practical. Attempts to obtain an indication of food habits of fishes were made instead, by examining the stomach contents of the first 25 specimens of each species collected at each sampling. If fewer than 25 specimens of a species were collected, all specimens of a species were collected, all specimens were examined for stomach contents.

RESULTS AND DISCUSSION

Samples of fish populations varied widely from station to station over the length of the river. Since sampling problems, fish populations and river conditions differed considerably from one station to the next, each station is discussed separately below.

Station 1

Station 1 was located about 3 miles south of the Grant County line in Coddington County, T. 119 N, R. 52 W, sec. 4. The river is crossed by a road over culverts at this point and is shallow and sandy except for a deeper pool below the culverts. Since there was no flow later in the year, only one sample was taken at this station (with cyanide).

The only large fish taken were black bullheads and one northern pike (Table 1). Young-of-the-year northern pike were present early in the summer when the sample was taken and probably moved downstream as water levels went down. A large amount of inundated grass and semi-aquatic vegetation prevented seines from being used and probably also prevented complete sampling with cyanide.

Station 2

Station 2 was just north of the Big Sioux Conifer Nursery northwest of Watertown, T. 118 N, R. 52 W, sec. 35 and T. 117 N,

Table 1. Fishes taken from the Big Sioux River in 1966 and 1967 at station 1.

Species	Total number	Length (cm) range	Length (cm) mean	Weight (g) range		Weight (g) mean	K_{TL} range		K_{TL} mean
Black bullhead	30	12.6-24.8	19.9	29	227	133	1.23	1.95	1.36
Carp (YY)*	31								
Northern pike	1		39.3			350			0.58
Northern pike (YY)	7								
White sucker (YY)	31								
Emerald shiner	1								
Common shiner	7								
Sand shiner	50								
Bluntnose minnow	2								
Fathead minnow	28								
Creek chub	1								
Johnny darter	1								

* (YY) = young-of-the-year

$$K_{TL} = \frac{W \times 10^2}{L^3}$$

Where: W = Weight in grams
L = Total length in centimeters
K_{TL} = Condition factor

R. 52 W, sec. 2. The river flows through culverts under the access road, but there are no deeper pools present. This probably accounts for the absence of large fish in samples from this site. The flow never ceased entirely but was reduced to only a trickle by late summer. Because of the absence of any pools, no fish were taken later in the summer. This was the only location at which the Iowa darter was collected (Table 2). Sand shiners were abundant and made up the majority of the fish collected.

Station 2a

Station 2a was located at a pair of culverts southeast of Watertown, T. 116 N, R. 52 W, sec. 5. The flow was never reduced as it was above Watertown, and was nearly the same except during runoff. Only water samples were collected at this site.

Station 3

Station 3 consisted of a section of the river 3 miles north of Castlewood, T. 115 N, R. 52 W, secs. 10 and 15, and another section just upstream from the gates of the dam for diversion of the river through Lake Poinsett, T. 114 N, R. 51 W, sec. 30. The river at both sites was shallow with a sand and mud bottom. These two areas are considered one station since they provided essentially the same type of habitat and had about the same types of fish but were sampled by different methods.

Table 2. Fishes taken from the Big Sioux River in 1966 and 1967 at station 2.

Species	Total number	Length(cm) range	Length(cm) mean	Weight(g) range	Weight(g) mean	K_{TL} range	K_{TL} mean
Black bullhead (YY)*	33						
Carp (YY)	22						
White sucker (YY)	153						
Orangespotted sunfish	2						
Yellow perch (YY)	4						
Stoneroller	1						
Emerald shiner	2						
Common shiner	13						
Sand shiner	566						
Fathead minnow	10						
Blacknose dace	2						
Creek chub	4						
Iowa darter	4						
Johnny darter	4						

* (YY) = young-of-the-year

This is the only station where adult walleyes were collected in the Big Sioux River (Table 3). It is also one of only three stations where adult northern pike were taken. Even at these stations northerns were scarce. The great abundance of young-of-the-year carp and of white suckers and the presence of adult yellow perch are unique at this station as is the presence in the collection of two brassy minnows. Since this station is just above the point where water is diverted into Lake Poinsett, there may be some movement of fish between the lake and the river. This may account for the difference in fishes taken at this station.

Station 4

Station 4 is again a composite of several locations. The river in all these locations is relatively swift with high banks constricting it to a small channel. Pools are not so common as they are in the lower sections, and those pools that occur have an appreciable current. The bottom is all sand, and a tree margin is present over much of this area. Many of the trees have fallen into the river, creating many obstructions and much fish cover. Thus, samples in this area were taken at any accessable site. Specific locations were 1 mile south of Bruce, T. 111 N, R. 51 W, secs. 12 and 13, 3 miles southwest of Brookings, T. 110 N, R. 50 W, sec. 32, and 7 miles south of Brookings, T. 109 N, R. 50 W, sec. 35.

Table 3. Fishes taken from the Big Sioux River in 1966 and 1967 at station 3.

Species	Total number	Length (cm) range		Length (cm) mean	Weight (g) range		Weight (g) mean	K_{TL} range		K_{TL} mean
Black bullhead	83	10.0	27.5	18.1	20	324	95	1.19	2.06	1.45
Black bullhead (YY)*	209									
Carp	67	12.8	27.0	23.2	104	260	195	1.09	1.91	1.45
Carp (YY)	1979									
Northern pike	3	29.0	31.0	29.7	150	185	162	0.62	0.62	0.62
White sucker	333	17.4	46.4	22.9	54	998	165	0.82	1.19	1.16
White sucker (YY)	299									
Green sunfish	4									
Orangespotted sunfish	6									
Walleye	2	30.7	31.0	30.8	287	295	291	0.99	0.99	0.99
Yellow perch	20	14.1	22.2	15.9	34	160	55	0.77	1.96	1.32
Yellow perch (YY)	30									
Brassy minnow	3									
Emerald shiner	12									
Common shiner	3									
Sand shiner	36									
Fathead minnow	600									
Johnny darter	27									
Stonecat	11									

* (YY) = young-of-the-year

The number of sand shiners in the samples from this station increased relative to those stations upstream, but the fathead minnow was still the dominant minnow (Table 4). Only black bullheads, carp, and white suckers were larger than approximately 8 cm in length.

Station 5

Station 5 was located in an impoundment 3 miles southwest of Egan, T. 106 N, R. 49 W, secs. 22 and 23. This impoundment is long, relatively narrow, and quite deep in most places. Bottom materials were sand and mud, and at the lower end of the impoundment several freshly deposited mud bars were present. There is a noticeable current present in this impoundment, especially at the upper end. No areas suitable for seining were present, and the volume of water was too large for sampling with the available amounts of cyanide, so no small fishes were collected from this station. Because of the current and narrow twisting channel of the river in this impoundment it was not possible to fish gill nets either.

After sampling was completed, it was discovered that biologists of the South Dakota Department of Game, Fish and Parks had stocked bullheads a few miles north of this station at Flandreau. These fish were taken from various sources and were of undetermined numbers and condition. The length, weight, and condition data on bullheads obtained at this site, therefore, had to be disregarded, since it

Table 4. Fishes taken from the Big Sioux River in 1966 and 1967 at station 4.

Species	Total number	Length (cm) range	Length (cm) mean	Weight (g) range	Weight (g) mean	K_{TL} range	K_{TL} mean
Black bullhead	132	10.2 27.6	17.9	20 332	84	1.08 2.07	1.35
Carp	13	20.8 51.5	39.5	139 2361	1120	1.17 2.13	1.47
Carp (YY)*	83						
White sucker	10	15.0 34.8	20.8	25 636	146	1.11 1.51	1.22
White sucker (YY)	112						
Emerald shiner	130						
Common shiner	1						
Red shiner	21						
Sand shiner	353						
Bluntnose minnow	1						
Fathead minnow	845						
Johnny darter	2						

* (YY) = young-of-the-year

is probable that some of the stocked bullheads were taken in the samples. Buffalo first appeared in the samples from this station (Table 5), though they are undoubtedly present further upstream since the Big Sioux River is connected with Lake Poinsett, which has a large population of buffalo, by inlet and outlet channels between stations 3 and 4.

Station 6

Station 6 is again a composite of two separate locations. Sampling was conducted in the impoundment above the upper dam at Baltic, T. 104 N, R. 49 W, secs. 29 and 32, and 2½ miles below the lower dam at Baltic, T. 104 N, R. 49 W, sec. 17. The impoundment above the upper dam at Baltic is long, deep and relatively wide. No current is detectable in most parts of it but the water is still very turbid. Several sandy bars and some small areas at the upper end of the impoundment appeared suitable for seining. A large amount of barbed wire was present in one of these areas and quickly stopped seining at that point. This situation appears to be fairly common in the Big Sioux River. The lower sampling location at this station was a sand and gravel riffle area. Depth ranged from 1 to 2 inches in periods of low flow to about 1 foot during the largest flows possible to sample.

It was necessary to disregard data for bullheads and crappies from this station due to the state's stocking efforts. It should be noted that the majority of the bullheads collected above the

Table 5. Fishes taken from the Big Sioux River in 1966 and 1967 at station 5.

Species	Total number	Length(cm) range	Length(cm) mean	Weight(g) range	Weight(g) mean	K_{TL} range	K_{TL} mean
Bigmouth buffalo	95	32.0 55.2	44.1	454 2270	1224	0.72 2.70	1.48
Black bullhead**	152						
Carp	19	26.4 50.8	33.1	185 1724	517	0.99 2.37	1.23
Stonecat	2						

** No data for length, weight, or condition are given because the samples are thought to include fish which were stocked near this site by work crews of the South Dakota Department of Game, Fish, and Parks, and are, therefore, not representative of the river population.

dam were emaciated. Since the original condition of the stocked fish is not known, further statements about bullheads would be speculative. Buffalo were abundant and were most easily taken in trap nets (Table 6). Whether the leads were set along or across the stream appeared to make no difference. Gill nets proved almost completely unsuccessful in taking buffalo. They did take some carp, however, and were effective for taking bullheads. Northern redhorse were also abundant, though they were not taken farther upstream. No northern pike were taken above the dam, and those taken below the dam were only found in one sample. The only channel catfish taken were young-of-the-year. The lack of adults in this and other areas may be due only to gear selectivity. Trout-perch were found here and at the next station downstream. Their presence throughout the upper portion of the Big Sioux River is probable since they have been taken in the vicinity of station 2 (Bailey and Allum, 1962). Red shiners are abundant and approximately equal to sand shiners in the samples. Few fathead minnows were taken in contrast to stations farther upstream.

Station 7

Station 7 was located just above Sioux Falls at the crossing of highway 38A, T. 102 N, R. 39 W, sec. 32. At this point, the river is divided in two by the diversion dam that channels water around Sioux Falls. Water levels were quite variable depending on the position of the dam gates. Current was also variable with

Table 6. Fishes taken from the Big Sioux River in 1966 and 1967 at station 6.

Species	Total number	Length (cm) range	Length (cm) mean	Weight (g) range	Weight (g) mean	K_{TL} range	K_{TL} mean
Bigmouth buffalo	382	37.1 61.5	46.5	300 3311	1853	0.24 2.42	1.56
Black bullhead**	1082						
Black bullhead (YY)*	1						
Carp	45	28.5 47.0	34.7	250 1500	548	0.86 2.11	1.22
Carp (YY)	19						
Channel catfish (YY)	33						
Black crappie**	11						
White crappie**	1						
Northern pike	4	27.0 52.2	42.0	210 771	475	0.41 1.07	0.68
Northern redhorse	64	17.7 40.0	27.0	80 620	241	0.80 1.80	1.07
White sucker	1		34.6		364		0.88
White sucker (YY)	21						
Green sunfish	7						
Emerald shiner	2						
Red shiner	742						
Sand shiner	697						
Bluntnose minnow	1						
Fathead minnow	40						
Creek chub	2						
Trout-perch	44						
Stonecat	6						

* (YY) = young-of-the-year

** No data for length, weight, or condition are given because the samples are thought to include fish which were stocked near this site by work crews of the South Dakota Department of Game, Fish, and Parks, and are, therefore, not representative of the river population.

speed and direction dependent on the water level. Since this area is constantly used by fishermen, no attempts were made to set nets or use cyanide, and sampling was only by seining. The bottom was either fine hard gravel or mud depending on the water level. As the deeper water areas could not be sampled adequately, fewer large fish were taken than were probably present. Fishermen's catches were almost exclusively bullheads and carp; yet few bullheads and no adult carp were taken in the samples (Table 7). One specimen of the silvery minnow was taken; the only specimen of this species identified from all the sampling.

Station 8

Station 8 was located 3 miles east of Sioux Falls (downstream from Sioux Falls), T. 101 N, R. 49 W, sec. 11, and T. 102 N, R. 49 W, sec. 36. The river is quite wide here with a few deep holes where obstructions have caused cutting of the river bed. The water was extremely dirty and smelled of sewage. Mud was the predominant bottom material except for some sand and gravel where the current was swifter. The heat added to the river by Sioux Falls was sufficient to keep this station ice-free, at least where current was present, at all times of the year. Riffles often had abundant growths of filamentous algae where they were only 3 or 4 inches deep, but this growth was absent if the water was deeper. The mud bottom contained large quantities of gas; mainly hydrogen sulfide.

Table 7. Fishes taken from the Big Sioux River in 1966 and 1967 at station 7.

Species	Total number	Length (cm) range	Length (cm) mean	Weight (g) range	Weight (g) mean	K_{TL} range	K_{TL} mean
Bigmouth buffalo	2	38.2 46.6	42.4	772 1362	1015	1.35 1.38	1.37
Black bullhead**	3						
Black bullhead (YY)*	1						
Carp (YY)	75						
White sucker (YY)	17						
Green sunfish	2						
Orangespotted sunfish	3						
Walleye (YY)	1						
Silvery minnow	1						
Emerald shiner	2						
Red shiner	87						
Sand shiner	137						
Bluntnose minnow	1						
Fathead minnow	19						
Trout-perch	18						
Johnny darter	8						

* (YY) = young-of-the-year

** No data for length, weight, or condition are given because the samples are thought to include fish which were stocked near this site by work crews of the South Dakota Department of Game, Fish, and Parks, and are, therefore, not representative of the river population.

Carp were very abundant here, and bullheads and green sunfish were numerous but small (Table 8). Minnows were predominantly fathead minnows plus sand and red shiners.

Station 9

Station 9 was located 1 mile southeast of Lake Alvin, T. 100 N, R. 48 W, secs. 26 and 35. This station was mostly riffle. The depth averaged 3 feet and the current was generally very swift over soft shifting sand or hard fine gravel. The evidences of pollution at this station were much less apparent than at station 8, however, the flow at this station appeared to have increased considerably. This station and all the others downstream did not show any effects of the heat added by Sioux Falls.

This is the farthest upstream that quillback were taken (Table 9). The large number of fathead minnows and relative scarcity of other types of minnows is notable. This preponderance of fathead minnows may be due to the influence of pollution from Sioux Falls, or it may be due only to a natural change in the character of the stream.

Station 10

Station 10 was located a few miles downstream from station 9, about 2 miles southeast of Lake Alvin, T. 100 N, R. 48 W, sec. 7. It was not considered together with station 9 because the types of

Table 8. Fishes taken from the Big Sioux River in 1966 and 1967 at station 8.

Species	Total number	Length (cm) range	Length (cm) mean	Weight (g) range	Weight (g) mean	K_{TL} range	K_{TL} mean
Black bullhead	98	8.9 26.3	18.0	9 274	98	0.61 1.94	1.61
Black bullhead (YY)*	16						
Carp	226	9.7 65.0	37.2	14 3946	994	1.13 1.90	1.46
Carp (YY)	22						
Black crappie	6	14.0 17.1	15.8	32 68	56	1.17 1.60	1.40
White sucker	1		30.6		376		1.31
White sucker (YY)	51						
Green sunfish	111						
Orangespotted sunfish	1						
Pumpkinseed	1						
Red shiner	145						
Sand shiner	106						
Fathead minnow	224						
Stonecat	4						

* (YY) = young-of-the-year

Table 9. Fishes taken from the Big Sioux River in 1966 and 1967 at station 9.

Species	Total number	Length(cm) range		Length(cm) mean	Weight(g) range		Weight(g) mean	K_{TL} range		K_{TL} mean
Black bullhead	11	16.5	25.6	21.7	62	284	175	1.38	1.96	1.61
Carp	22	12.2	52.4	31.3	34	2177	586	1.17	1.87	1.38
Carp (YY)*	9									
Quillback	10	19.0	36.3	27.2	70	544	296	1.04	1.42	1.21
Quillback (YY)	4									
Channel catfish (YY)	12									
White crappie	4	12.7	16.5	14.3	29	67	44	1.43	1.49	1.45
Northern redhorse	9	25.2	44.6	35.1	172	907	474	0.85	1.16	1.03
White sucker	73	16.0	41.0	29.4	48	545	230	0.79	2.36	1.18
White sucker (YY)	8									
Green sunfish	1									
Walleye (YY)	1									
Red shiner	6									
Sand shiner	10									
Fathead minnow	2537									
Creek chub	12									
Johnny darter	17									

* (YY) = young-of-the-year

habitat are quite different. The river here flows in wide shallow sandy and gravelly riffles or in deeper slow flowing pools. Mud bars are evident in many places, and the current is much slower. Access at this station is not good and such equipment as shockers, bulky nets, and boats could not be used.

Minnows, especially the fathead, were abundant (Table 10). Sand shiners were quite abundant though they were virtually absent only a few miles upstream. Large fish were scarce with only redhorse and suckers present in quantity; however, they made up relatively little of the total poundage.

Station 11

Station 11 was located above and below the dam at Klondike, Iowa, T. 99 N, R. 48 W, secs. 16, 17, and 21. This old mill dam is beginning to break up, and no apparent effort is being made to repair it so this impoundment may be temporary. There was much silting above this dam in spite of an appreciable current in most areas. This is in contrast to the dam at Baltic which showed little silting and little current. The deep silt deposits prevented any seining above the dam and even made finding a place to process the fish taken in nets difficult. The large volume of water again prevented cyanide sampling. The area below the dam was not so heavily silted, but there was always a thin layer of silt left when water receeded, giving the appearance of mud bars to the gravel and sand bars that are normal in this river.

Table 10. Fishes taken from the Big Sioux River in 1966 and 1967 at station 10.

Species	Total number	Length (cm) range		Length (cm) mean	Weight (g) range		Weight (g) mean	K_{TL} range		K_{TL} mean
Black bullhead	2	21.4	21.4	21.4	159	160	160	1.62	1.63	1.62
Carp	7	9.9	34.4	17.0	18	544	154	1.34	1.98	1.74
Carp (YY)*	7									
Quillback	4	19.2	37.0	27.4	100	544	300	1.07	1.41	1.25
Quillback (YY)	46									
Channel catfish	1			18.2			53			0.88
Channel catfish (YY)	138									
Northern redhorse	52	15.3	43.1	34.0	35	816	433	0.75	1.22	1.05
White sucker	55	17.0	33.8	26.6	52	390	140	1.00	1.35	1.14
White sucker (YY)	13									
Orangespotted sunfish	2									
Emerald shiner	20									
Red shiner	257									
Sand shiner	1167									
Fathead minnow	3264									
Creek chub	21									
Johnny darter	7									
Stonecat	13									

* (YY) = young-of-the-year

Quillback were more numerous here than at any other station (Table 11). The smallmouth buffalo was also taken only at this station. This site is a popular fishing spot. The usual catch was carp and bullheads, though catfish and northern pike are reported to be taken also. Carp attempting to pass the dam upstream were numerous and many bow fishermen took large numbers of these fish early in the summer each year.

Station 12

Station 12 was located at Newton Hills State Park 5 miles south southeast of Canton, T. 97 N, R. 49 W, sec. 12. An old ford is located here on a long rocky riffle with pools just above and below it. The bottom in this area is sand or gravel except for the rocky ford. Again many people fish in this area, and their catch was carp or bullheads though catfish are reliably reported from this area.

Seining was the only method used here since equipment limitations prevented use of other methods. Young-of-the-year channel catfish and sand shiners were most numerous in the sample from this station (Table 12).

Station 13

Station 13 was located 1½ miles south of Fairview, T. 97 N, R. 48 W, secs. 23 and 26. The area of the river between Fairview

Table 11. Fishes taken from the Big Sioux River in 1966 and 1967 at station 11.

Species	Total number	Length (cm) range		Length (cm) mean	Weight (g) range		Weight (g) mean	K_{TL} range		K_{TL} mean
Bigmouth buffalo	6	38.2	55.0	47.6	790	2812	1719	1.34	1.69	1.51
Smallmouth buffalo	2	42.3	49.0	45.6	1125	2086	1656	1.62	1.77	1.70
Black bullhead	71	15.8	27.9	20.2	52	388	131	1.17	1.87	1.44
Carp	8	25.9	43.5	32.8	214	1043	450	1.03	1.62	1.26
Carp (YY)*	56									
Quillback	47	20.5	45.8	31.8	126	1724	480	0.71	3.22	1.41
Quillback (YY)	39									
Black crappie (YY)	1									
White crappie	2	14.1	16.7	15.4	38	69	54	1.36	1.48	1.42
Freshwater drum	1			17.0			80			1.63
White sucker	8	17.3	21.2	19.2	56	119	82	1.02	1.25	1.13
White sucker (YY)	1									
Walleye (YY)	1									
Emerald shiner	3									
Red shiner	96									
Sand shiner	215									
Fathead minnow	126									
Johnny darter	6									

* (YY) = young-of-the-year

Table 12. Fishes taken from the Big Sioux River in 1966 and 1967 at station 12.

Species	Total number	Length(cm) range	Length(cm) mean	Weight(g) range	Weight(g) mean	K_{TL} range	K_{TL} mean
Black bullhead	1		18.0		86		1.48
Quillback (YY)*	1						
Channel catfish	1		25.0		127		0.81
Channel catfish (YY)	40						
Red shiner	30						
Sand shiner	106						
Fathead minnow	14						
Johnny darter	1						

* (YY) = young-of-the-year

and Hudson (approximately to where the Rock River enters from Iowa) appeared to have the most promising habitat for catfish on the entire river. Flow was rapid over clean sand and gravel riffles and through deep pools (often choked with snags where green ash and cottonwood trees have fallen into the river). Because there is no reasonable access to the river in this section, few fishermen use the river and no reports on the fishing in this area are available.

The Iowa Conservation Commission's river biologist cooperated in sampling this site with rotenone. Unusually heavy fall rains which occurred at that time increased the flow and greatly lowered the water temperature until rotenone was only partly successful. The most promising sections could not be sampled since flow was too great for block nets to be used. A sample at a less desirable area where flow was more spread out yielded the data in Table 13. Since more fish probably passed over the block net than were collected by it, the results were seriously biased. Time limitations prevented sampling this station again in 1967, so data for this area possibly do not indicate the true fish populations. White bass, gizzard shad, and goldeye were present and were not taken in any other area (Table 13). Notable also is the large number of young-of-the-year channel catfish. This is also the only station where young-of-the-year redhorse were collected though they were probably present in other parts of the river, especially above Sioux Falls,

Table 13. Fishes taken from the Big Sioux River in 1966 and 1967 at station 13.

Species	Total number	Length (cm) range	Length (cm) mean	Weight (g) range	Weight (g) mean	K_{TL} range	K_{TL} mean
White bass	5	23.6 25.7	24.6 **				
Black bullhead	6	20.3 23.4	21.2				
Carp (YY)*	1						
Quillback	3	35.0 35.9	35.2				
Quillback (YY)	66**						
Channel catfish	1		33.3				
Channel catfish (YY)	938						
Black crappie (YY)	1						
Freshwater drum	1		34.0				
Freshwater drum (YY)	46						
Gizzard shad	25	11.6 30.3	19.1				
Goldeye	1		31.4				
Northern redhorse	7	22.6 40.4	29.7				
Northern redhorse (YY)	11						
White sucker (YY)	3						
Green sunfish	3						
Red shiner	141						
Sand shiner	433						
Fathead minnow	57						
Johnny darter	2						

* (YY) = young-of-the-year

** Data collected during rotenone operation with the Iowa river biologist. Scales for weighing fish were not available on this occasion. Difficulty maintaining the block nets precluded collection of most of the minnows and small fishes.

since the adults were common in those areas and migration of young upstream over the falls is unlikely to occur with any regularity.

Station 14

Station 14 was located 1 mile northwest of Akron, Iowa, T. 93 N, R. 48 W, sec. 31. The river was made up of wide shallow pools and riffles. Most of the pools had mud bottoms which prevented seining in them. Seining, where practical produced mostly sand shiners and young-of-the-year catfish (Table 14). Bullheads were the fish most frequently taken by fishermen; although fishing pressure is low in this area, possibly due to the absence of deep pools.

General Distribution

It is apparent from the foregoing results that several species were present throughout the river; others were restricted in their distribution. With the exceptions of stations 12, 13 and 14, the sampling at each station was of approximately the same degree of thoroughness. While the thoroughness cannot be determined with enough precision to permit quantitative statements as to relative populations or species compositions, some subjective ideas can be gained in these areas. A list of approximate abundance by species and station is given in Table 15, and a list of all species taken is included as Appendix A.

Table 14. Fishes taken from the Big Sioux River in 1966 and 1967 at station 14.

Species	Total number	Length(cm) range	Length(cm) mean	Weight(g) range	Weight(g) mean	K_{TL} range	K_{TL} mean
Carp (YY)*	4						
Quillback (YY)	30						
Channel catfish (YY)	116						
White crappie	2	14.2 14.6	14.4	30 43	36	1.05 1.38	1.22
White sucker (YY)	5						
Emerald shiner	1						
Red shiner	9						
Sand shiner	445						
Fathead minnow	57						
Johnny darter	3						

* (YY) = young-of-the-year

Table 15. Relative abundance of the species of fish collected at various locations on the Big Sioux River in 1966 and 1967.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Species														
White bass													C	
Bigmouth buffalo					A	A+	S				C			
Smallmouth buffalo											S			
Black bullhead - adult	A		A	A	A	A+	S	A	C	S	A	S	C	
Black bullhead (YY)*		A	A+			S	S	C						
Carp			A	C	C	A	A	A+	A	C	C			
Carp (YY)	S	A	A+	A		C		A	C	C	A			S
Quillback									C	S	A		S	
Quillback (YY)									S	A	A	S	A	A
Channel catfish										S		S	S	
Channel catfish (YY)						A			C	A		A	A+	C
Black crappie						C		C			S		S	
White crappie						S			S		S			S
Freshwater drum											S		S	
Freshwater drum (YY)													C	
Gizzard shad													A	
Goldeye													S	
Northern pike	S		S			S								
Northern pike (YY)	C													
Northern redhorse						A			C	A			C	
Northern redhorse (YY)													C	
White sucker			A+	C		S		S	A	A	C			
White sucker (YY)	A	A	A+	A		A	C	A	C	C	S		S	C

Table 15. (continued)

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Species														
Green sunfish			S			C	S	A	C				S	
Orangespotted sunfish		S	C				S	S		S				
Pumpkinseed								S						
Walleye			S											
Walleye (YY)							S		S		S			
Yellow perch			A											
Yellow perch (YY)		S	A											
Stoneroller		S												
Brassy minnow			S											
Silvery minnow							S							
Emerald shiner	S	S	C	A		S	S			A	S			S
Common shiner	C	C	S	S										
Red shiner				A		A+	A	A	C	A+	A	A	A	C
Sand shiner	A	A+	A	A+		A+	A	A	C	A+	A+	A	A+	A+
Bluntnose minnow	S			S		S	S							
Fathead minnow	A	C	A+	A+		A	C	A+	A+	A+	A	C	A	A
Blacknose dace		S												
Creek chub	S	S				S			C	A				
Trout-perch						A	C							
Iowa darter		S												
Johnny darter	S	S	A	S			C		C	C	C	S	S	S
Stonecat			C		S	C		S		C				

* (YY) = young-of-the year
A+ = very abundant
A = abundant
C = common
S = scarce

Northern pike, yellow perch, common shiners, and trout-perch were not found below Sioux Falls though they were at least common at one or more stations above Sioux Falls. The stoneroller, brassy minnow, silvery minnow, blacknose dace, and Iowa darter were only found above Sioux Falls also, but as they were each only taken at one station and in small numbers, it is possible that they were present, but not taken in the samples below Sioux Falls. Similarly, quillback, freshwater drum, white bass, gizzard shad and goldeye were not found above Sioux Falls. A biasing factor in the case of minnows and small fishes is that there were relatively fewer areas suitable for seining below Sioux Falls than above, and thus a better sample of small fish can be expected above Sioux Falls.

The presence or lack of a species above or below Sioux Falls cannot, of course, be attributed soley to the effect of Sioux Falls on the river. The falls which are present at Sioux Falls are an effective barrier to the passage of fish in normal water conditions and probably during extremely high water as well. A diversion canal around the city which flows down a long spillway during high water may, however, permit the passage of rapid-swimming forms around the falls and city and into the upper river. Whether this occurs is questionable as the distance is long (about 150 yards) and the current is very swift. There was never sufficient flow during 1966 or 1967 for this to be possible, so no direct observation was possible. Downstream movement over either route should be possible, though passage over the falls might cause significant injury. Because of the large changes in water quality above and below Sioux Falls, it is probable that other factors are more prominent in the presence or absence of a species above or below Sioux Falls.

Condition Factors

The condition factor K_{TL} was calculated for each fish as outlined by Lagler (1956). K_{TL} was calculated directly from the formula:

$$K_{TL} = \frac{W \times 10^2}{L^3}$$

Where: K_{TL} = condition factor

W = weight in grams

L = length in centimeters

Mean values of K_{TL} were plotted against length for fish above and below Sioux Falls in Figures 1, 2, 4, and 6. Values of K_{TL} were also plotted against age group for fish above and below Sioux Falls (Figures 3, 5, and 7). This was only possible for carp, northern redhorse, and white sucker, and with black bullheads for length vs. K_{TL} only. Other species were not obtained in sufficient numbers for meaningful determinations.

In the calculation of condition factors, a correction factor is usually used to compensate for discrepancies caused by changes in shape as the fish grow longer. That is, the formula for K_{TL}

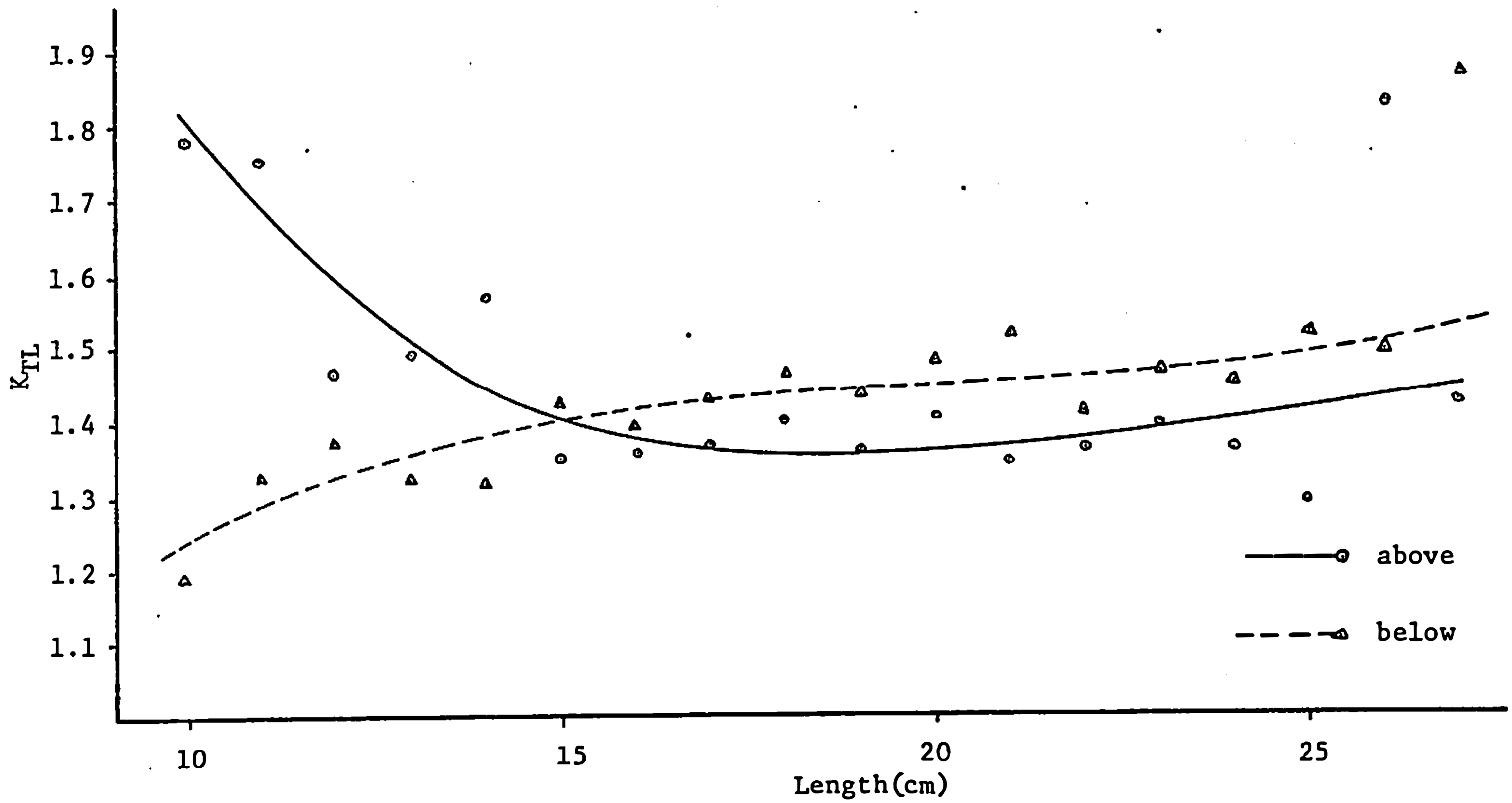

Figure 1. Mean condition factor (K_{TL}) vs. length for black bullheads above and below Sioux Falls.

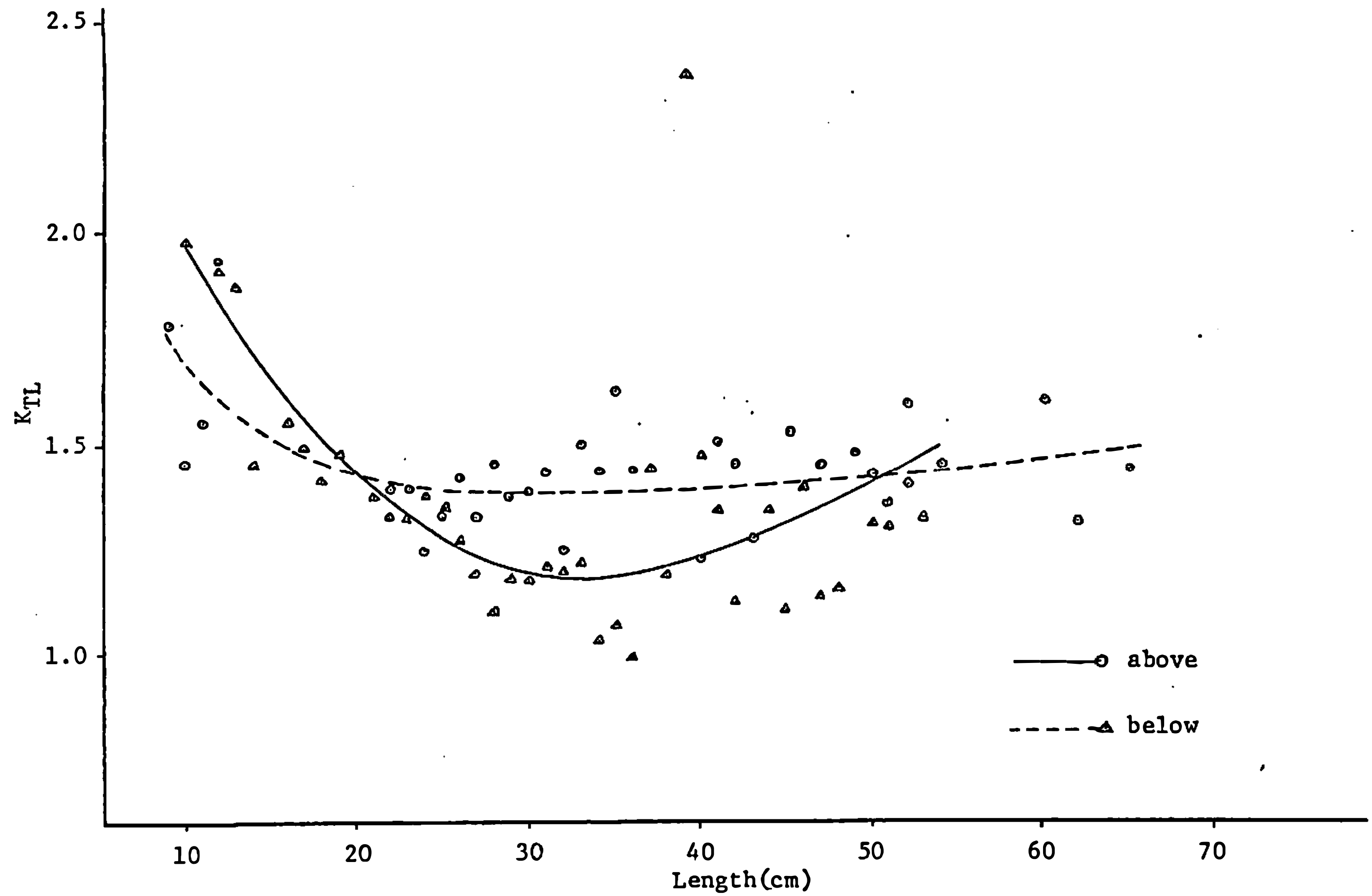

Figure 2. Mean condition factor (K_{TL}) vs. length for carp above and below Sioux Falls.

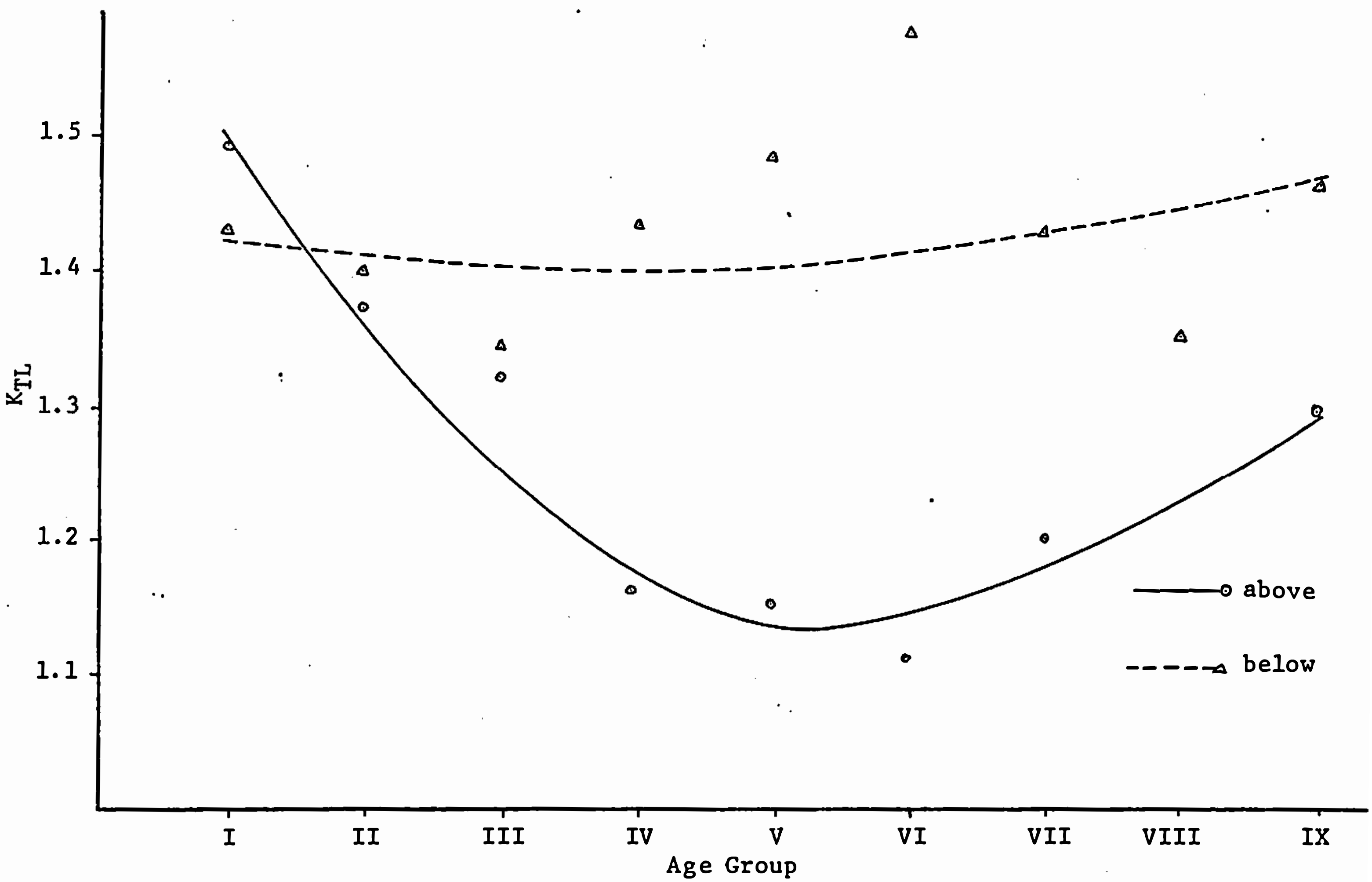

Figure 3. Mean condition factor (K_{TL}) vs. age group for carp above and below Sioux Falls.

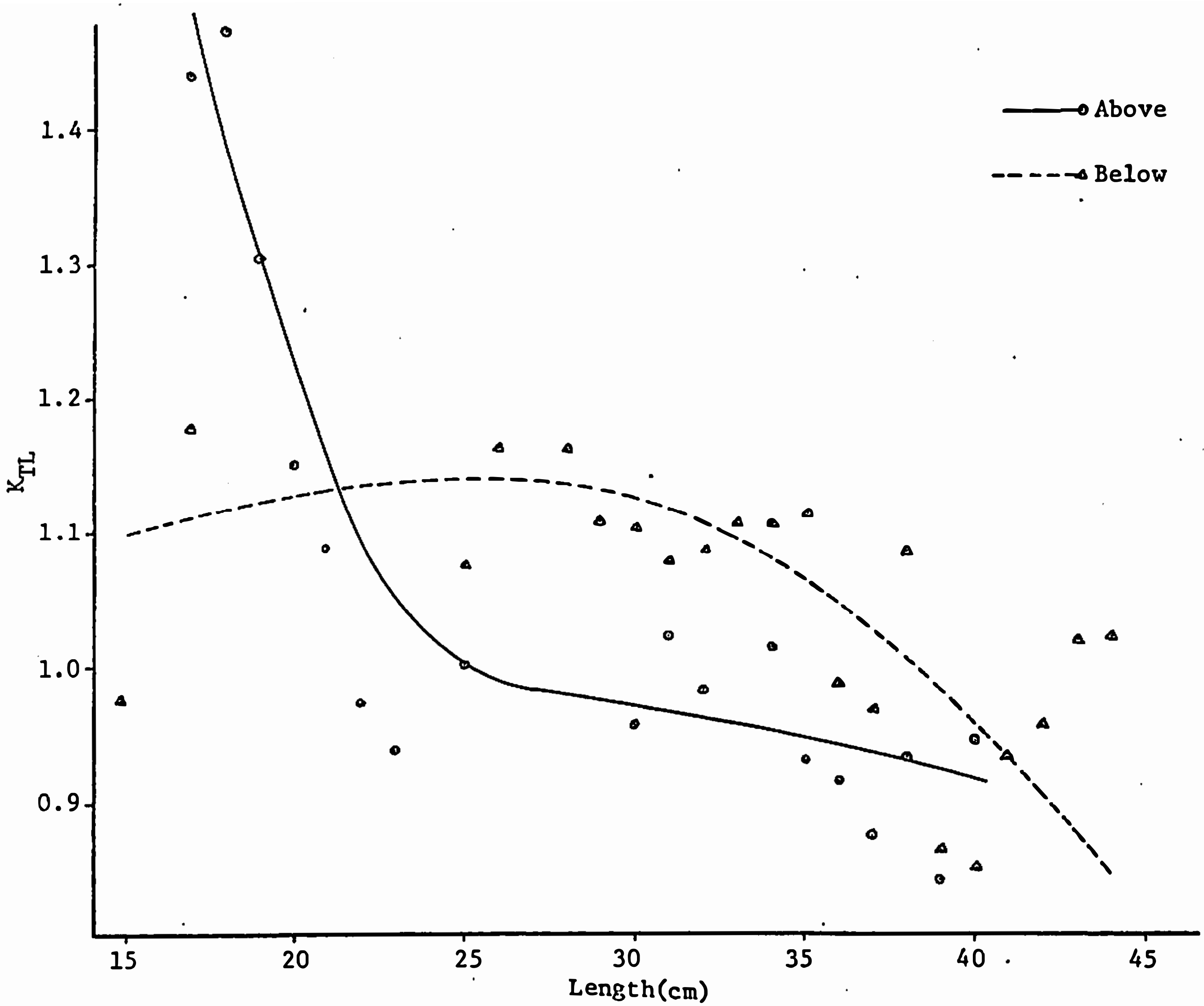

Figure 4. Mean condition factor (K_{TL}) vs. length for northern redhorse above and below Sioux Falls.

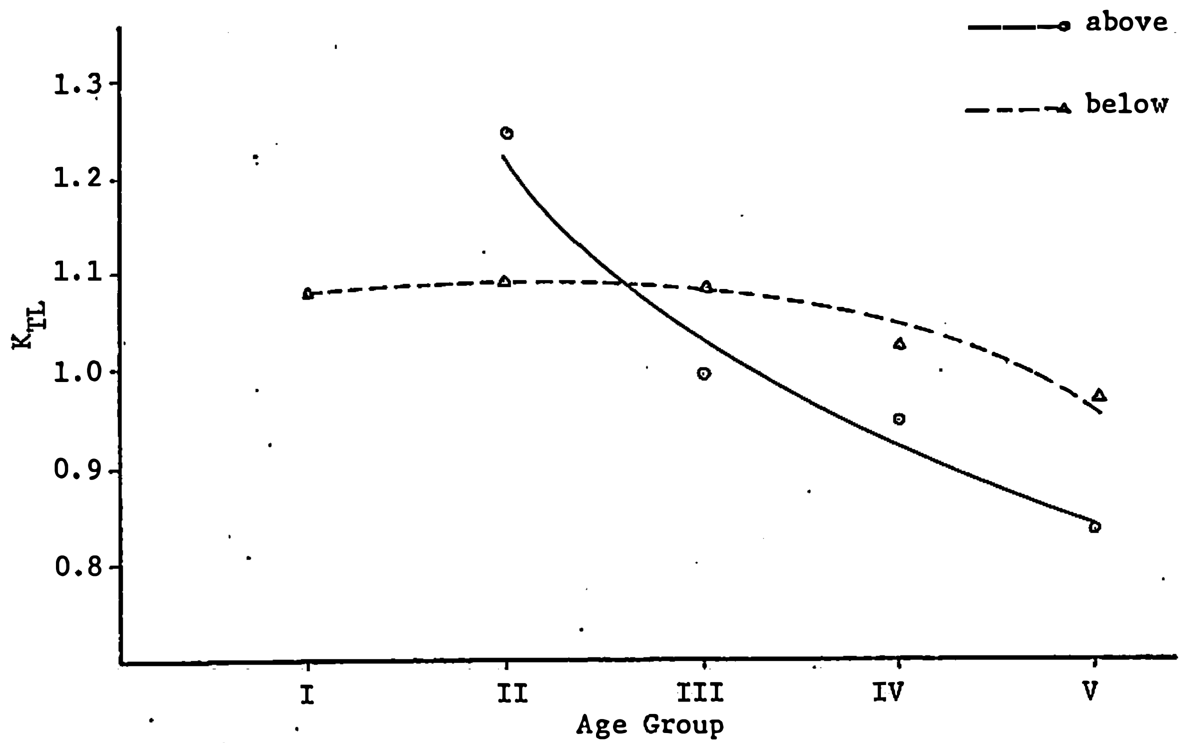

Figure 5. Mean condition factor (K_{TL}) vs. age group for northern redhorse above and below Sioux Falls.

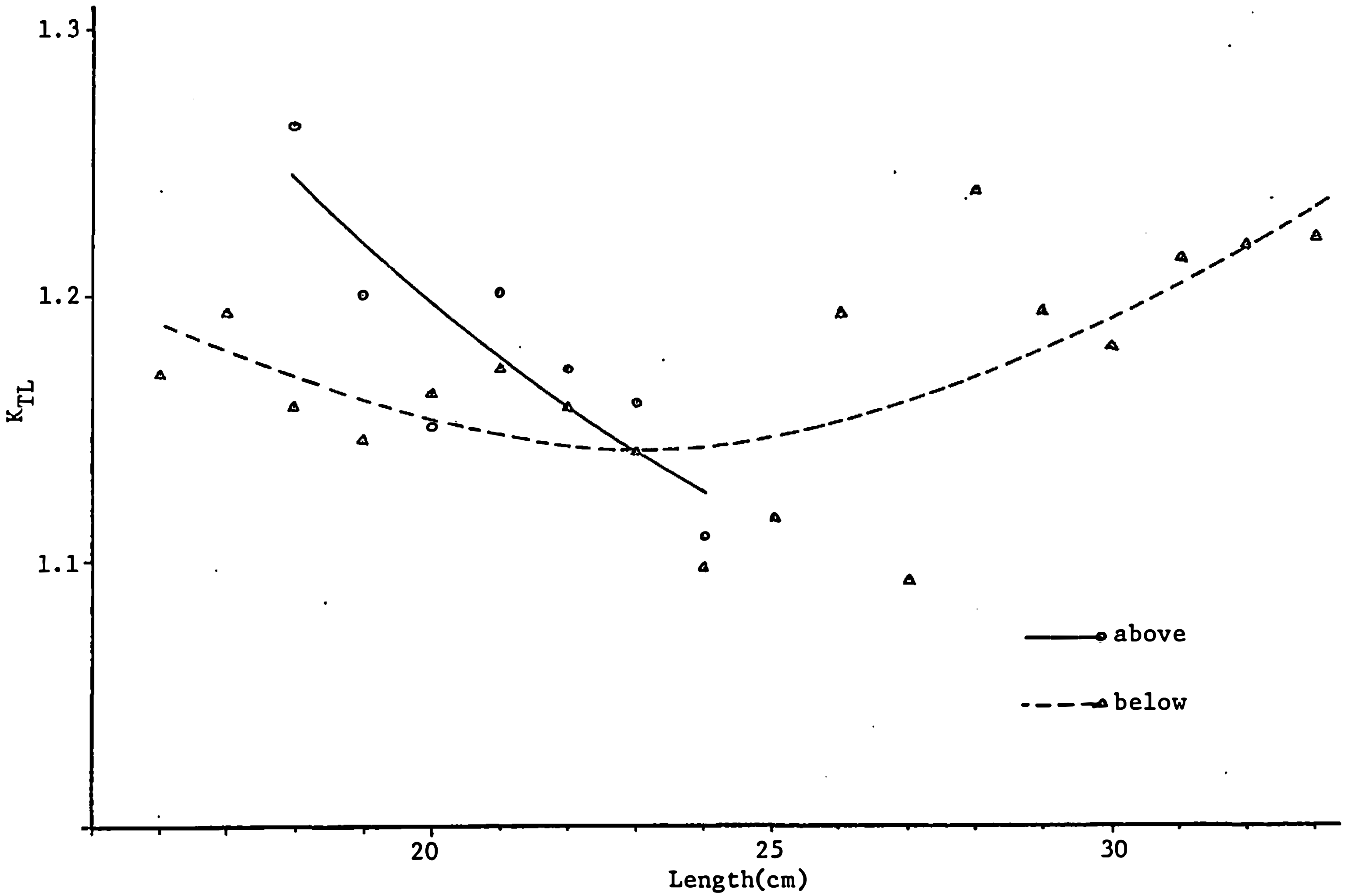

Figure 6. Mean condition factor (K_{TL}) vs. length for white suckers above and below Sioux Falls.

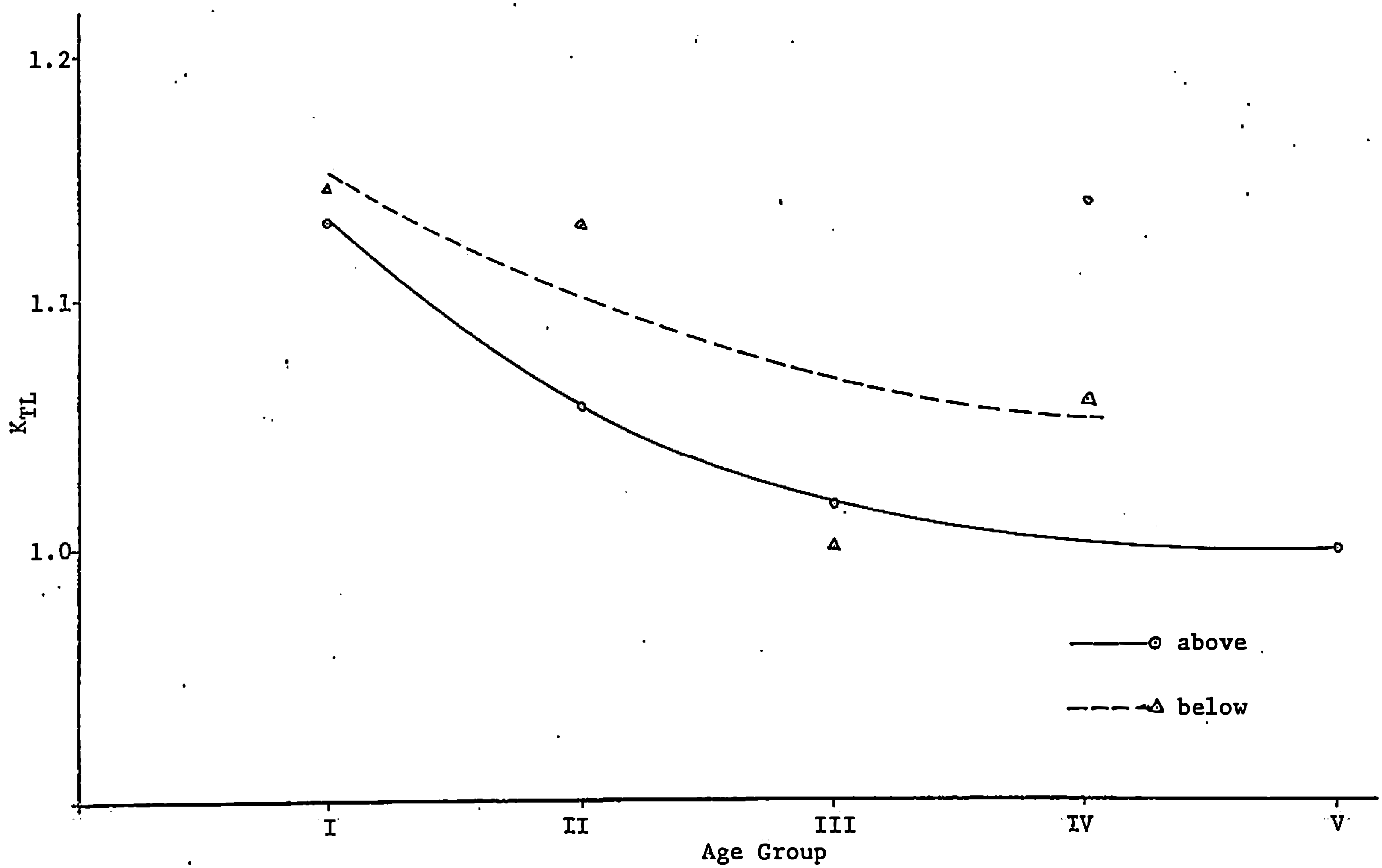

Figure 7. Mean condition factor (K_{TL}) vs. age group for white suckers above and below Sioux Falls.

that I used assumes that the specific gravity of the fish remains constant and that the volume of the fish is directly proportional to the cube of its length. In practice, this is not the case. The body of most fish changes shape and proportions as it grows longer. If the fish caught are considered as one population, then the required correction factor will take on a very strange form. This can be seen from Figure 4, for example. Complex curves such as these require higher order equations for correction. In this case the correction factor would have to show that the body shape changed in one direction for a time and then changed in another direction. Normally a fish changes shape in one direction throughout its life, though it may change at different rates. What is probably shown in Figure 4 for northern redhorse above Sioux Falls is two (or more) populations, one above 25 cm and the other below 25 cm in length. Each population contributes only a part of the composite curve. That this same shape curve is not present when K_{TL} is plotted against age group (Figure 5) only indicates the wide variation within each indicated age group.

Only K_{TL} vs. length could be plotted for bullheads since no means of ageing these fish was available. As a result of the stocking of bullheads and crappies of unknown age and condition at several locations in the Big Sioux River, fishes of these species taken from these and adjacent stations were not included in any analysis of data. It is possible that some of these fish (which were probably in poor condition) migrated farther than the adjacent station and thus may have been included in the data for other stations. It is unlikely that this applies to any appreciable number of fish however, so no large effect should be expected.

Young bullheads were not as abundant below Sioux Falls as they were above. This may be because river conditions are not as suitable for reproduction below Sioux Falls as above. The higher condition factor of bullheads under 15 cm above Sioux Falls indicates better growth for young bullheads above the city at any rate.

Condition factors for adult fishes were generally larger for fishes from below Sioux Falls than for fishes from above (Figures 1 through 7). The opposite situation usually held for smaller fishes. Since the higher condition factor indicates a "fatter" fish, it appears conditions above Sioux Falls are better for smaller fishes and conditions below better for larger fishes. Which specific factors are responsible for these effects is not known. It is possible that severe conditions below Sioux Falls (oxygen depletion) have kept the populations to a lower level and thus allowed greater growth. It is also possible that less favorable conditions for reproduction below Sioux Falls have kept the population lower, or simply that small fishes may exhibit a higher condition factor than large fishes in smaller waters and large fishes exhibit a higher condition factor than small fish in larger waters. A more limited number of species generally indicates more severe ecological conditions. This is almost certainly the situation immediately below Sioux Falls.

Attempts to relate condition to food supply were inconclusive. The fact that only three fishes had food in their stomachs suggests that little food was available. The excellent condition of others belies this, at least for the fishes in good condition. A more probable situation is that sampling was long enough after feeding to allow the fishes to complete digestion of food taken at the last feeding. Of course, such drastic methods of collection as poisoning could cause the fish to regurgitate any food present. Trap nets are also known to cause fishes' stomachs to be empty when they are collected. Seines and shockers, however, should have yielded some stomach contents if they were present. It is interesting to note that the three fishes that did have stomach contents were taken with cyanide.

Ageing

Ageing of fishes by scale annuli was difficult and led to inconsistent results. Many times small fishes had more annuli than larger fishes. Furthermore, there was no clear cut distinction between the two extremes; they intergraded completely. No correlations were apparent either with location or the time of year of collecting. This requires either that several separate populations of each species are present in each sample or that scale growth is not proportional to the length of the fish. In the first case, length frequency analyses will be meaningless, and samples must be large enough to include an adequate sample of each population present. This presents a problem in determining how large a sample is required to make any statements about the populations. Assuming the age data are correct and each different growth pattern on a scale represents a separate population, a statistically valid sample of each population would approach 100 per cent of the fish in any sample area. This type of sample is usually impractical. The second possibility is that growth of the fish and growth of the scale in different years are not proportional to the same degree. If false annuli or growth checks are present, this could easily occur. It is in fact, more likely in a river with its harsher and more variable environment than in a lake. In the first possibility, the number of populations could be disregarded and the entire complement of fish treated as one population if limitations on the conclusions to be drawn are imposed. This, of course, would considerably reduce the required sample size. In the second possibility, and especially if both possibilities occur simultaneously, ageing from scales is invalidated. This, I believe, is the situation that now occurs in the Big Sioux River. In a river such as this (i.e. a medium sized river) it is unlikely that any other method of ageing fish could be applied, both because of the difficulty of sampling this particular size of river adequately and because of the apparent mingling of populations through migration and movement. Fish could be marked, and an idea of the growth of other fish related to the recaptured, marked fish's growth, but this has obvious size and movement limitations at the very least. These factors place severe limitations on practical age and growth work in this river.

Sampling Effectiveness

Due to the large amount of floating debris in the stream during high water periods, especially in the upper portions of the river, fishing with nets was not practical at these times. Use of poisons was also precluded since block nets could not be used effectively. An electric shocker was not available during these periods, but it is unlikely that it would have proved more effective than it did later. It appeared that fishes were more widely distributed during high water and thus explosives were not very effective. Thus no practical methods were found for sampling fishes during periods of high water. No attempts were made to fish under the ice since methods for doing so were not available. These factors limited fishing to periods of lower water levels.

Seines were greatly limited by current and submerged snags. Only a small part of the river could be sampled by seining. In addition, seines appeared to be very selective for small fishes. Other sampling methods used in area previously seined yielded a much greater proportion of larger fishes. Trap and hoop nets were also very selective as to species in addition to the limit on size of fishes taken imposed by mesh size. Gill nets were only moderately successful at best and at times were almost totally unsuccessful. In addition to sampling only certain species of fishes, (Moyle, 1950; Cleary and Greenbank, 1954) the gill nets used were often completely empty, sometimes for two or three days, and then they would have a large catch the next day. This emphasizes the statement by Moyle (op. cit.) that "the size of the gill net catch is a product of the size of the population sampled and the movement of the fish making up the population". In every case where nets were used, water level and current were the factors governing usability of a net. Since these are both highly variable in a river such as this, it becomes possible to sample an area with nets only at certain times. This alone introduces a serious bias into the data obtained, since the fishes in a river necessarily have to move to different locations when water level or current become unsuitable or they will perish. Thus the population present in an area and sampled by a net is usually different from that present in the river as a whole.

The electric shocker proved quite effective in stunning or drawing fishes to the positive electrode in most cases. The chief drawback in its use was due to the turbidity of the water. Unless a fish was drawn to within a few inches of the surface, it usually was not observed in time to be netted. Often, a swirl or flash of tail was seen as the fish passed out of the shocker field. Previous experience in clearer waters indicates that many more fishes, especially the smaller ones, do not manage to swim to very near the positive electrode before being stunned by the electric field. Thus I feel future fishing with electroshocking gear in the Big Sioux River will not be effective unless a considerable reduction in turbidity occurs.

Explosives would appear to be ideal for sampling those pockets which are likely to contain fish but cannot be sampled by other methods because of mechanical limitations. In practice, they are less than ideal for this purpose, since many of the stunned fish sink. In the turbid Big Sioux, this drastically limits the quantitative sampling used of explosives, though they are still of some use for qualitative samples. This technique was tried in an effort to sample during periods of high water, but results were poor, probably due to dispersion of fishes by the high water. It proved more useful during lower water levels, but since poisons were less selective and could sample a larger area with more types of habitat, they were more frequently used. Explosives should be considered in any quick survey of clear water streams, however.

Rotenone supplied by the Iowa Conservation Commission's river biologist was tried in September 1966. Abnormally high water limited the effectiveness by dilution and also made use of the block nets extremely difficult. A crew of seven men plus 10 or 12 seine stakes could not keep the nets effective as they rapidly filled with floating debris and caused the water and poisoned fish to flow over the top of the net. Since rotenone was not readily available in 1967, sodium cyanide was used. This has a distinct advantage over rotenone in that at the concentrations used it does not kill the fishes (except small fishes and minnows) as rotenone does. Most of the same considerations for the use of rotenone apply also to cyanide. In addition, cyanide is a deadly poison to humans and animals and must thus be used with much more care (Bridges, 1958; Lewis and Tarrant, 1960). No problem occurred with sodium cyanide except the loss of small fishes. This apparently occurred when the fishes beached themselves in an effort to avoid the poison, and was not caused directly by the poison. Those fishes (both large and small) that did not beach themselves suffered no apparent ill effects. Cyanide also showed some selectivity for species. No adult channel catfish were taken with cyanide, for example, but numerous young-of-the-year catfish were collected. While it is known that there is considerable migration of channel catfish in the lower sections of the Big Sioux River (B. D. Welker, personal communication), it is unlikely that all the adults could migrate out of the extensive areas sampled. (This would also require passing the falls at Sioux Falls and several dams.)

A more apparent means of selectivity in poison sampling is that the dip net operators tend to collect the larger specimens preferentially. After one or two large fishes are in the dip net, it is much harder to move it through the water and consequently the operator then tends to select the larger fishes (which requires less effort to fill the net) rather than the smaller fishes and minnows. In addition the small fishes tend to beach themselves and get mired in the mud and debris along the river bank where they are easily overlooked. This is especially noticeable during high water temperatures. Thus, purely from human error, poison is selective as to species (larger species as opposed to minnows and smaller species) and size of fishes. This effect also appears to be somewhat temperature dependent. Some selection must also operate with a block net. Larger fishes do not always float down to the net. Current is also a factor. Some species are also more affected by a given poison than others, which of course gives a species selection. In addition fishes at the upper end of the section sampled are less likely to be affected long enough to reach the block net than those lower down in the section, especially if the current is sluggish. This will introduce selection as to habitat if the type of habitat differs throughout the section sampled.

Water Chemistry

Water samples showed wide variations (Tables 16-19). This was due partly to seasonal changes. Thus, in winter dissolved ions were present in higher concentrations than in the runoff of snow-melt water in the spring. While dissolved ions were highly variable with the season, turbidity was not appreciably different at any season. Only a part of the turbidity appears to be from silt. A major portion appears to be fine organic detritus. This probably reflects poor agricultural practices observed in the watershed.

Some variations in the concentrations could not be definitely explained. Under apparently stable conditions of flow, weather, and other factors that might affect the water chemistry, wide variations were observed in several ions. Sulfate, for example, varied widely between Baltic and highway 38A bridge north of Sioux Falls. A reconnaissance of the river between these points yielded no reason for such variation. Moreover, the variation was as often in one direction as in the other. Chloride also showed these variations. Several areas below Sioux Falls also showed variations at times that could not be definitely explained.

Table 16. Data from analyses of Big Sioux River water for conductance (micromhos), total hardness (ppm), total alkalinities (ppm), and pH.

	CONDUCTANCE			HARDNESS(tot)			ALKALINITY(MO)			pH		
STN	mean	range		mean	range		mean	range		mean	range	
1	330	*		222			258			8.1		
2	322	290	350	228	220	238	239	231	251	8.2	8.1	8.4
2a	492	365	650	264	244	283	242	223	270	8.5	8.1	9.0
3	460	*		231			201			9.0		
4	240	*		233			264			8.2		
5	448	430	465	292	289	296	239	238	240	8.6	8.6	8.6
6	586	210	1100	347	120	679	227	103	384	7.3	6.7	7.6
7	620	235	1200	331	100	452	242	105	362	7.5	7.4	7.5
8	1079	310	2300	340	134	708	246	89	390	7.7	7.4	8.2
11	889	330	1650	312	140	389	258	90	411	7.4	7.2	7.8
12	740	230	1200	274	138	334	173	107	220	7.6	**	
13	859	330	1100	258	142	316	158	110	210	7.6	**	
14	642	450	930	248	208	281	176	147	217	7.8	**	

* Only one sample taken at this station.
** Equipment was not available at the time the sample was collected.

Table 17. Data from analyses of Big Sioux River water for chloride, sulfate, sodium, and potassium in ppm.

STN	CHLORIDE mean	range		SULFATE mean	range		SODIUM mean	range		POTASSIUM mean	range	
1	3.2 *			75			16			4.4		
2	3.2	2.0	4.2	64	56	77	14	12	16	4.9	3.7	5.6
2a	44.3	13.6	93.4	100	81	138	48	22	90	6.4	4.7	9.0
3	44.6	37.0	52.2	129	122	136	50	47	53	6.5	6.3	6.7
4	7.3 *			108			15			5.3		
5	13.3	13.0	13.8	152	148	156	24	23	25	5.9	5.6	6.2
6	26.0	7.0	45.5	200	64	417	35	5	55	7.1	4.9	8.1
7	22.1	6.0	33.0	193	28	308	33	4	48	6.9	5.2	9.4
8	188	14.4	530	206	36	428	121	11	270	9.8	8.2	13.2
11	123	18.0	250	156	24	312	92	14	240	8.8	7.6	11.8
12	78.4	10.0	146	178	60	240	68	11	101	8.9	7.4	9.5
13	83.4	10.5	146	192	67	248	73	13	115	9.0	7.8	9.5
14	40.1	15.6	57.0	166	95	236	40	19	54	7.3	6.9	8.1

* Only one sample was taken at this station.

Table 18. Data from analyses of Big Sioux River water for water temperature (centigrade), oxygen (ppm), nitrite (ppm), and total phosphate (ppm).

	WATER TEMP(C)			OXYGEN			NITRITE			TOTAL PHOSPHATE		
STN	mean	range		mean	range		mean	range		mean	range	
1	17	*		6.8			0.006			0.21		
2	21	20	24	7.9	7.0	8.7	0.000	*		0.25	0.12	0.41
2a	22	20	26	10.6	7.4	12.5	0.021	0.043	0.061	1.64	0.72	2.88
3	22	22	22	15.3	12.8	17.3	0.002	0.000	0.003	0.57	0.45	0.70
4	20	*		8.9			0.018			0.54		
5	27	27	27	11.1	10.6	11.6	0.000	0.000	0.001	0.46	0.35	0.57
6	11	0	29	10.6	3.4	17.1	0.015	0.000	0.041	0.59	0.10	1.18
7	7	0	27	10.7	5.2	15.5	0.014	0.000	0.035	0.58	0.04	1.57
8	9	0	27	9.1	4.8	12.2	0.113	0.020	0.380	4.48	0.94	9.90
11	9	0	29	5.7	0.1	11.0	0.072	0.000	0.250	3.81	0.76	7.20
12	20	11	26	10.4	7.3	12.7	0.206	0.059	0.452	1.92	0.48	4.28
13	22	7	29	11.0	6.2	15.5	0.073	0.000	0.310	1.44	0.38	3.82
14	22	10	29	10.0	6.3	13.6	0.018	0.000	0.049	0.66	0.25	1.05

* Only one sample was taken at this station.

Table 19. Data from analyses of Big Sioux River water for ammonia (ppm), nitrate (ppm), and Secchi disc turbidity (cm).

STN	AMMONIA mean	range		NITRATE mean	range		TURBIDITY (cm) mean	range	
1	0.29	*		0.22			**		
2	0.30	0.29	0.32	0.55	0.01	1.44	**		
2a	0.62	0.32	1.00	1.39	0.64	1.88	**		
3	0.41	0.29	0.53	0.52	0.45	0.60	**		
4	0.30	*		0.45			**		
5	0.29	0.29	0.29	0.52	0.22	0.81	**		
6	1.00	0.22	2.55	0.52	0.20	1.10	27	24	32
7	1.00	0.20	1.26	0.52	0.02	1.40	22	20	24
8	10.6	0.52	23.7	0.64	0.20	1.10	28	26	31
11	8.90	0.58	19.5	0.77	0.10	1.20	23	21	24
12	1.03	0.50	1.90	0.69	0.20	1.25	24	21	27
13	1.01	0.56	1.90	0.78	0.20	1.40	22	19	25
14	0.90	0.30	1.90	0.52	0.30	1.00	16	11	27

* Only one sample was taken at this station.
** Equipment was not available at the time the sample was collected.

A possible explanation is that the water entering the river from the aquifer has highly variable ion concentrations throughout the length of the river. This would probably also require a considerable portion of the surface flow to enter the aquifer and be replaced by water from the aquifer. In several places the river changes in flow, without any tributary present, enough to be apparent without measurement. Further, this change is often to lower flows as well as to higher flows.

Some of the variations were more readily accountable. Sodium, chloride, nitrite, ammonia, nitrate, and phosphate increased considerably below the sewage outflow of towns on the river. The increase below Sioux Falls was usually severalfold, especially during low water conditions. The Biochemical Oxygen Demand added to the river by Sioux Falls must also have been high but facilities for its measurement were not available. Oxygen was depleted at the Klondike, Iowa dam for almost two months (January and February 1967) when cold weather caused the river to ice over. As freezing of the river occurred above Sioux Falls much sooner, and as flow and other conditions apparently did not change appreciably during the entire winter period, it appears that the heat and salts added to the river by Sioux Falls were sufficient to keep it open (and therefore oxygenated) for a considerable distance downstream until the weather got very cold. This would allow the Biochemical Oxygen Demand to decrease. The added heat would also increase the rate of oxidation.

Thus, in this respect, pollution added by Sioux Falls is both helpful and harmful. The oxygen depletion which eventually occurred, however, was complete enough to kill even the Diptera larvae as well as the fish and other aquatic organisms in the area above the dam at Klondike. In spite of this fish kill, fish were not scarce the next summer, indicating that the river can repopulate, at least, short sections rapidly.

As can be seen in Table 16, several values for oxygen are considerably above saturation. This is probably not actually the case. A more likely explanation is that some organic matter in the water reacted with some of the thiosulfate titrant to give high readings. The color of the liberated iodine before titration was not noticeably different for these high-reading samples than for samples giving normal readings of near saturation.

Phosphate and nitrogen levels are high throughout the entire river, as are alkalinities. The phosphate and nitrogen levels are greatly increased below towns of any size. It was expected then that algal blooms would occur. These were absent, however, probably because the rapid current and high turbidity made conditions unsuitable for their development. Any modification of the river which would reduce either or both of these two factors (such as the large impoundments proposed by the U. S. Army Corps of Engineers) would almost surely create serious algae nuisances unless there was a corresponding reduction in nutrient levels. It would also be more difficult for a very large impoundment to repopulate with fish if it killed out during the winter. It is likely that it would kill out during the winter due to oxygen depletion since a large amount of organic matter is carried by the river and would settle out in an impoundment, thus building up an oxygen-demanding sediment. This effect would be in addition to the oxygen demand of suspended material and of the algae produced due to the nutrient enriched water present in the river. Because of the large amount of silt apparently carried by the river, an impoundment would rapidly fill with silt and the reduced volume of water would further increase the probability of winter kill, since there is less total oxygen present in a smaller volume of water.

CONCLUSIONS

The relative abundance of each species in a population is important. This can be obtained without much difficulty and may well be as accurate as a more detailed population estimate. It will be accurate enough for most fish management work in any case.

The selectivity of the sampling methods available and the heterogeneous fish populations apparently present in the Big Sioux River make population estimates highly questionable. If the population is actually as mobile as the samples indicate, a population estimate made one week would be quite different from one made the next. This makes any population estimate of questionable accuracy unless it covers the entire river in a relatively short period. Such an estimate would be impractical since, in order to be reliable it would have to be completed in a very short time, perhaps only a few days.

On the basis of the samples, carp and bullheads are the dominant large species with suckers and redhorse respectively, the next most abundant. Sand shiners or fathead minnows are the dominant minnow species depending on which particular area is sampled. Abundance of each species in the river is influenced by combinations of factors including water quality and the physical habitat. Water quality is probably the most important factor, particularly the lower limits of oxygen, turbidity and silt load, and toxic pollutants.

The population of game fishes, at least in the river above Fairview, appears to be too small to provide much fishing. The only game fishes taken were the northern pike, walleye, and the two species of crappies. All were scarce considering the river as a whole. Catfish in this part of the river are apparently not common, but this may only be due to selectivity in sampling.

Of the various fish sampling methods tried, only poison gave useable results on all species. Except for the difficulty introduced by turbidity, electroshocking probably would be the second choice for a universal method. Minnows could be sampled in most instances with seines, but poison gives a larger and probably more complete sample so it is to be preferred. Poison, in addition is less limited by the physical characteristics of the stream than are seines. Various passive-fishing devices would be useful, but only for certain species. Explosives are probably of little use in a turbid river, but may be the best means of taking qualitative samples in clear waters. In all cases the drawbacks of each method must be recognized and either avoided or allowed for when analyzing the resulting data.

The apparent mixing of several populations of each species which showed different growth characteristics made analysis of data difficult. This was discovered by scale ageing, although the differences could easily have been overlooked if they had not been so great. Therefore, scale ageing should be done in any fish study where severe ecological conditions prevail or migration from one ecological situation to another is possible. Where mixed populations occur age and growth data from scale ageing may not have any management use but may serve to indicate that the mixed populations are present.

Condition factors can also be very misleading in situations where migration and mixed populations occur. While the usefulness and reliability of condition factors depends on the management use to which they are put, limiting them to fish taken from a relatively small area over a short period of time eliminates many of the factors that limit them in most situations. In fact, most difficulties in analysis of data will be minimized by only considering a small section of a stream that has been sampled over a short period of time.

The most important conclusion relative to water quality is that sampling must be nearly continuous, and even then, attaching significance to the data will be difficult until more relationships are determined between water quality and actual conditions present in the ecosystem. Even with this serious limitation, though, it is obvious that any grab sample with a paramater or parameters lower than a known limiting value is significant. The oxygen depletion at Klondike is a good example of this. More work is necessary though in the area of actual limiting values for successful population development, since these values may be higher than the lethal values.

In this river, chloride, nitrite, phosphate, and sodium appear to be the best indicators of urban pollution. Rural or industrial pollution do not have any set indicators; the parameter changed will vary with the cause of the pollution. This, of course, is all relative to additions of chemical components and does not consider such factors as land abuse (or others) which are also a form of pollution.

Future fish surveys on rivers such as this could benefit greatly from a more representative sampling method. While the best method available in this study appears to have been cyanide, it was severely limited by water levels and volumes. It would be very desirable to limit both the area covered and the time of sampling for fish in future surveys on rivers such as this. The base of operations is impractically far from the sampling location if the driving time exceeds two hours.

Water sampling should be as continuous as possible if any conclusions are to be considered reliable. Other parameters such as insecticides, organic pollution, and certainly the unexplained flow changes, which indicate that some of the (polluted) surface flow is getting into the aquifer, need investigation before any more major changes affecting the river are made.

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Appendix A. List of species taken from the Big Sioux River in 1966 and 1967.

Species Number	Common and scientific name
1	White bass (Roccus chrysops)
2	Bigmouth buffalo (Ictobius cyprinellus)
3	Smallmouth buffalo (Ictobius bubalus)
4a	Black bullhead (Ictalurus melas) - adult
4b	Black bullhead (YY)*
5a	Carp (Cyprinus carpio) - adult
5b	Carp (YY)
6a	Quillback (Carpiodes cyprinus) - adult
6b	Quillback (YY)
7a	Channel catfish (Ictalurus punctatus) - adult
7b	Channel catfish (YY)
8	Black crappie (Pomoxis nigromaculatus)
9	White crappie (Pomoxis annularis)
10a	Freshwater drum (Aplodinotus grunniens) - adult
10b	Freshwater drum (YY)
11	Gizzard shad (Dorosoma cepedianum)
12	Goldeye (Hiodon alosoides)
13a	Northern pike (Esox lucius) - adult
13b	Northern pike (YY)
14a	Northern redhorse (Moxostoma macrolepidotum) - adult
14b	Northern redhorse (YY)
15a	White sucker (Catostomus commersoni) - adult
15b	White sucker (YY)
16	Green sunfish (Lepomis cyanellus)
17	Orangespotted sunfish (Lepomis humilis)
18	Pumpkinseed (Lepomis gibbosus)
19a	Walleye (Stizostedion vitreum vitreum) - adult
19b	Walleye (YY)
20a	Yellow perch (Perca flavescens) - adult
20b	Yellow perch (YY)
21	Stoneroller (Campostoma anomalum)
22	Brassy minnow (Hybognathus hankinsoni)
23	Silvery minnow (Hybognathus nuchalis)
24	Emerald shiner (Notropis atherinoides)
25	Common shiner (Notropis cornutus)

Appendix A. (continued)

Species Number	Common and scientific name
26	Red shiner (*Notropis lutrensis*)
27	Sand shiner (*Notropis stramineus*)
28	Bluntnose minnow (*Pimephales notatus*)
29	Fathead minnow (*Pimephales promelas*)
30	Blacknose dace (*Rhinichthys atratulus*)
31	Creek chub (*Semotilus atromaculatus*)
32	Trout-perch (*Percopsis omiscomaycus*)
33	Iowa darter (*Etheostoma exile*)
34	Johnny darter (*Etheostoma nigrum*)
35	Stonecat (*Noturus flavus*)

* (YY) = young-of-the-year