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ANALYSIS OF THE COMPOSITION OF FISH POPULATIONS IN MINNESOTA'S RIVERS AND STREAMS

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By

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SUMMARY

In an electrofishing sample from a large river, about 71 percent of the catch is Catostomids (suckers) and carp, 14 percent is game fish such as smallmouth bass, walleyes, northern pike, channel catfish, and white bass, 4 percent is sport fish (Centrarchids such as sunfish, crappies, and rock bass), and a trace is small fishes such as minnows and darters, and 9 percent is other fish such as bullheads, yellow perch, dogfish, and sheepshead. In larger rivers, optimum catches of warmwater game fish were made when they made up 14 to 30 percent of the sample. In a coldwater stream, trout make up more than 22 percent of the total catch.

Where small fishes are abundant, as in small warmwater streams, the diversity index is usually high (over 2.6) because several species are present. Where considerable environmental stress is present resulting from pollution and eroding sandy soils, the diversity index, excluding small fishes, is usually below 1.0. An abundance of young-of-the-year fishes can also cause the diversity index to be low. In rivers, the diversity index usually ranges between 1.8 and 2.6.

INTRODUCTION

The objective of this report is to determine how the diversity index and related ideas can be used to analyze fish species compositions. However, this does not replace standing crop measurements such as number or weight per unit which will also be considered.

Assessing meaning or value of various types of fish species compositions has been a subjective rather than an objective fisheries investigative procedure. Recent advances in the use of the diversity index ($\bar{d}$) appear to have some value for solving fish species composition problems. Variations of the diversity index, as proposed by Margalef, are being used to evaluate samples of invertebrate and plankton populations. This index, which measures species richness and distribution of individuals among species, appears to be useful for evaluating fish species compositions.

From the following, it can be ascertained that stress on an aquatic environment can take many forms, such as: excessive wastes from cities, farms, and industries; cold water temperatures; or unstable soils. Stress tends to lower the diversity index below 1.0 in extreme situations and is above 2.0 in more normal environments. Stress, as indicated by low diversity indexes, may be viewed as desirable when amount of the target species produced is high. For example - trout in coldwater streams. In warmwater streams, stress appears to favor an abundance of large rough fish where the streams and rivers are larger and deeper, and small fishes, such as minnows, in small shallow streams.

BACKGROUND

Hutchinson (1967) describes the diversity index and its background as it applies to plankton. The U.S. Environmental Protection Agency (1973) presents a convenient form of the index and an updated summary for its use with macro-invertebrates.

Hutchinson (1967) notes that when the assemblage consists of a single species, the diversity index ($\bar{d}$) equals zero. He also notes the diversity index ($\bar{d}$) is maximal when all species are equally abundant. When all species are equally abundant, the diversity index ($\bar{d}$) increases as the number of species increase. He also states that six perennial (or almost perennial) species of phytoplankton contribute about half of the value of the diversity index ($\bar{d}$). The 1973 U.S. Environmental Agency manual notes the use of the diversity index based on the generally observed phenomenon that relatively undisturbed environments support communities having large numbers of species with no individual species present in overwhelming abundance. Many forms of stress tend to reduce diversity by making the environment unsuitable for some species or by giving other species a competitive advantage. There are naturally occurring extreme environments in which the diversity of macroinvertebrate communities may be low.

This index has been used extensively in pollution investigations. The U.S. Environmental Protection Agency in its 1973 manual notes that a diversity index ($\bar{d}$) of less than one was usually associated with polluted water, and an index ranging from three to four was associated with unpolluted water. A table showing the hypothetical number of species for various diversity index values is presented which shows that where the index ranges from zero to one there are zero to two species present, from diversity index one to two there are three to five species, from diversity index two to three there are six to eleven species, and from diversity index three to four there are twelve to twenty-three species present. By dividing the hypothetical number of species by the observed number, an index of equitability can be calculated. Where the index of equitability is less than 0.2, the water was generally polluted and degraded below 0.5. In streams unaffected by oxygen demanding wastes, the equitability index was between 0.6 and 0.8.

Skrypek (1969) investigated the fisheries of the Mississippi River from above the junction of the Minnesota River to Hastings. This study included the area where the amount of dissolved oxygen present is frequently minimal, nearly 0.0 ppm. He reports rough fish, primarily carp, were 94 percent of the net catches. The diversity index calculated for these catches was 0.62 in the degraded section and 2.01 above the zone of degradation. The equitability index was 0.2 in the degraded section and 0.4 above the zone of degradation. The diversity index calculated from electro-fishing samples were similar, except that the diversity index above the zone of degradation was 2.96 and the equitability index was 0.8. Note that these results agree with the macroinvertebrate standards for polluted and non-polluted water. Skrypek also notes that game fish were a smaller portion of the catch (20 percent) in the degraded area than they were much farther downstream (85 percent of the catch) where better water and bottom conditions exist.

In Minnesota's game fish lakes, large rough fish are about eight percent of the fish population's total weight, but in lakes subject to winterkill and other problems, large rough fish are about 81 percent of the fish population's total weight, recalculated from Moyle (1948). Moyle (1948) notes that the weight per acre of game fish and small forage in rough fish and game fish lakes is nearly equal and that large rough fish, primarily carp and buffalo, are a large proportion of the total fish population in Minnesota's southern rough fish lakes. Moyle's 1948 data for lakes is similar to Skrypek's 1969 Mississippi River data. The data shows that large rough fish predominate in areas where excessive environmental stress is present. In rough fish lakes, the stress is usually low oxygen levels in the winter.

Cold water in trout streams creates environmental stress and limits the number of species present. In the coldest and best streams, trout, suckers, sculpins, and one or two species of minnows are found. In the warmer coldwater streams, trout and sculpins are much less abundant and many species of minnows and large rough fish are more abundant. Johnson (1946) discusses the size of fish populations in Minnesota's southeastern trout streams and enough electrofishing data on numbers of fish caught is available to calculate a diversity index. In the stream where the trout population was highest (38.7 percent of the total weight), the diversity index ($\bar{d}$) was 1.69, the minnow population was very low (2.4 percent of the total weight), and the white sucker population was higher than the trout population. In a stream which was much warmer and where the trout population was very low (4.2 percent of the total weight), the diversity index ($\bar{d}$ = 2.23) was higher, several species of minnows comprised the bulk of the population (58.3 percent), and white suckers were 37.5 percent of the total weight.

Johnson (1946) also notes that there is evidence of an erratic decrease in the size of fish populations in streams from their middle sections to their mouths. Johnson (1949) frequently notes in his descriptions of the streams, that the lower parts of the streams are fine and easily erodable soils.

In larger creeks and rivers with no water regulation and with sandy soils such as the St. Croix, the highest density of fish occurred where the standing crop of benthos was highest. Ordinarily, the standing crop of benthos was highest on stable non-eroding bottoms. Coarse textured soils, gravel and rubble, are stable where water velocities are high. In the St. Croix River, the water velocity was about 1.7 feet per second during the summer at an ordinary river stage, and this was enough to move sand particles along the bottom but not suspend them in the water. Where the soils were stable, some aquatic plants were present.

The diversity indexes calculated for the fish catches changed from 0.45 over eroding sandy soils, to 0.97 over adjacent more stable soils. The diversity index for the whole river was 2.47 so most of the species and numbers of fish were caught where the habitat was best. One genera of fish, redhorse, was 94 percent of the catch at a diversity index of 0.45, 87 percent at 0.97, and 63 percent at 2.47. Game and sport fishes were about nine percent of the catch at diversity index 2.47. In the Upper Mississippi below Winnibigoshish Reservoir, yellow perch were the most frequently caught species (42 percent). Game and sport fishes were 16 percent of the catch at a diversity index of 3.17. In the section sampled, aquatic vegetation was abundant on a sandy river bottom where the water velocity was low. On the sandy river bottom, the velocities were 0.3 to 0.9 feet per second in pools and 1.0 to 1.4 feet per second in the riffles.

METHODS

This study is essentially a survey of existing records so previous collection methods and taxonomic skill will influence the results. Inconsistent results from preliminary calculations were caused by variable reporting procedures and/or taxonomic skill in two groups of fishes and these were the redhorse, genus Moxostoma, and the small fishes such as the minnows and darters. In the electro-fishing samples in larger rivers, small fish, such as minnows, are normally less than five percent of the total weight of fish caught so they might not be counted, but their presence or absence is usually noted. In smaller streams less than 30 feet wide, small fish are more abundant and can be as much as 50 percent of the total weight in the sample and are ordinarily weighed and counted. So, two sets of calculations were made; those where small fishes were excluded (all larger rivers) and those where small fishes were included (small streams and some larger rivers). Compositions of the catch were calculated for the following five categories because the species present varies considerably from stream to stream and have a similar generalized composition. The five categories are as follows:

1. Large rough fish which include carp and all members of the family Catostomidae.

2. Game fish which include northern pike, walleye, sauger, white bass, smallmouth bass, largemouth bass, catfish, and muskellunge.

3. Sport fish which include sunfish, crappies, and rock bass.

4. Others - this includes yellow perch, bullheads, dogfish, sheepshead, burbot, and other large fishes.

5. Small fishes which include minnows, darters, sculpins, mudminnows, killifishes, madtoms, and sticklebacks.

In larger rivers, the fifth category is excluded from the calculations of composition and included for smaller streams.

There is a convenient method of calculating the diversity index in the EPA manual, so no search of the literature was made for calculations procedures and were calculated as outlined in the manual. The formula as presented is $\bar{d}=c/n\ (N \log_{10} N - \sum n_i \log 10\ n_i)$.

$\bar{d}$ = diversity index

c = a constant which is 3.3219

N = number of individuals in whole sample = total fish of all species

n_i = number of individuals in each species

$n_i \log 10\ n_i$ = number of individuals of each species multiplied by logarithm of the number of each species

N log 10 N = number of individuals in the whole sample (all species) multiplied by logarithm of the number of individuals in the whole sample

The diversity index uses a mathematic quirk related to the exponential function of numbers which is as follows: where N = number of individuals sampled of all species, n = number of individuals in each species, ${n_1}^n + {n_2}^n + {n_3}^n + \ldots$ is not equal to N^N except where n_1 is equal to N, and all other values of n are zero. Since the numbers involved are large, the logarithmic values are used. The logarithmic sum of ${n_1}^n + {n_x}^n + {n_3}^n \ldots$ is subtracted from logarithum of N^N, converted to a natural logarithm, then the average logarithmic difference is calculated by dividing by the number of individuals (N) in the sample. Where the average difference (diversity index) is low, one or two species dominate the sample. Where the difference (diversity index) is large, several species are well represented in the sample.

When the first 21 calculations of the $\bar{d}$ were made, some very high values (over six) were obtained. It was noted that no species of large rough fish dominated the catch where it was expected. It was also noted that where the $\bar{d}$ was unreasonably high, several species of redhorse, genus Moxostoma, were present. The $\bar{d}$ values were recalculated using the genus Moxostoma as the distinct taxonomic group, and the result was that all values were less than four (mean 2.1) and 14 percent, or three of the 21 values, were more than three. Where redhorse species were separated, 43 percent of the values were more than three. A chi square test showed that these distributions were not similar. So, all species of redhorse were lumped in later calculations because the range of values were similar to those noted for invertebrates.

SPECIES PRESENT IN STREAMS AND RIVERS

When some species lists for various sized streams were compiled, it became apparent that most warmwater species were present to some extent in streams and rivers of various sizes, that the coldest streams had fewer and frequently different species of fish, that some warmwater fishes were present in coldwater streams, that larger sized fishes dominate the fish populations of larger rivers, and that small fishes, such as minnows, were likely to be most abundant in small streams.

Most of the larger rivers and streams were inhabited by Catostomids and carp in varying amounts, and as a group these species usually were more than 50 percent of the catch. Excepting smallmouth bass and rock bass, Centrarchids were a small proportion of the catch except where stream or river conditions allowed the development of communities similar to lakes. One or more of species such as smallmouth bass, walleye, northern pike, channel catfish, trout, and white bass occur in most waters, but tend to be found in specific kinds of habitat. While small fishes such as minnows, darters, and sculpins were present in all waters, they were only abundant in small streams. Some species were only abundant where conditions were favorable. Other fishes were a small fraction of the catch except that sometimes yellow perch and bullheads were abundant in streams below lakes or where lake-like conditions occurred.

Since species of fish tend to be arranged according to temperature and size of stream, the following lists were prepared to illustrate what species might occur in various kinds of streams.

Coldwater Streams

In coldwater streams, the fish which occur commonly are trout (rainbow, brook and/or brown trout), sculpins, blacknose dace, and white suckers with pearl dace and creek chubs. Johnny darters occur more commonly in the warmer coldwater streams and white suckers occur least commonly in the coldest streams. Very cold portions of streams might be predominantly trout.

Warmwater Streams and Rivers

Small warmwater streams less than 20 feet wide are frequently inhabited by small sized fishes. Species such as creek chubs, johnny darters, common shiners, blacknose dace, longnose dace, redbelly dace, fathead minnows, bluntnose minnows, brassy minnows, mudminnows, and yellow perch occur frequently. Larger sized species are ordinarily white suckers, northern pike, and sometimes burbot and smallmouth bass.

In small rivers and streams from 20 to 40 feet wide, fish which occur are northern pike, smallmouth bass, rock bass, white suckers, hog suckers, blacknose dace, longnose dace, common shiner, spotfin shiner, johnny darter, yellow perch, black bullhead, burbot, and stonecats.

In intermediate sized rivers from 40 to 100 feet wide, fish which commonly are found are northern pike, walleye, smallmouth bass, channel catfish, white sucker, redhorse, quillback, carp, hog sucker, white bass, rock bass, stonecat, and black bullhead. To a lesser extent, small fishes such as longnose dace, blacknose dace, common shiner, spotfin shiner, and johnny darters are present.

In rivers wider than 100 feet, minnows are present, but not very abundant. Johnny darters, log perch, madtoms, and trout perch might be fairly abundant, but the main species of fish are northern pike, walleye, channel catfish, smallmouth bass, redhorse, white sucker, buffalo, carp, sheepshead, hog sucker, white bass, carp suckers, dogfish, bullheads, and sturgeon.

DISTRIBUTION OF BIOMASS

Comparing the biomass of fish in various waters can become complicated because habitat needs differ and because low or high water temperatures restrict the abundance of some species. Peterson (1974) notes that, going from south to north, Minnesota is located where southern species disappear and northern species become abundant, and that distribution of many fishes was related to average summer air temperature. Where dominant species vary, several species must be lumped into broad groups to compare them. The groups used must occur naturally and be used by fishery workers.

The kinds of fish present in streams and rivers were arranged into the following broad species groups which are as follows: large rough fish (suckers, redhorse, carp suckers, buffalo, and carp), game fishes (smallmouth bass, walleye, sauger, northern pike, channel catfish, trout, and white bass), sport fishes (Centrarchids, except smallmouth and largemouth bass), small fishes (minnows, mudminnows, darters, trout perch, sculpins, and brook stickleback), and other fishes (ordinarily bullheads and yellow perch and occasionally drum, gar, burbot, dogfish, and sturgeon).

To gain insight into the way the biomass was distributed between the groups in various waters in the state, Table 2 was compiled.

Table 2 - Composition of the fish populations by weight in various kinds of Minnesota waters

	Percent				
Category of fish	Centrarchid lakes	Rough fish lakes	Rivers 1/	Southeastern streams 2/	North Shore trout waters
Game fishes	12.0	3.2	9.0	12.8	65.1
Sport fishes	38.6	16.0	0.6	0.0 3/	0.0
All rough fish	28.0	80.0	90.4	67.9	11.8
Catastomids-carp	8.0	69.0	90.1	67.9	10.3
Others	20.0	11.8	0.3	0.0	1.5
Small fishes	21.4	7.4	trace	29.4	18.2

1/ Average yearly flow over 100 cfs. 2/ Mostly trout streams.
3/ Ordinarily 4% or less in warmwater streams.

It can be observed in Table 2 that the distribution of biomass varies between species groups in various kinds of waters. Small fishes are likely to be a major part of the catch in smaller streams. Large rough fish are frequently a small part of the catch in coldwater streams and a large part of the catch in larger rivers. Game fish are a small part of the catch in larger rivers and a much larger proportion in most coldwater streams. In our northeastern trout waters, large rough fish (white suckers) are ordinarily a small proportion of the total biomass. The dominant fish are brook trout in the smaller streams, and rainbow trout dominate in the lower ends of the North Shore streams. In other trout waters, large rough fish, especially white suckers, are the most abundant fish.

Several measurements of the size of the standing crop of fish in trout streams have been made in various parts of the state and they are summarized in Table 3. The streams are not listed individually because they represent small 200 to 1000 foot segments of streams, and the samples within a stream can vary considerably. The median standing crop of all fish in trout streams varied from 33 pounds per acre in the northeast to 251 in the southeast. The median standing crop of trout was 20 pounds per acre (range 3 to 34). As a group, the northwestern and north central streams had nearly average standing crops of fish and were quite variable, but the maximum standing crop of trout was found there.

Table 3 - Standing crops of all fish and trout in coldwater streams in various parts of Minnesota

	Standing crop				
	Pounds per Acre				Percent
	All Fish		Trout		
Location	Median	Range	Median	Range	Trout
Southeast					
Root River System	251	91-547	34	6-112	13.6
Other	105	50-135	14	7-21	13.0
North Central and Northwest	74	12-158	18	tr-143	23.8
Central	47	4-181	23	2-45	50.5
East Central	35	5-117	3.0	1-36	9.3
North Shore	33	25-49	22	8-46	66.5
Median	62	-	20	-	-

Where trout are less than 20 percent of the total biomass, some environmental stress is present; for example, stress caused by erosion and high run-off. This also appears to be true in warmwater streams and rivers. In eastern

Minnesota, where the run-off was highest (8-10 inches per year), trout were the smallest portion of the fish population; 9-14 percent. Trout were a larger proportion (over 20 percent) in northwestern Minnesota where the run-off was lowest; 4-6 inches per year. Where stream gradients are high and the bed has stable materials, such as bedrock and large rocks, trout are more abundant. Hiner (1947) notes the effects of floods on some southeastern Minnesota high gradient streams; there was a large loss of fish and benthos. The streams with the highest trout populations in northwestern Minnesota are reported to have fairly stable flows.

The fish biomass in the Root system coldwater streams is 67 to 78 percent lower than it is in warmwater backwater lakes. Excluding small fishes, Christenson (1965) reports an average standing crop of 324 pounds per acre in Mississippi backwaters. Game fish were 21 percent of the biomass. Moyle (1948) reports 375 pounds per acre in southern rough fish lakes. In the Root River system trout streams, the average standing crop of fish was 251 pounds per acre. Moyle (1947) reports coldwater and warmwater streams have similar numbers of benthos, but the weight of benthos in coldwater streams is lower (49 percent). The benthos was 48 grams per square foot in coldwater streams and 99 grams per square foot in warmwater streams.

The biomass of fish present in warmwater streams is higher than in coldwater streams, but any individual warmwater stream might be an exception. For example, the Kettle River, which is located in east central Minnesota, has a standing crop of 11.1 pounds per acre (range 5.5 to 41.9) at five sampling stations. This was lower than the 35 pounds per acre in the east central Minnesota trout streams. The total game fish population was low; 1.7 pounds per acre or 15.7 percent of the total population.

SPECIES COMPOSITION (NUMBERS AND DIVERSITY ($\bar{d}$))

The diversity index is used to measure environmental stress, but it's actually a statistic which shows how dominant the most abundant species are; so, it does not indicate stress directly. It does, however, measure the effect of stress on the species composition. At times, large catches of young-of-the-year fish can cause the index to be low. The population can be quite diverse and composed of undesirable kinds of fish. The problems associated with the use of the diversity index are as follows: (1) determining what various values mean in terms of species composition, (2) determining what the values in streams and rivers are, and (3) determining what species or groups of fish are found at various diversity values.

Since the diversity index is a statistic, it measures a specific characteristic of the species distribution. Figure 10 shows that the density of two or more species is closely correlated and described by the equation $y=108-17.4X$. Y is the percent of the total catch and X = the diversity index. There was a much poorer correlation with the most abundant species. When the diversity was one or below, the equation of the line described the density of the most abundant species. Above a diversity value ($\bar{d}$) of 1.6, the density of the most abundant species was sometimes slightly more than 50 percent of the value of Y.

Coldwater Streams

In the best trout streams where cold water stress is present, the diversity index ($\bar{d}$) values are below $\bar{d}$ = 1.7. Where streams are warmer and small fishes are abundant, the values are higher (range 2.1 - 3.3, median 2.6). Higher values (above 2.6) indicate environmental conditions are variable, and none or parts of streams are suitable for trout. Warmwater fishes are present in the warmest parts of those streams. The trout streams of the St. Louis River basin are an illustration ($\bar{d}$ = 3.14). The trout waters tend to be the small headwater streams, warmwater species dominate the larger lower portions of rivers and streams, and small fishes utilize the warmer, more favorable habitat in small rivers and streams.

Larger Warmwater Rivers

Excluding small fishes, the median diversity index for the electrofishing catches was 2.23, and the values ranged from 0.00 in a large polluted river to 3.54 in one of the small rivers. Ninety percent of the values ranged from 1.24 to 3.13. Values below 1.23 were from samples below known sources of sewage effluents. Samples below the sewage treatment plants showed higher $\bar{d}$ values than the sample where no treatment was present. Dropping small fishes from the calculations lowered the diversity index 20 percent. In larger rivers, the index is decreased about 10 percent, but in smaller rivers, the index can decrease about 30 percent when small fish are excluded.

At a median diversity index of 2.23, 71 percent of the fish caught were large rough fish, 14 percent were game fish, 5 percent were sport fish, and nine percent were other fish. Where the diversity index was low (below 1.0), more than 90 percent of the fish were large rough fish and were less than 50 percent of the fish where the diversity index was high (3.0 or more). Above a diversity index 1.7, game fish were 10 to 20 percent of the fish present and below 10 percent where the diversity index was below 1.7 (see Figure 9). Sport fish (small Centrarchids) were a small fraction of the catch , and the maximum was eight to ten percent above 3.0 on the diversity scale. Other fish, such as bullheads and yellow perch, were a small fraction of the catch, except above 3.0, they were sometimes 30 percent of the catch.

Lower Mississippi River backwater samples were excluded from the sample because large numbers of young-of-the-year shad lowered the diversity values which ranged from 0.8 to 1.3. When all young-of-the-year fish were excluded from the calculations, the diversity index increased from 0.8 to 3.75 which was approximately a normal value (3.1) for the river channel. At the same time, the sample size decreased about 93 percent (young-of-the-year fish) which indicates that the lake was a nursery area. In the main channel, young-of-the-year fish were 35 percent of the sample.

In the Upper Mississippi above Pokegama Reservoir, young-of-the-year were 33 percent of the catch and diversity index was 2.09. Between Brainerd and Grand Rapids, young-of-the-year were 30 percent of the catch at 3.44, but the amount for each species varied from about less than one to 70 percent of the catch. In a typical shocking run near Monticello on the Mississippi River, young-of-the-year fish were 34 percent of the total catch, but between species, it ranged from zero for carp to 96 percent for smallmouth bass. Smallmouth bass were 81 percent of the young-of-the-year fish caught.

Variations Related to Stream Characteristics

The diversity index can vary from one part of the river to another, so values calculated from several miles of electrofishing are average values. For example, the average diversity index for the Snake River was 2.71 (range 1.39 to 2.97). Slightly lower than average values (2.27 to 2.36) were characteristic of the steeper gradient rocky bottoms (over 4.0 feet per mile). The area with the lowest value had a steep gradient and was below two large lakes and a town.

In areas of steep gradient where few pools are present, only fish that are strong swimmers can exist, so limiting the number of species lowers the diversity index. Larger fish are the strongest swimmers; usually large rough fish and a few game fish. In areas of steep gradient where riffles and a variety of pools are present, both strong swimmers and fishes which frequent quieter waters of rivers and streams are present. See Table 3 for extent of variation. So, where more species are present, the diversity index can become quite high. In a lower gradient stream, ordinarily there is a small variation in the type of habitat present, so the diversity indexes frequently range from low to average. In impoundments, Centrarchids are more abundant and river gradients are nearly zero. In impoundments, diversity index values are higher because more species of fish are present.

Unstable (eroding) soils create enough environmental stress so that the diversity index was low (0.45 to 0.96 in the St. Croix), and most of the fish population is composed of rough fish. In contrast, the diversity index was fairly high (2.65) in a St. Croix River rapids where rocks predominate and large rough fish were only 35 percent of the fish population. Where stream bottoms are mostly stabilized sand, Upper Mississippi below Winnebigoshish Reservoir, the diversity index was 2.09. In the Mississippi River near Monticello, where rocky gravel bottoms are likely to prevail, the diversity index was about 1.85.

Table 3 - Variations in diversity index as related to stream gradient

Type of Location	Gradient Ft. Mile	Diversity Index	Large Rough Fish
Steep gradient			
Snake River (Lower)	10.3	1.39	75%
St. Croix (Kettle Rapids)	8.3	2.65	35%
Ordinary Channel			
Mostly unstabilized bottom			
St. Croix (Upper)			
unstabilized sand	1.7	0.45	95%
stabilized gravel and rubble	1.7	0.96	88%
Stable bottoms			
Mississippi (Monticello)	1.7	1.85	72%
Mississippi (below Winnibigoshish)	0.26	2.09	20%
River and impoundment			
Mississippi (Grand Rapids to Brainerd)	0.43 (tr. to 1.0)	3.44	61%
Impoundment			
Mississippi (Pokegama)	trace	2.93	19%

DISCUSSION

The diversity index is a statistic which measures how dominant the most abundant species are. The equation $y = 108-14.4x$ expresses this relationship. The two most abundant species (y) are expressed as a percentage of the total catch, and x represents the diversity index. Below a diversity index of 1.0, usually one species is over 90 percent of the value of y and 90 percent of the total catch.

Above a diversity index of 1.7, the most abundant species is less than 80 percent of the total catch. Sometimes two species are co-dominant, 50 percent of the value of y. A low diversity index (below 1.0) is an indication of some form of stress, but can also mean that a large year class of fish is present. For example, young-of-the-year fish may be numerous. Where streams and rivers are cold, fewer species of fish are present so the diversity index tends to be low. In the best trout streams, the diversity index is usually lower than 2.23 which is the median for warmwater streams. When the index is higher than 1.8, the number of warmwater fish, minnows and suckers, increases. When the diversity index is very low, trout are a large part of the catch.

Most of the diversity index values for larger rivers ranges from 1.8 to 2.8 with the median being 2.23. In warmwater streams, when the diversity index is lower than 1.8, a considerable amount of stress is usually present which may be caused by pollution, other environmental problems such as unstable bottoms, or a lack of habitat variation. When the diversity index is 2.8 or higher, major changes in the character of the river is indicated. For example, impoundments, pools, or backwaters are present where fish of slack water, such as sunfish, crappies, or largemouth bass, are likely to be abundant. It is possible to have a high diversity index where the fish population is composed of undesirable species.

Before any diversity index figures can be used effectively, it must be determined to what extent the total biomass is composed of desirable fishes (25 percent game fish) and preferred sizes, because one of the objectives of fish management is to produce as many desirable fish as possible. In large warmwater rivers where large rough fish are abundant, nine percent of the total biomass is game fish. About 65 percent of the biomass in the North Shore streams tributary to Lake Superior is game fish, but only 13 percent of the biomass was game fish in the southeastern trout streams.

Trout waters have an average standing crop of fish which is 60 pounds per acre and the standing crop of trout was 20 pounds per acre. The total standing crop of fish was higher (34 pounds per acre) in the southeast than in the North Shore streams (20 pounds per acre). The northwestern trout streams ordinarily have standing crops similar to the North Shore streams, but a few streams had the highest standing crops of game fish in Minnesota (maximum 143 pounds per acre). Trout streams in east central Minnesota have low standing crops of game fish (three pounds per acre).

The standing crop of game fish should be 20 pounds per acre (range - perhaps 15 to 20 pounds per acre) in any good quality water stream or river, or 19 to 31 percent of the total biomass. In Mississippi backwaters, game fish are 21 percent of the standing crop. It appears that an average Minnesota river (nine percent game fish) should have more game fish (ten percent) to be considered a good quality fish water. Moyle's 1948 tabular data shows that the standing crop of game fishes, northerns, walleyes, and basses, was 16.8 and 12.2 pounds per acre in southern Minnesota's game fish lakes and rough fish lakes, respectively. In a winterkill lake in northern Minnesota, the annual removal was 5.3 to 30.3 (average 15.6) pounds of game fish (northern pike).

Since many samples are expressed only as numbers of fish, standards for evaluating catches are needed. In the warmwater catches examined, 71 percent of the fish caught were large rough fish, 9 percent were other fish, 4 percent were sport fish, and 14 percent were game fish. In 59 percent of the samples, game fish were 8 to 20 percent of the total catch. Low game fish catches (below six percent) occurred in 16 percent of the samples and high game fish catches (above 23 percent) occurred in 25 percent of the lakes. In those samples where the sampling effort was recorded, the average catch per hour was about 100 fish.

Graphing the catch of game fish per hour and the percent of game fish provided a useful summary of the data (see Figure 12). A median catch of 12 game fish per hour was associated with their being 12 percent of the total catch. The highest catches of game fish (above 20 per hour) were recorded when game fish were 14 to 30 percent of the catch. When more than 20 percent of the total catch was game fish, the catch per hour of game fish declined as the percentage increased, but the game fish catch per hour was ordinarily above average.

Average statistics develop comparative data about the status of the fishery, but they don't assess the relationships between species. There are two basic problems which are,(1) analyzing a single sample of several species, and (2) comparing two or more sets of species samples. When the amount of each species caught is graphed on a semi-logarithmic three cycle paper, the relative importance of each species can be compared. Figures 2 to 7 are examples of catches from various rivers at different levels of diversity. The young-of-the-year are represented in the shaded portion of the graph. In Figures 5 and 7, other immature fish were also separated to illustrate the population structure in terms of adults, young-of-the-year, and older immature fish.

Included in Figure 8, are bands showing mature fish as 50 percent of the catch, young-of-the-year as 30 percent of the catch, and other immature fish as the remainder of the catch. Figure 8 was constructed by assigning rank numbers to each species; highest species, catch one, and next highest, two, and so forth. Then a line was fitted to the data by converting both the percent composition and the species rank to a logarithm form; a straight line can be calculated. The equation takes the form of $\text{Log } y = a + b \log x$ where y is the percent composition of a species and x is the species rank number.

A regular component of the fish population should have a good proportion of adult, older immature, and young-of-the-year fish in it. A variable component of the fishery will be entirely all young-of-the-year adult fish or older immature fish. Where spawning is frequently unsuccessful,both older immature and adult fish might be present that have been raised at another location.

Comparisons between Figures 5, 7, and 8 suggest that while adult fish are regular components of the catch, older immature and young-of-the-year fish are variable components of the catch, especially young-of-the-year fish. When small numbers of a species are caught, usually few or no immature fish are caught. Electrofishing samples from backwaters are likely to be dominated by small fish, frequently young-of-the-year (see Figure 3). In river channels, the catches of a large number of species are sometimes characterized by the absence of young-of-the-year fish (see Figures 2 and 7).

APPLICATION OF FINDINGS

The objective of fish sampling in any water is to provide a concise statement about the fishery from an analysis of the information. To provide that statement about the fishery, information must be presented on the following: (1) the important species, (2) the comparative amount of game fish present, (3) whether or not the important species are regular or variable components of the fishery, (4) whether or not there is stress on the environments, and (5) a preliminary statement about the form of stress.

A statement based on Figure 4 might be written as follows: smallmouth bass, redhorse, carp, white suckers, and walleyes are the most important species present in the river. Except for carp, young-of-the-year fish of all important species were present, so those species can be regarded as regular components of the fishery. Carp populations might be more variable. Game fish were 58 percent of the catch; mostly young-of-the-year smallmouth bass, and older fish were only five percent of the total catch. Normally, 70 percent of the game fish catch is older immature and adult fish, so the expected catch of game fish would be seven percent of the total catch. Some environmental stress is present because the diversity index (1.9) is at the low end of the range of variation (1.8 to 2.8). Since young-of-the-year fish are present and older game fish are a small part of the fishery, habitat for adult fish might be scarce.

Representative important species can be determined by making a list of species which are more than one percent of the catch. This will be about 95 percent of the total catch. When small fish are abundant, biomass figures should be used. The diversity index should be between 1.8 and 2.6 in an ordinary stretch of warmwater river. Lower numbers indicate stress; higher numbers indicate a wide variation in habitat types. An optimum number of game fish is present when they are 14 to 30 percent of the catch. The catch of any species should be about 50 percent adult, 20 percent older immature, and 30 percent young-of-the-year fish.

Two statistical tests will help to define the accuracy of any conclusion about game fish abundance. To make the first test, it must be assumed that the number of game fish caught is the lowest number that is associated with a maximum game fish catch. The second test is made by assuming the number of game fish caught is the highest number associated with a maximum game fish catch. When these assumptions are made, an expected catch can be calculated from the total sample size, and then a chi square test can be made to determine if the observed catch is similar to the calculated catch.

In a sample of 200 fish, (14)(200) or 28 game fish would be the lowest expected catch in the optimum range and (30)(200) or 60 game fish would be the highest expected catch in the optimum range. If 43 game fish were caught, then the chi square values would be $(43-28)^2/28$ or 8.02 for the lowest and $(60-43)^2/28$ or 10.31 for the highest. Using the 0.05 significance level value of 3.84, it can be concluded from the test the observed value is not the same as either expected value because the chi square values are higher than 3.84. Since the observed value is between both expected values, it can also be concluded that the sample catch was within the expected optimum range. Some of the other answers this test will provide are the number caught are (1) lower or not different than the lowest expected number or (2) not different than or higher than the highest expected number.

In coldwater streams, more than 22 percent of the sample should be game fish (trout). So, in a sample of 200 fish where 44 of them are trout, the expected catch would be (22)(200) or 44 trout. The test would be chi square value equals $(44-44)^2/44 = 0$. The catch would be considered average because it is not different than the expected catch.

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Table 4 - Composition (numbers of fish) and diversity of Minnesota's rivers with warmwater fish populations

		Diversity index		Percent Composition (large fish)				
Location	Year	Large fishes	all sizes	Large rough	Game fish	Sport fish	Others	Catch per hour
Mississippi River System								
Root River								
Above Lanesboro	1964	3.08	-	71	21	4	4	-
Zumbro River (South Fork)								
Above Mayowood Dam	1962	2.47	3.08	73	11	5	11	-
Mayowood Dam to Rochester	1964	1.92	-	83	8	0	9	-
Below Rochester	1964	0.94	-	99	0	0	1	-
St. Croix River								
Upper	1959	2.17	2.47	71	12	3	14	88.1
Upper (Kettle Rapids)	1959	2.65	-	35	61	0	4	-
Lower	1959	1.92	2.46	85	12	0	3	90.1
Snake River (all sectors)	1964	2.71	-	69	15	5	11	144.7
Sector I	1964	1.39	-	75	14	8	3	111.2
Sector II	1964	2.27	-	70	8	4	18	161.3
Sector III	1964	2.36	-	75	16	3	6	293.4
Sector IV	1964	2.91	-	61	20	9	10	123.0
Sector V	1964	2.83	-	67	17	5	11	125.0
Sector VI	1964	2.97	-	47	33	4	16	37.8
Minnesota River								
Above Granite Falls	1965	1.24	-	95	4	0	1	47.6
Below Granite Falls	1965	2.19	-	92	5	0	3	54.4
Blue Earth River								
Lower	1968	2.94	-	76	16	0	8	-
Rum River	1974	3.54	4.45	33	24	6	37	-
Lower	1958	1.92	-	87	8	1	4	110.7
Near Onamia	1972	2.45	3.02	29	8	1	62	34.3
Near Onamia	1974	3.13	3.73	36	16	55	43	-

Table 4 - Composition (numbers of fish) and diversity of Minnesota's rivers with warmwater fish populations (Cont.)

Location	Year	Diversity index		Percent Composition (large fish)				
		Large fishes	all sizes	Large rough	Game fish	Sport fish	Others	Catch per hour
Crow River	1974	2.51	3.66	61	5	7	27	-
Crow Wing River	1964	2.23	-	74	10	12	4	207.2
Shell River (lower)	1963	8.43	-	25	13	11	42	-
Long Prairie	1965	1.80	-	81	11	3	5	-
Mississippi								
Near Prairie Island	1973	3.10	-	35	31	7	27	-
Minnesota to L.&D. 2		0.62	-	92	2	4	2	77.8
Minnesota to Ford Dam		1.99	-	47	14	36	3	51.1
Monticello to Elk River	1970	1.85	2.02	72	24	3	1	109.6
	1973	1.84	-	40	58	2	0	24.9
	1974	1.90	-	67	30	1	2	113.1
Monticello Plant	1966	1.38	-	95	4	1	0	126.5
	1974	1.87	2.06	72	26	1	1	140.0
St. Cloud to Monticello	1974	2.73	3.27	57	30	6	7	-
Brainerd to Elk River	1966	2.81	-	77	12	7	4	68.7
Grand Rapids - Brainerd	1965	3.44	-	61	14	14	11	74.0
Pokegama Reservoir	1962	2.93	3.57	19	27	25	29	55.4
Winnibigoshish to Pokegama	1962	2.09	3.17	20	12	9	59	128.8
Other Rivers								
Cloquet River	1966	2.39	-	72	12	4	12	48.5
Whiteface River	1967	2.85	-	49	14	23	14	-
St. Louis								
Below Fond du Lac Reservoir	1966	0.00	1.28	100	0	0	0	-
Roseau River	1971	1.84	-	51	48	1	0	15.4
Red Lake River (near Huot)	1971	2.15	-	59	11	0	30	112.9

Table 5 - Composition and diversity of fish populations in cold and warm water streams as determined by electrofishing

Location	Year	Diversity Index: Large Species	Diversity Index: All	Percent Composition: Game Fish: All	Game Fish: Trout	Large Rough Fish	Small Fishes	Sport Fish	Other
Northeast Streams									
North Shore (below barrier)	60-63	0.79	-	66.5	66.5	2.2	30.6	0.0	0.7
(upper reaches)	55-58	1.05	-	12.5	12.5	1.4	86.1	0.0	0.0
St. Louis System									
Main Stem (average)	68	1.34	3.14	29.0	28.0	11.0	56.0	3.0	1.0
(best)	68	0.63	1.25	74.0	73.0	3.0	29.0	3.0	1.0
Cloquet System (average)	66	1.42	2.77	42.9	41.1	3.1	48.8	2.8	2.4
(no trout)	66	2.69	3.82	6.3	0.0	19.9	50.0	8.7	15.1
East Central Streams									
(average)	67-68	2.18	3.32	13.1	11.8	15.4	66.0	0.5	5.0
(no trout)	67-68	2.07	3.77	0.2	0.0	15.2	72.1	0.5	12.0
Southeastern Streams									
Root River System (best)	46	1.00	1.68	38.7	38.7	58.9	2.4	0.0	0.0
(average)		0.52	2.00	17.3	17.3	53.3	29.4	0.0	0.0
(poor)		0.24	2.23	4.2	4.2	37.5	58.3	0.0	0.0
Zumbro (S. Fork - upper)	64	2.47	3.08	21.8	0.0	40.9	44.6	4.9	1.1
Whitewater System (average)	46	0.80	-	3.6	3.6	11.2	85.2	0.0	tr.
Other streams	46	0.70	-	2.6	1.6	16.6	80.8	0.0	0.0
Central (Stearns, Sherburne)									
(average)	49,68	1.73	1.89	22.4	17.0	17.3	16.5	0.6	43.2
(no trout)	49,68	0.54	2.66	0.0	0.0	43.4	54.3	0.6	1.3
Northwestern and Central									
Others	47	2.03	2.57	60.6	35.2	8.8	23.8	0.0	6.8
Kabekona Creek	58	0.96	2.12	20.7	20.7	10.4	68.8	0.1	0.0
Straight River	47	1.32	2.62	25.3	24.7	37.1	36.5	0.2	0.9
" "	61	1.19	-	21.5	18.7	76.4	-	1.6	1.1
Shell River (upper)	63	1.77	-	1.6	0.0	2.8	3.5	0.7	90.4

FIGURE 1. FREQUENCY OF OCCURRENCE OF DIVERSITY INDEX VALUES OF ELECTROFISHING CATCHES FROM MINNESOTA'S WARMWATER RIVERS.

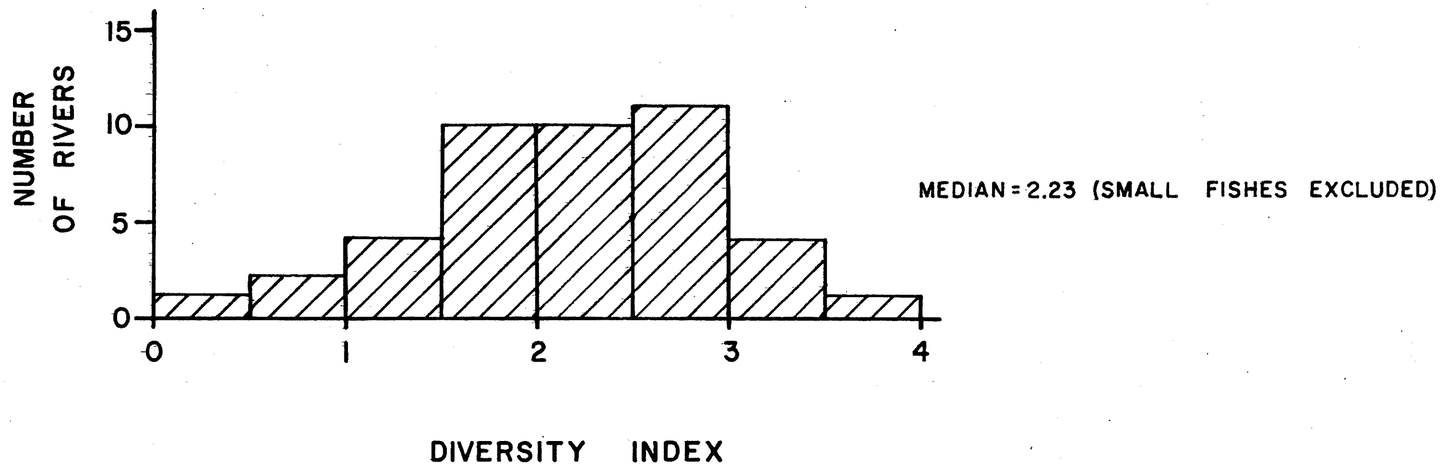

FIGURE 2. SPECIES OF FISH COMPRISING MORE THAN ONE PERCENT OF THE ELECTROFISHING CATCHES IN THE MISSISSIPPI RIVER NEAR PRAIRIE ISLAND (GOODHUE COUNTY, MINNESOTA) IN 1974.

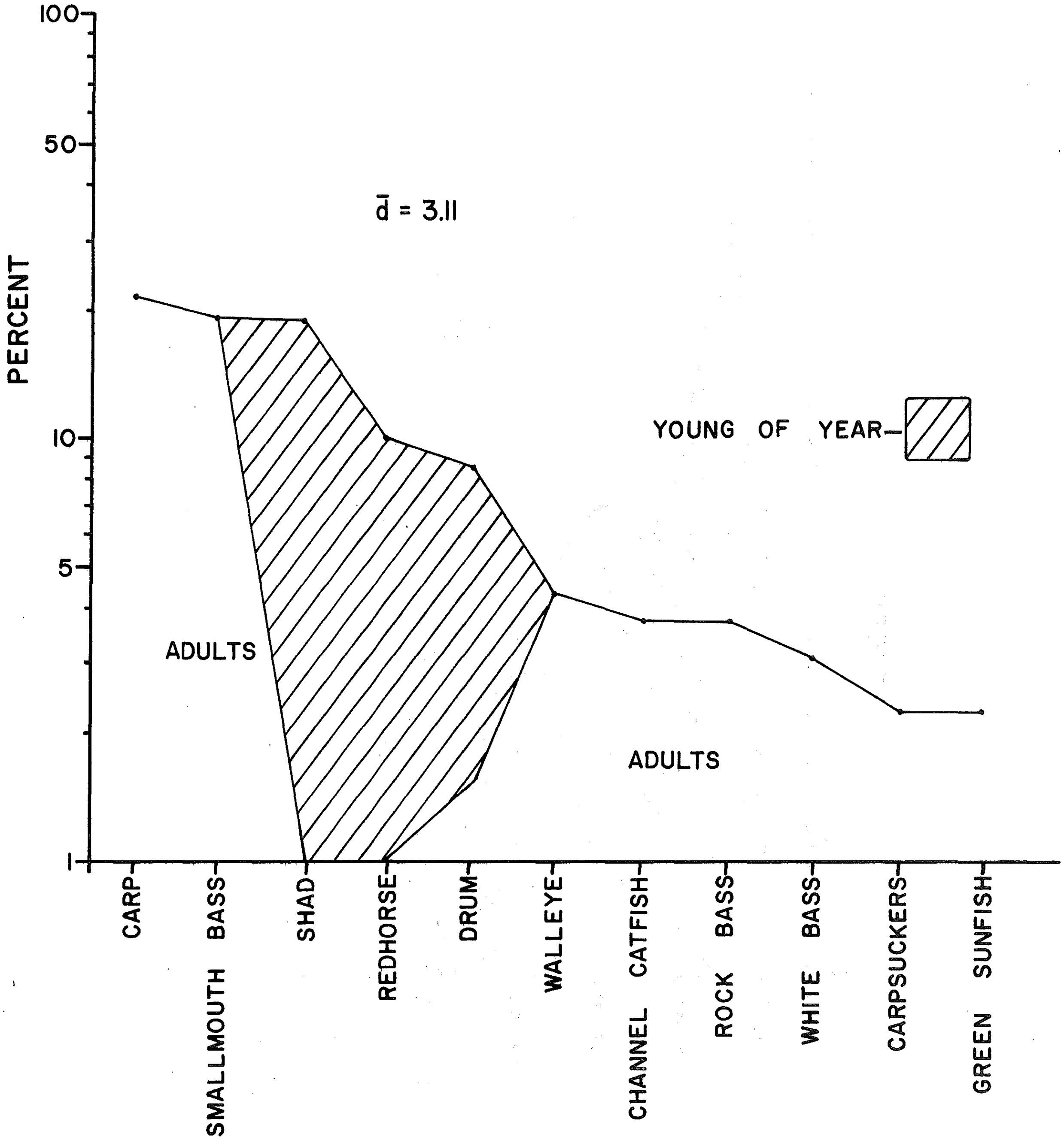

FIGURE 3. SPECIES OF FISH COMPRISING MORE THAN 0.5 PERCENT OF THE ELECTROFISHING CATCHES IN NORTH LAKE, A MISSISSIPPI RIVER BACKWATER, (GOODHUE COUNTY, MINNESOTA) IN 1974.

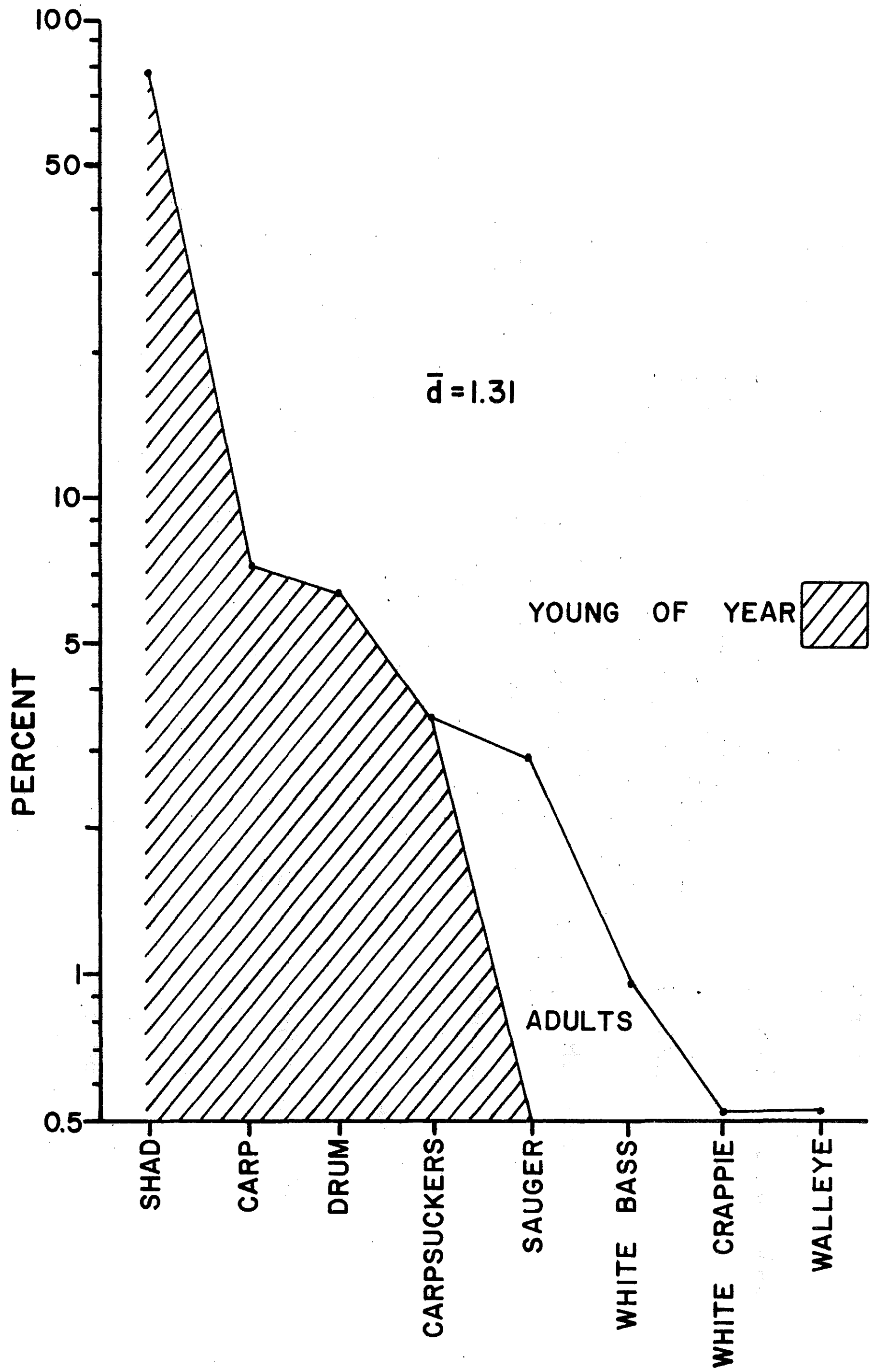

FIGURE 4. SPECIES OF FISH COMPRISING MORE THAN 0.5 PERCENT OF THE ELECTROFISHING CATCHES IN THE MISSISSIPPI RIVER NEAR MONTICELLO (WRIGHT AND SHERBURNE COUNTIES) IN 1974.

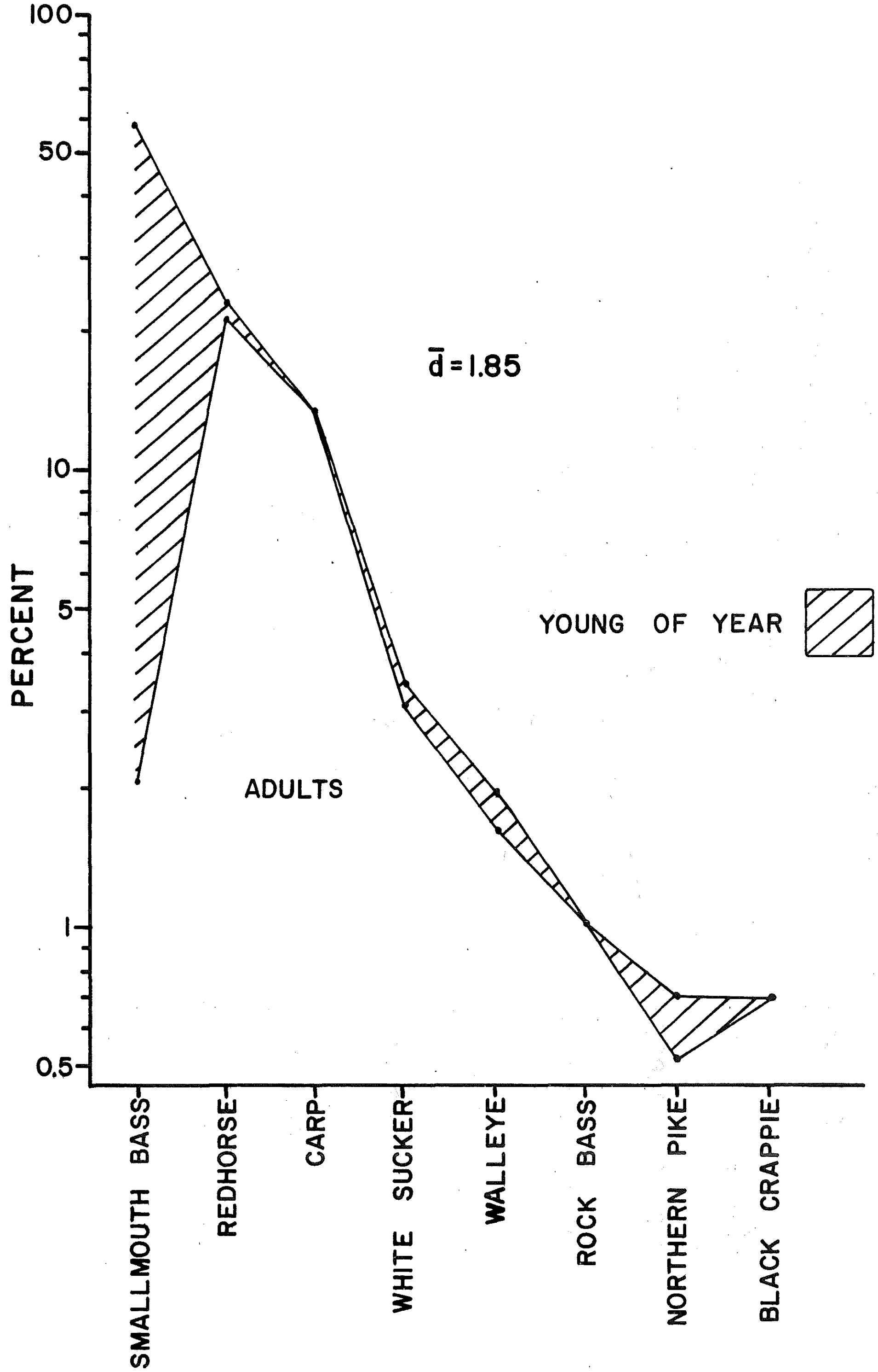

FIGURE 5. SPECIES OF FISH COMPRISING MORE THAN 0.5 PERCENT OF THE ELECTROFISHING CATCHES IN THE MISSISSIPPI RIVER BETWEEN GRAND RAPIDS AND BRAINERD, MINNESOTA IN 1965.

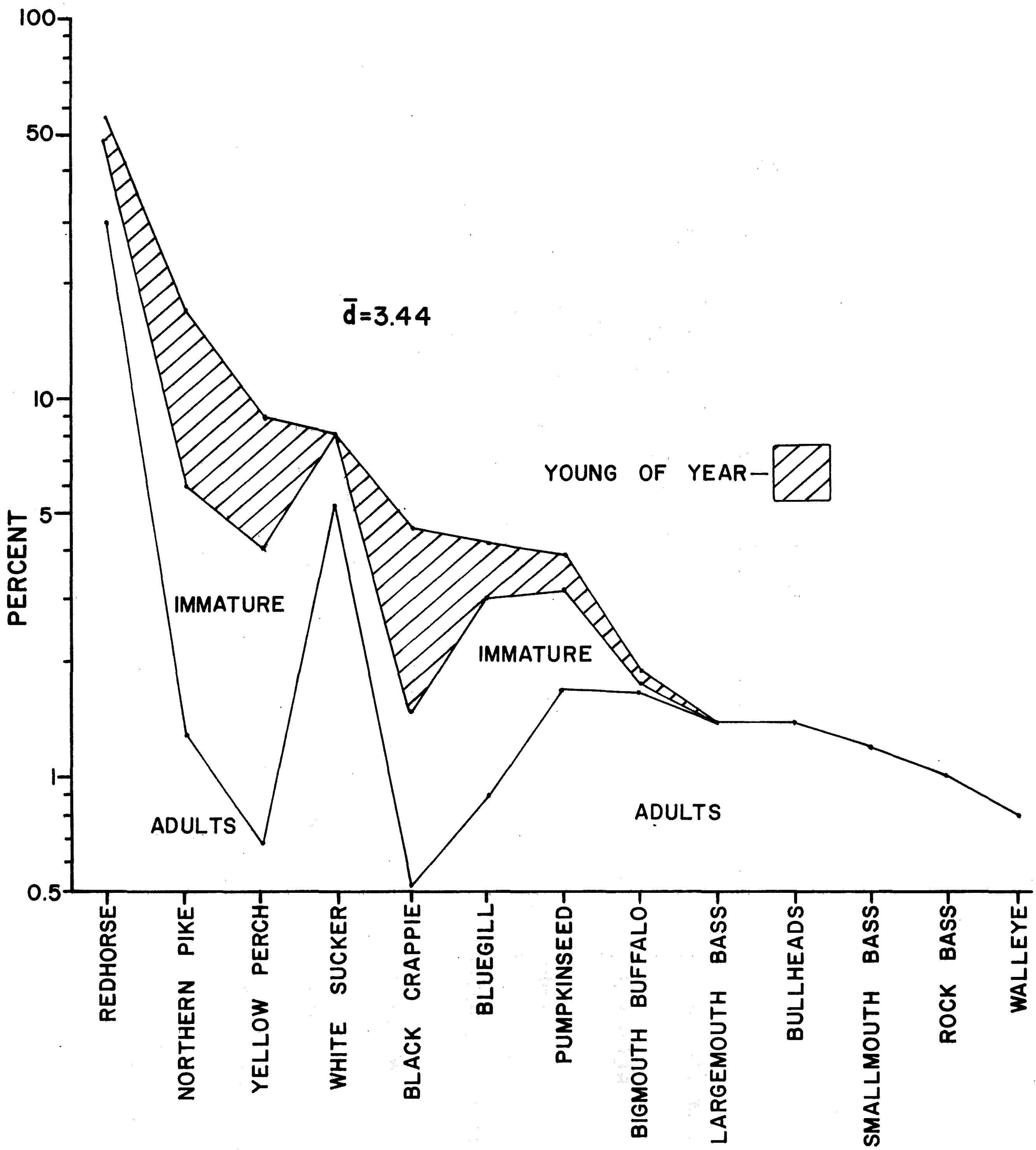

FIGURE 6. SPECIES OF FISH COMPRISING MORE THAN 0.5 PERCENT OF THE ELECTROFISHING CATCHES IN THE STRAIGHT RIVER IN HUBBARD AND BECKER COUNTIES, MINN., IN 1961.

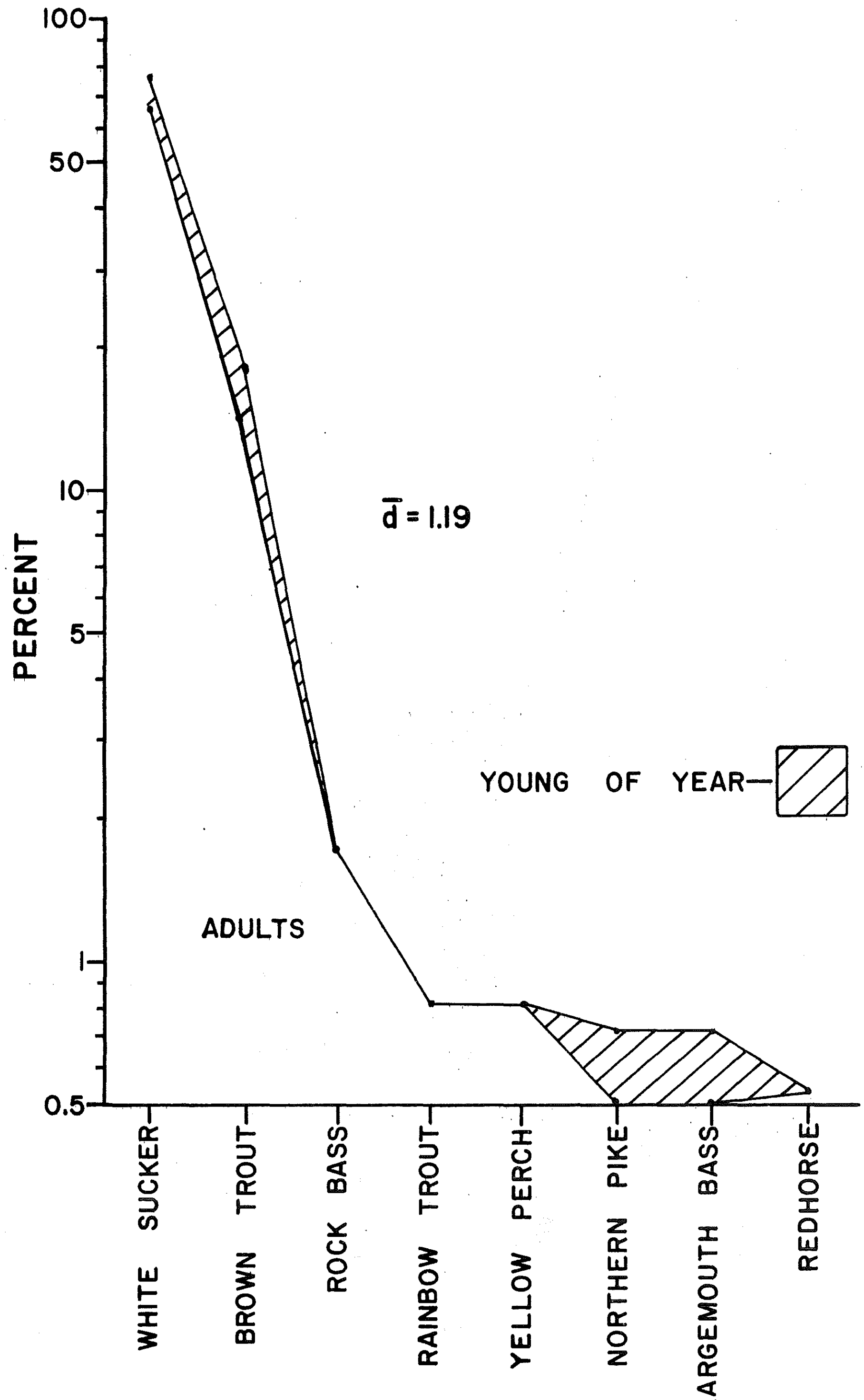

FIGURE 7. SPECIES OF FISH COMPRISING MORE THAN 0.5 PERCENT OF THE ELECTROFISHING CATCHES IN THE LOWER ST. CROIX RIVER IN 1959.

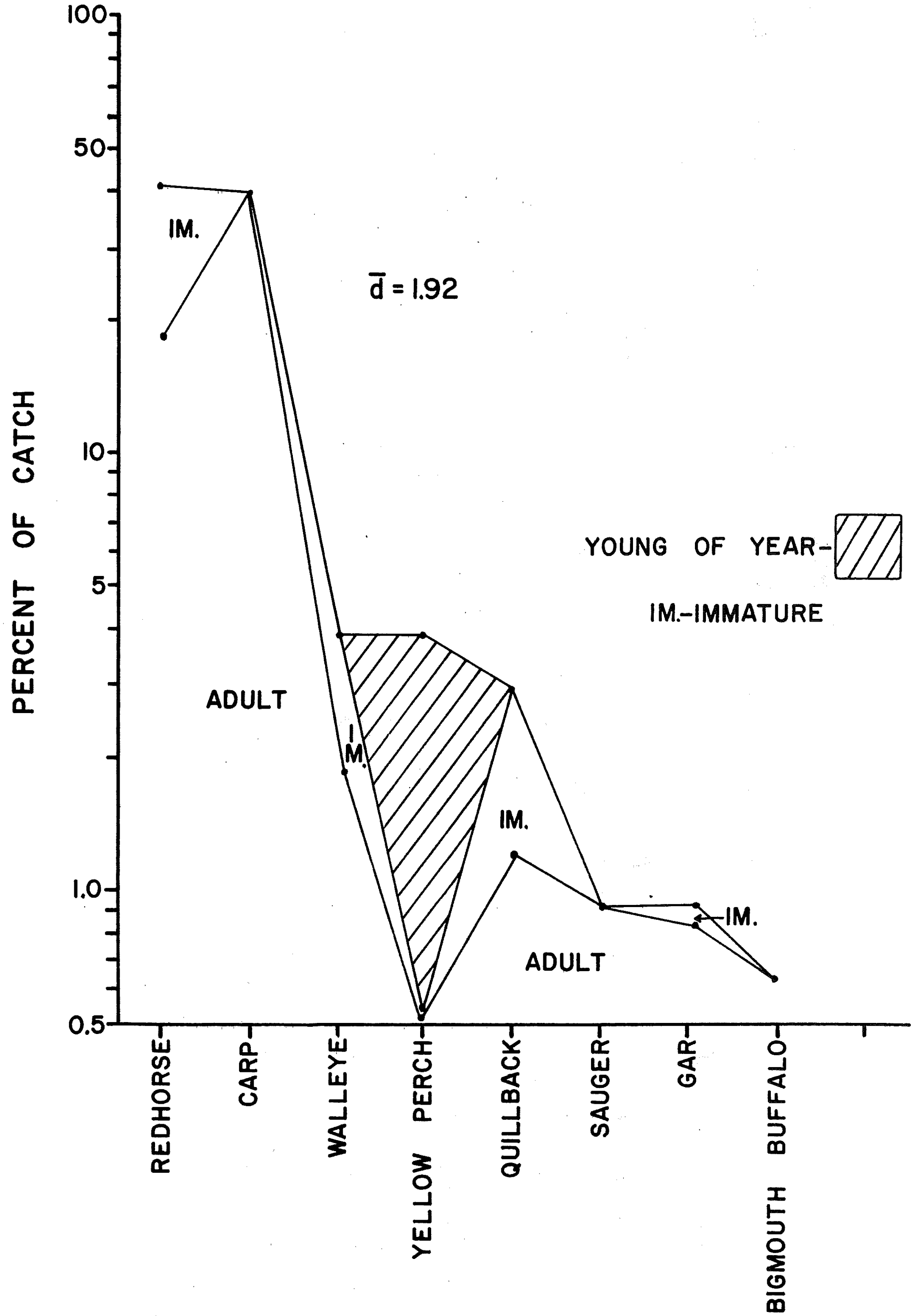

FIGURE 8. A HYPOTHETICAL STRUCTURE OF A FISH POPULATION IN A RIVER AS DETERMINED BY ELECTROFISHING.

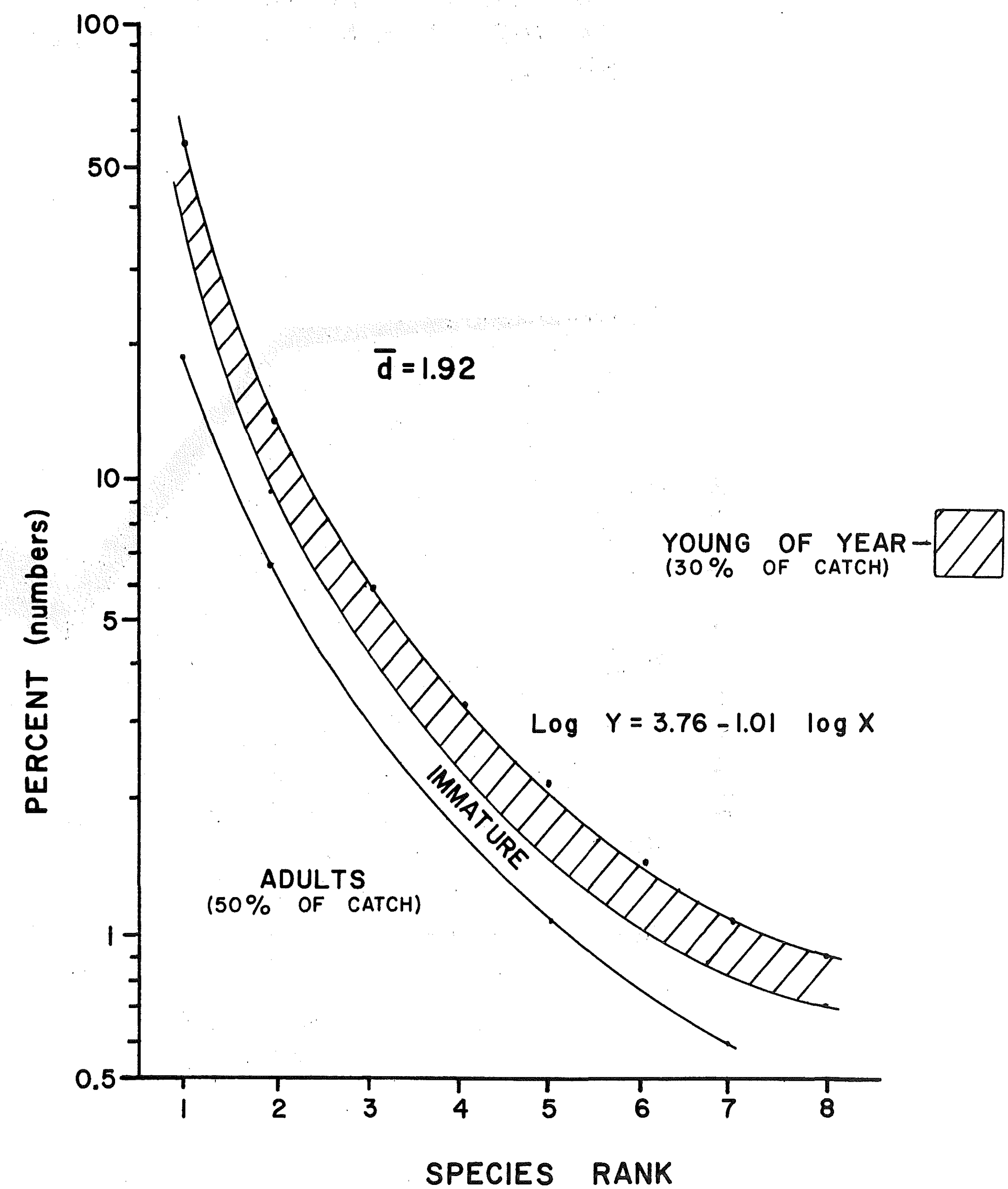

FIGURE 9. RELATIONSHIP OF DIVERSITY INDEX ($\bar{d}$) TO COMPOSITION OF ELECTROFISHING CATCHES IN MINNESOTA'S WARMWATER RIVERS.

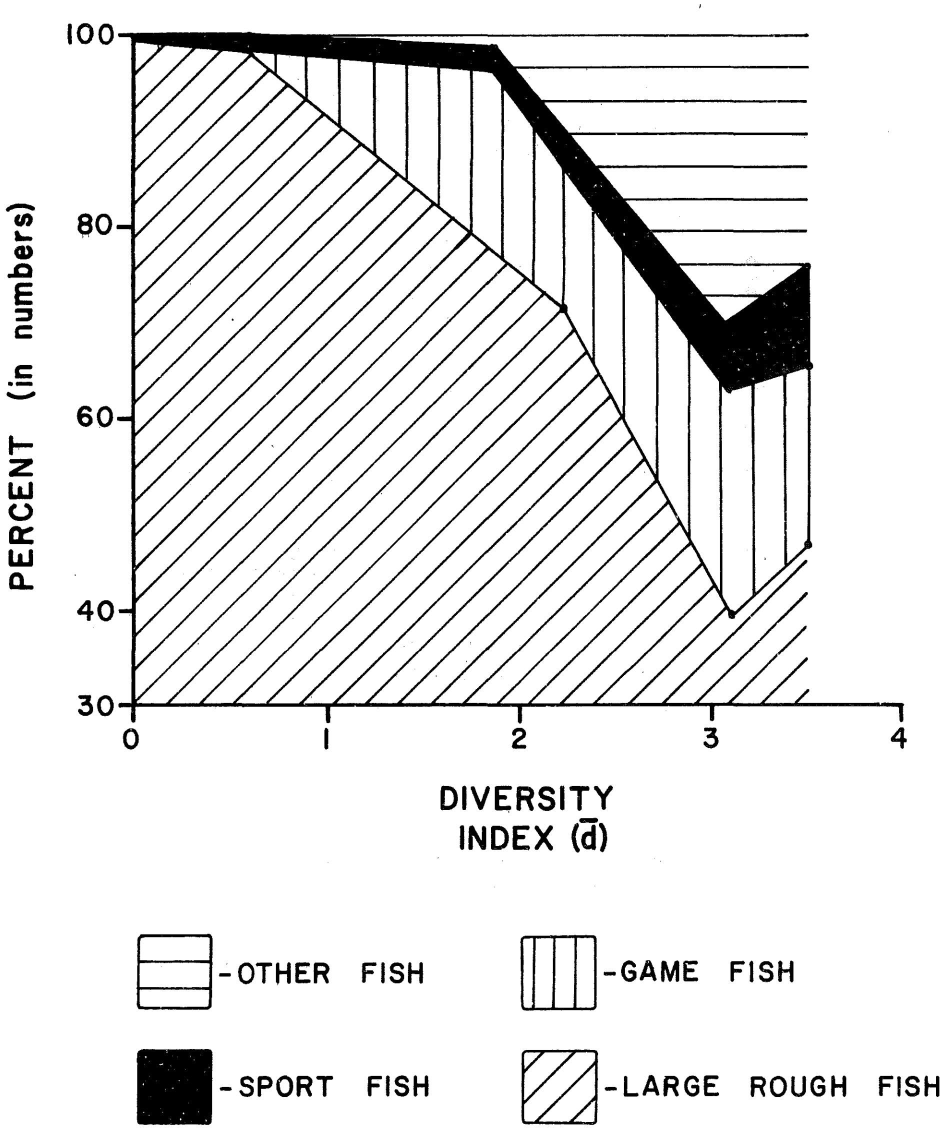

FIGURE 10. RELATION OF THE DIVERSITY INDEX TO THE EXTENT (PERCENT) THE MOST FREQUENTLY CAUGHT SPECIES ARE PART OF THE TOTAL CATCH.

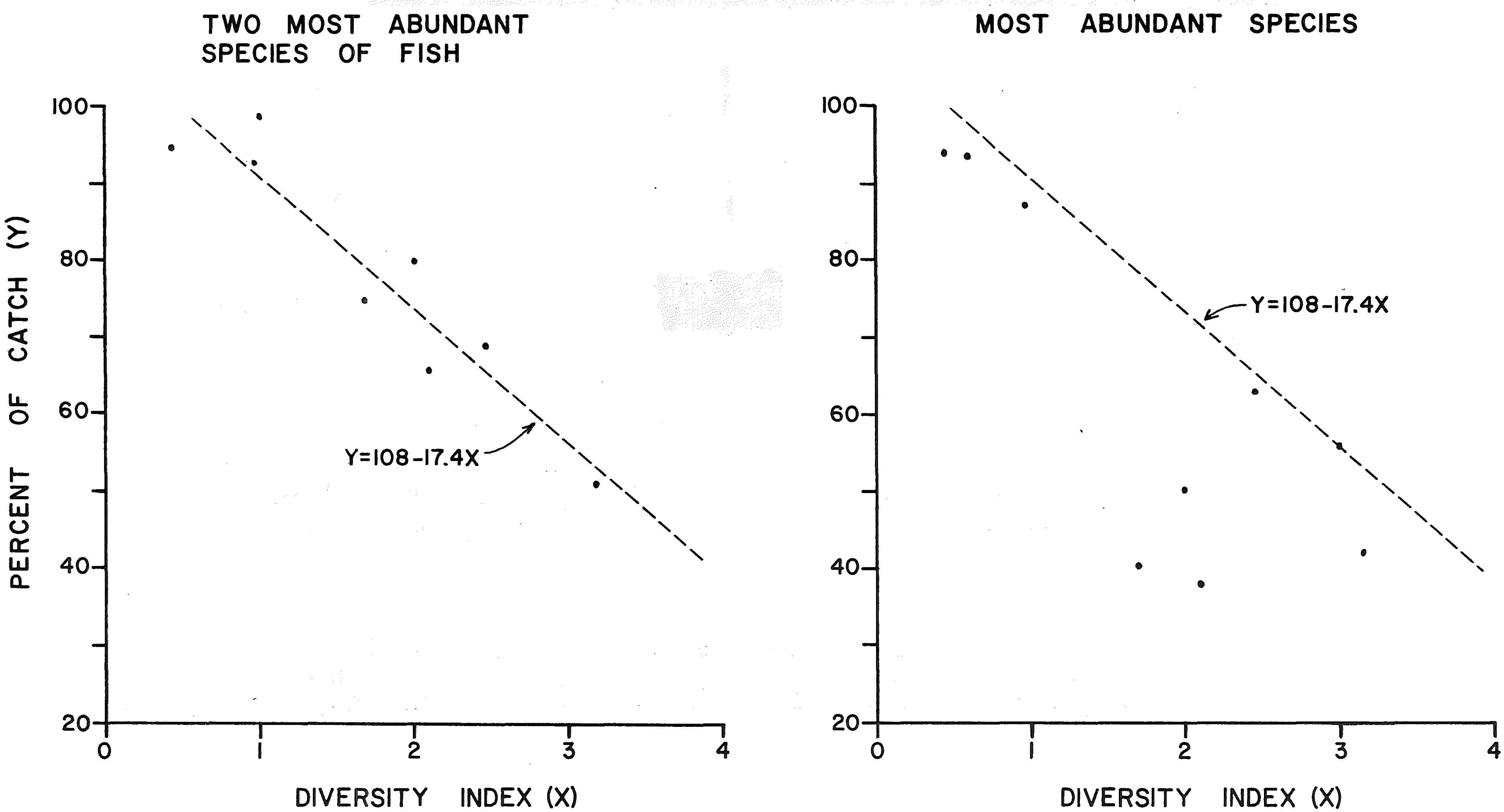

FIGURE II. DISTRIBUTION OF BIOMASS BETWEEN VARIOUS CATEGORIES OF FISH IN MINNESOTA HARDWATER STREAMS AND RIVERS, EXCEPTING THE NORTH SHORE, AS DETERMINED BY ELECTROFISHING.

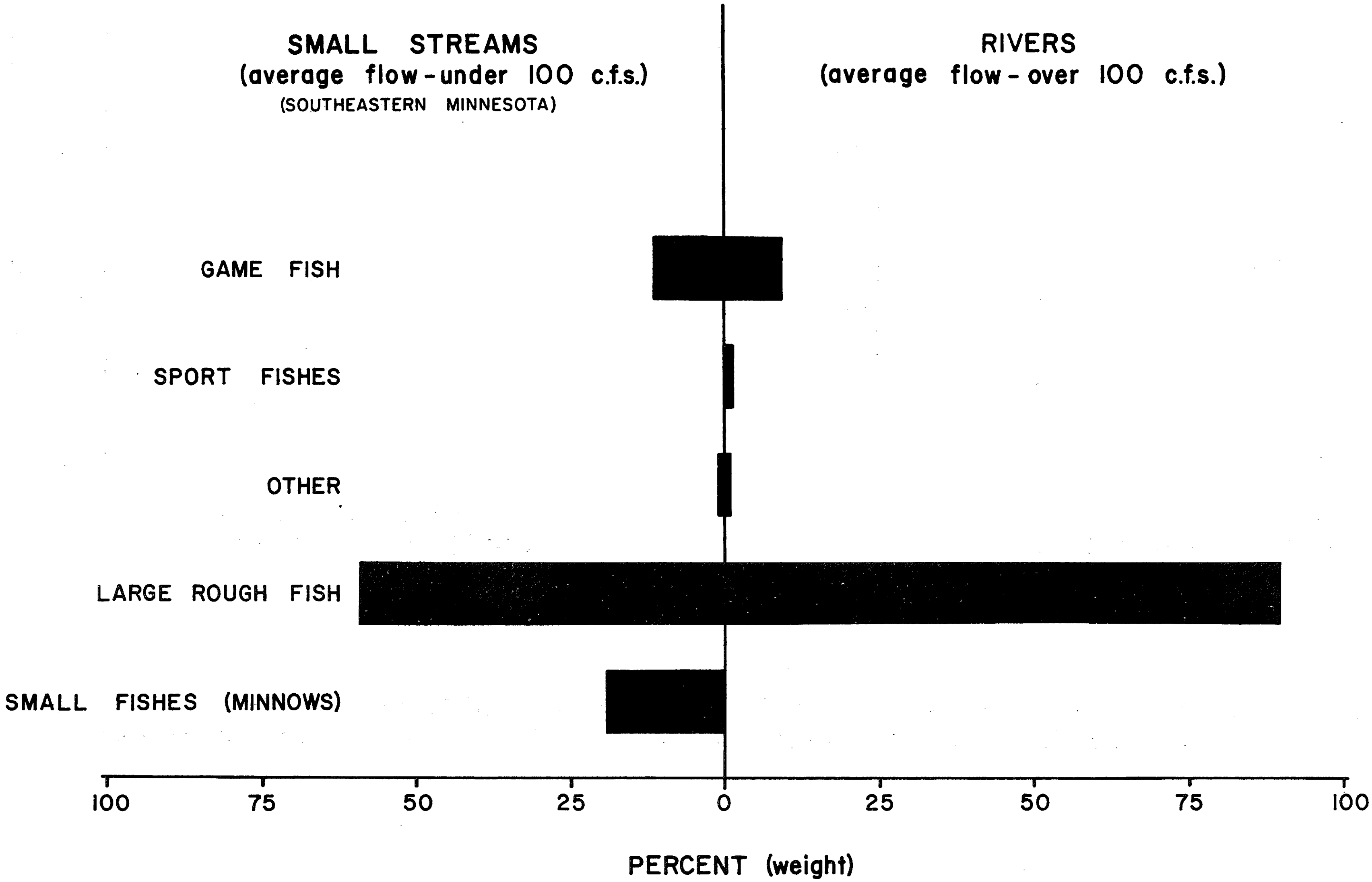

FIGURE 12. SIZE OF GAME FISH CATCH AND RELATIONSHIP TO THE PERCENTAGE OF GAME FISH FROM 28 ELECTROFISHING SAMPLES FROM WARM-WATER RIVERS.

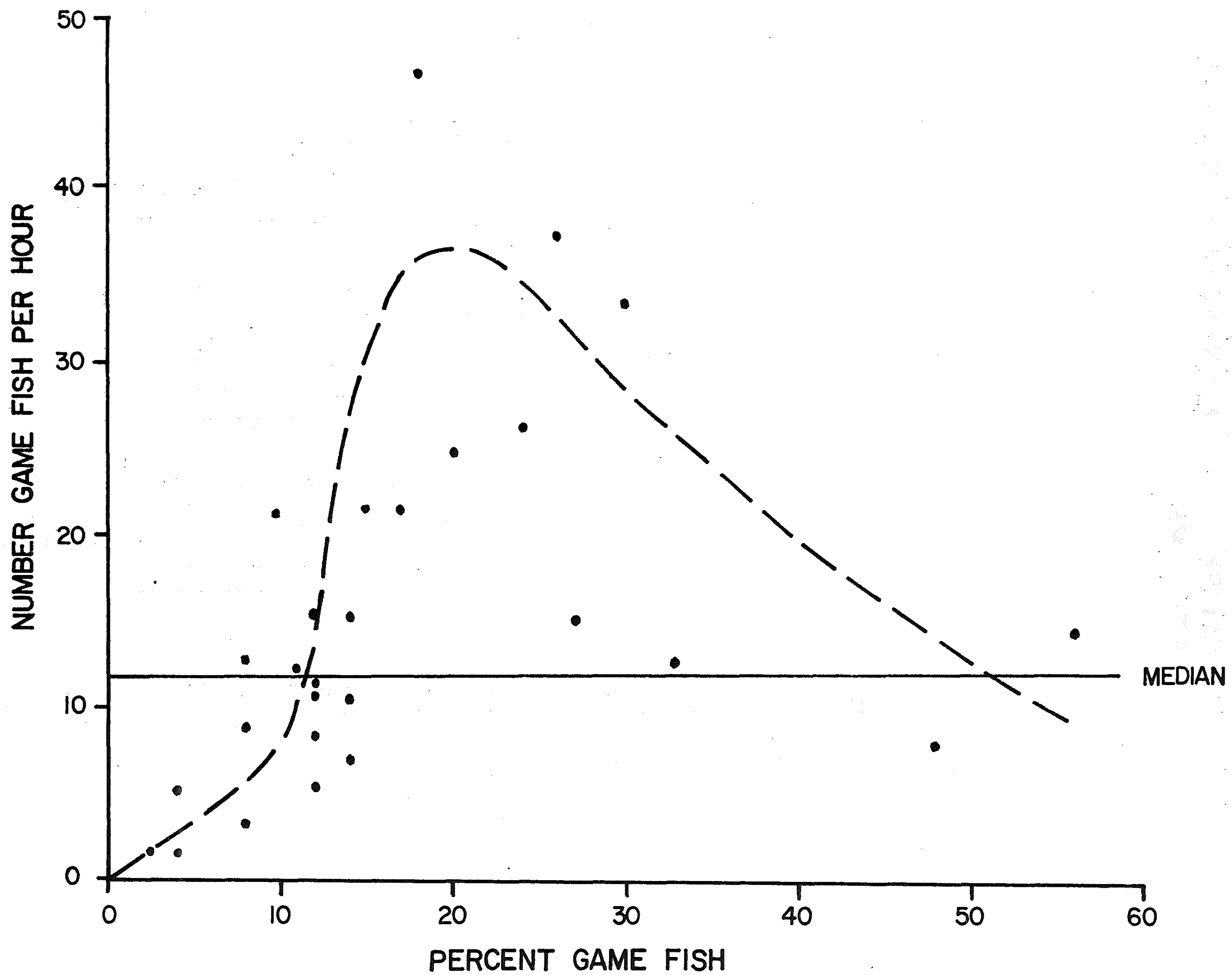

FIGURE 13. VARIATION IN ELECTROFISHING CATCHES (WEIGHT) IN MINNESOTA'S SOUTHEASTERN STREAMS.

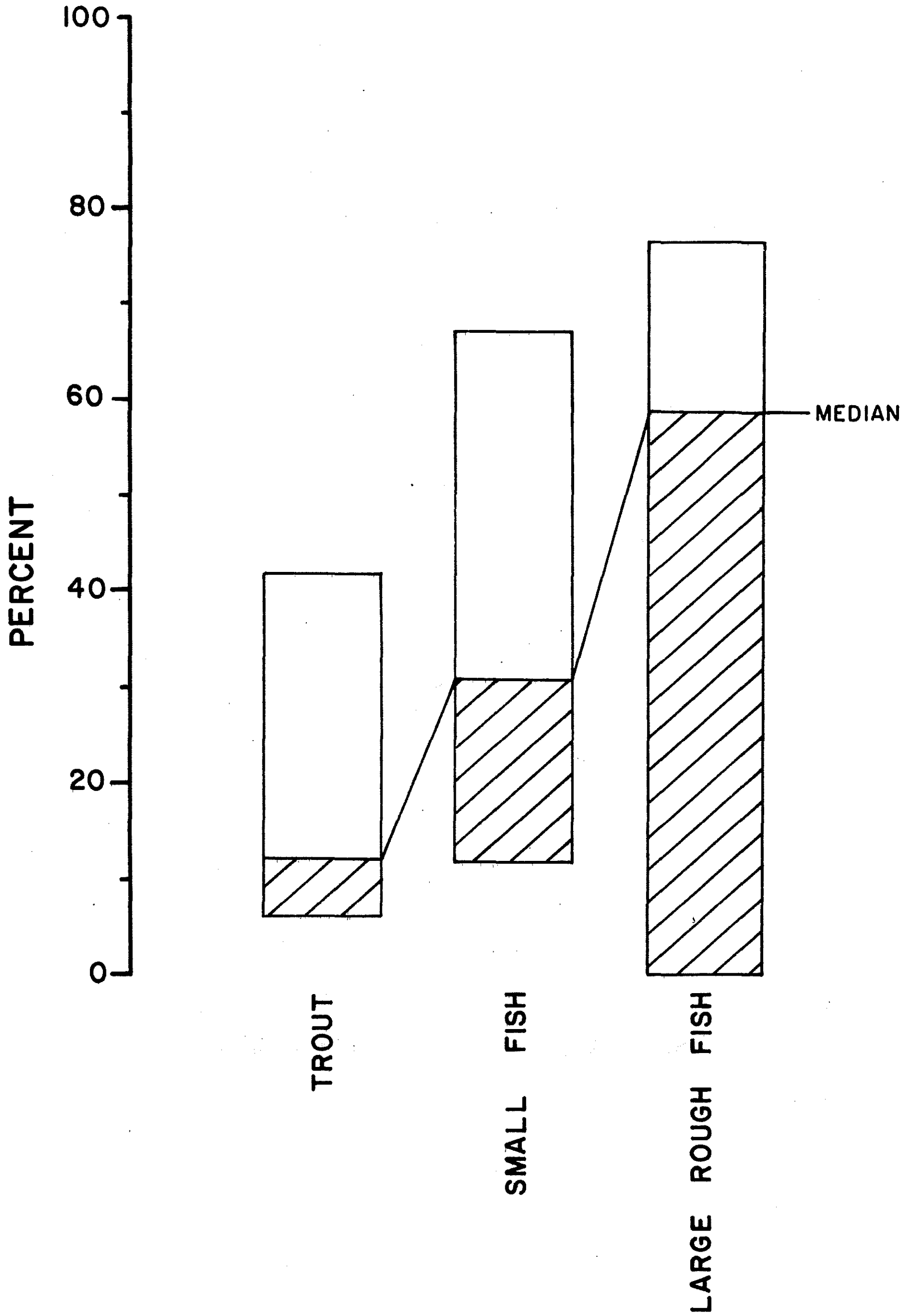

FIGURE 14. RELATIONSHIP OF VARIOUS AMOUNTS (WEIGHT) OF SUCKERS AND TROUT IN ELECTROFISHING CATCHES.

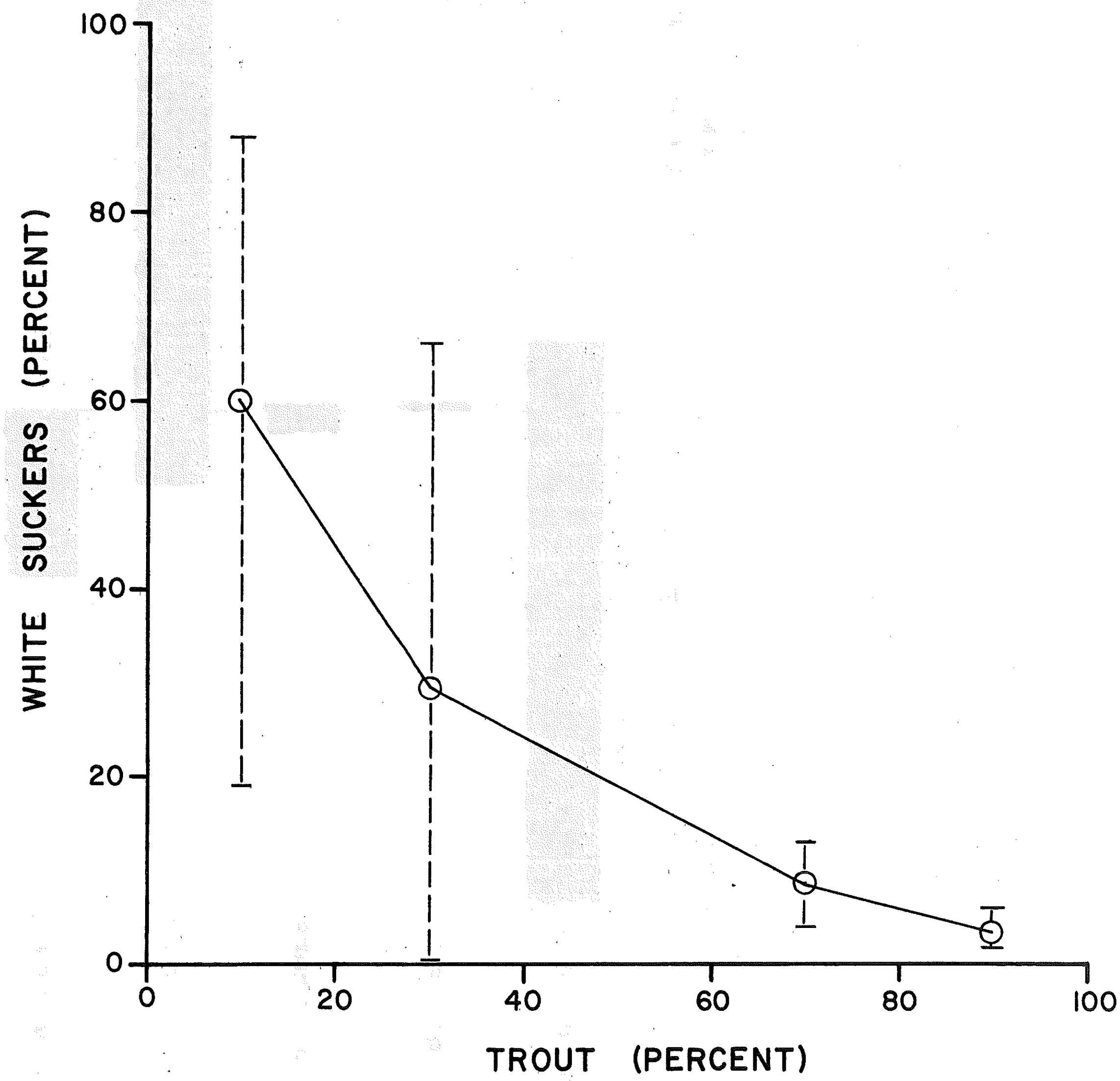

FIGURE 15. DISTRIBUTION OF BIOMASS BETWEEN VARIOUS CATEGORIES OF FISH IN MINNESOTA'S NORTH SHORE RIVERS AND OTHER MINNESOTA RIVERS AS DETERMINED BY ELECTROFISHING.