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The Distribution, Ecology, and Management of the Lake Sturgeon (Acipenser fulvescens Rafinesque) in Michigan

James Philip Baker

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THE DISTRIBUTION, ECOLOGY, AND MANAGEMENT OF THE LAKE STURGEON (ACIPENSER FULVESCENS RAFINESQUE) IN MICHIGAN *

By James Philip Baker

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ABSTRACT

Significant populations of lake sturgeon exist in Burt, Mullett, and Black lakes, Cheboygan and Presque Isle counties; the Menominee River, Menominee County; and Lake St. Clair and the St. Clair River. Remnant populations of lake sturgeon exist in all of the Great Lakes and lake sturgeon are occasionally reported in the lower reaches of most of the larger rivers draining into the Great Lakes. Landlocked remnant populations of lake sturgeon are found in Otter Lake, Houghton County; Manistique Lake, Mackinac and Luce counties; Indian Lake, Schoolcraft County; Brevoort Lake, Mackinac County; and Monacle Lake, Chippewa County.

On Black Lake estimated fishing pressure in 1975 during the winter spearing season was 2,332 shanty hours and in 1976, 3,972 hours. Estimated catch per hour was 0.0142 sturgeon in 1975 and 0.0086 in 1976. The population of lake sturgeon 48.6 inches and larger in Black Lake was estimated to be 1,599 in 1975, with 95% confidence limits of 714 to 3,998. The rate of exploitation in 1976 was estimated to be 2.1%.

The growth rates of lake sturgeon from Black and Mullett lakes and the Menominee River were very similar. The parameters of the von Bertalanffy growth equation for a combined sample of lake sturgeon from these waters were $L_\infty = 69.6411$ inches, $K = 0.0558$, and $x_0 = -0.8815$. The allometric mean length-mean weight relationship for lake sturgeon from the same localities was $\ell nW = 8.8949 + 3.1393\, \ell nL$.

The annual mortality rate for Black Lake sturgeon, age 25 years and older, was 0.097, the instantaneous total mortality rate 0.102. A fishing rate of 0.026, corresponding to an exploitation rate of 2.5% was assumed for the purpose of evaluating yield per recruitment. Using this rate, the natural mortality rate was calculated to be 0.076. The instantaneous total mortality rate for the Menominee River population was 0.098.

Fishing regulations for lake sturgeon were evaluated using Ricker's equilibrium yield model. Growth and mortality rates of lake sturgeon from Black and Mullett lakes and the Menominee River were used in the equation. With age at entry into the fishery held constant at 22 years, a doubling of the original fishing rate (2.5%) causes a 51% increase in yield per recruitment and reduces the biomass of the spawning stock by about 50%. Since the relationship between the size of the spawning stock and the number of recruits produced is unknown, it seems prudent to protect the stock of sexually mature fish if exploitation increases.

The mean annual recruitment to the fishable stock of the Black Lake population was 4.8%. Annual harvest should not exceed annual recruitment. The maximum allowable catch for Black Lake was calculated to be 77 fish. The winter spear fishery, which takes 20 to 40 fish yearly, appears to be operating with a considerable margin of safety.

The 50-inch minimum size limit currently in effect appears adequate to protect the fish until they become sexually mature. The apparent size limit in the winter spear fishery is higher than the legal minimum size limit. Validation of speared sturgeon by Michigan Department of Natural Resources biologists should be continued. If more stringent regulations become necessary in the future, decreasing the length of the season would be a more enforceable method of limiting harvest than increasing the minimum size limit. Controls on the poaching of spawning sturgeon in the upper Black River above Black Lake should be strictly enforced. The taking of lake sturgeon during the months of May and June should be prohibited statewide to protect spawning sturgeon in the St. Clair River and elsewhere. The season creel limit for lake sturgeon statewide should be decreased from two to one to promote the status of the sturgeon as a trophy fish.

INTRODUCTION

The lake sturgeon (*Acipenser fulvescens* Rafinesque) is a member of the family Acipenseridae, a group of fishes which displays such primitive characteristics as a cartilaginous skeleton, a heterocercal tail, rows of large, bony plates instead of scales and a large, cellular swim bladder. A detailed description of the lake sturgeon can be found in Scott and Crossman (1973).

There are 25 species of sturgeons, and representatives of this family are found throughout Europe, Asia, and North America. Seven species are native to North America, of which four are anadromous, spending most of their lives in the sea. The remaining three species live entirely in fresh water. They include the lake sturgeon, the shovelnose sturgeon (*Scaphirhynchus platorhynchus* Rafinesque), and the pallid sturgeon (*Scaphirhynchus albus* Forbes and Richardson). The shovelnose and pallid sturgeons are found only in the Mississippi River drainage.

The lake sturgeon has the widest distribution of the three freshwater sturgeons, occurring throughout the Mississippi, Great Lakes, and Hudson Bay drainages. It is the only sturgeon found in Michigan waters. Harkness and Dymond (1961) give a detailed account of the distribution of the lake sturgeon. It is now a rare fish throughout most of its range due to overexploitation of the stocks by commercial fishermen during the last century and destruction of spawning habitat by dams and pollution. It is officially classified as rare by the U.S. Department of the Interior (1966) and threatened by the Michigan Department of Natural Resources (1976). Because of the current status of the lake sturgeon as a threatened species, this study was initiated in the hope that information thereby procured could be utilized in the future management of Michigan's remaining populations.

Most study of the lake sturgeon has been carried out in Canada, where it remained an important commercial fish well into this century. The life history of the lake sturgeon in Canada has been intensively investigated and has been documented by Harkness and Dymond (1961) and Scott and Crossman (1973). In Wisconsin, the lake sturgeon is the object of an important winter spear fishery in several large inland lakes (Winnebago, Winneconne, Poygan, and Butte Des Morts) and various aspects of this fishery have been examined by Priegel and Wirth (1975, 1977, 1978).

The literature concerning lake sturgeon populations in Michigan, by contrast, is depauperate. Williams (1951) and Fogle (1975) have published general articles on lake sturgeon, and some analyses of creel census data collected during the spearing season on Black, Mullett, and Burt lakes have been completed (Vondett 1975; Vondett and Williams 1961). The sturgeon fishery of the Menominee River, a border stream between Michigan and Wisconsin, has been surveyed by Priegel (1973). Shouder (1975) attempted to estimate the size of the lake sturgeon population in Black Lake but had only limited success.

It is the intention of this investigation to assess the various lake sturgeon stocks of the state of Michigan with respect to distribution, ecology, and population size; to identify local populations of lake sturgeon heretofore undocumented, and to evaluate the adequacy of current sturgeon management practices.

BRIEF HISTORY OF THE LAKE STURGEON FISHERY IN MICHIGAN WATERS

No other freshwater species has had such a broad spectrum of economic value as had the lake sturgeon. Before the middle of the 19th century, it was considered a worthless nuisance. Today, the flesh and roe of the lake sturgeon command higher prices per pound than any other freshwater fish.

Before the appearance of the white man in North America, the lake sturgeon was exceedingly abundant throughout its range, particularly in the Great Lakes region. Tody (1974) estimated the standing crop of lake sturgeon in the Great Lakes prior to 1830 to be in the tens of millions of pounds. Sturgeon were utilized to varying degrees by several Indian tribes. Due to its great size, a single sturgeon would provide as much food as many smaller fish, and the oily flesh was easily smoked. Harkness and Dymond (1961) state that the Jesuit Relations (historical writings of early French missionaries) contain numerous accounts of the use of lake sturgeon by the Indians, and that Pere Francis Xavier Charlevoix, writing in 1761, outlined one of the methods by which the Indians captured sturgeon.

Though the sturgeons have always been held in high regard in Europe (particularly eastern Europe) and Russia, early white settlers in North America considered the lake sturgeon to be a trash fish. The bony plates of the small sturgeon and the weight of the large ones ruined fishermen's nets, which were set for more valuable fishes such as whitefish, lake herring, and lake trout. Lake sturgeon taken incidentally in commercial fishing operations were often piled on the beach like cordwood and burned. There is an account in Harkness and Dymond (1961) of sturgeon being used in place of wood to fire the boilers of steamships on the Great Lakes. At this time (prior to 1860), the flesh was considered fit only for Indians and half-breeds (Wing 1890) and the roe was worthless.

The value of the lake sturgeon as a commercial species began to be realized about the time of the Civil War, when it was discovered that caviar could be produced from the roe, and that smoked sturgeon was an acceptable substitute for smoked halibut. A sturgeon processing plant was established at Sandusky, Ohio, in 1860 (Harkness and Dymond 1961). By 1872, it was handling between 10 and 18 thousand lake sturgeon, of an average weight of 50 pounds each, annually (Milner 1874). The flesh was smoked, caviar was made from the roe, the offal was rendered for its oil, and isinglass (a clarifying agent used in beer and wine) was produced from the swim bladders. Even at this time, Milner remarks that sturgeon caught in Green Bay, Lake Michigan, were still being wantonly destroyed. The Ninth Biennial Report of the Michigan State Board of Fish Commissioners (1890) documents the existence of a caviar factory in Algonac, which processed sturgeon taken in the many channels of the St. Clair River.

After the commercial value of the lake sturgeon was established, fishing pressure on the species increased tremendously and the stocks began a rapid decline to very low levels from which they have never recovered. Although formal catch records are incomplete, Tody (1974) reported that in 1880, the landings of lake sturgeon in Michigan amounted to 4,300,000 pounds. By 1890, the total landings had fallen to 1,481,000 pounds, and in 1900, only 177,000 pounds of lake sturgeon were harvested. The dramatic drop in lake sturgeon landings from the very high levels of the 1880's is illustrated in Table 1.

As it became evident that the lake sturgeon fishery was in dire straits, interest in the artificial propagation of the species began to develop. The first documented attempt to artificially hatch lake sturgeon eggs took place on the Detroit River between 1883 and 1887. This information was recounted by the President of the American Fisheries Society during the discussion of a paper by Carter (1904). Over the next 25 years, further attempts to propagate sturgeon were made at Algonac, Michigan, in 1889 (Post 1890), the Detroit River in 1890 (Leach 1920), 1893 and 1894 (Michigan State Board of Fish Commissioners 1895), the Missisquoi and Lamoille rivers of Vermont in 1900 and 1901 (Stone 1901), and Lake of the Woods, Minnesota in 1911 and 1912 (Eddy and Surber 1943). None of these endeavors met with anything more than limited success.

There were a number of recurrent problems which beset all attempts at sturgeon culture. Perhaps the greatest was the difficulty of securing ripe male and female fish at the same time. Another problem, related to the first, was the scarcity of truly ripe females among those participating in the spawning migration. As an example, Post reported

Table 1.--Total lake sturgeon landings (in thousands of pounds) by Michigan commercial fishermen from the Great Lakes (including Lake St. Clair) from 1879 through 1970.

Year	Lake					Total
	Erie	St. Clair	Huron	Michigan	Superior	
1879	-	999	204	-	-	1,202+[b]
1880	-	-	-	-	-	-
1881	-	-	-	-	-	-
1882	-	-	-	-	-	-
1883	-	-	-	-	-	-
1884	-	-	-	-	-	-
1885	91	228	216	925	131	1,591
1886	-	-	-	-	-	-
1887	-	-	-	-	-	-
1888	-	-	-	-	-	-
1889	2	97	559	475	83	1,216
1890	33	309	366	733	40	1,481
1891	22	76	398	254	75	825
1892	14	96	179	196	40	525
1893	17	101	201	107	31	457
1894	13	62	87	112	21	295
1895	13	30	92	84	6	225
1896	56	28	48	83	10	225
1897	46	33	36	58	8	181
1898	47	21	91	68	9	236
1899	41	19	85	64	9	218
1900	48	19	23	76	11	177
1901	27	9	22	69	5	132
1902	17	3	25	38	23	106
1903	17	*	34	50	8	109
1904	16	1	32	46	6	101

(continued, next page)

Table 1.--continued

Year	Lake					Total
	Erie	St. Clair	Huron	Michigan	Superior	
1905	8	6	24	38	5	81
1906	10	1	17	40	7	75
1907	11	11	24	44	3	93
1908	7	1	7	48	5	68
1909	-	a	-	-	-	-
1910	-		-	-	-	-
1911	-		-	14	*	14+
1912	2		3	14	2	21
1913	1		8	12	1	22
1914	*		7	11	1	19
1915	*		28	12	2	42
1916	5		7	7	*	19
1917	8		4	6	-	18+
1918	3		4	26	*	33
1919	*		7	7	3	17
1920	1		12	13	*	26
1921	-		4	7	*	11+
1922	*		3	8	1	12
1923	*		3	7	1	11
1924	*		10	4	4	18
1925	-		3	6	*	9+
1926	-		4	6	*	10+
1927	-		2	3	*	5+
1928			*	2	-	2+
Taking of lake sturgeon prohibited, 1929-1950						
1951	-		1	*	*	1+
1952	-		2	3	*	5+
1953	-		1	5	*	6+
1954	-		1	2	*	3+

(continued, next page)

Table 1.--concluded.

Year	Lake					Total
	Erie	St. Clair	Huron	Michigan	Superior	
1955	-		1	2	*	3+
1956	-		1	1	*	2+
1957	-		*	1	*	1+
1958	-		1	1	*	2+
1959	-		1	1	*	2+
1960	*		1	1	*	2+
1961	*		1	2	*	3+
1962	*		1	1	*	2+
1963	*		1	3	*	4+
1964	-		1	3	*	4+
1965	-		*	2	*	2+
1966	-		*	2	1	3+
1967	-		1	*	-	1+
1968	-		*	2	*	2+
1969	-		*	3	-	3+
1970	-		-	-	-	-
Taking of lake sturgeon prohibited December 1, 1970.						

‡ Includes Detroit and St. Clair rivers.

- Landings unknown.

* Landings amounted to less than 500 pounds.

a Commercial fishing in Michigan waters of Lake St. Clair prohibited in 1909.

b A number followed by a + indicates that the number is a minimum, i.e., the landings from one or more lakes are unknown.

Data included in Table 1 were taken from Baldwin and Saalfeld (1962) and Great Lakes Fishery Commission (1970 and unpublished).

that although he and his co-workers at Algonac handled some 4,000 sturgeon, only two ripe females were found. Still another complication was that the lake sturgeon eggs seemed to be especially susceptible to attack by fungus.

The last documented attempt at artificial lake sturgeon culture was made by Harkness in 1924. Several thousand sturgeon fry were hatched in Seth Green floating boxes in the Gull River about 20 miles above Lake Nipigon, Ontario. Attempts to rear the fry failed, as no suitable food could be found for them (Harkness and Dymond 1961).

Declining sturgeon stocks brought a trend toward increasingly stringent fishing regulations. In the 13th Biennial Report of the Michigan State Board of Fish Commissioners (1899) the statistical agent of that body recommended the prohibition of the taking of small sturgeon and curtailment of the use of unbaited set-lines (used to grapple sturgeon as they roll and root about on the bottom during spawning). Whether or not these suggestions were followed is unclear, but in any case the decline in the sturgeon catch continued. By 1929, the catch had dropped to such low levels that the taking of lake sturgeon, both commercially and for sport, was prohibited statewide.

Beginning in 1948, a limited sport fishery was allowed during the months of January and February on inland lakes open to spearing. The regulations governing this spear fishery during 1948 and 1949 are somewhat vague. In 1950, spearing through the ice was allowed on Lake St. Clair. Commercial fishermen were allowed to sell sturgeon taken incidentally in their nets beginning in 1951 (Williams 1951). Hook-and-line fishing for sturgeon became legal in 1952. Commercial fishing for lake sturgeon in Lake Erie ended in 1964 and in 1970, Lakes Huron, Michigan, and Superior were closed.

The size limit on lake sturgeon taken by sport fishermen was set at 36 inches when the season was first reopened in 1948. It was subsequently raised to 42 inches in 1952 and 50 inches in 1974. The creel limit for lake sturgeon taken in Lake St. Clair and inland waters has remained set at two fish per season since 1951.

Fishing regulations for the Menominee River have generally been formulated by the state of Wisconsin, but have followed a pattern of increasing size limits and decreasing creel limits similar to that of Michigan.

Since lake sturgeon are highly vulnerable to capture during the spawning migration, regulations aimed at protecting the fish on their spawning run have been applied in one particular case. The Upper Black River from its confluence with Black Lake to Kleber Dam, the major spawning area for the sturgeon population of Black Lake, is closed to all fishing during the months of April and May.

Current (1980) fishing regulations concerning lake sturgeon in Michigan waters are listed below.

Hook-and-line seasons

Trout streams, designated trout lakes	No open season
Non-trout streams, inland lakes	January 1-February 29
Great Lakes, Lake St. Clair, Detroit, St. Mary's, and St. Clair rivers	No closed season
Menominee River	September 1-November 1

Spearing season

February, on non-trout waters.
All sturgeon speared in Black, Burt, or Mullett lakes must be validated at the Indian River DNR field office or at the Black Lake Hotel within 48 hours.

Size limit (includes both spearing and hook-and line): 50 inches.

Creel limit (includes both spearing and hook-and-line): two per season.

Special provisions:

Cheboygan County: During April and May, unlawful to fish in any manner on the Black River between Kleber Dam and the Red Bridge (Sec. 5, T 35 N, R 1 E). (This regulation is to protect spawning lake sturgeon, which run upstream from Black Lake.)

SYNOPSIS OF THE LIFE HISTORY OF THE LAKE STURGEON

A brief account of the biology of the lake sturgeon follows with special regard (where possible) to the populations of Michigan. Lake sturgeon are exclusively bottom feeders, preferring large, shallow lakes and large rivers with abundant bottom fauna such as mayfly nymphs, fingernail clams, crayfish, caddis flies, and chironomid larvae. Although small fishes are occasionally found in the stomachs of sturgeon, they constitute only a miniscule portion of the diet.

Lake sturgeon live to the greatest age of all the freshwater fishes. There is a documented account of a 208 pound fish, taken in Lake of the Woods, Ontario in 1953, which was determined to be 152 years old (MacKay 1963). The oldest lake sturgeon ever taken from Michigan waters (of which the writer has knowledge) was a 98 year old fish speared in Mullett Lake in 1975. Ages are generally determined by examination of the annular rings in a cross section of the ossified first ray of the pectoral fin (Cuerrier 1951). This fin ray can easily be removed with a hacksaw and a pocket knife with no harm to the living fish. Age can also be ascertained from annular markings in otoliths and opercular bones, but these methods require the sacrifice of the fish. All age data used in this study were determined from fin ray sections. Very old sturgeon are exceedingly difficult to age accurately. Age determinations of very large fish are probably accurate only to within 5 or 6 years.

Lake sturgeon in Michigan leave their home lakes and move up rivers to spawn during the months of May and June, depending upon the water temperature. Priegel and Wirth (1977) stated that lake sturgeon in Wisconsin usually spawn when the water temperature reaches 53 F, but noted that, during years of low water discharge and more rapid increases in water temperature, they may spawn at temperatures of 58-59 F. I observed lake sturgeon on their spawning run in three different localities in May and June of 1979. Locations, dates, and water temperatures were -- Indian River, Schoolcraft County: May 22-23: 53 F; Black River, Cheboygan County: May 24: 52 F; and St. Clair River, St. Clair County: June 16: 52 F. Michigan lake sturgeon spawn at water temperatures very similar to those observed in Wisconsin.

The spawning act takes place in rapids and deep pools, where the current is swift enough to provide a substrate of large, clean rubble. Lake spawning is also known to occur, mainly in wave-swept areas where the bottom is composed of large rubble. No nest is constructed; the eggs and milt are scattered over the bottom where the fertilized eggs adhere to the rocks. The eggs receive no parental care.

Very little is known of the life of the lake sturgeon, from the time the eggs are deposited until the end of the first growing season. Harkness and Dymond (1961) reported that at water temperatures of 60-64 F lake sturgeon eggs hatched in 5 to 8 days and that newly hatched fry were 1/3 inch in length. It is not known how long the lake sturgeon fry remained in the river before descending to the lake. Shouder (1975) reported that attempts to capture small lake sturgeon in the upper Black River during August 1973, were unsuccessful. No lake sturgeon younger than 9 years old has ever been captured in Black Lake. However, the continual appearance of new year classes in the monitoring nets led Shouder to conclude that reproduction was taking place and that the construction of a dam on the upper Black River in 1949 had not adversely affected reproduction. Information concerning year class strength gathered since the time of Shouder's study supports this conclusion. The year class frequencies of Black Lake sturgeon netted and speared from 1970 through 1977 are illustrated in Figure 1. Year classes more recent than 1955 are omitted, as these cohorts were inadequately sampled by the fishing gear.

Young-of-the-year lake sturgeon have been found in significant numbers in the Menominee River (Priegel 1973) and several very small sturgeon have been taken by Department of Natural Resources research vessels in Lake St. Clair.

Growth of the lake sturgeon is quite rapid during the first 10 years of life, then slows down and becomes extremely variable among different individuals. As an example of this variability, one sturgeon tagged in 1973 was 51.75 inches long. When recaptured in 1974 it had grown to 53.25 inches, an increase of 1.5 inches in a single year. In contrast, a 48-inch sturgeon which was tagged in 1974 was recaptured in 1975 and had not grown at all.

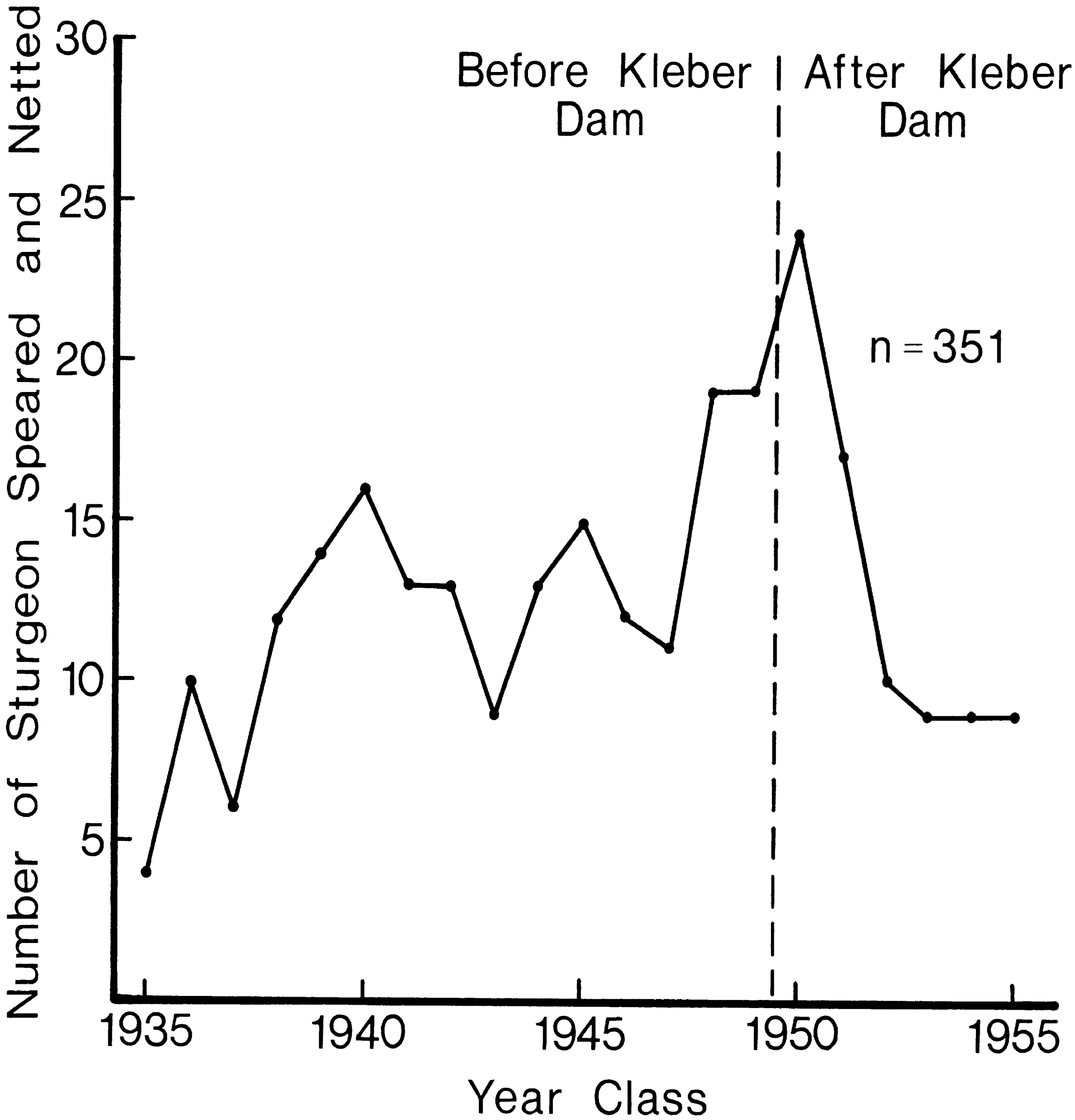

Figure 1.--Year class frequency of lake sturgeon speared and netted in Black Lake, 1970-1977.

The largest lake sturgeon ever taken in Michigan, for which there is documentation, was 7 feet 11 inches long and weighed 310 pounds (Van Oosten 1956). A photograph of this leviathan is included in the July-August (1943) issue of Michigan Conservation magazine (Vol. 12, No. 6, p. 11). It was captured by swimmers in 1943 in Lake Michigan, near the mouth of the St. Joseph River. It had apparently been injured by a collision with a boat propeller.

The current state angling record for lake sturgeon is a 193 pound fish, speared in Mullett Lake in 1974. However, most sturgeon taken by spearers during the February season are 4 1/2 to 5 feet long and weigh 45 to 60 pounds.

Priegel and Wirth state that male lake sturgeon in Wisconsin reach sexual maturity at 14-16 years of age, and females at 24-26 years old. Also, instead of spawning every year, females spawn only once every 4 to 6 years, while males may spawn every other year. Because of the similarity of latitude and length of the growing season, it is felt that these ages at maturity and intervals between successive spawnings also apply to sturgeon in Michigan waters (Mason Shouder, personal communication).

Roussow (1957) reported that the spawning periodicity of lake sturgeon could be determined by examination of the spacing of the annuli in the pectoral fin ray cross sections. According to Roussow, the growth of the sturgeon in the years just prior to the year of spawning is quite slow, resulting in a series of annuli located very close together. After the year of spawning, the growth rate increases, and this increase is reflected in the wider spacing of subsequent annuli. As the fish begins to produce sex products prior to the next spawning, growth slows down again and the cycle is repeated.

I examined the fin ray sections of 32 lake sturgeon in an attempt to determine the spawning periodicity of Michigan populations, but could not distinguish the wide and narrow bands of annuli which Roussow discussed. The sturgeon upon which Roussow conducted his investigations were taken from lakes in northern Quebec, where the growing season is much shorter. It is possible that Michigan lake sturgeon, having a longer growing season, do not suffer from as great a disruption in growth during the formation of the sex products as do fish from areas farther north.

Natural mortality in lake sturgeon is very low throughout most of the life span. By the end of the second growing season, the average length of a lake sturgeon is nearly 12 inches, thus rendering them too large a prey for all but the largest of the predatory fishes. The sharp, bony plates in the skin also make them a very unpleasant mouthful. There are no records to indicate that young lake sturgeon have ever been found in the stomachs of any other fish, but this might reflect the scarcity of the prey rather than its lack of utilization by predators. Once a lake sturgeon has reached about 20 inches in length (about 5 years of age) its size has rendered it an unfit prey even for the large muskellunge. From this point on, the chief predator of the lake sturgeon is man.

Male and female lake sturgeon are apparently subject to different rates of mortality after the first 10 or 15 years of life. Among the older and larger sturgeon there is a predominance of females.

The sex ratio for 151 lake sturgeon 50 inches and larger taken from Black and Mullett lakes by spear fishermen during the years 1974-1979 was 71% female and 29% male. Among larger fish the preponderance of females was even greater. Eighty percent of the sturgeon over 60 inches long were females, and among fish 70 inches and larger, 86% were females. This imbalance of the sex ratio is known to occur in other lake sturgeon populations. Probst and Cooper (1955) reported that 96% of the lake sturgeon over 59 inches long speared in Lake Winnebago were females. Probst and Cooper attributed the predominance of females among larger sturgeon to either a longer natural life span for females or a lower rate of exploitation, suggesting that males might be subjected to a significant illegal harvest in the rivers during the spawning run. The latter might indeed be the case for at least one Michigan population. Even though the upper Black River above Black Lake is closed to all fishing during April and May, poaching of spawning sturgeon remains a serious problem (Eugene Elsenheimer, conservation officer, personal communication). Mason Shouder (personal communication) has speculated that most of the mortality not directly attributable to legal fishing in the Black Lake population can be attributed to the illegal harvest of sturgeon during the spawning run.

Lake sturgeon compete with other bottom-feeding fishes for the same food items. Probably the greatest competitors with the lake sturgeon for food are the various species of suckers (Catostomidae). However, the extent of this interspecific competition is not known.

Lake sturgeon are hosts to a variety of parasites. The most serious of these are the lampreys. The sea lamprey (*Petromyzon marinus*) is known to attack and even kill large lake sturgeon in the Great Lakes. In Black Lake, sturgeon are parasitized by the smaller silver lamprey (*Ichthyomyzon unicuspis*). The extent of parasitism by the silver lamprey in Black Lake is not known, but two of the first three sturgeon speared in Black Lake in 1980 were found to have lampreys attached to them. I identified one of the lampreys taken from these fish as *I. unicuspis*.

Hoffman (1967) listed 12 parasites found in lake sturgeon. Margolis and Arthur (1979) listed the following 17 parasites of lake sturgeon: Monogenea, 3 species; Trematoda, 8 species; Nematoda, 3 species; Acanthocephala, 1 species; Hirudinoidea, 1 species; Branchiura, 1 species. Neither of these lists include the Coelenterate *Polypodium* sp. which has been found in the ovaries of sturgeon taken in Black Lake (Hoffman et al. 1974). This is the only North American record of this unique parasite. About 20% of the female sturgeon in Black Lake are believed to be infested with *Polypodium* in varying degrees (Mason Shouder, personal communication). John Hnath, fish pathologist for the Michigan Department of Natural Resources, and I examined for parasites in December 1979, a dead male lake sturgeon, 35 inches long and weighing 10 pounds, 2 ounces. This fish was captured alive, but floundering, in the Saginaw River (Saginaw County) within the city limits of Saginaw in late July 1979. The only parasites found were a single specimen of *Cucullanus chitellarius*, found in the hind gut, and 23 specimens of *Spinitectus gracilis* from the esophagus, both species being nematodes. These are tentative identifications, done by Hnath, and are included because there are so few records of lake sturgeon parasites for Michigan populations.

Very little is known concerning the bioaccumulation of chemical toxicants by lake sturgeon. The lake sturgeon has very fatty flesh and lives to great age, which suggests that it could accumulate high concentrations of fat soluble toxicants such as chlorinated hydrocarbon pesticides and polychlorinated biphenyls (PCB's). Evans et al. (1972) reported that 1970 mean mercury levels in lake sturgeon taken from Lake St. Clair and the St. Clair River were 2.0-3.0 ppm.

DISTRIBUTION OF THE LAKE STURGEON IN MICHIGAN WITH NOTES ON THE FISHERIES

In order to identify existing lake sturgeon populations, a questionnaire was sent to all Michigan Department of Natural Resources regional and district fishery biologists, fishery habitat biologists, and Great Lakes research stations (Fig. 2). Each questionnaire was followed up by a telephone interview within 2 weeks so that responses might be obtained more quickly. The results of this questionnaire survey, and of subsequent field investigations that I conducted are discussed below.

There are three significant populations of lake sturgeon known to exist in Michigan. These populations are located in:

(1) Burt, Mullett and Black lakes in the Cheboygan River system, Cheboygan and Presque Isle counties;

(2) the Menominee River, a boundary stream between Wisconsin and the Upper Peninsula (chiefly Menominee County); and

(3) Lake St. Clair and the St. Clair River.

Burt, Mullett, and Black lakes

The populations of Burt, Mullett, and Black lakes are essentially landlocked, connection with Lake Huron having been blocked by a dam with lock on the Cheboygan River in the 1920's.

LAKE STURGEON QUESTIONNAIRE

1. Do you have any lake sturgeon in your district?

2. Have you had any reports of sturgeon in your district?

3. If a population of lake sturgeon is present, where is it located? (Please give county, township, range, section, and site.)

4. How recent is your latest information concerning the existence of sturgeon in your district?

5. Do you have any information regarding the size of the population(s)?

6. Do you have any specific biological information (lengths, weights, exploitation, etc.) about the population(s)?

7. Do you know of anyone else who might have information about sturgeon populations in your district?

Figure 2.--Questionnaire regarding lake sturgeon distribution.

The lakes have supported a significant winter spear fishery since 1948. Characteristics of this fishery were described by Williams (1951). The Michigan Department of Natural Resources has closely monitored the fishery in these lakes since 1974. It is known that Black Lake (the shallowest of the three lakes) has a substantial population of sturgeon, and most of the annual harvest is taken there. However, the largest sturgeon taken each year invariably come from Mullett Lake. No sturgeon have been speared in Burt Lake since 1974, and the population there is believed to be very small. Fishermen no longer actively pursue lake sturgeon in Burt Lake, the fishery now being confined to Mullett and Black lakes.

Since 1974, all successful sturgeon spearers on Burt, Mullett, and Black lakes have been required to have their catch verified and tagged by a state fishery biologist within 48 hours. Thus, the total catch is known for each of these three lakes for the past 7 years (Table 2). In these years a total of 203 lake sturgeon have been harvested by sport fishermen, 166 from Black, 36 from Mullett, and 1 from Burt Lake.

The upper Black River, from its confluence with Black Lake to Kleber Dam, is the principal spawning area for the Black Lake population. In 1972, four artificial spawning reefs were built in the river to provide the spawning sturgeon with more suitable substrate. In 1973, the Northern Michigan Electric Coop., Inc. (which owns and operates Kleber Dam) agreed to provide a minimum flow of approximately 80 cfs from May 1 through July 31 each year. This minimum flow serves to keep the artificial

Table 2.--Annual lake sturgeon spearing harvest in Burt, Mullett, and Black lakes, 1974-1980.

Year	Lake			Total
	Burt	Mullett	Black	
1974	1	9	13	23
1975	0	1	33	34
1976	0	7	34	41
1977	0	0	29	29
1978	0	4	24	28
1979	0	9	19	28
1980	0	6	14	20
Total	1	36	166	203

spawning reefs submerged and free of silt during the spawning season (Shouder 1975). Sturgeon are also known to run down the lower Black River, as far as Alverno Dam during the spawning season (Mason Shouder, personal communication).

The lake sturgeon population of Mullett Lake utilizes the Pigeon River as a spawning ground. Sturgeon from Burt Lake may spawn in the Sturgeon River (Mason Shouder, personal communication). The extent of the spawning runs and suitable spawning habitat for these populations is unknown.

The Menominee River

The Menominee River population is landlocked, being confined to the portion of the river between the White Rapids Dam upstream and the Grand Rapids Dam downstream, a distance of 26 river miles (Priegel 1973). It is the object of a hook-and-line fishery each year during the months of September and October. Burdick (1968) has described the nature of this fishery. Management of the Menominee River population is carried out jointly by Wisconsin and Michigan. Priegel (1973) has conducted detailed investigations of the Menominee sturgeon population and its fishery.

Lake St. Clair and the St. Clair River

Very little is known about the lake sturgeon population of Lake St. Clair, except that a substantial (and largely illegal) fishery has taken place in the North Channel of the St. Clair River for many years.

Each year during the month of June, lake sturgeon migrate up the North Channel to a series of deep holes along the mainland shore, across from Dickinson Island. They advertise their presence by rolling on the surface and jumping, thus alerting local anglers. It is believed that the sturgeon spawn in these deep holes, as they concentrate in very localized areas. Local residents report that the bottom in these areas is composed of large cinders, dumped by steamships many years ago. The current is very strong in the North Channel, and if the substrate is as reported, then conditions would be ideal for spawning sturgeon. Further proof of spawning activity is the occurrence of ripe female sturgeon in the anglers' harvest. I was shown a color photograph, taken by a local resident, of several gallons of ripe sturgeon roe removed from a fish caught by the person's son in 1978.

Very small sturgeon, estimated to be only 1 or 2 years old, have been taken by Michigan Department of Natural Resources research vessels in Anchor Bay (Robert Haas, personal communication). Also, larger lake sturgeon of varying sizes and ages have occasionally been collected all over Lake St. Clair over the past 12 years. Thus the sturgeon, though still rare, are apparently reproducing.

Some local residents catch spawning lake sturgeon in much the same manner as is employed in the Menominee River fishery. Very heavy tackle is utilized, and bottom fishing with nightcrawlers is the preferred method. The taking of sturgeon in this manner is legal, as there is currently no closed season with respect to sturgeon fishing in the Great Lakes and connecting waters. However, most of the sturgeon taken in this fishery are snagged, not caught on live bait. Violations are the rule rather than the exception in this fishery. The most common terminal fishing gear consists of a heavy sinker (1 to 1 1/4 pounds) and two to four very large treble hooks. A single point of each treble hook is baited with a plastic worm, thus circumventing the fishing regulation which states that all lines must be baited. This type of gear bears great resemblance to the equipment used to snag paddlefish in the large rivers of the western United States.

The violator thus equipped allows the current to carry his sinker and hooks into the deep hole where the sturgeon are concentrated. The slack line is taken up and the gear is allowed to remain on the bottom until a sturgeon swims into it, thus jerking the line. The violator then heaves back on his heavy rod, hoping to drive the points of the treble hooks into the fish's body. Though apparently crude, this method accounts for the majority of the sturgeon taken in this fishery.

Set-lining, though illegal, is also a popular method among the local residents for taking sturgeon, and heavy set-lines can be seen tied to many docks in the vicinity of the "sturgeon holes."

The harvest of lake sturgeon from the North Channel, by both legal and illegal methods, is substantial. One resident, who has kept meticulous records concerning the number of sturgeon he has caught or seen caught from the main fishing area since 1963, told me that in 1969 he saw more than 100 sturgeon taken in 2 days, all of them snagged. Even if this figure is greatly exaggerated, it still indicates a very large number of spawning sturgeon is being taken. Residents report that the catch of sturgeon during the June fishery was much larger in past years than it is now, and that many more people are now fishing for sturgeon than formerly did.

Apprehension of violators operating in this fishery is exceedingly difficult. Most of the fishing goes on at night, making observation of fishermen difficult. In the case of the snaggers, a fish must be caught and in possession or no violation can be charged. At times, no fish may be caught for several days. This makes direct observation of the fishery by conservation officers a relatively fruitless endeavor.

From June 15 through June 24, 1979, I conducted a creel census on the North Channel of the St. Clair River. Several lake sturgeon were observed jumping and rolling on the surface, but no legal-size sturgeon were caught by any of the anglers that were interviewed. One sublegal sturgeon was reported caught and released. Anglers and local residents stated that several large sturgeon were taken on the weekend prior to the beginning of the creel census. Not enough data were collected for an estimate of fishing pressure to be made.

Lake St. Clair and the St. Clair River apparently still support a significant population of lake sturgeon. However, more stringent regulations governing the taking of sturgeon during the spawning season are necessary if the population is to be given an opportunity to increase.

Other Michigan sturgeon populations

In addition to the populations discussed above, lake sturgeon are still present in all of the Great Lakes, though not in numbers approaching their abundance of a century ago. Sturgeon are reported only occasionally by commercial fishermen in pursuit of other species and by state research vessels. Commercial fishing for lake sturgeon has been illegal since 1970. Organ et al. (unpublished) report that, based on information gathered from commercial fishermen, lake sturgeon have spawned or are spawning in parts of Lake Erie, the Detroit River, the St. Clair River, Lake Huron, and Lake Michigan. Maps showing the locations of these spawning areas are included in that publication.

Lake sturgeon are occasionally reported in most of the larger streams flowing directly into the Great Lakes. The fish are most often seen during the months of May and June, when they come in from the lakes to spawn. Reports of sturgeon are almost exclusively from the lower reaches of the rivers, below the first dam. In two cases, reports of sturgeon have come from lakes at the end of river systems. Both of these lakes communicate directly with Lake Michigan, so these fish do not belong to landlocked populations.

Rivers in which lake sturgeon have been reported at least once during the last 10 years are listed in Table 3.

Lake sturgeon are occasionally encountered in Pere Marquette Lake, Mason County, but have not been reported from the Pere Marquette River.

Table 3.--Rivers in which lake sturgeon have been reported during the last 10 years.

River	County	Comments
Upper Peninsula		
Millecoquins	Mackinac	below Millecoquins Lake
Sturgeon	Houghton, Baraga	below Prickett Dam
Waiska	Chippewa	
Lower Peninsula		
Cheboygan	Cheboygan	below paper mill dam in Cheboygan
Au Sable	Iosco	below Foote Dam
Manistee	Manistee	below Tippy Dam
Muskegon	Muskegon	below Croton Dam, also Muskegon Lake
Grand	Ottawa, Kent	below city of Grand Rapids
St. Joseph	Berrien	below Berrien Springs Dam

Several local populations of lake sturgeon exist in various lakes in the Upper Peninsula. Most of these populations are landlocked, connections with the Great Lakes via river systems having been blocked by impoundments. Lakes harboring such populations include: Otter Lake, Houghton County; Manistique Lake, Mackinac and Luce counties; Indian Lake, Schoolcraft County; Brevoort Lake, Mackinac County; and Monacle Lake, Chippewa County. Not much is known concerning the sturgeon populations of any of these lakes. The only direct attempt to assess one of these populations was made in 1979.

In late May 1979, I assisted the U.S. Forest Service in an assessment of the magnitude of a lake sturgeon spawning run in the upper Indian River in Schoolcraft County, near Manistique. The sturgeon population of Indian Lake spawns in the upper reaches of the Indian River. In 5 days of electrofishing, six lake sturgeon were captured and length, weight, and girth measurements were taken. Pectoral fin bones were removed from all sturgeon for the purpose of age determination. Twelve other lake sturgeon were observed but not captured by Forest Service personnel. Approximately 20 lake sturgeon were observed by a local resident on the night of May 15, about 7 miles upstream from the site of the electrofishing (Charles Basset, personal communication). (The electrofishing boat could only travel about 1 mile upstream from the mouth of the river, due to the width of the stream and the frequency of obstructions.) Some illegal harvest is taken from the Indian Lake population during the spawning run, but the severity of this problem is not known.

Evidently, these small inland populations do not support significant fisheries. Lake sturgeon are occasionally speared through the ice during the winter spearing season on Indian Lake, but the number of fish harvested is not known. More research is necessary to determine the size of these populations and rates of exploitation.

Outside of the three major fisheries discussed above, the angler harvest of lake sturgeon from the other sturgeon populations of Michigan, including the Great Lakes, is very small. A few sturgeon are taken on hook and line each year in the Great Lakes and at the mouths of rivers by anglers fishing for other species. The number of legal sturgeon taken under these conditions probably amounts to less than ten fish annually.

ESTIMATES OF FISHING PRESSURE AND CATCH PER UNIT EFFORT

Estimates of fishing pressure and catch per unit effort were only possible for the Black Lake spear fishery and the hook-and-line fishery of the Menominee River, as these were the only fisheries for which adequate creel census information was available.

Black Lake

A creel census of the sturgeon fishery in Black Lake was conducted by Department of Natural Resources personnel during the 1975 and 1976 spearing seasons. Sturgeon anglers returning from fishing were interviewed at random and the numbers of hours spent fishing and fish speared were recorded. Counts of occupied shanties on the sturgeon spearing grounds were made, but it was later found that the shanty counts for both years were not made in a random manner, so the shanty count data were not used in the development of the effort estimates. Since each sturgeon speared in Black Lake must be validated by a DNR fishery biologist, the total catch for the entire season was known, thus allowing estimates of fishing pressure and catch per unit effort to be made using only the interview data and the total catch.

It was assumed that the interviews of spearers comprised a random sample of the population of all sturgeon spearers. Catch per hour was calculated for each day of the season on which interviews were conducted. The mean catch per hour $\hat{\mu}_c$ for the entire season was then calculated as follows:

$$\hat{\mu}_c = \frac{\sum_{i=1}^{n} \gamma_i}{n}$$

where γ_i is the catch per hour calculated for day i, and n is the number of days sampled.

The estimated variance of $\hat{\mu}_c$ was determined using the following formula:

$$\hat{V}(\hat{\mu}_c) = \frac{\Sigma\gamma_i^2 - \frac{(\Sigma\gamma_i)^2}{n}}{n(n-1)}$$

Fishing effort was measured in shanty hours. The estimated number of shanty hours $\hat{H}$ was then calculated from the known catch and the estimated mean catch per hour.

$$\hat{H} = \frac{\text{known catch}}{\hat{\mu}_c}$$

The estimated variance of the fishing pressure is

$$\hat{V}(\hat{H}) = \hat{H}^2 \left[\frac{\hat{V}(\hat{\mu}_c)}{\hat{\mu}_c^2} \right]$$

because, if B and C are any two random variables, and $A = B/C$, then according to Cochran (1963)

$$V(A) = A^2 \left[\frac{V(B)}{B^2} + \frac{V(C)}{C^2} - 2\,COV(B, C) \right]$$

In this case, the known catch is a constant. Since the variance of a constant is zero the B term is omitted from the equation. It was assumed that the covariance of the known catch and $\hat{\mu}_c$ was zero.

Confidence intervals (level of significance = 0.05) were constructed for estimates of total shanty hours and catch per hour.

Estimates of effort and catch per unit effort, confidence intervals, and the known catch for the 1975 and 1976 spearing seasons are listed in Table 4.

A shanty hour is a unit indicating that a spearing shanty is occupied by an angler or anglers for a period of 1 hour. One shanty hour is essentially equivalent to one angler hour, since there is no relationship between the number of anglers in a single shanty and spearing success. Catch per hour estimates are made more meaningful by converting to hours per fish which is the reciprocal of catch per hour.

In 1975, 70.4 shanty hours of effort were expended for every sturgeon harvested. In 1976, each sturgeon speared represented 116.8 shanty hours of effort. The mean number of hours expended per fish in 1975 and 1976 is 93.6 hours per fish.

There are statistically significant differences between 1975 and 1976 for both fishing effort and catch per hour. These differences were shown by the techniques of hypothesis testing, using a level of significance

Table 4.--Estimates of effort and catch per unit effort for the spear fishery of Black Lake, 1975-1976.

Year	Effort (shanty hours)	95% confidence limits	Catch per unit effort (fish per shanty hour)	95% confidence limits	Total known catch
1975	2,332	1895, 2769	0.0142	0.0115, 0.0168	33
1976	3,972	3503, 4441	0.0086	0.0075, 0.0096	34

of 0.05. It is interesting that the total catch in 1975 and 1976 remained essentially the same. Catch per hour decreased in 1976, but this decrease was evidently balanced by an increase in the number of shanty hours. The reason for the differences in fishing effort and catch per unit effort between 1975 and 1976 is not known.

Vondett (1957) estimated the fishing pressure on Black Lake during the 1956 spearing season to be 5,076 angler hours. (Vondett's angler hour is equivalent to the shanty hour used in this investigation, since Vondett sent questionnaires to the owners of shanties at the end of the spearing season.) The estimated total catch in 1956 was 55 sturgeon. The greater number of fish taken in 1956 (55 as compared with 33 in 1975) can be attributed to the 2-month-long fishing season in 1956 (January and February), and to the 42-inch minimum size limit then in effect, rather than to a decline in the sturgeon population. Vondett also estimated that 84 hours of effort were expended for every sturgeon speared. This agrees fairly well with the mean estimated effort per sturgeon for 1975 and 1976 (93.6 hours per fish).

Menominee River

Priegel (1973) estimated the fishing pressure and total catch for the Menominee River hook-and-line fishery in 1969 to be 14,300 angler hours and 59 lake sturgeon, respectively. In 1970, the estimated fishing pressure was 11,400 angler hours and the estimated total catch was 48 lake sturgeon.

The amount of effort expended for each sturgeon harvested was calculated using Priegel's estimates of fishing pressure and total catch. In 1969, 242.4 angler hours were expended for each legal sturgeon, while in 1970, the effort was 237.5 hours per fish. These estimates of the number of hours fished per sturgeon harvested are much higher than similar estimates for the Black Lake spear fishery. The difference in the amount of effort necessary can partially be accounted for by the different types of gear employed. Also, Priegel did not mention in his report whether or not sturgeon fishermen were distinguished from anglers fishing for other species. If all anglers were considered together, the estimated number of angler hours spent in pursuit of sturgeon would be inflated, since the time spent by anglers not fishing for sturgeon would also be included.

POPULATION AND EXPLOITATION ESTIMATES

Black Lake

A mark-and-recapture study was conducted by Shouder (1975 and personal communication) in which he captured and marked lake sturgeon in Black Lake during the month of June from 1970 through 1978. Each fish handled was marked, total length was recorded, and a pectoral fin-bone was taken for aging. I obtained Shouder's raw data for the purpose of making population estimates and thereby estimating exploitation rates, since the total catch for each year by sport fishermen was known. Because of the nature of the mark-and-recapture data available, it was necessary to make several modifications so that the data could be analyzed by a standard estimation method.

The Chapman modification of the Petersen estimator was used to estimate the population size for a given year. The formula is as follows:

$$\hat{N} = \frac{(M + 1)(C + 1)}{(R + 1)}$$

where $\hat{N}$ is the estimated size of the population, M is the number of marked fish at large in the population, C is the size of the second, or recapture sample, and R is the number of marked fish recaptured in the second sample. This estimator is slightly biased, but the bias becomes negligible when MC is greater than 4N (Robson and Regier 1964).

Because of the small number of fish marked in any given year and the small number of recaptures, it was necessary to combine the groups of fish marked over a period of several years in order to obtain realistic population estimates.

Since annual mortalities occurring over several years would tend to reduce the number of marked fish at large in the population, a correction was made in the size of the marked population using the following procedure. All of the fish marked in a given year i were considered as a single cohort m_i. For each year that the cohort was at large in the population, the percent annual mortality was subtracted from it. It was assumed that both marked and unmarked fish were subject to the same annual mortality. The annual mortality rate was obtained from the instantaneous total mortality rate which was calculated by least squares regression of the descending leg of a catch curve, as will be described later. By this method, annual mortality was found to be 0.097 or 9.7%.

As an example, suppose that in 1970, 16 sturgeon were marked, and that we wish to know how many of these fish should still be available for a population estimate in 1974. Using the formula

$$m_i + 1 = m_i - a m_i$$

where a is the annual mortality rate, the results would be as follows:

1971: 16 - 9.7% = 14.45

1972: 14.45 - 9.7% = 13.05

1973: 13.05 - 9.7% = 11.78

The result for the year under consideration was then rounded off to the nearest whole number.

When a Petersen estimator is used, the population estimate obtained applies to the time when the marked fish were released. Since in this case the marked fish were released over a period of several years, the population estimate was arbitrarily assigned to the year immediately preceding the year of the recapture sample.

When the fish were marked, both sublegal fish and fish of legal size were tagged. During the winter spearing season, only sturgeon 50 inches and larger can be legally taken. I wished to use the catch records from the spearing season in conjunction with the netting data so as to increase the size of the second sample, C, in the Petersen estimator. Therefore, I decided to consider only fish 50 inches and larger in evaluating C.

In order to allow for the sublegal fish, and to increase the number of legal-size marked fish available at the time of recapture, fish which would be 50 inches long by the year of recapture were included in the marked population M. Predictions of growth were obtained from the von Bertalanffy growth curve, which will be discussed later. Since the marked sublegal fish ranged in size from 38 inches to 50 inches, the mean predicted annual growth increment was calculated for fish in this size range from the predicted lengths at age of the von Bertalanffy model. The mean annual growth increment for lake sturgeon from 38 inches to 50 inches in length is 1.4 inches.

I used the growth increment calculated from the von Bertalanffy model in preference to the increments derived directly from mean lengths at age, because in the empirical data the mean length at age x + 1 is often less than the mean length at age x due to the small sample size of fish in each age class.

For each sublegal fish in a cohort of marked fish, the mean annual growth increment was added to its length successively until a length of 50 inches was reached. For example, a 42-inch sturgeon marked in 1970 would not be considered available for recapture until 1976 when it reached 50 inches in length.

It should be noted that since the population estimate has been assigned to the year previous to that of the recapture sample, the estimate resulting from the use of data treated in the manner described above will be of the number of sturgeon 48.6 inches and larger. This is because the last mean growth increment will not yet have been added. Since these fish are of nearly legal size, the estimated size of the population of legal fish would be very close to the estimated population of fish 48.6 inches and larger.

By integrating the aforementioned procedures, and applying them to each cohort of marked fish, the size of M at the time when the second sample (C) was made was determined. For example, consider the cohort of fish marked in 1970. I wanted to know how many of these fish were available when the recapture sample (C) was taken in 1974. The number of fish marked in 1970 was 17. Three of these fish were not of legal size, but by adding the mean annual growth increment to each fish's length four times, I found that two of them would be of legal size by 1974. Thus I had 16 fish which either were of legal size or would be legal by 1974. I then subtracted successive annual mortalities for 1971-1973 and obtained a final figure of 12 marked fish still available for recapture in 1974.

This procedure was carried out for each group of fish marked in successive years. The numbers of marked fish from each group which would be available at the time of the recapture sample were summed and the number of marked fish of legal size (M) was thereby obtained. The second, or recapture sample (C) was composed of the combined netting and spearing data for the following year. Since some of the netted fish were not of legal size, these were not included in the second sample. In simple form, fish in recapture sample equaled fish speared plus fish netted minus sublegal fish netted. Tagged fish which were speared and netted were combined to give the number of recaptures in the second sample (R). A 95% confidence interval for each estimate was calculated using a table, based on the Poisson frequency distribution and found in Ricker (1975).

Exploitation rates for sport fishing were calculated by dividing the known catch for a given year by the population estimate for the previous year and extreme values of exploitation were determined by calculating exploitation rates using the confidence limits of the population estimates. The estimates of population size and exploitation rates for the years 1973-1976 are listed in Table 5.

Population estimates for 1976 were not possible because no marked fish were recaptured in 1977. Marked fish were taken in 1978 and 1979, but data for the netting surveys of 1978 were unavailable and no netting was done in 1979. Therefore, population and exploitation estimates for these later years were not feasible.

I feel that the population estimate for 1975 and the resulting exploitation estimate for 1976 are the most representative of the true conditions, as the 1975 estimate is based on the largest number of recaptured marked fish (4) and therefore has a smaller bias than the other two estimates.

Menominee River

Priegel (1973) estimated the population of legal size (42 inches and larger) lake sturgeon in the Menominee River to be 243 ± 71% in 1969 and 185 ± 30% in 1970. He estimated the exploitation rates to be 13% and 17% in 1969 and 1970, respectively.

Table 5.--Estimates of population size and exploitation rates for lake sturgeon, Black Lake, 1973-1976.

Year	M_1	M_2	R	Population estimate	95% confidence limits	Exploitation rate	
						%	Limits
1973	97	33	1	1,666	505, 3029		
1974	117	41	1	2,478	751, 4505	0.8	0.4, 2.6
1975	122	64	4	1,599	714, 3998	1.3	0.7, 4.4
1976						2.1	0.8, 4.8

It should be noted that the size limit for sturgeon in the Menominee River has been raised to 50 inches since Priegel conducted his investigations, so presumably the present exploitation rates are not the same as they were in 1970.

STOCK ASSESSMENT

An evaluation of the adequacy of the current spearing regulations for lake sturgeon in Michigan's inland lakes was carried out using the equilibrium yield equation of Ricker (1958). This is a dynamic pool model of the general form

$$\frac{dY}{dx} = FN(x)\,W(x)$$

where Y is yield, x is age, F is the instantaneous fishing mortality rate, $N(x)$ is the number of individuals of age x, and $W(x)$ is the weight of an individual of age x. A derivation of the model is given in Ricker (1975). With the Ricker model yield can be calculated for a given weight or number of recruits at various levels of fishing mortality and ages at entry into the fishery, so that the combination of regulations which will give a maximum yield from the fishery can be ascertained. Although this analysis deals primarily with spearing regulations, the results concerning maximum rates of exploitation are equally applicable to hook-and-line fisheries, such as those of the Menominee and St. Clair rivers.

Growth in Length and Weight

Age-length relationship

Raw length and age data for fish taken in Black and Mullett lakes and the Menominee River were procured from files and reports of the Michigan Department of Natural Resources. Due to the methods of collection employed in the different locations, no single data set considered alone adequately represented the growth of the lake sturgeon through its entire lifetime. In the Menominee River, sturgeon were collected by electrofishing (Priegel 1973), and the sample was predominantly composed of fish less than 20 years old. By contrast, the fish captured in Black and Mullett lakes were taken either by spearing during the February fishing season or in large mesh gill nets as described by Shouder (1975). The fish taken by these two methods were predominantly older than 20 years.

Because of the very small amount of data from Mullett Lake, information from this location was combined with that from Black Lake. The small sample size precluded any attempt to show a statistically significant difference in growth rates between the two lakes, thus Black and Mullett lakes were considered together and identified simply as the inland lakes.

In order to evaluate the growth of the lake sturgeon over its entire theoretical life span, it was necessary to combine the age-length data from the inland lakes and Menominee River populations. The length-age relationships of the two data sets are so similar that I judged the growth rates of the inland lake and Menominee River populations were not significantly different (Figure 3).

The growth equation of von Bertalanffy (1938) as developed by Beverton and Holt (1957) was fitted to the length-age data by the method of least squares using FORTRAN program BGC3 from Abramson (1971). The equation is of the form

$$\ell_x = L_\infty[1 - e^{-k(x-x_0)}]$$

where ℓ_x is length at age x, L_∞ is the theoretical asymptotic length, k is a growth coefficient, and x_0 is the theoretical time when length is zero. The parameters of the von Bertalanffy model for Michigan lake sturgeon are

$$L_\infty = 69.6411 \text{ inches}, \quad k = 0.0558, \quad x_0 = -0.8815$$

Graphic analysis of residuals showed no significant biases in the model. The predicted von Bertalanffy growth curve for Michigan lake sturgeon is given in Figure 3. Lengths predicted by the model and observed mean lengths for ages 1-65 are given in Table 6.

It should be noted that sturgeon of length greater than L_∞ are not uncommon. These large sturgeon are generally taken by spear fishermen during the February season. They tend to be very old, and aging these fish accurately is nearly impossible. Since very large

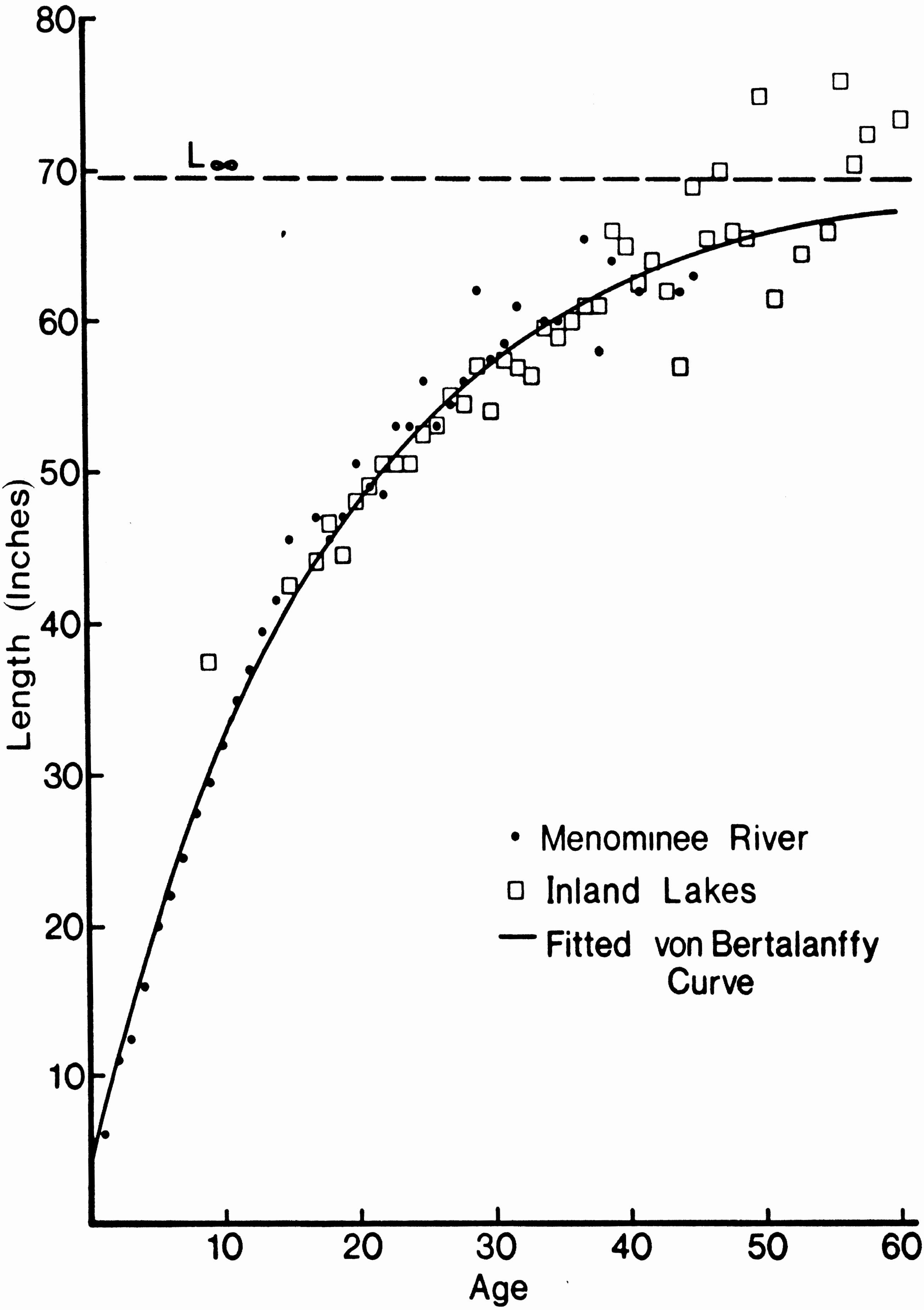

Figure 3.--Combined empirical length-age relationship for lake sturgeon from the Menominee River and the inland lakes, with fitted von Bertalanffy curve.

Table 6.--Observed and predicted values of length (inches) at each age for Michigan lake sturgeon.

Age (years)	Length	
	Observed (empirical mean)	Predicted (von Bertalanffy)
1	6.0	6.9
2	11.0	10.3
3	12.5	13.6
4	16.1	16.6
5	20.2	19.5
6	22.1	22.2
7	24.7	24.8
8	27.5	27.2
9	30.3	29.5
10	31.9	31.7
11	34.8	33.8
12	37.0	35.7
13	39.7	37.6
14	41.5	39.3
15	44.6	40.9
16		42.5
17	46.1	44.0
18	46.1	45.4
19	46.2	46.7
20	48.9	47.9
21	49.0	49.1
22	50.3	50.2
23	50.7	51.3
24	50.9	52.3
25	52.8	53.2
26	52.9	54.1

(continued, next page)

Table 6.--continued.

Age (years)	Length	
	Observed (empirical mean)	Predicted (von Bertalanffy)
27	54.8	55.0
28	54.7	55.8
29	57.6	56.5
30	54.5	57.2
31	57.7	57.9
32	57.2	58.5
33	56.7	59.1
34	59.5	59.7
35	58.9	60.2
36	60.2	60.8
37	61.3	61.2
38	60.7	61.7
39	64.5	62.1
40	65.0	62.5
41	62.6	62.9
42	63.9	63.3
43	62.0	63.6
44	57.8	64.0
45	66.0	64.3
46	65.5	64.6
47	69.9	64.8
48	65.8	65.1
49	65.6	65.3
50	75.0	65.6
51	61.5	65.8
52		66.0
53	64.5	66.2
54		66.4

(continued, next page)

Table 6. --concluded.

Age (years)	Length	
	Observed (empirical mean)	Predicted (von Bertalanffy)
55	66.3	66.6
56	76.0	66.7
57	70.3	66.9
58	72.3	67.0
59		67.2
60	73.5	67.3
61	69.5	67.4
62		67.6
63	72.3	67.7
64		67.8
65		67.9

sturgeon constitute only a very small portion of the total population, only fish of age 65 years and younger were considered in this analysis.

Length-weight relationship

Only mean length and mean weight data for each age were available for the Menominee River population, so mean length and mean weight data from the inland lake stocks were used in conjunction with the Menominee River data for the purpose of determining a length-weight model for a typical Michigan lake sturgeon population.

The allometric length-weight relationship was fitted to the mean length and weight data by the technique of simple linear regression. The relationship is of the form

$$W = a L^{b}$$

where W is weight, L is length, and a and b are parameters.

The length-weight relationship for Michigan lake sturgeon was

$$\ell n W = -8.8949 + 3.1393 \, \ell n L .$$

The coefficient of determination for this model was 0.986. The standard deviation of the regression was 0.169, which is considered to be large. The discrepancies between the predicted and observed values were quite large, amounting to as much as 15 pounds in some of the largest fish. However, in fish of over 100 pounds (which constitute only a small portion of the total catch) such an error was not of great consequence.

It is reasonable to suppose that the variation in the length-weight model could be reduced appreciably by considering male and female fish separately. However, as determination of sex generally requires dissection, it is not a feasible procedure when fish are to be released alive. For this reason very little raw data where sex was recorded were available, and such data as could be procured came exclusively from fish of 50 inches and larger taken by sport fishermen. These data would be unrepresentative of the full life span of the fish.

Mean weights at age were calculated from lengths at age (predicted by the von Bertalanffy equation) using the length-weight relationship described above. These weights were incorporated into the Ricker equilibrium yield model.

Mortality

Black Lake

Due to the small number of sturgeon taken in any one year, no single data set adequately represented the relative abundances of several consecutive age groups. In order to construct a catch curve, it was necessary to combine age and frequency data collected over a period of several years.

Data concerning age frequencies of lake sturgeon captured in gill nets were utilized in the construction of the catch curve. The number of fish of known age netted from 1970 through 1976 was larger than the number of fish speared from 1974 through 1977, for which age was known, and the netting sample exhibited a more uniform representation of frequencies over several consecutive year classes than did the spearing sample.

Ages of fish taken in gill nets ranged from 9 to 55 years, while ages of speared fish ranged from 20 to 63 years. However, only 5 fish older than 55 years were speared from 1974 through 1977 out of 107 aged fish. Since there is a significant amount of overlap of the age distributions of netted and speared sturgeon, it was felt that the netting data would provide an adequate estimate of the mortality rate of recruited fish.

The age-frequency data for sturgeon netted from 1970 through 1976 were transformed by subtracting the age of each individual from the year in which the individual was captured, thereby obtaining the year class of each fish. Each year class was then further transformed by assigning to it the age which fish of that year class would attain in the year 1976. This latter transformation was done arbitrarily, its purpose being to give the resulting catch curve its traditional configuration, with the right leg descending. Age frequencies resulting from this manipulation are listed in Table 7. The top of the dome of the catch curve was chosen by inspection of a graph of the natural logarithm of frequency against assigned age. Fish of less than 25 years old (assigned

Table 7.--Year classes, assigned ages, and frequencies of lake sturgeon netted in Black Lake, 1970-1976.

Year class	Assigned age	Frequency
1966	10	1
1959	17	1
1956	20	3
1955	21	6
1954	22	7
1953	23	7
1952	24	8
1951	25	14
1950	26	15
1949	27	10
1948	28	17
1947	29	10
1946	30	7
1945	31	13
1944	32	7
1943	33	6
1942	34	5
1941	35	11
1940	36	10

(continued, next page)

Table 7.--concluded.

Year class	Assigned age	Frequency
1939	37	8
1938	38	7
1937	39	5
1936	40	7
1935	41	1
1934	42	2
1933	43	2
1932	44	2
1931	45	3
1930	46	3
1929	47	2
1928	48	1
	Total	201

age) were not considered to have been randomly sampled. Data concerning these fish were deleted, and a line was fitted to the remaining data by the method of least squares. The slope of this line is a point estimator of the instantaneous total mortality rate, Z , for the range of ages encompassed by the data.

The following assumptions must be made in order to consider the descending leg of the catch curve described above to be an age-specific survival curve.

1. Survival is constant over the range of age groups in question.
2. There has been no change in the survival rate with time.
3. The samples taken from the age groups involved are random.
4. The age groups under consideration were equal in numbers at the time each age group was recruited into the fishery.

The instantaneous total mortality rate forBlack Lake sturgeon was 0.102. The coefficient of determination for the regression model was 0.727 and the standard deviation of the regression 0.452, which is considered to be large.

The survival rate S was calculated by the formula

$$S = e^{-Z}$$

and was found to be 0.903. Subtracting the survival rate from one (1) gives, a , the annual mortality rate. The annual mortality rate for Black Lake sturgeon was 0.097, which was utilized in the construction of population estimates discussed earlier.

The large amount of variation in the regression model can be accounted for in two possible ways. First, it must be remembered that the total number of fish of known age netted from 1970 through 1976 was only 205. Thus, the sample size for each age group was quite small when the number of age groups sampled was taken into consideration. Secondly, some of the variation in year class strength was no doubt due to fluctuations in recruitment from year to year.

Instantaneous total mortality is defined as the sum of the instantaneous natural and fishing mortality rates

$$Z = F + M$$

Fishing mortality F is generally calculated, and the remaining mortality is assigned to natural or non-fishing causes (M).

The instantaneous fishing mortality rate was calculated using the following formula, taken from Everhart, Eipper, and Youngs (1975):

$$F = \frac{EZ}{1 - S}$$

in which F is the instantaneous fishing mortality rate, E is the rate of exploitation, Z is the instantaneous rate of total mortality, and S the survival rate.

For the purpose of the yield analysis, an exploitation rate of 0.025 (2.5%) was assumed. Using this exploitation rate, together with the estimates of Z and S calculated from the catch curve, the instantaneous fishing mortality rate was calculated to be 0.026.

Instantaneous fishing mortality rates were calculated for the years 1974 through 1976, based on the rates of exploitation for those years, which were calculated as described earlier. The results are as follows:

Year	F
1974	0.008
1975	0.014
1976	0.022

Menominee River

The Menominee River population was sampled by electrofishing, and although this fishing method was not obviously selective for fish of any particular size range, most of the sample consisted of sturgeon less than 20 years old. Priegel (1973) attributed the predominance of smaller fish to a lack of larger fish in the population, rather than gear selectivity.

A line was fitted to a plot of the natural logarithm of frequency versus age and the instantaneous total mortality rate was determined in the same manner as for the Black Lake population.

The instantaneous total mortality rate for Menominee River sturgeon was 0.098. The coefficient of determination for the model was 0.757; the standard deviation of the regression 0.714. The large amount of variation can again be ascribed to the small sample sizes for individual age groups and annual fluctuations in reproduction. The corresponding survival and annual mortality rates were 0.907 and 0.093 respectively.

Instantaneous rates of fishing mortality were determined in the same manner as was used for the Black Lake population. Exploitation estimates taken from Priegel (1973) were used in conjunction with the above estimates of instantaneous total mortality and survival, and the instantaneous fishing mortality rates for 1969 and 1970 were found to be 0.137 and 0.179 respectively.

Priegel and Wirth (1975) estimated the instantaneous total mortality rates in the Lake Winnebago population to be 0.054 for sturgeon from 16 to 36 years of age, and 0.134 for older fish. Since the mortality estimates were made by using regression techniques on two segments of the descending leg of a single catch curve, instead of fitting a single line to the entire descending leg (as has been done for the Michigan populations here), the Winnebago estimates are not directly comparable with the mortality estimates for Michigan lake sturgeon. It should also be noted that Priegel and Wirth worked with a much larger sample of fish.

Incorporation into the yield equation

Since Ricker's yield model allows the use of different mortality rates for different age groups in the calculation of the yield equation, it was thought prudent to partition natural mortality according to the quantity of information available for different segments of the age distribution. The instantaneous total mortality rate for Menominee River sturgeon was developed for a sample of fish which was composed mainly of individuals less than 20 years old. Therefore, the instantaneous total mortality rate for Menominee River fish was used as the natural mortality rate in the yield model for sturgeon up to 20 years of age. Under the present fishing regulations, fish of less than 20 years old suffer virtually no fishing mortality.

Natural mortality for lake sturgeon of ages greater than 20 years was calculated using the instantaneous total mortality rate for the Black Lake population. The arbitrary fishing mortality rate of 0.026, mentioned earlier (page 61), was subtracted from the instantaneous total mortality rate (0.102) to give an instantaneous natural mortality rate of 0.076.

The instantaneous fishing mortality rate of 0.026 (calculated from a hypothetical exploitation rate of 0.025) was utilized in the yield model. Multipliers used in conjunction with this fishing rate, resulting multiples of the original fishing rate, and rates of exploitation corresponding to each multiple are listed in Table 8.

Yield per Recruitment

The Ricker equilibrium yield model operates under the assumptions that recruitment is constant and that fluctuations in population density are not of sufficient magnitude to facilitate changes in the growth or mortality rates of the population under scrutiny (Ricker 1975).

For the purpose of this analysis, recruitment consisted of 1,000 age-1 sturgeon. Under the current fishing regulations, lake sturgeon enter the fishery at an age of 22 years, by which time they are 50 inches long. For a population in a steady state, with an exploitation rate of 2.5%,

Table 8.--Multipliers of the instantaneous fishing rate used in the Ricker yield model and corresponding rates of exploitation.

Multiplier	Fishing rate	Exploitation rate
0.5	0.013	0.012
1.0	0.026	0.025
2.0	0.052	0.049
3.0	0.078	0.074
4.0	0.104	0.099
5.0	0.130	0.124
6.0	0.156	0.148
7.0	0.182	0.173
8.0	0.208	0.198
9.0	0.234	0.223
10.0	0.260	0.247

the yield was calculated to be 1,522 pounds for every 1,000 recruits. This calculation was repeated for ages at entry ranging from 1 to 65 years, and 11 multiples of the original instantaneous fishing rate of 0.026 such that the fishing rates evaluated corresponded to exploitation rates ranging from 1.25 to 25%. All calculations were performed using the computer program of Paulik and Bayliff (1967). Isopleths were fitted to the resulting yield matrix (Figure 4). The x indicates the point at which the Black Lake spear fishery was operating in 1976, with an age at entry into the fishery of 22 years and an instantaneous fishing rate of 0.022, corresponding to an exploitation rate of 2.1%. The circle and square represent the locations of the Menominee River hook-and-line fishery in 1969 and 1970, respectively. Here, age at entry was 16 years, as a 42-inch minimum size limit was then in effect.

The maximum yield attainable for any given fishing rate occurs at the point where a vertical line originating at the fishing rate of interest is tangent to the left edge of a contour. The loci of all such tangents form the eumetric fishing line of Beverton and Holt (1957). A segment of the eumetric fishing line, extending over the fishing rates under consideration is included in Figure 4 as line AA'. For each fishing rate, the age at entry which will provide the maximum yield can be found by drawing a vertical line from the fishing rate to line AA', then drawing a horizontal line from AA' to the vertical axis. As an example, for a fishing rate of 0.026 (2.5% exploitation rate), the maximum yield is 2,157 pounds for every 1,000 recruits. This maximum occurs when age at entry into the fishery is 8 years.

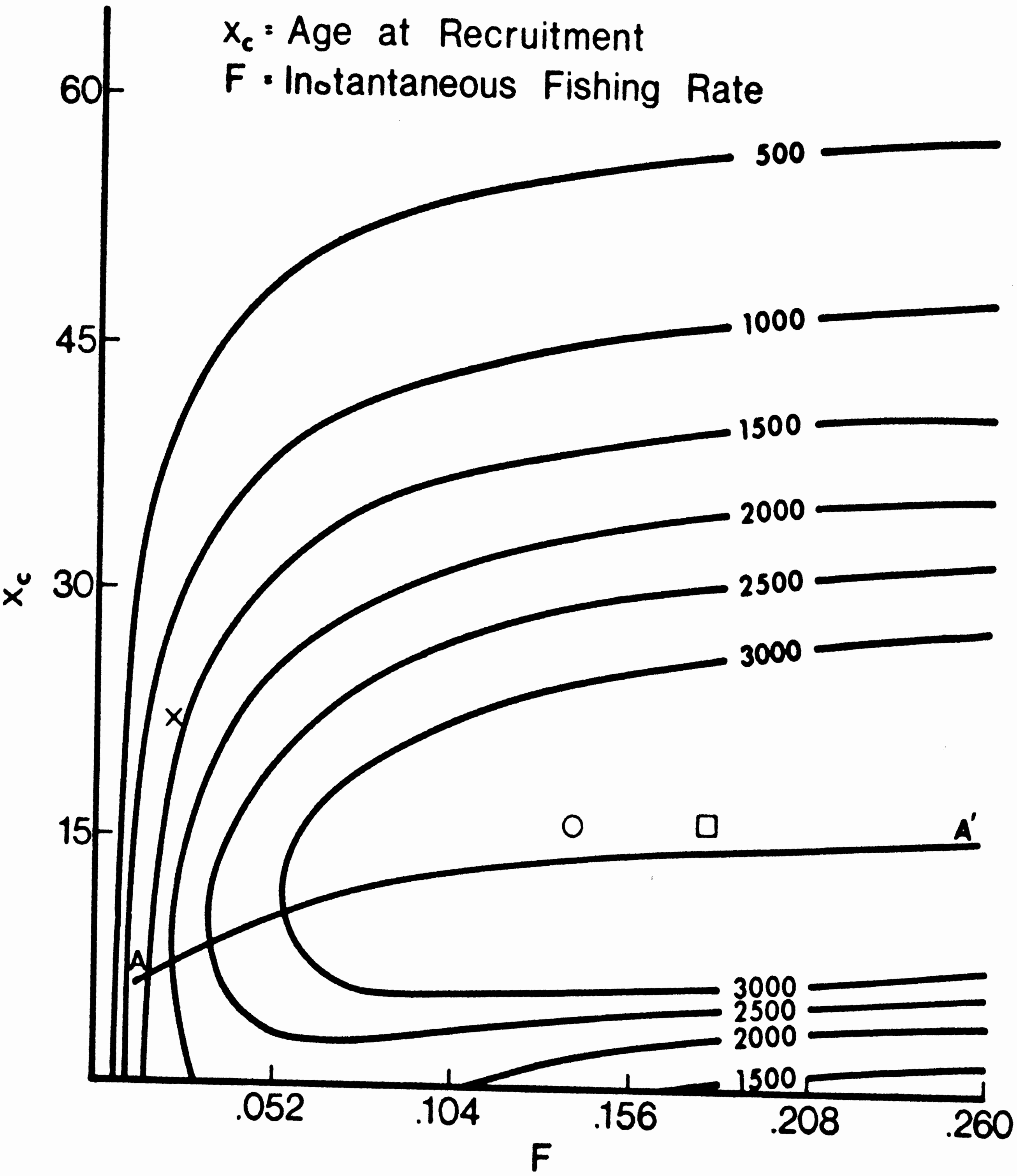

Figure 4.--Yield in pounds per thousand age-1 recruits as a function of age at entry into the fishery, x_c , and the instantaneous fishing mortality rate, F .

As the rate of fishing F increases, the age at entry corresponding to the maximum yield $x_{c\ max}$ also increases, but the amount of increase in $x_{c\ max}$ per unit increase in F is very small and the increment of increase becomes miniscule at high levels of F. For example, a doubling of the original rate of fishing causes an increase of $x_{c\ max}$ of only 2 years. Multiplying the original fishing rate by 10 causes $x_{c\ max}$ to increase by only 7 years. Thus, the eumetric fishing line approaches an asymptote corresponding to a very low age at entry into the fishery.

Since natural mortality rates are difficult to determine accurately in exploited stocks, it seems appropriate to evaluate yield per recruitment at various rates of natural mortality. The relationship between yield per recruitment and instantaneous fishing mortality for four possible rates of natural mortality with age at entry into the fishery held constant at 22 years is shown in Figure 5. It is evident that, due to the slow growth rate of the lake sturgeon, small changes in the natural mortality rate cause large changes in the yield per recruitment. For example, the fishery in Black Lake is currently believed to be operating with a natural mortality rate of 0.076. If I have underestimated the true natural mortality rate, then there is a possibility that the stock is being overexploited. If the true natural mortality rate is as high as 0.20 (not a large figure when compared with natural mortality rates of most freshwater species) then yield per recruitment is very low at all practical fishing rates.

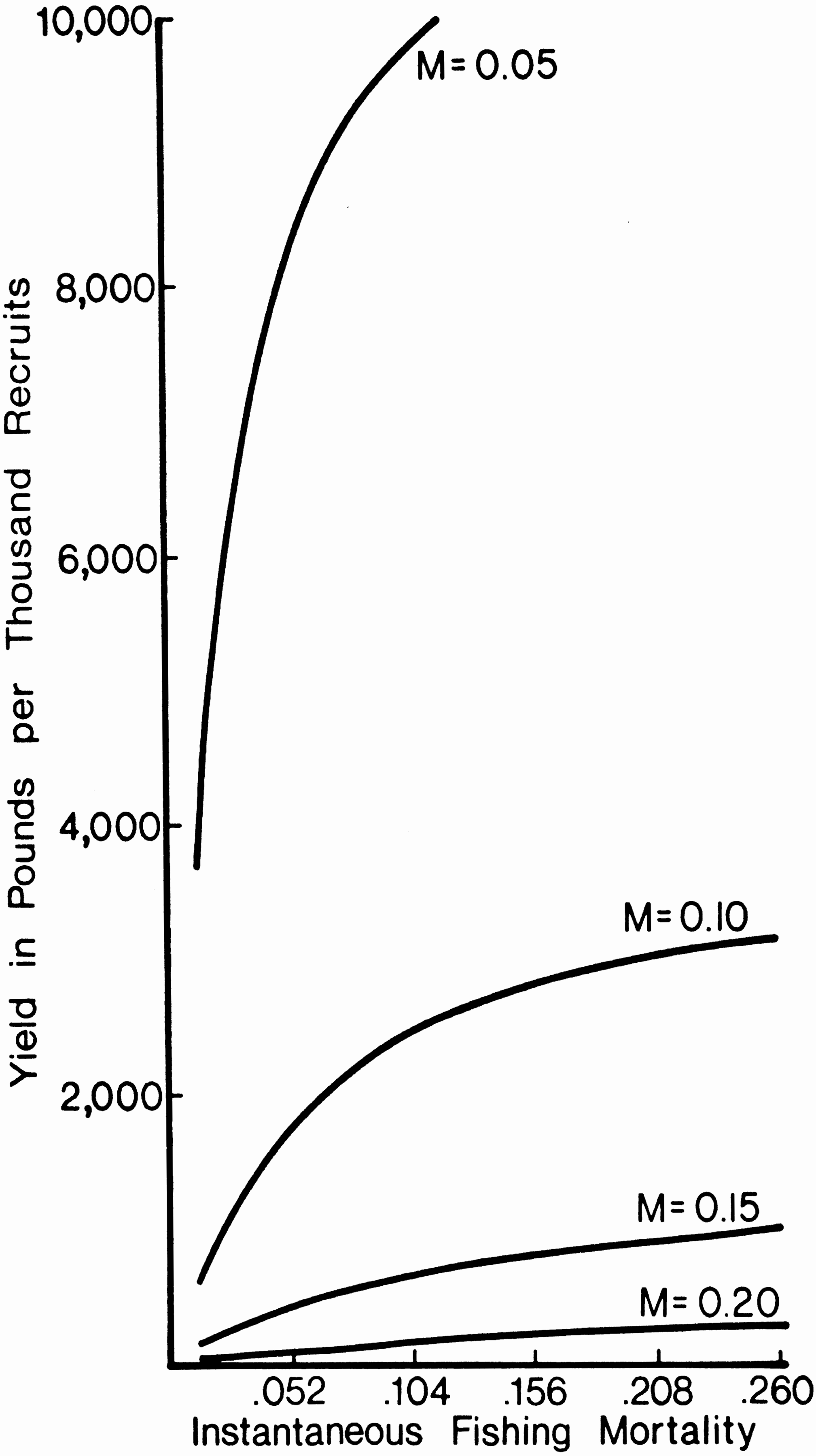

Figure 5.--Yield per recruitment as a function of the instantaneous fishing mortality rate for different levels of natural mortality with recruitment at age 1 year and entry into the fishery at age 22 years.

There is no reasonable fishing rate which will give a true maximum yield, as all of the yield curves approach asymptotes (Figure 5). This is because the weights of individual fish do not increase by a large amount during their life in the fishery (Cushing 1968). If the age at entry into the fishery was 5 years, instead of the current age of 22, there would be at least a tenfold increase in the weights of individual fish during their lifetime in the exploitable stock, and the resulting yield curve would have the conventional domed shape. With age at entry set at 22 years, the weight of individuals during their lifetime in the fishery increases only by a factor of about 2.5.

Since the trend in sport fisheries is toward increased fishing pressure as the number of participants increases, an evaluation of the effects of increased rates of exploitation on equilibrium yield per recruitment is in order. If age at entry into the fishery is held constant at 22 years, increasing the rate of exploitation from 2.5% to 5% (corresponding to a doubling of the original instantaneous fishing rate of 0.026) changes the equilibrium yield from 1,522 pounds to 2,293 pounds for every 1,000 recruits, an increase of 51%. Tripling the original rate of exploitation produces an 80% increase in yield over the original value. The effect of doubling the instantaneous fishing rate upon yield per recruitment for all possible ages at entry into the fishery is illustrated in Figure 6.

Inspection of the isopleth diagram (Figure 4) with respect to the yield from the Black Lake spear fishery operating in 1976 (and still

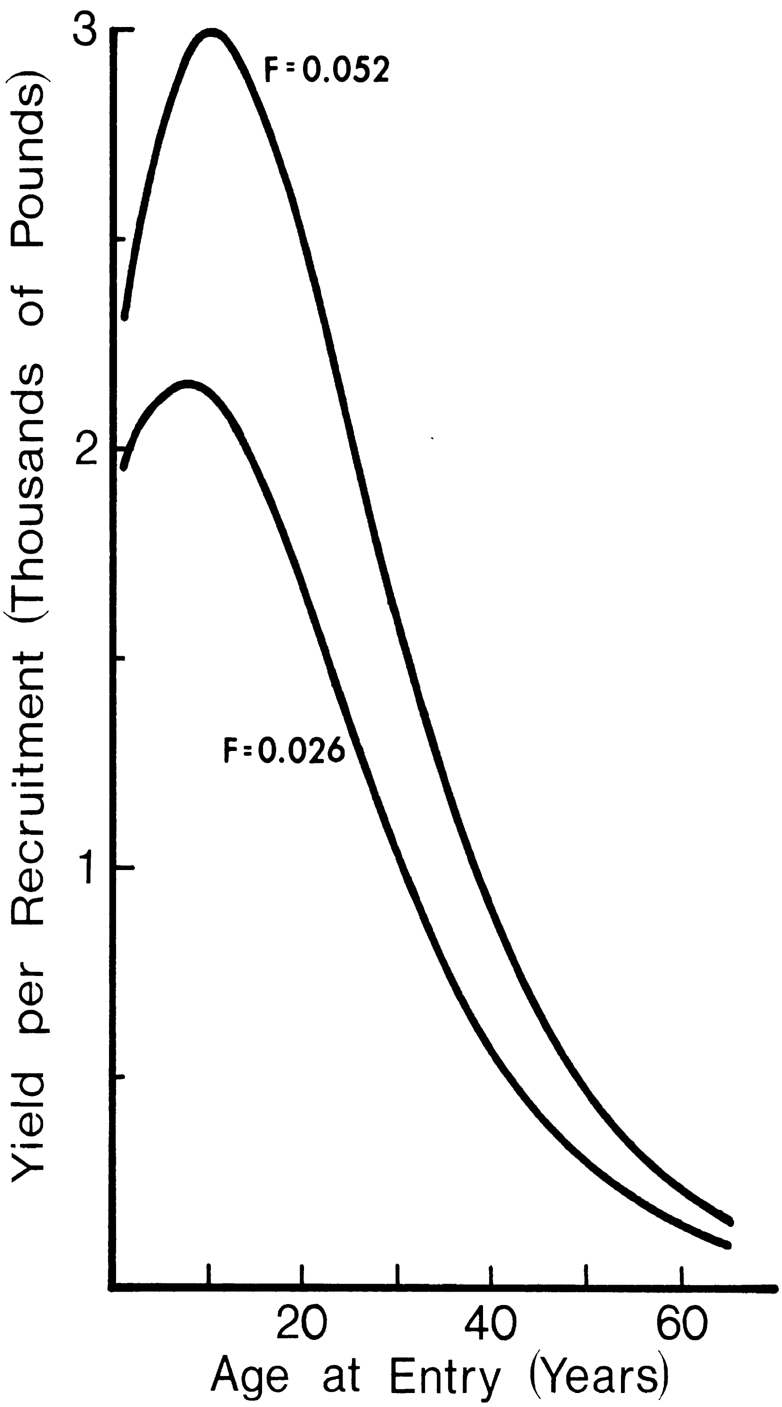

Figure 6.--Yield per recruitment as a function of age at entry into the fishery for two instantaneous rates of fishing mortality, F.

believed to operate at the same level today) leads to the conclusion that the fishery is underexploited. In order to maximize yield at the current instantaneous fishing rate (0.022) the age at entry into the fishery would have to be lowered to about 7 years. This would correspond to a 25-inch minimum size limit. However, it must be taken into account that male lake sturgeon do not become sexually mature before an age of 14-16 years and females do not mature until 24-26 years of age (Priegel and Wirth 1977). Since the relationship between the size of the spawning stock and the number of recruits produced is unknown, it only seems prudent to protect the fish until at least some of them have had the opportunity to spawn once.

Assuming that all sturgeon are sexually mature by an age of 25 years, the total biomass of fish 25 years and older can be regarded as the biomass of the spawning stock. For the purposes of this analysis, the total biomass of the spawning stock will consist of the sum of the individual biomass values for fish of ages 25 through 65 years. Very few lake sturgeon live past 65 years, and their contribution to the biomass of the spawning stock, as predicted by the model, is miniscule.

The yield model predicts the total biomass of the spawning stock for a population from which no harvest is taken to be 70,276 pounds per thousand age-1 recruits. If an exploitation rate of 2.5% and an age at entry of 22 years is imposed upon the stock, the total biomass of the spawning stock decreases to 48,057 pounds, a 32% decline. Doubling the rate of exploitation (5%) causes a 51% decrease in spawning stock biomass. If the rate of exploitation rises to 25% (not a high figure for most other fish species) the remaining total biomass of the spawning stock is only 10% of the pre-harvest value.

If the age at entry into the fishery is lowered to 7 years, and the exploitation rate is set at 2.1% (the age at entry and exploitation rate which should theoretically produce maximum yield from the fishery at its 1976 level of operation, as discussed above) the total remaining biomass of the spawning stock is 36,485 pounds, a 48% decrease from the pre-harvest level. If, at this exploitation rate, age at entry into the fishery is raised to 22 years (corresponding to the 50-inch minimum size limit currently in effect) the total remaining biomass of the spawning stock is 50,749 pounds, a decrease from the pre-harvest figure of only 28%.

What is the highest rate of exploitation which a lake sturgeon population can tolerate without showing a decline in numbers and what effect will a high rate of fishing have upon the stock? Cushing (1975) has described two types of overfishing: growth overfishing and recruitment overfishing. If recruitment does not change as fishing mortality increases, but the increased fishing rate causes yield to decrease because mortality exceeds growth, growth overfishing is occurring. This type of overfishing usually occurs in situations where the individual fish grow significantly during their lives in the fishery. Species such as plaice and halibut may grow in weight by a factor of ten or more during their recruited lifetime, and graphs of yield per recruitment against instantaneous fishing mortality for these species will reveal that the yield curves increase to a maximum at some intermediate fishing rate and then decrease as the fishing rate continues to increase. When these characteristics are present in an analysis of yield per recruitment for a particular species, growth overfishing becomes a possibility. Examination of a graph of yield per recruitment as a function of fishing mortality for a slow-growing fish will show that the yield curve continuously increases toward an asymptote, indicating that there is no fishing rate which will produce a true maximum yield. The graph of yield per recruitment as a function of instantaneous fishing mortality for lake sturgeon (Figure 5) is of this type.

Recruitment overfishing occurs when the mortality of the adult stock due to fishing is sufficient to adversely affect the level of subsequent recruitment. Recruitment overfishing is difficult to document because stock-recruitment relationships are hard to establish; the necessary data seldom exist. However, Priegel and Wirth (1975) estimated the annual recruitment of legal size sturgeon into the Lake Winnebago fishery to be 4.7%, based on the average portion of the catch of all age groups for the years 1955 through 1967, and suggested that the annual harvest should not exceed the annual recruitment. In a similar manner, I calculated recruitment into the fishable stock for the Black Lake population.

I assumed that the size of the adult stock in Black Lake was constant. Since there have been no significant changes in the size or age distributions of the catch for the years 1974 through 1979, this assumption appears reasonable. If the population of adults is stable, then recruitment will fluctuate about some mean value. Since lake sturgeon enter the fishery over a broad range of ages, and annual growth of lake sturgeon near the minimum size limit is only about 1 inch, I examined the proportion of fish in the annual catch which were between 50 and 51 inches in length. Fish taken by spearing and netting were combined where possible, in order to increase the size of the samples. The percentage of the total catch which was from 50.0 to 50.9 inches in length was calculated for the years 1970 through 1979. Results are shown in Table 9.

The mean percentage of sturgeon 50.0 to 50.9 inches long in the total catch, for the years 1970 through 1979, is 4.8% which agrees very well with Priegel and Wirth's estimate.

The natural mortality rate of adult lake sturgeon is believed to be very small. It is likely that the only significant source of mortality other than legal fishing is the illegal harvest of adult sturgeon during the spawning run (Mason Shouder, personal communication). If this is the case, then the maximum allowable exploitation rate for Black Lake is approximately 4.8%. Using the 1975 population estimate of 1,599 legal size lake sturgeon and the above exploitation rate, the maximum allowable catch of sturgeon from Black Lake was calculated to be 77 fish. The average annual harvest of sturgeon from Black Lake during the years 1974 through 1980 was 24 fish, less than half of the calculated maximum,

Table 9.--Estimation of annual recruitment to the fishable stock in Black Lake. (Sturgeon from 50.0 to 50.9 inches in length were considered recruits.)

Year	Spearing catch	Recruits	Netting catch	Recruits	Total catch	Total recruits	Percent recruitment
1970	No record	No record	17	1	17	1	5.9
1971	No record	No record	42	2	42	2	4.8
1972	No record	No record	30	1	30	1	3.3
1973	No record	No record	49	2	49	2	4.1
1974	13	0	27	1	40	1	2.5
1975	33	2	11	2	44	4	9.1
1976	34	1	31	2	65	3	4.6
1977	29	0	25	2	54	2	3.7
1978	24	0	No record	No record	24	0	0.0
1979	19	2	No record	No record	19	2	10.5

so the fishery currently appears to be operating with a considerable margin of safety.

MANAGEMENT RECOMMENDATIONS

In order to insure the continued survival of Michigan's remaining lake sturgeon stocks, each individual population should be managed according to the best information available concerning that population. Fisheries for other species of fish must be managed on a statewide basis because of the tremendous number of populations present in the many lakes and streams of the state. In contrast, there are only a very few populations of lake sturgeon remaining in Michigan.

The Menominee River

Fishing regulations for the Menominee River population have traditionally been formulated jointly by the states of Michigan and Wisconsin. The Wisconsin Department of Natural Resources conducted a survey of the sturgeon population during the summer of 1978, but the final report has not yet been published. The report is being written at the present time and should be published sometime this year (Thomas Thuemler, Wisconsin DNR, personal communication). In lieu of making recommendations concerning the management of the fishery based on information which is 10 years old, it would be preferable to review the management policies after this new information becomes available.

Black, Mullett, and Burt lakes

These three lakes have traditionally been managed as a single stock, and at the present time, there is no reason to alter that strategy. The fishing regulations currently in effect are, at the present time, sufficient to protect the sturgeon populations from overexploitation. If the maximum exploitation rate which a sturgeon population can tolerate without showing a decline in numbers is 6% (as postulated earlier), then the present exploitation rate of 2 to 2 1/2% allows a margin of safety. Apparently the greatest factor affecting sturgeon harvest in any given year is water clarity, rather than availability of legal size fish. (Sturgeon spearing is done in areas where the water depth is about 20 feet. If the water is turbid due to adverse weather conditions, the spearer cannot detect his quarry at those depths.)

The 50-inch minimum size limit currently in effect appears to be adequate to protect the sturgeon until they are sexually mature. Male lake sturgeon become sexually mature at ages ranging from 14 to 16 years, and so are sexually mature before they reach 50 inches in length. Female lake sturgeon mature at 24 to 26 years of age and lengths of 52 to 55 inches.

Examination of Figure 7 reveals that, for the years 1974-1979, the great majority of the sturgeon speared in Black Lake were more than 55 inches long. Virtually all of the fish taken in Mullett Lake during the same period were more than 55 inches in length.

The catch from Black Lake for each individual year, divided by length into two classes: those fish from 50-59 inches in length, and those

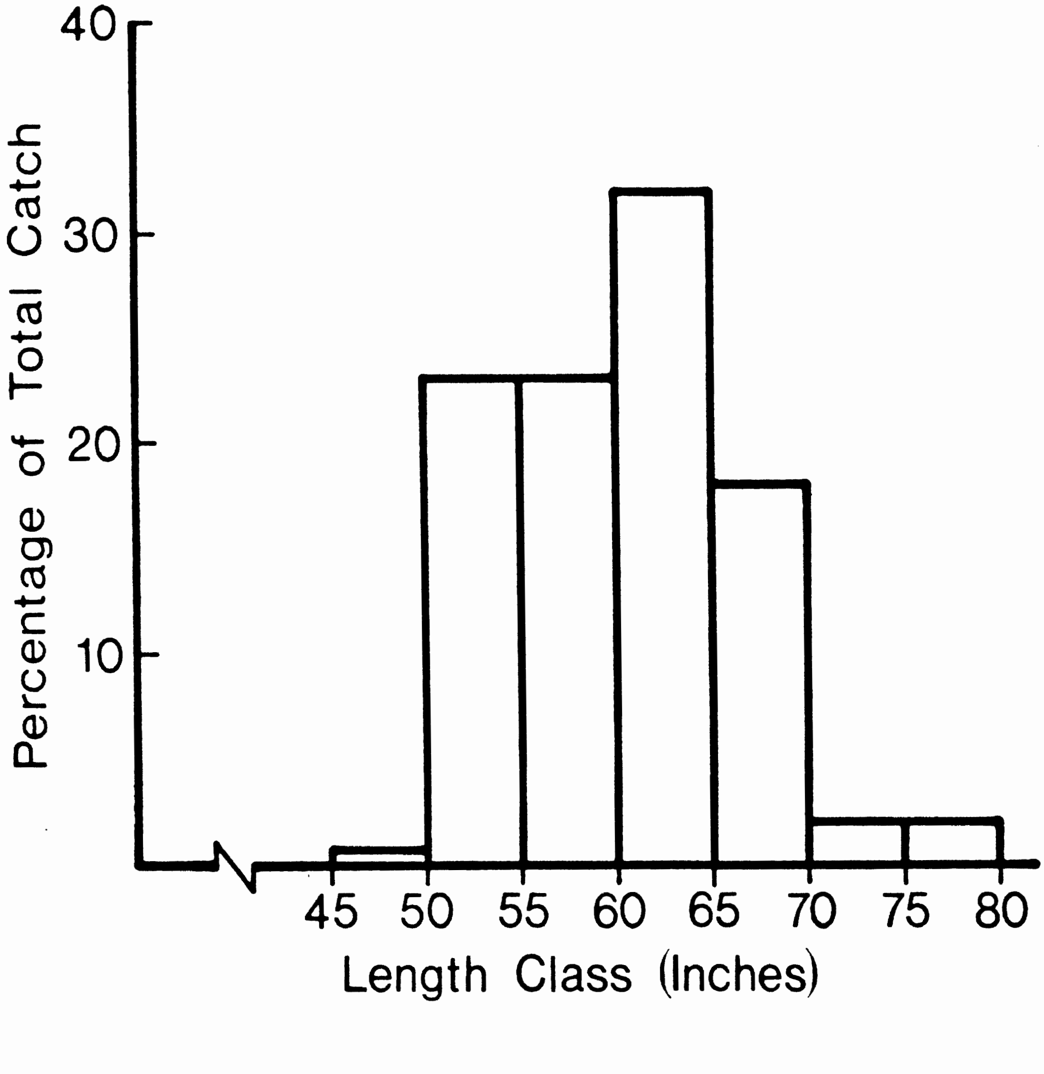

Figure 7.--Length frequency of lake sturgeon speared in Black Lake, 1974-1979 (class length = 5 inches).

60 inches and larger is shown in Figure 8. In 5 years out of 6, the percentage of the catch 60 inches and larger exceeds the percentage of 50- to 59-inch fish. This does not reflect a lack of the smaller sturgeon, as Shouder (1975 and personal communication) has found a substantial population of lake sturgeon from 40 to 60 inches long during his netting and tagging operations. Judging from all available information it would appear that either the smaller sturgeon do not frequent the grounds where the winter spearing takes place, or that they are being passed up by spearers because the spearers do not judge them to be of legal size.

Spear fishermen on Black Lake report that they seldom see small sturgeon in the areas where sturgeon fishing activity is concentrated. Vondett (1957) mapped the traditional sturgeon spearing grounds of Burt, Mullett, and Black lakes. My investigations reveal that these areas have not changed in the ensuing years. Since most of the fishermen told me that they attempt to spear any fish that even approaches what they judge to be legal size, and since most of the fish they spear are larger than 55 inches, it would appear that (1) the traditional sturgeon spearing grounds are frequented by the larger fish, and (2) that the spearers may tend to err in favor of the larger fish when judging whether or not a fish is of legal size. Thus, the apparent size limit is higher than the legal minimum size limit due to this combination of factors.

Based on the above information, it is recommended that the 50-inch minimum size limit be retained. Since the apparent size limit

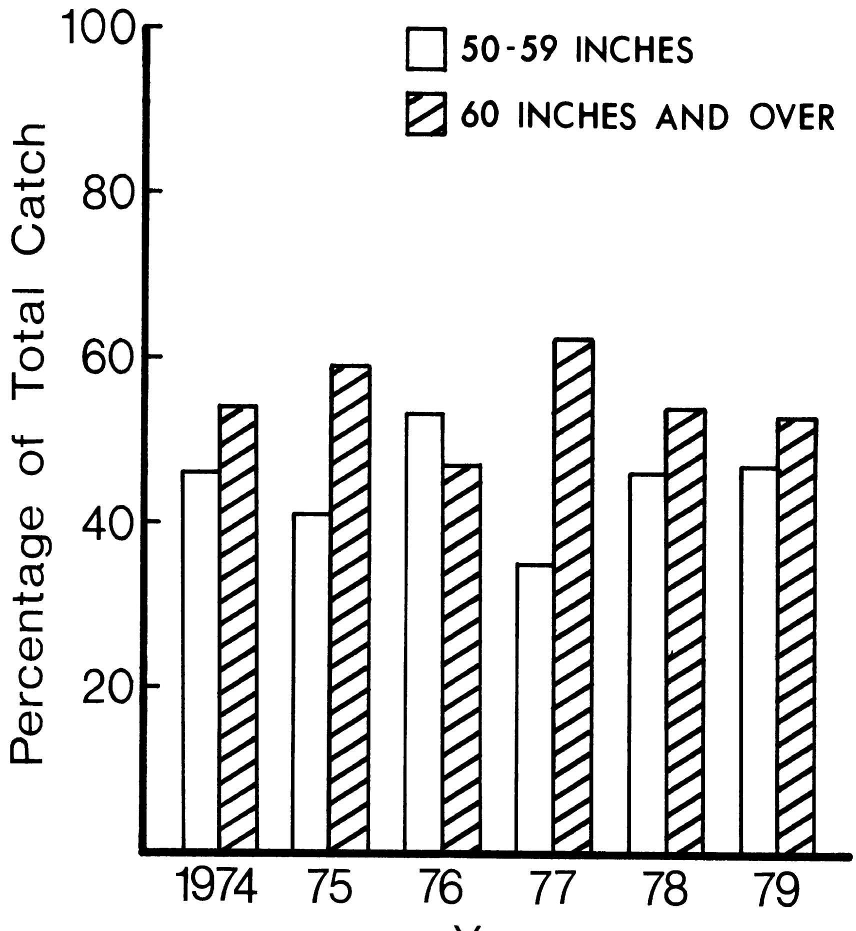

Figure 8.--Percent composition of Black Lake sturgeon harvest by individual years 1974-1979, for two length classes.

is closer to 55 inches, most of the fish should have the opportunity to spawn at least once before becoming completely vulnerable to the fishery. Raising the size limit to 60 inches (for example) would decrease the harvest, but might also result in a larger number of sublegal sturgeon being speared, since fish 55 inches and larger appear to frequent the spearing areas, and also because spearers probably cannot estimate the size of a fish within a margin of error closer than about 5 inches at the depths where sturgeon are speared (usually about 20 feet). Thus the minimum size limit, while effective in protecting smaller individuals in hook-and-line fisheries where fish can be measured and released with a fairly good chance of survival, is of less value in a spear fishery where size must be estimated prior to capture and speared sublegal fish usually do not survive.

Validation of speared sturgeon by a DNR fishery biologist should be continued. Acceptance of this program by the fishermen has been very good, and information gathered from speared fish is vital in order to monitor the effect of the fishery upon the population. Length, weight, sex, and condition of the gonads should be recorded for all speared fish. A pectoral fin-bone should be collected from all sturgeon under 100 pounds in weight. Especially important are the ages of the smaller fish which have just entered the fishery, in order to estimate the magnitude of recruitment into the fishery, the relative strength of individual year classes and the ages of first and subsequent spawnings. This information, together with the total catch, will give an indication of the size and age structure of the population, the rate of exploitation, and trends in the population with regard to numbers, growth, and mortality.

If it should become necessary at some future time, due to increased fishing pressure and exploitation rates, to more severely restrict the fishery, the most enforceable regulation would be to shorten the season, rather than raise the minimum size limit. Cutting the length of the season to the first 2 weeks of February would decrease the harvest by an average of 34%. If the season were closed every other year, the harvest would be cut by 50%. It is, of course, possible that the fishing pressure would increase with a shorter season, thus partially negating the desired effect.

The poaching of spawning lake sturgeon in the upper Black River remains a serious problem. Since the magnitude of this illegal harvest is unknown, it is potentially a much more serious threat to the Black Lake population than is the legal fishery. Because of the remoteness of the area surrounding the upper Black River from Black Lake to Kleber Dam, enforcement of the fishing ban in effect during April and May is very difficult. In the future, it may be necessary to initiate continuous patrols of the upper Black River by conservation officers during the sturgeon spawning season, in order to discourage poachers. The Black Lake sturgeon population is the largest inland stock in the state of Michigan and supports most of the winter spear fishery. In order to maintain this population and fishery, some extra effort by the law enforcement agencies is certainly justifiable.

More research is necessary to determine the size of the sturgeon populations of Mullett and Burt lakes. Almost all of the sturgeon speared in Mullett Lake are very large, and only a few fish are speared there annually. It may be that reproduction is not occurring in the Mullett Lake stock. It is possible that this population could benefit from the construction of artificial spawning reefs like those installed in the upper Black River. A study of possible sites for reef construction in the Pigeon River would not be expensive or time consuming.

Sturgeon fishing pressure on Mullett Lake has traditionally been low, but may increase rapidly in the next few years. During the 1980 spearing season, a group of about 60 fishermen from Wisconsin fished on Mullett Lake. These fishermen are veteran sturgeon spearers, most having participated in the sturgeon fishery of Lake Winnebago. Two very large sturgeon (180 pounds and 104 pounds) were speared by Wisconsin fishermen on the first day of the 1980 season. If the spearers from Wisconsin continue to participate in the Mullett Lake fishery in the future, the increased fishing pressure may be more than the apparently small population can tolerate.

The sturgeon spear fishery of Burt Lake is, for all practical purposes, gone. No fish have been taken there since 1974, and the size of the remaining population is unknown. Virtually no fishermen actively pursue sturgeon in Burt Lake anymore (Mason Shouder, personal communication) and it seems likely that any sturgeon speared there in the future will be taken incidental to other species (e.g., northern pike). An assessment of the sturgeon population of Burt Lake, possibly during the spawning season, should be done to ascertain whether or not enough fish remain to justify a continued spearing season.

The Great Lakes and connecting waters

The illegal taking of spawning sturgeon from the St. Clair River cannot be allowed to continue. The Lake St. Clair sturgeon population is the only known Great Lakes stock with a suitable spawning area and a natural potential to increase in numbers.

Since the Great Lakes and connecting waters are traditionally considered as a management unit, it is proposed that the sturgeon season in all of these waters be closed during the months of May and June. If vigorously enforced, this closure will allow sturgeon in the St. Clair River and elsewhere to spawn with a minimum of interference. It does not seem unreasonable to protect a threatened species during the annual period of reproduction. In the case of lake sturgeon, the spawning run is the period of highest vulnerability to capture. During the rest of the year sturgeon in the Great Lakes are widely scattered and much less vulnerable to recreational fishermen.

There is no reason why the sturgeon fishing season in the Great Lakes cannot be allowed to continue during the rest of the year. The catch of lake sturgeon by recreational fishermen is very small, amounting to only a handful of fish annually. Thus, the harvest of lake sturgeon from the Great Lakes by sport fishermen (excluding those taken during the spawning season) has little or no impact upon the populations. In addition, it seems unfair to expect a fisherman who has accidentally caught the largest fish of his or her life to return it to the water.

Other lake sturgeon populations

The lake sturgeon populations present in the several inland lakes of the Upper Peninsula (discussed earlier) bear further investigation. Attempts should be made to ascertain the size of these populations and the extent of reproduction. Also, the extent of the winter spear fisheries (if any) should be determined.

It is known that Indian Lake (Schoolcraft County) harbors a fair number of sturgeon, as evidenced by the findings of the U.S. Forest Service survey in May 1979. At least one sturgeon was taken there during the 1980 spearing season, according to newspaper reports. It is suggested that a netting survey, similar to that of Shouder (1975) be conducted on this lake to determine whether or not the population is large enough to support a fishery. Otter Lake (Houghton County) is also known to contain a significant sturgeon population (Merle Galbraith, personal communication) and would benefit from further research.

Recommendations for management of lake sturgeon populations statewide

It is suggested that the season creel limit for lake sturgeon statewide be decreased from two fish per season to one. This will have very little effect upon the annual harvest. (In Black Lake it will decrease the harvest by only one or two fish annually.) Also, the creel limit is ineffective as a means of more evenly distributing the harvest among fishermen. Instead, the purpose of cutting the creel limit to one fish per season is to promote the status of the lake sturgeon as a trophy fish. The achievement of catching or spearing a large sturgeon is akin to that of bagging a trophy buck deer or a bear. (Indeed, catching a sturgeon, especially on hook and line, is a great deal more difficult.) The state of Wisconsin now allows only one sturgeon per spearer per year to be taken from Lake Winnebago.

Control of the illegal harvest of spawning sturgeon is essential if existing sturgeon populations are to maintain themselves. Habitat improvements aimed at creating more sturgeon spawning habitat, such as have been constructed in the upper Black River, should be made wherever such structures are feasible on streams which have significant sturgeon spawning runs. Spawning habitat improvement could be especially appropriate for some of the Upper Peninsula populations such as Indian Lake.

More research is necessary concerning the early life history of the lake sturgeon. The growth, mortality, movements, and food of lake sturgeon fry, and factors affecting spawning success and year class strength should all be thoroughly investigated. Knowledge of these factors is especially critical in fished populations, because of the 20-year time lag between the time the fish are born and their entry into the fishery. If after a thorough investigation it is found that reproduction is not occurring in a particular population, the fishery utilizing that population should be closed and remedial measures taken.

The Wisconsin Department of Natural Resources is about to undertake a study of the early life history of the lake sturgeon in the Lake Winnebago system. The work will begin in the spring of 1980 (James Kempinger, personal communication).

Artificial propagation of lake sturgeon is more feasible now than in the past. The Russians are currently hatching sturgeon eggs, and have released 243 million sturgeon fingerlings into the Volga River in the past 7 years (Whitney 1979). A detailed account of Russian sturgeon culture techniques is found in Bardach et al. (1972). Culture of lake sturgeon by the same methods is a distinct possibility. Lake sturgeon fingerlings could be stocked in inland lakes, and in time could provide spear fisheries similar to those of Black and Mullett lakes. Also, it is possible that artificially cultured sturgeon could be planted in some of the larger rivers flowing into the Great Lakes (the Grand River, for example). These fish would enter the Great Lakes and return when mature to spawn in their "home" river, thus making them available to hook-and-line fishermen. Both types of fisheries could be maintained by stocking.

In conclusion, the lake sturgeon populations of Michigan and the unique fisheries they provide can both be preserved (and in some cases possibly increased) if they are closely monitored to prevent recruitment overfishing and if suitable feeding and spawning habitat for sturgeon continues to be available.

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