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THE LAKE STURGEON FISHERY OF LAKE WISCONSIN, 1978-1985

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ABSTRACT

A significant sport fishery for lake sturgeon (Acipenser fulvescens Rafinesque) exists in the impounded portion of the Wisconsin River known as Lake Wisconsin. According to a 1979 creel survey, anglers spent 13,073 hours fishing for lake sturgeon during the 6-week hook and line fall fishing season. An estimated 2,510 sturgeon of all sizes were caught at a rate of 1 fish per 5.3 hours, with approximately 20 sublegal fish caught for every legal fish caught.

Annual harvest estimates, based on a mandatory registration program implemented in 1983, have averaged 73 legal fish (≥45 inches) with a high of 104 recorded during 1985. Population estimates, based on 1,971 tagged sturgeon (all sizes) captured in 8- and 10-inch entanglement nets from 1979-81, indicate that 1,000-4,000 legal lake sturgeon are present. Rates of annual mortality and recruitment were calculated but considered to be too high since the size-selective entanglement nets did not adequately sample the entire size range of the population. Random movement throughout the lake system was documented. Spawning movement to and from the upstream dam 40 miles away was noted. During the 3-5 years since fish were tagged, 9 tagged lake sturgeon have been recaptured by commercial fishers in the Mississippi River over 150 miles downstream. Age-growth parameters and condition factors were variable. Growth data indicated that legal (45-inch) fish were 12 years old. Limited sampling for PCB contamination found some sturgeon over 50 inches long which contained slightly higher levels than the present FDA guideline of 2.0 ppm.

The lake sturgeon fishery can be managed for sustained yield of bigger fish. To accomplish this, I recommend a maximum annual harvest of 50 fish, based on a conservative estimate of 1,000 available legal fish and a 5% rate of annual angler harvest. Since the percent of lake sturgeon between 45-49 inches is high (50%) compared to the total legal harvest and low compared to the numbers of sublegal fish, I recommend either a reduction in fishing pressure or an increase to a 50-inch size limit in order to increase the number of larger fish in the population. However, if more intensive PCB sampling finds lake sturgeon over 50 inches to contain PCB levels exceeding the FDA tolerance level (2.0 ppm), a 50-inch minimum size limit and a health consumption advisory on fish larger than 50 inches will essentially eliminate harvest. Given these circumstances, I would recommend retaining the 45-inch minimum size limit until PCB levels decline in larger fish.

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INTRODUCTION

The lake sturgeon (Acipenser fulvescens Rafinesque) is considered a rare species in the United States and is threatened or endangered in most areas of its range (Bureau of Sport Fisheries and Wildlife, Committee on Rare and Endangered Wildlife Species 1966). The state of Wisconsin has several fishable populations and has assigned the species a "watch" status (Les 1979). Studies have been conducted on significant Wisconsin lake sturgeon populations in the Menominee River (Priegel 1973), Lake Winnebago (Priegel and Wirth 1975), and the upper Fox River lakes (Priegel and Wirth 1978, Meyers 1982). These investigations support the need for intensive study of all lake sturgeon fisheries in Wisconsin to prevent overharvest and assure the perpetuation of present populations.

Lake Wisconsin, the lowermost reservoir on the Wisconsin River, presently supports a self-sustaining lake sturgeon population which provides a significant sport fishery. A 113-lb trophy caught from Lake Wisconsin in 1960 held the state record for 13 years. Recently, larger lake sturgeon have reportedly been caught on Lake Wisconsin by commercial fishers.

During the late 1940s the fishery was promoted by the Kacizak brothers at Hooker's Resort in Dekorra Township, and the area became popular with anglers from Illinois. Since that time, the lake sturgeon season has been of economic importance to local resorts, restaurants, and bait shops. Historically there has been a fall hook and line season from the first Saturday in September to 15 October. The season bag limit was reduced from 5 fish to 1 fish in 1951, and the legal size limit was increased, first from 30 to 40 inches and then to the present length of 45 inches in 1974.

The objectives of this study were to determine angler pressure on Lake Wisconsin lake sturgeon and to collect various biological statistics, including population and harvest estimates. Fish mortality caused by fin ray removal for aging and by hanging fish from the tail to obtain weights was also investigated. Because the lake sturgeon's long life span may allow it to accumulate substantial levels of toxic chemicals, various contaminants in the fish were also measured.

STUDY AREA

From its source on the Wisconsin-Michigan border in Vilas County, the Wisconsin River flows approximately 450 miles through central Wisconsin, entering the Mississippi River in the southwestern corner of the state at Prairie du Chien (Fig. 1). A total of 26 power dams have been developed along the river. The southernmost dam, at Prairie du Sac in Columbia County, creates 9,000-acre Lake Wisconsin. While the presence of lake sturgeon was originally documented as far upstream as Stevens Point, the only remaining fishable population is found in the 50 miles of river between the Wisconsin Dells dam and the Prairie du Sac dam and tailrace. Lake sturgeon within Lake Wisconsin appear to primarily occupy the upper half of the lake and the immediate upriver area. Water depth is typically 8-12 ft in these areas, whereas the lower portion of the lake is more channelized with depths of 20-30

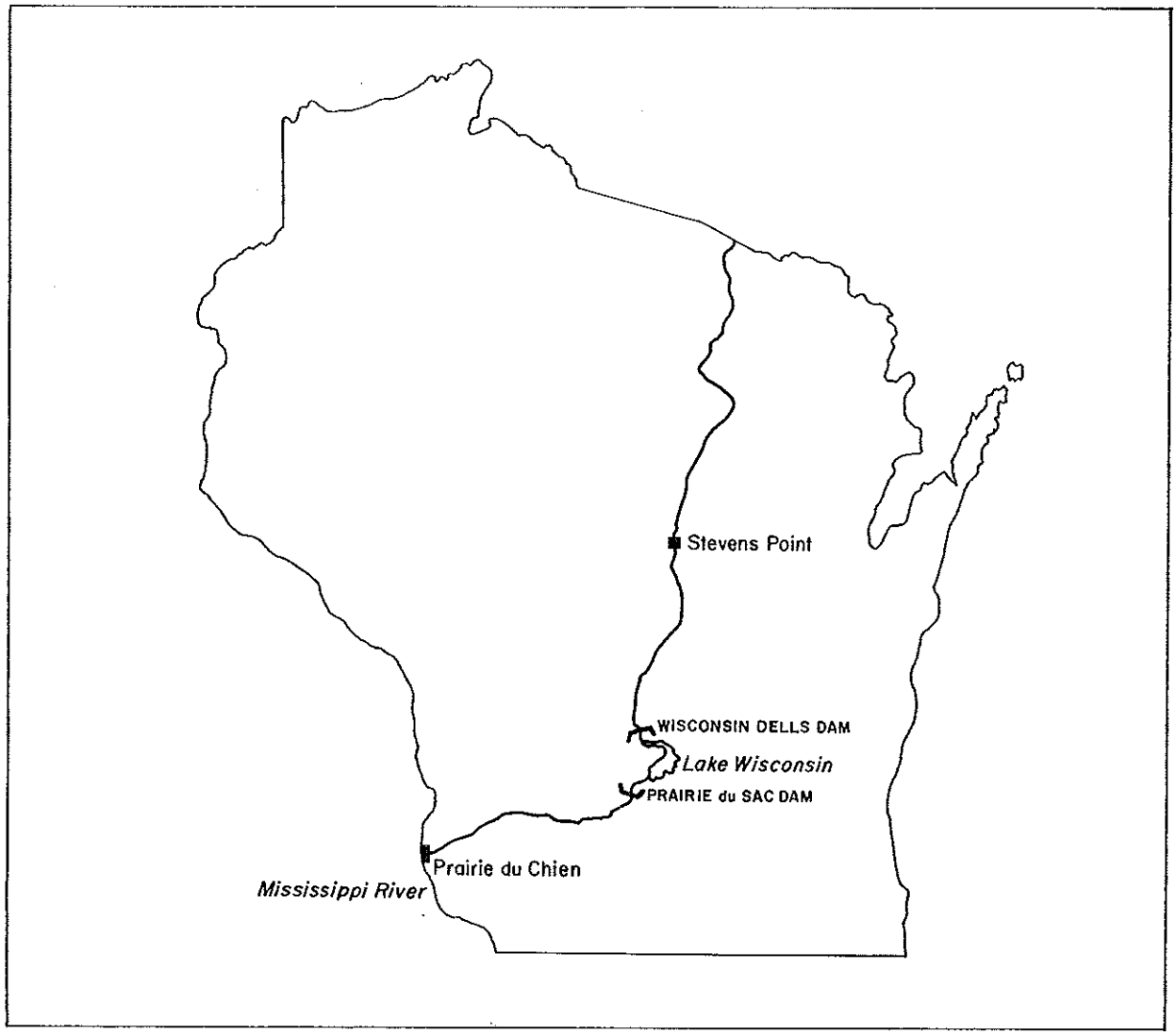

FIGURE 1. Location of the Wisconsin River and Lake Wisconsin.

ft. This study focused on the area of known lake sturgeon abundance. Spawning of lake sturgeon at the Wisconsin Dells dam was also investigated.

Many species comprise the fishery of Lake Wisconsin. The sportfishery is dominated by sauger (Stizostedion canadense Smith), walleye (Stizostedion vitreum vitreum Mitchell), white bass (Morone chrysops Rafinesque), white crappie (Pomoxis annularis Rafinesque), black crappie (Pomoxis nigromaculatus Lesueur), and bluegill (Lepomis macrochirus Rafinesque). Northern pike (Esox lucius Linnaeus), largemouth bass (Micropterus salmoides Lacepède), smallmouth bass (Micropterus dolomieui Lacepède), stocked hybrid musky (Esox lucius x Esox masquinongy Mitchell), and channel catfish (Ictalurus punctatus Rafinesque) are found in lesser abundance. Freshwater drum (Aplodinotus grunniens Rafinesque) are frequently caught by anglers and commercial fishers, who also harvest carp (Cyprinus carpio Linneaus) and buffalo fishes (Ictiobus spp.).

Nicknamed "the nation's hardest working river," the Wisconsin River accumulates many discharged domestic and industrial by-products. The water is stained reddish-brown, which limits visibility to only a few feet. Prior to the establishment of more stringent discharge regulations in the early 1970s, late-winter fish kills and off-flavored fish were typical. The water is very fertile, although aquatic vegetation is restricted to shallow bay areas, probably due to poor light penetration. Summer blooms of blue-green algae are common. A pH of 7.2 and alkalinity (MPA) of 70-175 µmhos conductance are typical values. The lake bed is mostly sandy muck, and the river bottom is predominately sand. Few rock-rubble areas are present throughout the system.

METHODS

Lake Wisconsin lake sturgeon were sampled from fall 1978 through spring 1981. Entanglement nets (8-inch and 10-inch stretch mesh) were fished from the close of the sturgeon angling season (15 October) until mid-November, during January and February under the ice (Fig. 2), and again for about 3 weeks after ice-out in March or April. Netting locations are shown in Figure 3. Equal netting effort did not occur at all stations. Netting effort was limited in the lower portion of the lake due to low efficiency. Upriver from the lake effort was limited by strong current, unsafe ice, and drifting debris.

Electrofishing, using 240V pulsed DC current, was conducted below the Dells dam during the early May spawning seasons in 1979 and 1980. All fish were measured to the nearest 0.1 inch in total length and tagged with both a numbered Floy anchor tag (FD-68B), inserted into the muscle tissue and locked

FIGURE 2. Fishing entanglement nets for lake sturgeon under the ice on Lake Wisconsin.

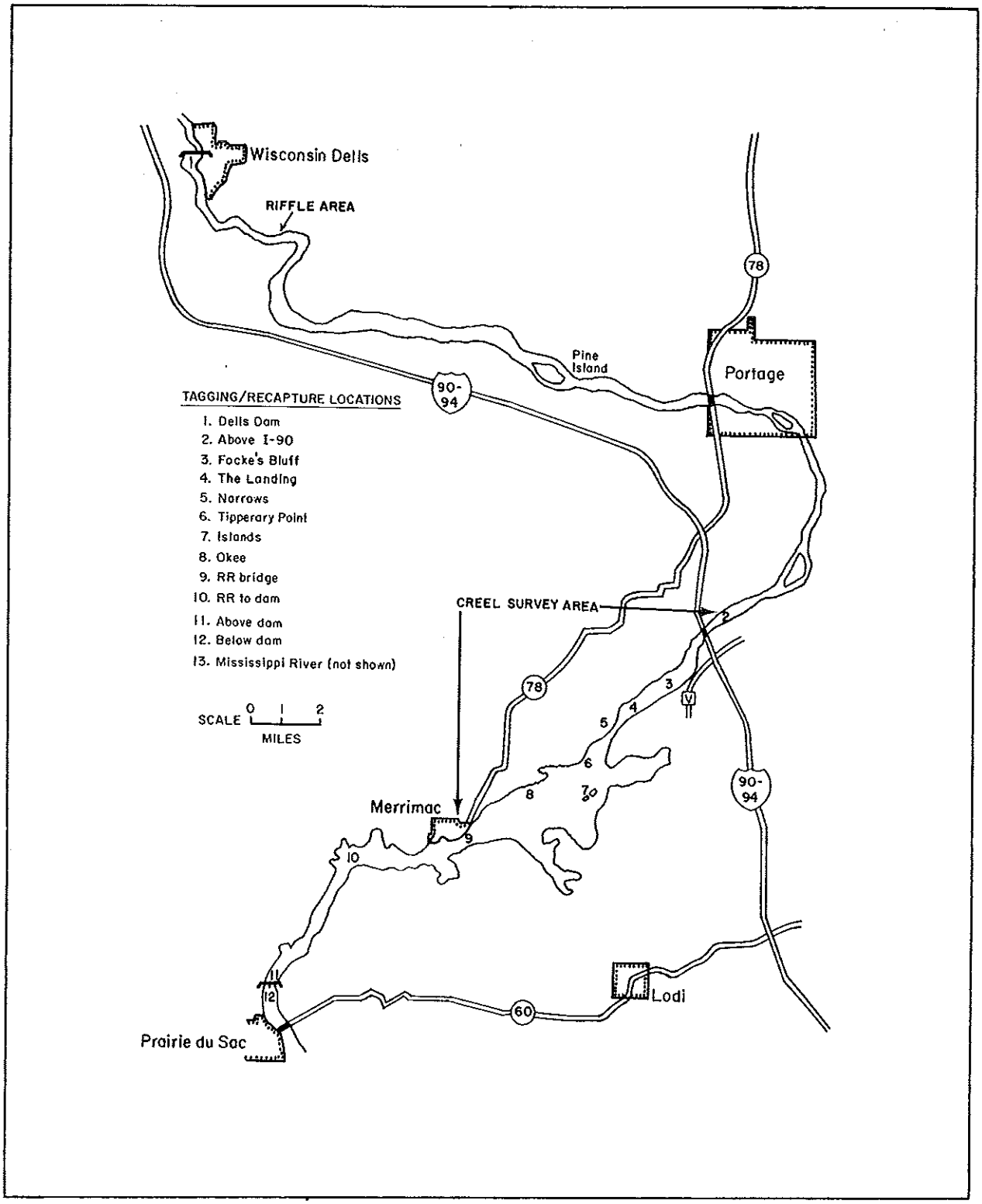

FIGURE 3. Sturgeon study area, Lake Wisconsin-Wisconsin River.

between the rays of the dorsal fin (Fig. 4), and a Floy dart tag (FT-1A) injected into the musculature below the dorsal fin region (Fig. 5). Due to their small size, lake sturgeon less than 35 inches long received only the anchor tag. Weights, recorded to 0.5 lb, were obtained on a subsample of captured sturgeon by hanging the fish by the caudal peduncle from a rope attached to a spring scale (Fig. 6). Ages were determined by examining the leading ray of the pectoral fin (Fig. 7). Ray annuli were counted on a thin cross-section of fin ray obtained with a very fine jeweler's saw blade.

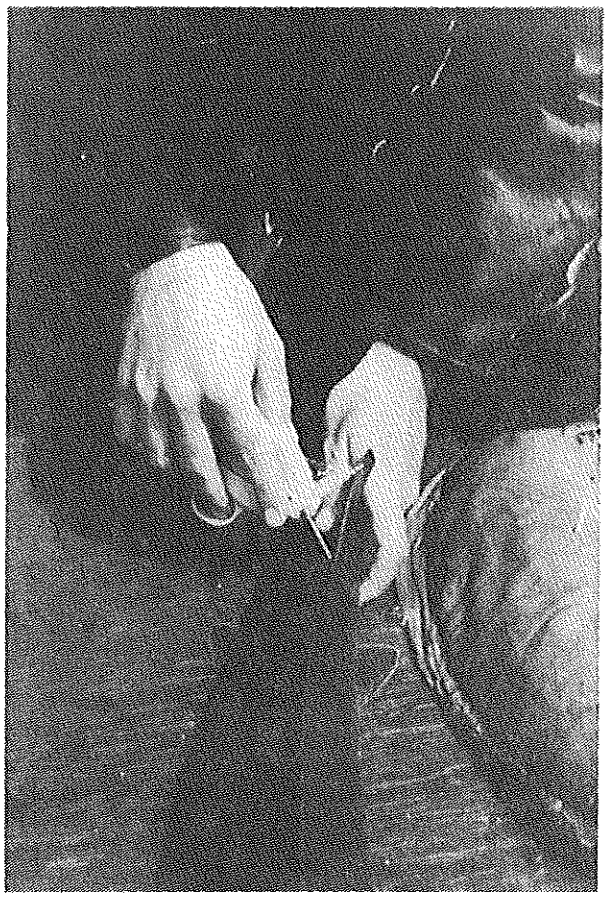

FIGURE 4. Injecting Floy FD-68B anchor tag with tagging gun.

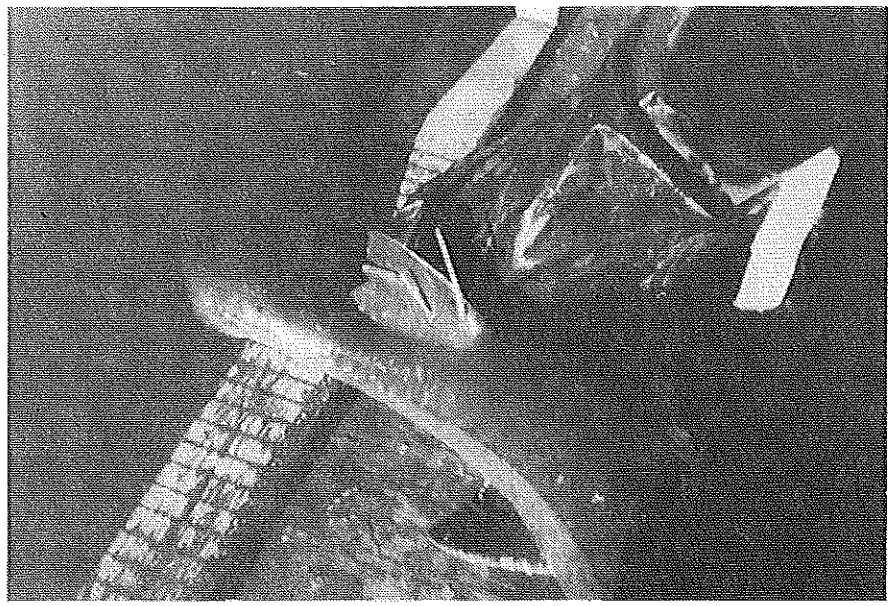

Figure 5. Double-tagged lake sturgeon with anchor and dart tags in place.

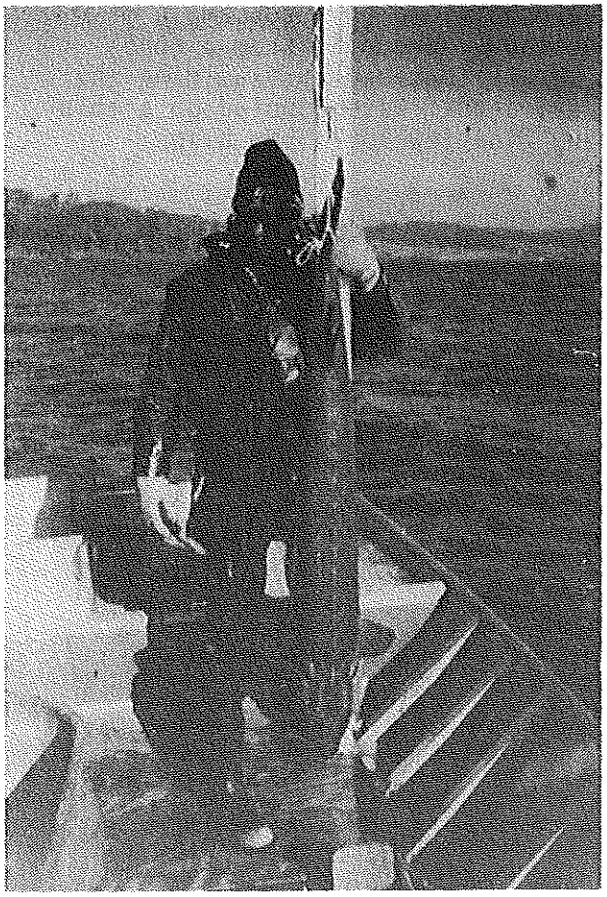

FIGURE 6. Weighing lake sturgeon with rope around caudal area attached to a spring scale.

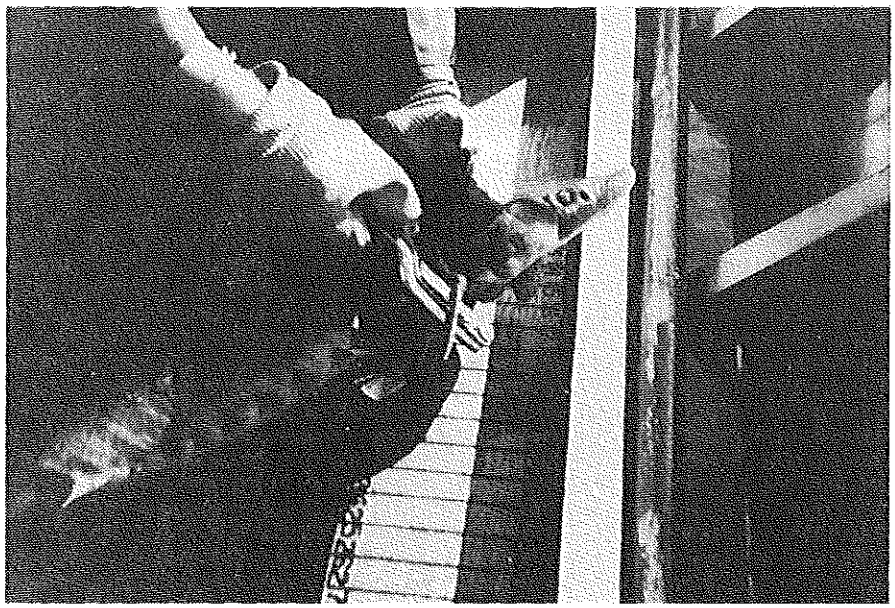

FIGURE 7. Removing leading ray of pectoral fin for aging.

The Chi-square contingency test was used to evaluate handling mortality by comparing the percent of recaptured sturgeon that had been weighed and fin clipped to the percent of those that had not. Growth data were fitted to the Von Bertalanffy growth equation

$$\underline{l}_t = L_\infty (1-e^{-K(t-t_o)})$$

where $\underline{l}_t$ is the length at age t, L_∞ is the theoretical maximum length, t_o is the age at length = 0, and K is the growth coefficient (Ricker 1975). Condition factors (K) were determined using the formula

$$K = \frac{\underline{w} \times 10^5}{\underline{l}^3}$$

where $\underline{w}$ = weight (lbs) and $\underline{l}$ = length (inches).

From 1977-81, a voluntary angler registration program was conducted by resorts and bait shops. Anglers noted the length of all legal and sublegal lake sturgeon caught, the location of catch, and the presence of tags on the fish. These data were used for estimating movement, population size, and harvest. Better harvest information became available in 1983 when mandatory registration of the lake sturgeon harvest was initiated.

Population estimates were calculated by various methods. The Peterson method was used each year to calculate estimates for all sizes of lake sturgeon and for legal-sized fish ($\geq$45 inches) using the formula

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

where $\hat{N}$ = estimated number of fish in the population, M = total number of marked fish in the population, C = number of fish in the sample, and R = number of marked fish recaptured in the sample (Ricker 1975). Marked fish were the total number of tagged lake sturgeon available prior to each fall angling season. Tag loss, mortality, movement downstream from the lake, and recruitment (in the case of the legal-sized fish estimates) were determined. Tag loss was calculated using a method described by Russell (1980) for double-tagged fish, and mortality was calculated using catch curve data for all DNR-netted fish. The number of fish known to have left the lake, based on the percentage of recaptured fish, was subtracted from the total number of marked fish. The number of sublegal fish recruited into the legal-size group was determined from the growth rate. Voluntary angler information was used for the recapture periods. Estimates from Bailey's and the Jolly-Seber multiple recapture methods combining data from all 3 years were also calculated (Ricker 1975). Only those fish that were handled by DNR personnel were used in these estimates. To evaluate movement within the system, tagging and recapture locations of sturgeon were analyzed by the Chi-square test.

Angler information was obtained during the 1979 season through a random stratified creel survey. Anglers were interviewed during five 8-hour survey periods each week, and they were counted at 2-hour intervals. Data was tabulated with a standard computer program to derive catch rates and projected fishing pressure.

Six lake sturgeon that died or were in poor condition as a result of netting were used for toxicant analysis. PCB levels were of primary concern; however, pesticide tests were also run on 2 fish.

RESULTS

Angling Characteristics

The area surveyed included only the favorable lake sturgeon fishing area, including the central portion of the lake and the river area immediately upstream--approximately 4,000 acres (Fig. 3, areas 2-9). During the 1979 lake sturgeon season, 409 anglers were interviewed. Anglers were 94% male and 6% female. Only 2.4% of all anglers were under 16 years of age and 4.8% were 65 years old or older. Nonresident anglers, almost exclusively from Illinois, accounted for 66% of all lake sturgeon anglers. Twenty-four percent of the anglers were residents of Columbia County, where Lake Wisconsin is located, and 8% were from Dane County, which includes the Madison area.

Anglers spent 13,073 hours fishing for lake sturgeon during 1979. The average catch rate was 0.192 lake sturgeon/hour or 5.26 hours/fish. Fishing diaries kept by 4 veteran sturgeon anglers revealed a catch rate of 2.1 hours/fish (494 hours/234 fish). Since approximately 20 sublegal sturgeon are caught per each legal fish caught, the average angler would spend 105 hours to catch a legal fish. During 1979, an estimated 2,510 lake sturgeon of all sizes were caught. Night crawlers were the bait unanimously favored by anglers.

Population Estimate

Several methods were used to calculate population estimates for both legal-sized fish (≥45 inches) and fish of all sizes (Table 1 and Append. A).

TABLE 1. Population estimates of lake sturgeon, Lake Wisconsin, 1979-81.

Size	Method	Year	Population	95% Confidence Interval
Legal fish (≥ 45 inches)	Peterson	1979	1,050	±1,128
		1980	1,884	±1,154
		1981	2,841	±1,524
	Bailey's		2,868	±4,022
	Jolly-Seber		4,304	*
All fish	Peterson	1979	14,138	±8,390
		1980	23,371	±8,954
		1981	21,281	±6,406
	Bailey's		8,038	±4,192
	Jolly-Seber		9,247	*

* No simple variance indicator available; approximations given in Ricker (1985) are identical to the Bailey's Method estimates.

The Peterson estimate was calculated annually using fish netted from fall through spring as the marked population and fish caught by anglers during the succeeding fall fishing season as the recapture sample. The Jolly-Seber and Bailey's multiple-recapture methods were based solely on data gathered during the 3 consecutive years of netting fish. These estimates of the population of legal lake sturgeon in Lake Wisconsin and the Wisconsin River upstream to the Wisconsin Dells dam ranged from 1,000 to 4,000. Applying the same methods to data on all sizes of lake sturgeon vulnerable to entanglement-net capture produced total population estimates ranging from 8,000 to 23,000.

Both the Peterson and the multiple-recapture methods are subject to bias due to entanglement-net sampling and fish movement. The 8-inch mesh was highly selective for fish about 38 inches long (33-43 inches), and the 10-inch mesh selected for 45-inch fish (40-50 inches) (Fig. 8). Therefore, smaller and larger fish were netted in lower proportions than their numbers in the population. The Peterson method used angler data for the recapture period, which is less selective and therefore compensates for some of the size bias. Though tagging was not randomly distributed throughout the lake/river system, distance between tagging locations and locations of angler recaptures elsewhere indicated considerable movement. Only 3 lake sturgeon were known to have moved downstream from Lake Wisconsin during the mark-recapture period, so movement out of the system was considered insignificant. Movement between the upstream Dells dam and the lake was documented, and angler effort, though limited in some areas, did occur throughout the river system; thus all lake sturgeon tagged at the Dells dam were considered in the population estimates.

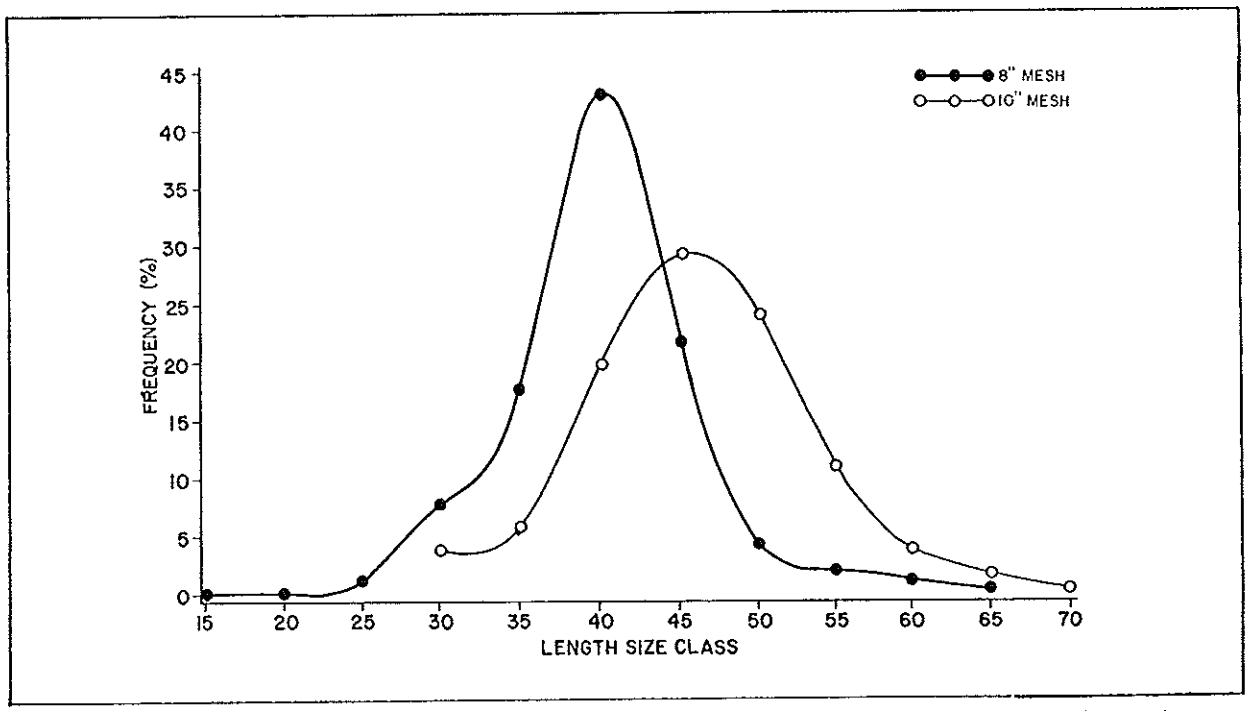

FIGURE 8. Length of lake sturgeon in different mesh sizes of entanglement nets.

The multiple-recapture methods account for annual mortality and recruitment, and tag loss was considered negligible since scars resulting from tag placement were evident even when both tags were missing. With the annual Peterson estimates, however, adjustments for tag loss, mortality, and recruitment were made. Tag loss of T-anchor tags was initially high--15.4% within the first 6 months--but almost nil thereafter. Tag loss of dart tags was also high initially and increased over time: 68.7% after 1 year, 81.1% after 2 years, and 86.4% after 3 years. The probability that a fish would lose both types of tags (the product of the 2 loss probabilities) was 10.6% after 1 year, 12.5% after 2 years, and 13.3% after 3 years. Tag loss due to annual mortality, which reduced the number of previously marked fish available in the year the estimate was made, was estimated by use of a catch curve (Fig. 9). The antilog of the slope of the regression equation ($\log_e$ frequency = 6.3216 - 0.1615 age, r^2 = .717) is equal to an annual survival rate of 85%. This mortality rate is likely an overestimate, due to the inefficiency of the entanglement nets for sampling fish >50 inches. Using the annual growth increment of 2 inches, recruitment of sturgeon to legal size was corrected by adding sublegal sturgeon that had been tagged in previous years to the number of available legal-sized marked fish.

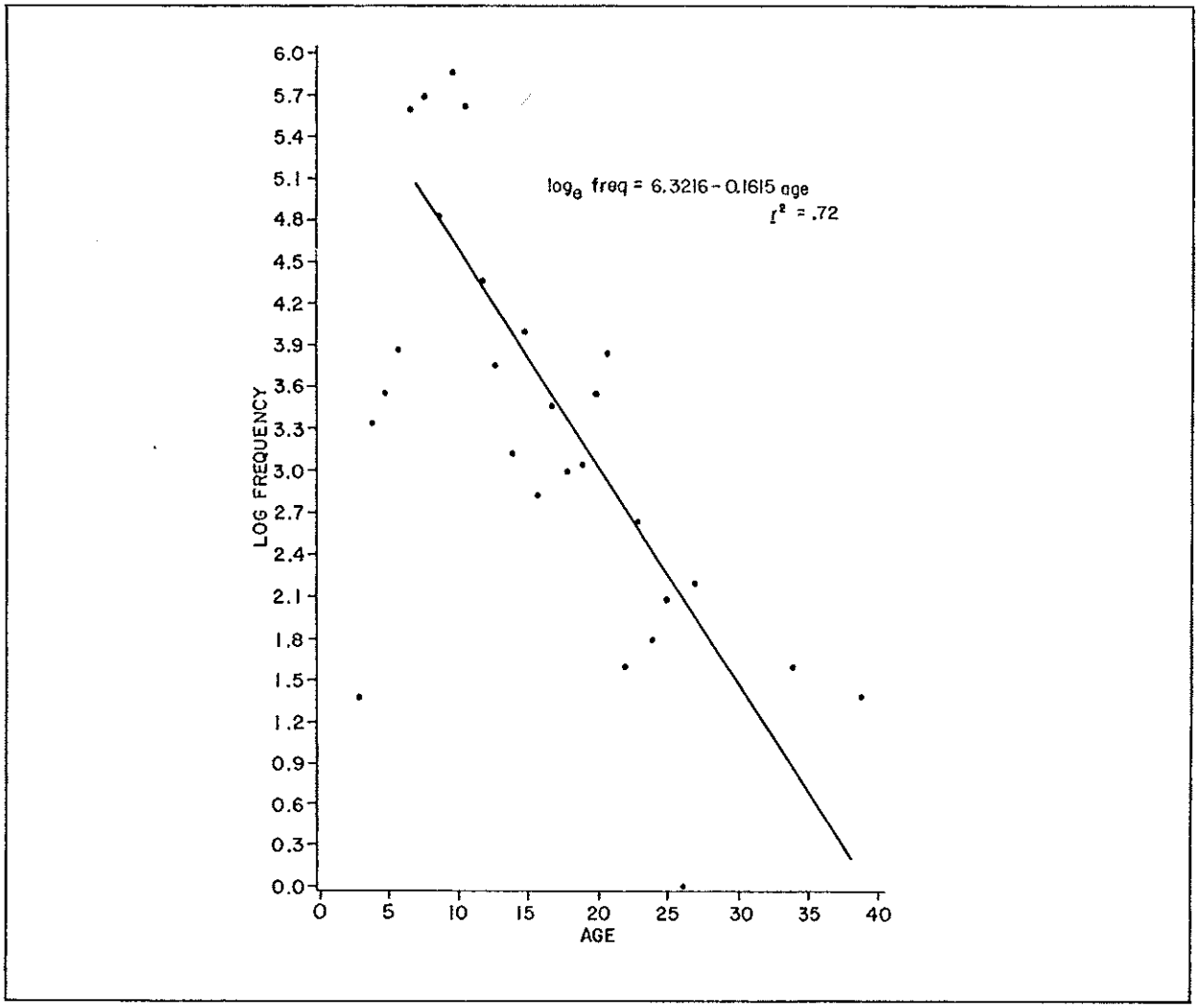

FIGURE 9. Log frequency by age of Lake Wisconsin lake sturgeon.

Recruitment

Recruitment into the fishery was estimated as the number of sublegal fish which would grow into the legal size range. Given an average annual growth increment of 2 inches, the ratio was calculated for netted lake sturgeon 43.0-44.9 inches long compared to the total number of fish ≥43 inches. The average rate of recruitment for 1979-81 was 23% (Table 2). The bias for entanglement-net sampling, which favored sturgeon 38-45 inches long, would cause these estimates to be too high.

TABLE 2. Recruitment rate of lake sturgeon to the fishery, Lake Wisconsin, 1979-81.

Year	Netted Lake Sturgeon 43.0-44.9 inches	Netted Lake Sturgeon >43.0 inches	Recruitment Rate*
1979	39	217	18%
1980	93	384	24%
1981	121	440	28%

* Recruitment rate = netted lake sturgeon 43.0-44.9 inches long divided by netted lake sturgeon ≥ 43.0 inches long.

Harvest

Beginning in 1977, voluntary angler registration of all sizes of lake sturgeon was encouraged. According to this angler information, the average number of legal lake sturgeon harvested annually from 1977-81 between the Prairie du Sac and Wisconsin Dells dams was 21 (Table 3). In 1983-85, after registration became mandatory, anglers took an average 73 legal sturgeon/year from this stretch of water. The average number of lake sturgeon reported harvested below the Prairie du Sac dam was 2 fish/year during voluntary registration and 9 fish/year during mandatory registration. It is expected that voluntary registration does not provide 100% compliance. Mandatory registration likely does not include all the lake sturgeon harvested, either.

The angler registration programs also provided information both on the percent of harvested legal sturgeon which were within 5 inches of the size limit (i.e., 45-49 inches long) and on the ratio of sublegal to legal fish caught. Voluntary data from 1977-81 indicated an increasing percentage of 45- to 49-inch fish in the harvest (average 47%). Mandatory registration data for 1983-85 indicated that 45- to 49-inch fish ranged from 40% to 59% of the harvest and averaged 49% (Table 4). The ratio of sublegal to legal sturgeon caught was fairly consistent at about 20:1 from 1979 to 1982 (Table 5). The rate of tag returns of legal-sized, tagged lake sturgeon was consistently 1% (Table 6). Exploitation was 7.3%, as estimated by the ratio of the average sturgeon harvest from 1983-85 (73 fish) to the conservative figure of 1,000 legal sturgeon available.

TABLE 3. Results of angler registration for legal lake sturgeon caught above and below the Prairie du Sac dam, Lake Wisconsin, 1977-85.*

Registration	Year	Location of Catch and No. Fish Registered	
		Above Dam**	Below Dam
Voluntary	1977	16	2
	1978	17	3
	1979	12	2
	1980	32	1
	1981	26	2
Average		21	2
Mandatory	1983	68	13
	1984	47	7
	1985	104	7
Average		73	9

* No data available for 1982.
** Between the Prairie du Sac and Wisconsin Dells dams.

TABLE 4. Ratio of size groups of angler-caught lake sturgeon, Lake Wisconsin, 1977-85.

Size Group (inches)	Length Frequency (%) of Legal Lake Sturgeon Harvested								
	1977	1978	1979	1980	1981	1982	1983	1984	1985
45-49	38	31	42	67	57	*	48	59	40
50-54	38	20	17	17	15	*	28	11	30
55-59	12	31	24	13	19	*	13	14	21
60-64	12	12	17	0	5	*	9	9	6
65-69	0	6	0	0	0	*	4	7	2
70	0	0	0	3	4	*	2	0	1
Total number of fish	16	17	12	32	26	*	68	47	104

* No data.

TABLE 5. Ratio of sublegal to legal lake sturgeon caught in Lake Wisconsin, 1979-82.

Year	Ratio	Sample Size
1979*	23:1	316
1980*	20:1	542
1981*	18:1	562
1982**	21:1	2,514

* Data based on voluntary registration.
** Data based on mandatory registration.

TABLE 6. Minimum exploitation rate of lake sturgeon based on angler tag returns, Lake Wisconsin.

Year	Tags Returned	Tagged Fish Available	Exploitation (%)
1979	1	139	0.72
1980	6	470	1.28
1981	8	798	1.01

Growth and Condition

During the 3-year sampling period 1,048 lake sturgeon were aged and measured; 570 were also weighed (Tables 7 and 8). A length-weight relationship based on length (inches) and weight (lbs) was log length = -4.319 + 3.398 (log weight) (Fig. 10). Note the increasing variation in weight and, to a lesser degree, in length, as the fish grows older. The age-length equation for Lake Wisconsin lake sturgeon was

$$l_t = 64.31(1-e^{-.0887(t+1.652)})$$

(Fig. 11). Again, a high degree of variability surrounds the predicted values.

TABLE 7. Mean weight, length, and K by age group of lake sturgeon, Lake Wisconsin.

Age	Number	Mean Weight	SD Weight	Number	Mean Length	SD Length	Mean K	SD K
2	--	--	--	1	15.0	--	--	--
3	2	2.5	0.71	6	23.3	3.13	14.1	0.57
4	15	2.9	0.58	34	25.2	1.64	16.2	3.10
5	7	4.6	2.46	13	29.2	3.24	16.7	3.58
6	20	8.0	1.70	35	33.6	2.45	19.6	3.67
7	89	9.5	2.09	160	35.5	2.80	19.9	2.32
8	45	9.8	2.26	149	37.6	2.63	20.2	2.67
9	31	12.4	3.23	62	39.2	2.52	20.7	3.21
10	104	14.8	3.13	145	41.0	2.91	21.3	2.53
11	34	16.6	3.86	96	42.9	2.49	21.9	2.09
12	12	20.9	5.37	35	44.8	3.69	21.1	2.44
13	12	25.3	5.97	27	46.5	4.76	21.9	3.59
14	12	28.2	7.58	22	47.6	5.03	22.9	2.49
15	19	34.4	8.45	31	50.8	4.45	23.0	2.48
16	12	31.8	9.38	24	49.9	5.25	22.4	2.49
17	16	32.9	8.59	28	52.0	5.03	23.0	3.02
18	18	32.8	8.27	26	52.7	3.36	23.0	2.63
19	22	42.4	12.15	30	54.7	5.04	23.0	2.42
20	19	36.8	8.56	23	52.4	3.37	25.1	2.52
21	21	39.5	10.54	29	54.4	4.35	23.9	2.10
22	7	47.5	16.44	9	57.1	5.26	24.0	2.22
23	9	45.8	7.84	12	56.0	3.76	25.8	2.40
24	13	40.9	11.09	16	56.1	4.84	23.4	2.24
25	8	45.6	9.15	9	57.6	4.05	23.9	2.12
26	5	58.8	28.42	7	62.1	7.76	23.9	3.13
27	6	62.5	18.80	6	61.7	5.51	26.0	0.81
28	2	49.7	13.79	2	59.0	4.24	23.9	1.55
30	4	51.5	12.79	4	59.8	5.72	23.8	2.14
31	3	73.3	5.77	4	63.7	2.63	26.7	2.39
33	1	68.0	--	1	61.0	--	30.0	--
34	1	51.0	--	1	59.5	--	24.2	--
39	1	58.0	--	1	63.0	--	23.2	--

TABLE 8. Mean weight and K by inch group of lake sturgeon, Lake Wisconsin.

Inch Group	Number	Mean Pred Weight	SE Weight	Mean K*	SD K
15	1	0.5	1.02	--	--
16	2	0.6	1.02	--	--
20	2	1.3	1.02	--	--
21	3	1.5	1.02	--	--
22	2	1.8	1.02	--	--
23	3	2.0	1.01	--	--
24	12	2.4	1.01	16.3	2.09
25	12	2.7	1.01	19.2	0.00
26	17	3.1	1.01	15.7	3.62
27	13	3.5	1.01	15.2	0.00
28	15	4.0	1.01	15.2	2.63
29	18	4.6	1.01	13.9	2.32
30	44	5.1	1.01	17.6	0.00
31	28	5.7	1.01	19.8	2.79
32	51	6.3	1.01	21.4	5.76
33	54	7.0	1.01	19.8	3.91
34	56	7.8	1.01	20.5	2.43
35	74	8.5	1.01	20.4	2.83
36	105	9.5	1.01	20.0	2.26
37	133	10.4	1.01	20.3	2.21
38	125	11.3	1.01	20.8	2.59
39	174	12.4	1.01	21.4	2.47
40	174	13.5	1.00	21.8	2.57
41	138	14.7	1.00	21.0	2.11
42	157	15.9	1.00	21.5	2.29
43	147	17.3	1.00	21.1	2.15
44	106	18.7	1.00	21.2	2.11
45	88	20.1	1.00	20.6	2.84
46	69	21.6	1.00	22.3	2.51
47	66	23.3	1.00	22.4	3.39
48	42	25.1	1.00	23.9	3.57
49	57	26.9	1.01	22.8	2.89
50	70	28.7	1.01	22.5	2.80
51	53	30.7	1.01	23.3	2.63
52	54	32.7	1.01	22.5	2.51
53	44	34.9	1.01	23.8	2.91
54	38	37.1	1.01	23.5	2.93
55	31	39.7	1.01	23.7	2.70
56	35	42.0	1.01	23.8	1.54
57	21	44.9	1.01	24.8	1.61
58	24	47.3	1.01	24.6	1.92
59	17	50.3	1.01	23.6	1.78
60	15	53.0	1.01	23.7	2.92
61	17	56.4	1.01	24.9	2.75
62	10	59.0	1.01	24.3	1.19
63	7	62.8	1.01	24.7	2.19
64	16	66.4	1.01	23.7	1.74
65	2	69.3	1.01	26.9	3.09
66	6	73.3	1.01	23.2	2.43
67	2	76.8	1.01	26.3	1.41
69	1	84.8	1.01	--	--
71	2	94.6	1.01	25.7	1.55

* Mean K is based on empirical data.

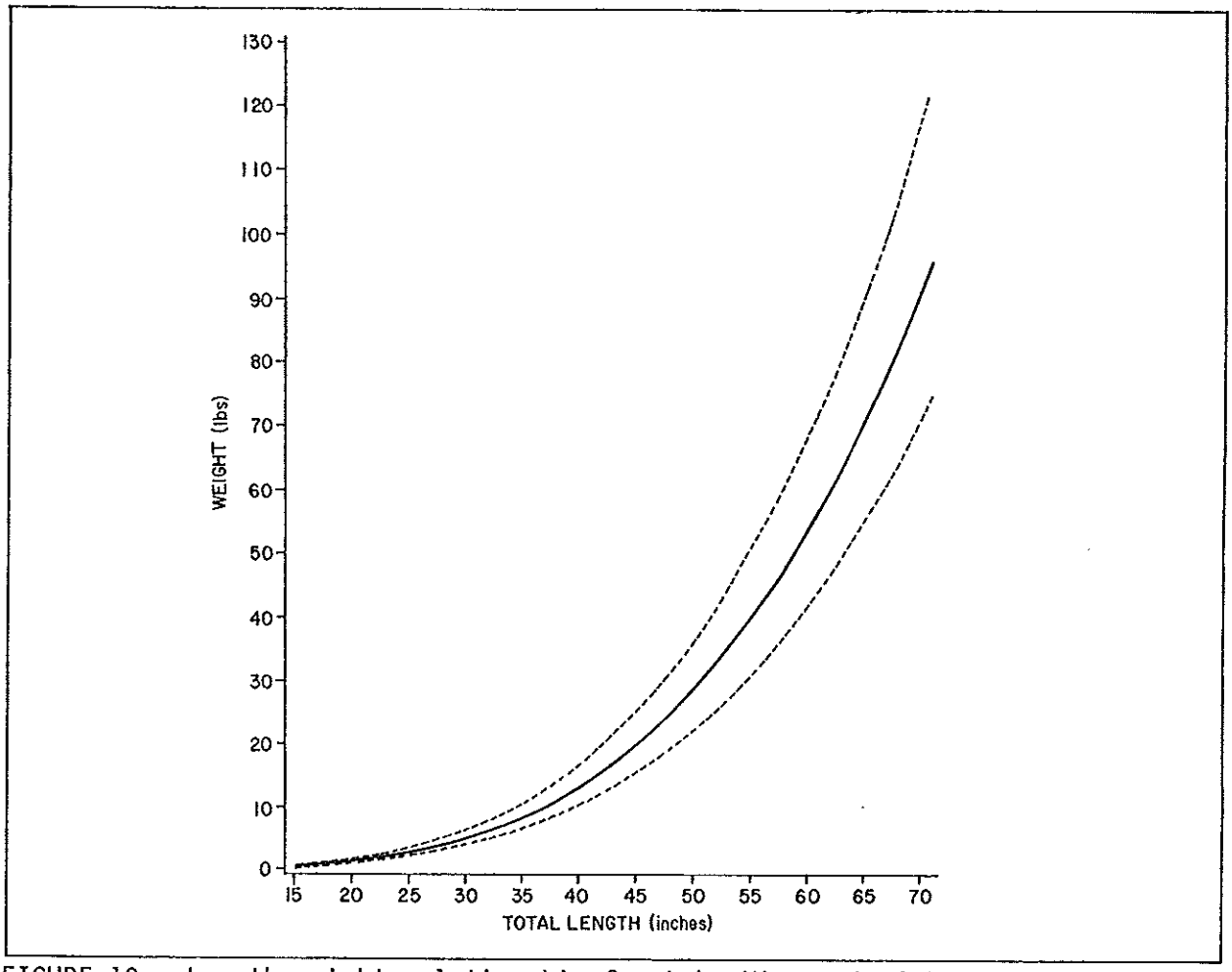

FIGURE 10. Length-weight relationship for Lake Wisconsin lake sturgeon with 95% confidence interval.

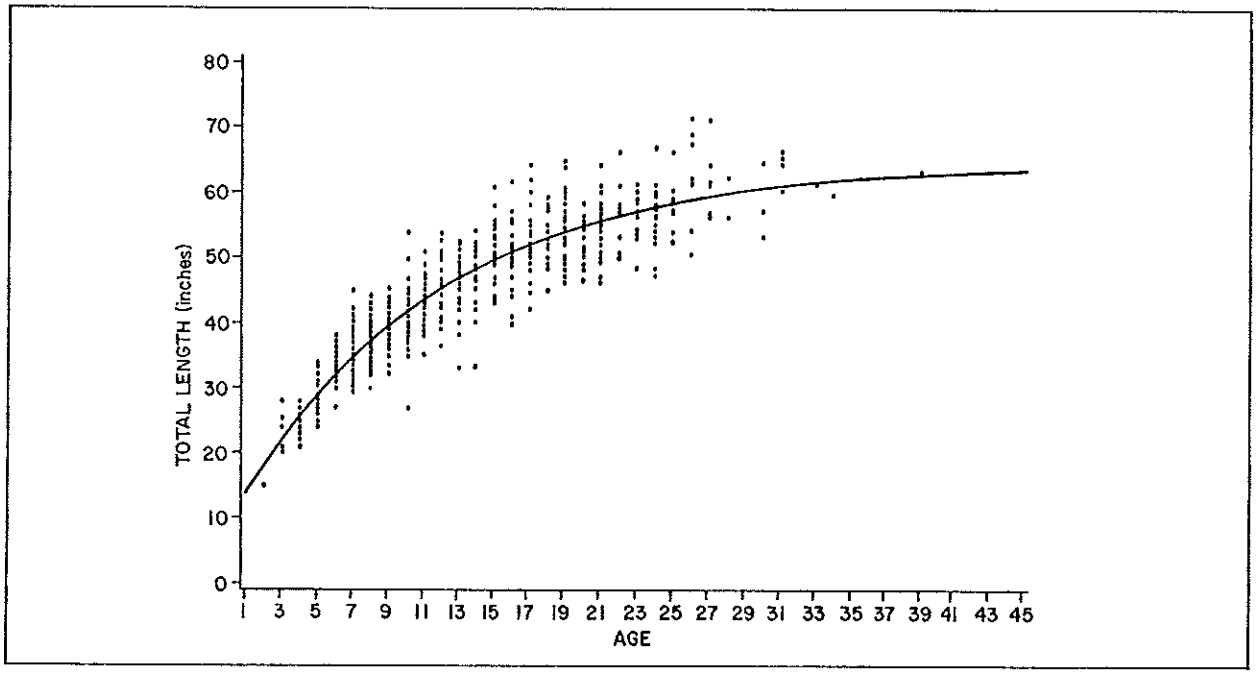

FIGURE 11. Von-Bertalanffy growth equation for Lake Wisconsin lake sturgeon.

Predicted sturgeon growth in Lake Wisconsin averaged 17.0 inches and 0.7 lb at age II, 25.5 inches and 2.9 lbs at age V, and 41.0 inches and 14.7 lbs at age X. An average legal-sized (45-inch) lake sturgeon weighed 20.1 lbs and was 12 years old. At 15 years of age, sturgeon averaged 49.5 inches and weighed 27.8 lbs. Thereafter, rate of growth slowed. A 20-year-old fish was 55.4 inches and 40.8 lbs, a 25-year-old was 59.0 inches and 50.3 lbs, and a 30-year-old was 60.5 inches and 54.7 lbs. The oldest fish was 39 years old, 63 inches long, and 58 lbs, while the largest fish was 26 years old, 71.5 inches, and 90 lbs. The condition factor of lake sturgeon (the K value) increased with length (Fig. 12).

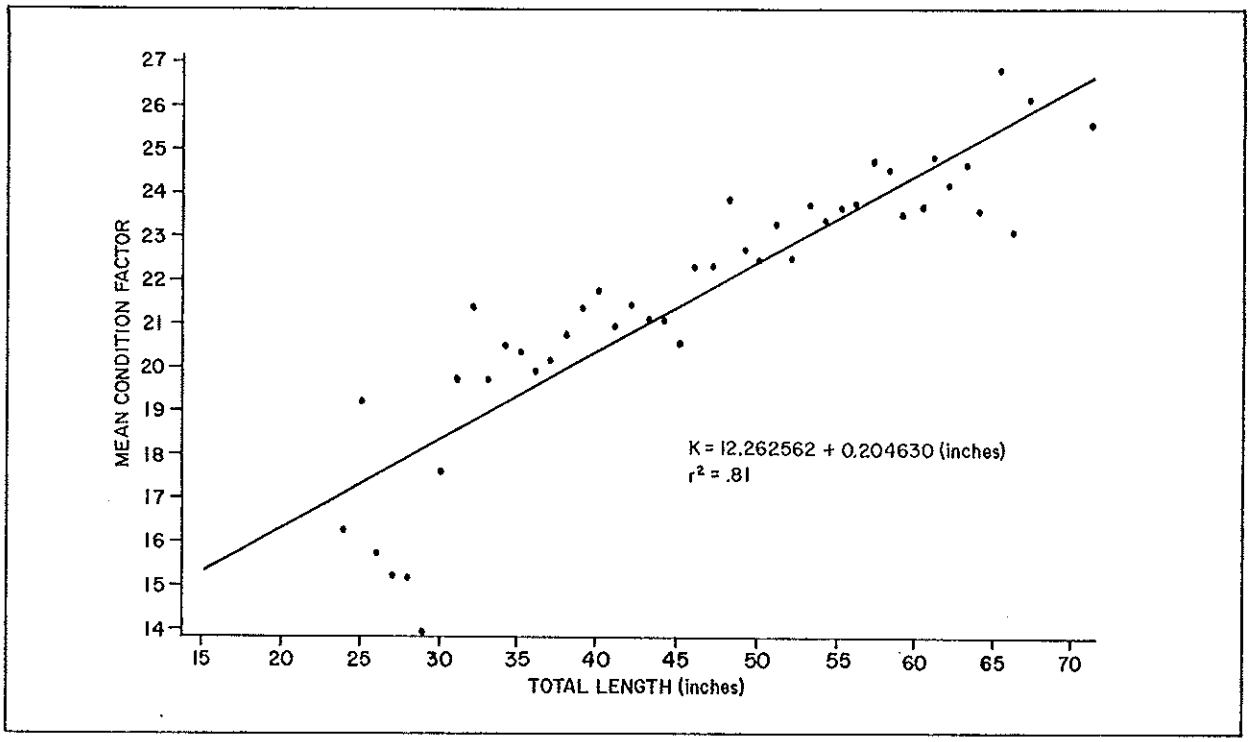

FIGURE 12. Lake sturgeon condition factors on Lake Wisconsin.

The growth rate of Lake Wisconsin lake sturgeon was equivalent to that of Lake Winnebago sturgeon until about age XII (Fig. 13). Thereafter, Lake Winnebago lake sturgeon grew faster and were about 3 inches longer than sturgeon from Lake Wisconsin at age XXX. Menominee River sturgeon grow considerably slower than the Lake Wisconsin and Lake Winnebago fish. A 50-inch, legal-sized lake sturgeon in the Menominee River would average 22 years old, whereas the same size fish from Lake Winnebago or Lake Wisconsin would average 15 years old.

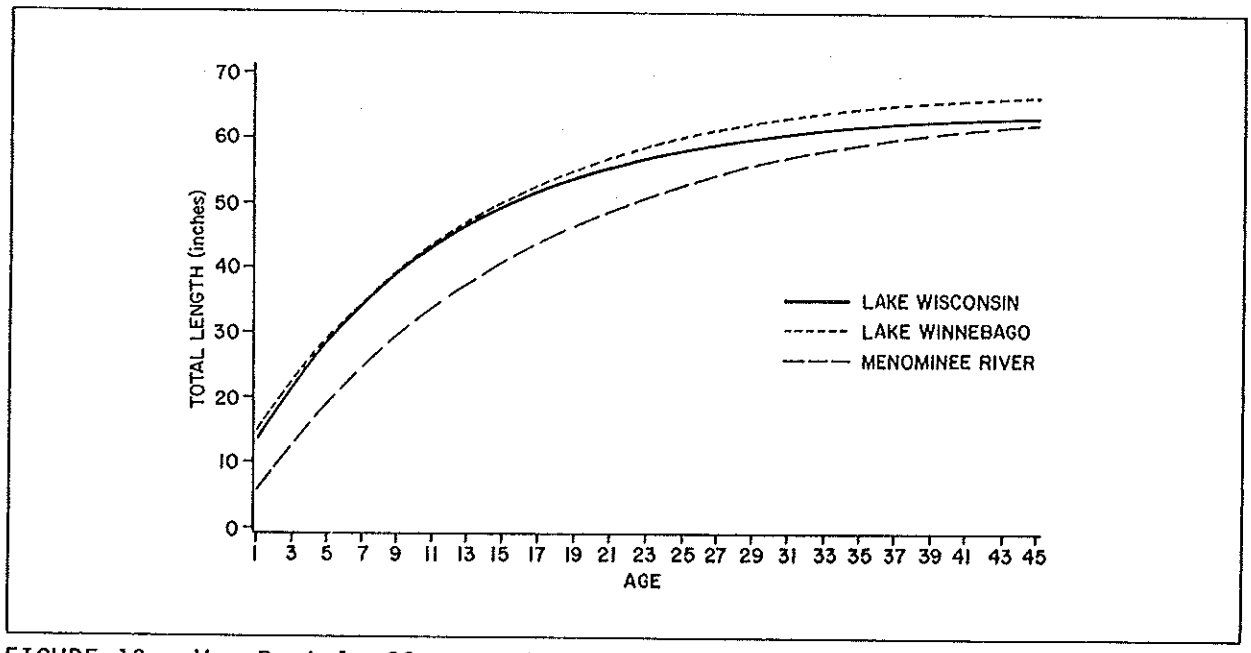

FIGURE 13. Von-Bertalanffy growth equations for Lake Wisconsin, Lake Winnebago, and the Menominee River.

Movement

Lake sturgeon movement within the lake was analyzed for the major areas netted by comparing the location of fish at recapture with their location at release (Fig. 3, sites 5-8). These fish were equally likely to be captured at any netting site as at the site where they were released (X^2 = 10.02, df = 9, P = 0.30), indicating that, even though lake sturgeon appeared to favor these areas, random movement between sites was occurring (Table 9). Also, anglers caught up to 16 tagged sturgeon at most sites where no tagging occurred, indicating that lake sturgeon moved around the entire lake area (Fig. 3).

TABLE 9. Chi-square test of areas of release vs. recapture of lake sturgeon within Lake Wisconsin.

	Area of Recapture				
Area of Release	Narrows	Tipperary Point	Islands	Okee	Total
Narrows (5)	33	26	7	6	72
Tipperary Point (6)	40	45	14	19	118
Islands (7)	21	28	2	9	60
Okee (8)	17	24	3	9	53
Total	111	123	26	43	303

Wisconsin Power and Light Company employees reported that every year 10-20 lake sturgeon were impinged on the upstream grate at the Prairie du Sac dam. From June 1980 to June 1981, these employees kept a diary of lake sturgeon raked off the grate. A total of 12 fish ranging in size from 25-38 inches were impinged, of which 4 were alive and 8 dead. In addition, commercial fishers in the Mississippi River, over 150 miles downstream from Lake Wisconsin, captured 9 tagged fish which ranged from 32-47 inches long when tagged. Three of these fish were captured within one year of the date originally tagged, one within 2 years, and the remainder within 4 years. They evidently swam over the roller gates on the Prairie du Sac dam during high water.

Spawning

Historically, employees at the Wisconsin Dells power dam have observed lake sturgeon spawning in early May. Electroshocking to sample and tag the spawning population was conducted from 9-14 May 1979 and 29 April-2 May 1980. During 1979 and 1980, 102 and 178 lake sturgeon were tagged, respectively. The fish ranged from 22 to 70 inches long, with 80% larger than 40 inches and 58% larger than 50 inches. Water temperatures of 50-51 F were associated with initiation of spawning during 1979 and 1980. Spawning activity was also reported to have occurred on 18 April 1981, 12 May 1983, and 16 May 1984.

Recaptures of tagged fish indicated a 30- to 40-mile spawning migration to and from the Wisconsin Dells dam. Sixteen lake sturgeon ranging in size from 34 to 58 inches were first netted in the lake during the fall-winter period and were then recaptured at the dam the following spawning season. Of the 280 lake sturgeon tagged and released at the dam, 14 (36-58 inches) were recaptured at various locations in the lake. Most recaptures occurred the following fall or winter but 2 sturgeon, one 36 inches and another 51 inches long, were captured from the lake within 3 days after release at the dam.

Documentation of prespawning movement and spawning at other locations on the river was obtained by electroshocking on 16, 27, and 28 April 1981. Rock riffle areas and shoreline riprap are very sparse along the river. The river bottom and shoreline consist mostly of sand. Electroshocking at a natural rock riffle area approximately 3 miles below the dam (Fig. 3 and 14) produced some small, immature lake sturgeon. On 16 April, at this riffle area, the water temperature was 50 F, and spawning white suckers were abundant. The riprap along County Highway V downstream from I-90 and the riprap upstream from Pine Island were also checked. No lake sturgeon were captured, and the majority of the fish captured were rough fish species. Water temperature ranged from 50-52 F, and congregating lake sturgeon were observed at the dam on 28 April. Further checks for the presence of lake sturgeon eggs on 30 April and 12 May 1981 were also unsuccessful. Lake sturgeon eggs were not observed at sites near the Dells dam where spawning fish had been observed (Fig. 15 and 16). High water level on 30 April made sampling difficult and it is possible that eggs may have already hatched by 12 May.

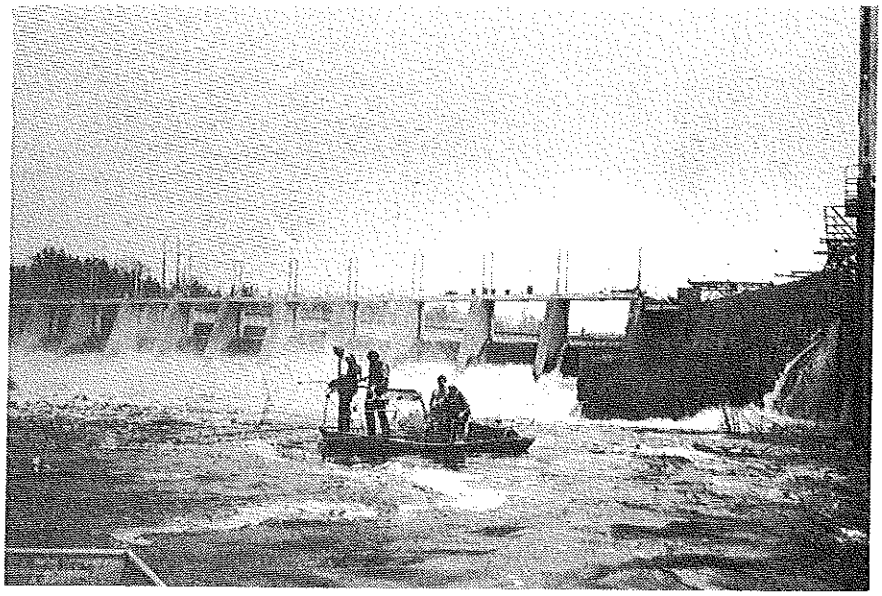

FIGURE 14. Boom shocking below Wisconsin Dells dam for spawning lake sturgeon.

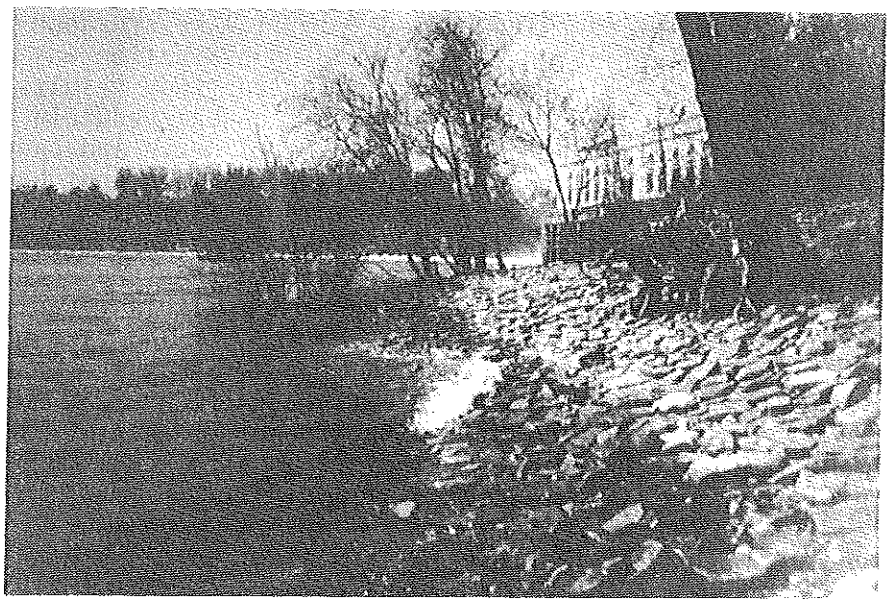

FIGURE 15. Sandstone rubble downstream from the Wisconsin Dells dam where lake sturgeon were captured during the spawning run.

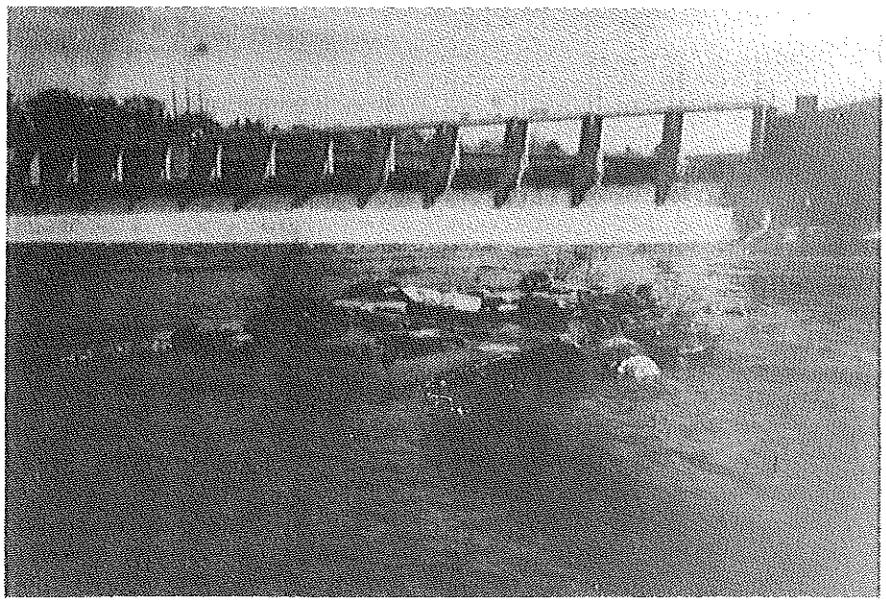

FIGURE 16. Island of rock rubble below dam at Wisconsin Dells. Spawning likely occurs here as many mature fish were captured by electroshocking at this site.

Handling Stress

During the 3 fall-to-spring sampling periods, 1,971 lake sturgeon were tagged through netting and electrofishing efforts, and an evaluation was conducted of mortality due to handling, which could have affected study results. Weighing lake sturgeon by looping a rope around the fish's caudal peduncle and hanging it from a scale can injure the notochord and central nerve and cause mortality. Therefore, the recapture rate of lake sturgeon that had been weighed was compared to the recapture rate for those that had not. To avoid bias, this comparison was limited to fish from which a fin ray had not been removed. Recapture data were not considered unless recapture occurred more than 30 days after the fish had been released, and multiple recaptures of individual fish were counted only as one recapture. Of 143 fish which had been weighed, 16.8% (24) were recaptured and of 992 fish which were not weighed, 13.2% (131) were recaptured, indicating that there was no significant difference ($X^2 = 1.357$, $P = 0.24$) between the recapture rate of fish which were weighed and those which were not weighed. Thus this method of weighing lake sturgeon did not significantly increase mortality.

Removal of the leading ray of the pectoral fin also can cause handling mortality. Excision of the fin ray near the base, necessary for valid aging, sometimes causes bleeding. During this study some recaptured fish were still bleeding several weeks after fin ray removal. Therefore during 1979-80 the fin ray was removed from every other lake sturgeon handled, and the rates of recapture for fish with and without an excised fin ray were compared. Recapture data were not used unless recapture occurred at least 30 days following release and the fish had not been weighed. Of the 247 lake sturgeon that had a fin ray removed, 20.2% (50 fish) were later recaptured. This rate compared to an 18.3% (59 fish) recapture rate of the 322 fish from which no fin was removed, indicating that fin ray removal had no significant effect on rate of mortality for fish that were not weighed ($X^2 = 0.033$, $P = 0.56$).

Although neither fin ray removal nor weighing had a significant impact on sturgeon survival, fish subjected to both handling stresses showed a significantly lower recapture rate ($X^2 = 6.548$, $P = 0.01$). Of 103 fish which were both weighed and had the fin ray removed, only 8 (7.8%) were later recovered, while of the 322 which were not subject to either treatment, 59 (18.3%) were later recaptured.

Contaminants

Five fish over 50 inches and one 30-inch fish were analyzed for PCB's. Two of the larger fish were also analyzed for pesticide and toxic metal contamination (Table 10). For pesticides and metals, levels were less than detection for most parameters. For PCB's, a low reading of 0.28 ppm for the 30-inch sturgeon was well below the current FDA tolerance level (2.0 ppm), while 3 of the 5 larger fish were at or slightly above the 2.0 ppm level.

TABLE 10. Results of chemical analysis of lake sturgeon, Lake Wisconsin.

	Date of Capture					
	1 Nov 79	1 Nov 79	16 Oct 80	17 Oct 80	2 Apr 81	24 Apr 81
Length (inches)	56.3	51.6	58.5	54.0	53.0	30.5
Weight (lb)	28.6	26.4	48.0	--	26.8	5.5
Sample form	Whole Fish	Whole Fish	Fillet	Fillet	Fillet	Fillet
Fat (%)	7.1	9.4	13.0	13.0	6.6	4.4
Contaminant						
PCB (ppm) (mg/L)	1.7 (1.3 fillet)	1.6 (1.3 fillet)	2.3	2.9	2.0	0.28
As*	<2.0	<2.0	--	--	--	--
Cd*	<0.2	<0.2	--	--	--	--
Cr*	<0.5	<0.5	--	--	--	--
Cu*	1.1	1.0	--	--	--	--
Pb*	<5.0	<5.0	--	--	--	--
Hg*	0.12	0.07	--	--	--	--
Aldrin*	<20	<20	--	--	--	--
Dieldrin*	<20	<20	--	--	--	--
Eldrin*	<20	<20	--	--	--	--
O,P DDE*	<50	<50	--	--	--	--
P,P DDE*	90	70	--	--	--	--
O,P DDD*	<50	<50	--	--	--	--
P,P DDD*	<50	<50	--	--	--	--
O,P DDT*	<50	<50	--	--	--	--
P,P DDT*	<50	<50	--	--	--	--
Cis-Chlordane*	<50	<50	--	--	--	--
Trans-Chlordane*	<50	<50	--	--	--	--
Cis-Nonachlor*	<50	<50	--	--	--	--
Trans-Nonachlor*	<50	<50	--	--	--	--
Hexachlorobenzene*	<10	<10	--	--	--	--
Pentachlorophenol*	<50	<50	--	--	--	--
Alpha BHC*	20	20	--	--	--	--
Gamma BHC*	<10	<10	--	--	--	--
Methoxychlor*	<50	<50	--	--	--	--

* Measured in ppb (µg/L).

DISCUSSION

Sturgeon fishing is very popular on selected areas of Lake Wisconsin and the Wisconsin River. The 1979 angler survey estimated that anglers spent 13,073 hours fishing for lake sturgeon. Using an average fishing trip length of 6.3 hours (determined from voluntary angler diaries, 1985), 2,075 angling trips occurred in 1979. Much of this fishing was done by repeat anglers. While many sublegal lake sturgeon are caught from these waters (1 fish/5.26 hrs), overharvest is still a critical problem in maintaining a quality fishery for legal sized-fish.

Harvest

In a balanced fishery providing a sustained yield, mortality must be balanced by recruitment. Total annual mortality of Lake Wisconsin lake sturgeon was estimated at 15%. Recruitment was an estimated 24%, based on the ratio of sublegal fish (43.0-44.9 inches) which would annually grow into the legal population. Both of these estimates are probably high due to the fact that entanglement nets do not effectively catch larger fish. Preigel and Wirth (1975) found recruitment and mortality to be approximately 5% in Lake Winnebago. Therefore, since angling likely accounts for the majority of annual mortality for a fish with the longevity of the lake sturgeon, the harvest level should not be allowed to exceed 5%.

A reliable estimate of exploitation of Lake Wisconsin lake sturgeon was not obtained. Angler tag returns for legal fish were about 1% of tagged legal fish available for 3 consecutive years, although the percentage of anglers who voluntarily returned tags is unknown. Also, the relationship between registered harvest and the actual population level is unclear. The registered harvest for the 3 years of mandatory registration was 68, 47, and 104 lake sturgeon, respectively, and population estimates of legal-sized fish ranged from 1,000-4,000. The harvest rate therefore ranged from 1-10%, excluding illegal harvest.

Length frequency can indicate overharvest of lake sturgeon if there is a large percentage of small fish in the harvest. During 1955-67, Priegel and Wirth (1975) determined that harvest of lake sturgeon on Lake Winnebago was in balance with recruitment. At that time harvest was allowed during an annual February spearing season (spearing through the ice) with a size limit of 40 inches. The size composition of that lake sturgeon harvest has remained fairly even, with 30.1% less than 50 inches, 40.4% between 50 and 60 inches, and 29.5% longer than 60 inches. This fairly even size distribution of harvested lake sturgeon occurs today, also, and the average size of fish harvested has increased from 54.5 to 56 inches since the size limit was raised from 40 to 45 inches in 1974 (Dan Folz, Wis. DNR, Oshkosh, pers. comm. 1985).

Ongoing studies on Lake Poygan, a 14,100-acre lake upstream from Lake Winnebago, indicate an improvement in the size distribution of lake sturgeon caught following a harvest restriction (Meyers, 1982). Regulations on this lake allowed a 2-day winter spearing season every 3 years until 1971, when harvest was restricted by allowing a season only every 5 years. Of the 227 sturgeon harvested in 1971, 84% were less than 50 inches long. By 1976 only 56% of the 85 sturgeon speared were less than 50 inches, and by 1981 only 41%

of the 57 fish speared were less than 50 inches. Though spearing success is greatly dependent on weather conditions and water clarity, improvement in the size distribution of the Lake Poygan fishery is evident.

The lake sturgeon population of Lake Wisconsin is most similar to the recovering 1976-81 population of Lake Poygan. Sample size of harvested lake sturgeon was small during the early years of voluntary registration (1977-79) when a more even size distribution was indicated, but anglers may have had a tendency to register only larger fish. As anglers became more aware of the voluntary registration the sample size increased, and a higher proportion of harvested fish were reported in the 45- to 49-inch size group (see Table 4). Percentages for this size group averaged 47% from 1983-85, when registration was mandatory. Further, the impact of angler harvest on the overall size distribution of angler-caught fish is evidenced by a dramatic decline in numbers caught during 1979-81 at the 45-inch limit (Fig. 17). During that

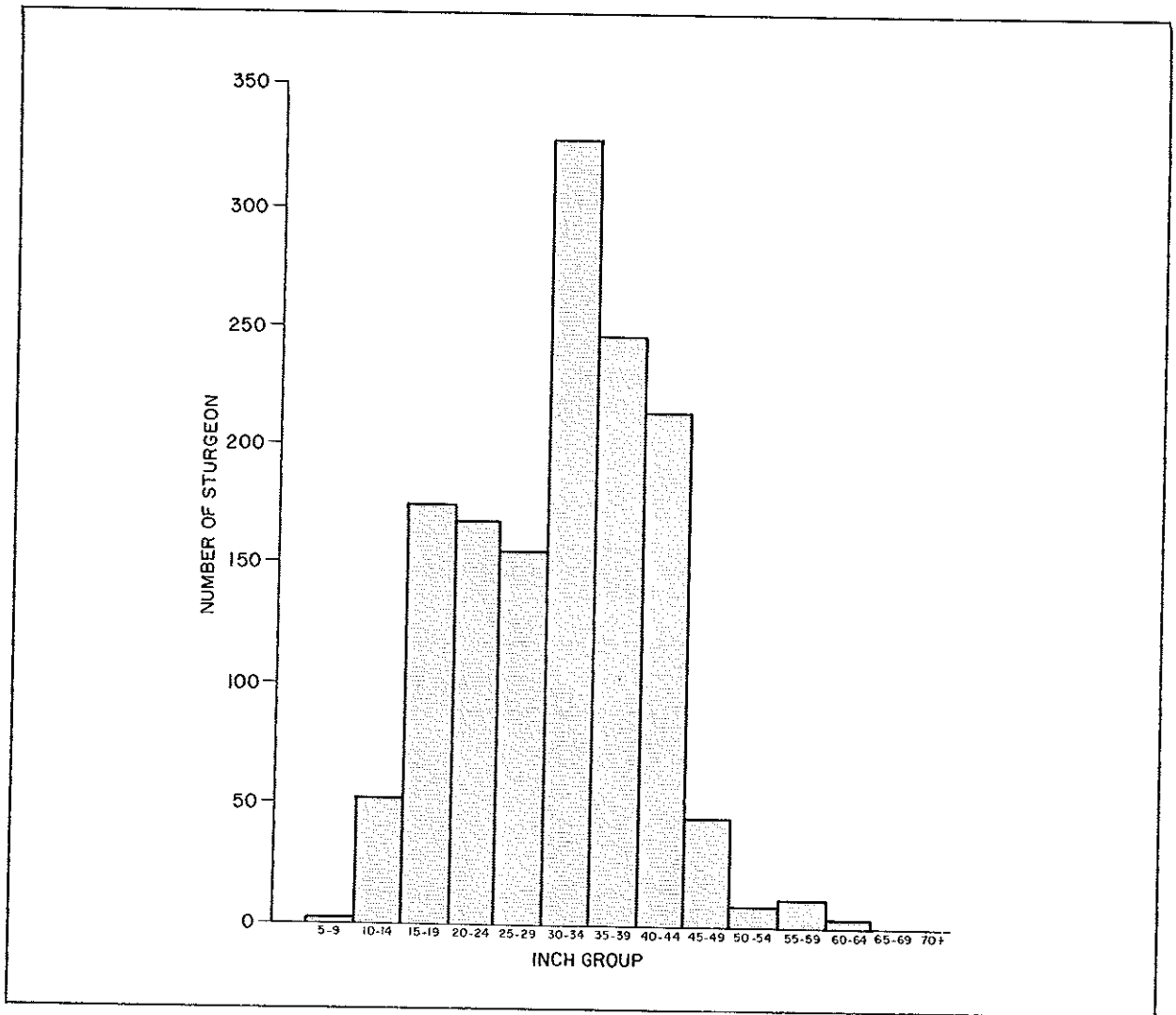

FIGURE 17. Length frequency of angler-caught lake sturgeon, 1979-81, Lake Wisconsin.

period there were 217 40- to 44-inch lake sturgeon landed vs. only 46 45- to 49-inch fish. A more even size distribution of lake sturgeon harvested from Lake Wisconsin is necessary, as female sturgeon do not spawn until they reach approximately 55 inches (Priegel and Wirth 1975). It is unlikely that the length composition of the Lake Wisconsin lake sturgeon population will ever achieve the even distribution found in Lake Winnebago because of the smaller annual growth increment of Lake Wisconsin fish after age XII (45 inches) (Fig. 13).

Change in Fishing Season

Recently, interest in postponing the opening of the fall hook and line season by extending the closure 2 weeks until the end of October has grown among sturgeon anglers and businesses. Reasons for this change include the desire to avoid conflicts with other lake users, such as power boaters and skiers in early September, and the feeling among some anglers that the catch rate is better late in the season. The Lake Wisconsin Chamber of Commerce believes a later lake sturgeon season would extend business into the fall when other recreational activities have tapered off. The negative aspects of a later season include more inclement weather during late October and a possible increase in overall harvest, which would not be desirable.

Harvest data from past lake sturgeon seasons show that significant harvest occurred during the last week of the season (through 15 Oct) during 1983-85 (Table 11). Only 35% of the total sturgeon creeled at the end of the 1983-85 seasons were 45-49 inches long. Anglers may be waiting until the end of the season to fill their season bag limit in hopes of catching a larger fish. A high percentage of a season's total harvest may thus occur at the end of the season regardless of the closing date. However, it is unwise to risk additional harvest of more and/or larger fish later in October while the population presently shows signs of overharvest.

TABLE 11. Lake sturgeon harvest during last week of season, Lake Wisconsin, 1983-85.

	Percent of Harvest		
Total Length (inches)	1983	1984	1985
45-49	38	29	38
50-54	15	47	24
55-59	31	12	26
50-64	8	4	6
65-69	8	8	6
70+	0	0	0
Total	100	100	100
Total number of fish	13	14	34
Percent of total season harvest	29	27	31

Recruitment

Maintenance of natural reproduction and recruitment to the fishery are vital to sustaining the sturgeon population. According to voluntary angler information obtained from local resorts and bait shops during 1979-81 and an angler questionnaire in 1982, there are 20 sublegal sturgeon caught per legal sturgeon kept. This ratio of legal to sublegal fish is a meaningful parameter to monitor, but in the future voluntary diaries kept by competent anglers during the fishing season may be a more reliable monitoring method than those previously used.

Spawning

The presence of congregating lake sturgeon below the Wisconsin Dells dam was documented, particularly near a small rock island off the southwest corner of the powerhouse and along the east shore sandstone rubble immediately downstream from the powerhouse. A riffle area approximately 3 miles downstream from the dam was also noted as a good sampling area for lake sturgeon, but most fish sampled there were in the 30-40 inch size range. Additional sampling of other riprap areas did not produce any lake sturgeon, and an attempt at egg sampling in 1981 at the known congregation areas did not prove successful.

Though very little shoreline riprap and rock riffle areas exist within the lake and river system, it is hard to imagine the entire lake sturgeon population of Lake Wisconsin originating from the few suitable spawning sites at the Dells area. It is possible that downstream movement of sturgeon from upstream reservoirs provides recruitment to the Lake Wisconsin fishery, though upstream populations are thought to be small. Movement of radio-tagged yearling sturgeon in the Menominee River documented significant movement from upper reservoirs (Tom Thuemler, Wis. DNR, Marinette, per. comm. 1985). Further investigation of lake sturgeon spawning areas and early life history would be beneficial.

Contaminants

The recent reduction of the PCB tolerance level from 5.0 ppm to 2.0 ppm causes some concern about consumption of Lake Wisconsin sturgeon. Of the 5 sampled fish exceeding 50 inches, the 2 sampled in 1979 were well under the 2.0 ppm level but the 3 sampled in 1980 ranged from 2.0 to 2.9 ppm PCB's. The 30-inch fish sampled in 1981 had only .28 ppm PCB. Since a typical 50- to 55-inch lake sturgeon is 15-20 years old and has consumed a large quantity of food during that time, the 2.0 ppm present in some fish is fairly indicative of a low level of PCB's present in the Lake Wisconsin system. However, the fact that concentration levels were often above 2.0 ppm warrants concern. Further sampling of various sizes of lake sturgeon should be done before any consumption guidelines are issued.

Importance of Fishery

The Lake Wisconsin lake sturgeon fishery is an important resource locally as well as statewide. Statewide mandatory lake sturgeon registration indicated

that anglers in the Lake Wisconsin-Wisconsin River area accounted for approximately 40% of total statewide angler use and harvest during 1983-85. Continued monitoring of the harvest, possible regulation changes, and further evaluation of PCB levels are necessary to ensure sound management of this valuable resource.

MANAGEMENT RECOMMENDATIONS

Estimating population size, mortality, and/or angler exploitation of the lake sturgeon population in an area as large as the Lake Wisconsin-Wisconsin River system is difficult. Angler catch and harvest information is a better means of evaluating the stability of the lake sturgeon population. Presently, numbers of 45- to 49-inch fish are too small in relation to the 30- to 44-inch group and have constituted too high a percentage of the harvest, except in 1985. A more even size distribution of harvested lake sturgeon is desired.

I recommend continued voluntary angler surveys to assess catch and mandatory registration to assess harvest. Additional length frequency information on the sublegal population should also be obtained from cooperating anglers through daily fishing diaries. The catch rate and the sublegal to legal ratio from such data should also be monitored.

Due to observed variance, a 5-year average of mandatory harvest registration data should be obtained. Using the 5% level of annual harvest as guidance, I recommend a conservative harvest of 50 lake sturgeon per year. I also recommend reducing the percent of harvested fish within the 45- to 49-inch size group by increasing the size limit to 50 inches. Other approaches to reducing harvest, such as reducing the season length or scheduling closures (both of which are done at Lake Poygan), limiting numbers of anglers by drawing for permits, or closing the season after an established quota of lake sturgeon has been registered, would also be effective, but these approaches would reduce angling opportunity and might harm businesses which cater to lake sturgeon anglers. Increasing the size limit would improve the fishery, yet allow present angling pressure to continue or to increase. Also, impact would be short-term, as the lake sturgeon harvest would be reduced for only 3-5 years until the more abundant fish presently under 45 inches exceed 50 inches. Trophy lake sturgeon fishing would also be promoted, since a 50-inch fish averages 28.7 pounds, a 45-inch fish only 20.1 pounds, while a 55-inch sturgeon averages nearly 40 pounds. Anglers would catch greater numbers of larger fish because these fish would constitute a greater percentage of the population. I do not recommend a later season closure because of the risk of increasing the harvest. Catch rates from voluntary angler diaries could help evaluate whether or not fishing is better at the end of the season.

Further sampling of PCB levels, particularly in legal-sized fish, is necessary. Fillet samples can be obtained from cooperating anglers. If data warrants it, a consumption advisory should be issued. Additional information is also necessary to determine the age or size at which contaminant levels approach the 2.0 ppm level. If a consumption advisory is necessary on fish larger than 50 inches, the recommended increase to a 50-inch size limit should be reevaluated with regard to increasing population levels of contaminated fish.

I also recommend: increased law enforcement during the fall hook and line fishing season; protection of lake sturgeon at the known spawning locations near the Dells; preservation of the rock, rubble habitat at these areas; identification of additional spawning areas by surveillance of other sites as well as by radio tagging and tracking of adult fish; and riprapping along the river banks to provide additional spawning habitat. Finally, a life history study should be conducted to determine habitat characteristics of fingerling and yearling lake sturgeon.

Evidence indicates that the Lake Wisconsin lake sturgeon has been harvested at levels too high to allow the sustained yield of a higher quality fishery. This lake sturgeon population is a very valuable resource. It provides local economic benefit to bait shops, resorts, and restaurants, and it is one of the few fishable populations remaining in the country. Sound management practices to ensure preservation of the lake sturgeon in Lake Wisconsin should be pursued.

APPENDIX A. Calculation of lake sturgeon population estimates, Lake Wisconsin.

Peterson Method: $\hat{N} = \frac{(M+1)(C+1)}{(R+1)}$ $\quad \hat{V}(\hat{N}) = \frac{N^2 (C-R)}{(C+1)(R+1)}$

$SD = \sqrt{V}$ $\quad$ 95% Confidence Interval = 2 x SD

All Sizes

1979

Number tagged Fall '78- Spring'79 = 498
Tag retention rate x .894
M = 445
C = 316
R = 9

$\hat{N} = \frac{446\ (317)}{10} = 14138$

$\hat{V}$ = 17,597,962
SD = 4195 CI = 8390

1980

Number tagged Fall'78 - Spring'79 = 498
Tag retention rate .875
Survival rate (catch curve) .85
Retain tag and survive x .744
Remaining tagged fish 370

Number tagged Fall '79 - Spring '80 = 788
Tag retention rate x .894
705

M = 370 + 705 = 1075
C = 542
R = 24

$\hat{N} = \frac{1076\ (543)}{25} = 23,371$

$\hat{V}$ = 20,040,620
SD = 4477 CI = 8954

1981

Number tagged Fall '78 - Spring '79 = 498
Tag retention rate .867
Survival rate $(.85)^2$ = .7225
Retain tag and survive x .626
Remaining tagged fish 312

Number tagged Fall '79 - Spring '80 = 788
Retain tag and survive x.744
Remaining tagged fish 586

Number tagged Fall '80 - Spring '81 685
Retain tag x .894
Remaining tagged fish 613

M = 1511
C = 562
R = 39

$\hat{N} = \frac{1512\ (563)}{40} = 21,281$

$\hat{V}$ = 10,261,090
SD = 3203 CI = 6406

Legal Size Fish (≥ 45")

1979 Number tagged Fall '78 - Spring '79

	$\geq$ 45"	=	125
Recruitment	43"-45"	=	30
Total tagged		=	155
Tag retention rate		x	.894
	M	=	139
	C	=	14
	R	=	1

$\hat{N} = \frac{(140)(15)}{(2)} = 1050$

$\hat{V} = 318{,}500$

SD = 564 CI = 1128

1980 Number tagged Fall '78 - Spring '79

	$\geq$ 45"	=	125
Recruitment	41"-45"	=	81
			206
Retain tag and survive		x	.744
Remaining tagged fish $\geq$ 45"			153

Number tagged Fall '79 - Spring '80

	$\geq$ 45"	=	272
Recruitment	43"-45"	=	82
			354
Tag retention rate		x	.894
Remaining tagged fish		=	317

M = 153 + 317 = 470

C = 27

R = 6

$\hat{N} = \frac{(471)(28)}{(7)} = 1884$

$\hat{V} = 332{,}762$

SD = 577 CI = 1154

1981 Number tagged Spring '78 - Fall '79

	$\geq$ 45"	=	125
Recruitment	39-45"	=	153
			278
Retain tag and survive		x	.626
Remaining tagged fish			174

Number tagged Fall '79-Spring '80

	$\geq$ 45"	=	272
Recruitment	41"-45"	=	172
			444
Retain tag and survive		x	.744
Remaining tagged fish			330

Number tagged Fall '80 - Spring '81

	$\geq$ 45"	=	242
Recruitment	43-45"	=	87
			329
Tag retention rate		x	.894
Remaining tagged fish			294

M = 174 + 330 + 294 = 798

C = 31

R = 8

$\hat{N} = \frac{799\ (32)}{9} = 2841$

$\hat{V} = 580123$

SD = 762 CI = 1524

Multiple Recapture Methods

All Sizes

$M_1 = 498 \qquad M_2 = 790$

$C_2 = 918 \qquad C_3 = 684$

$R_{12} = m_2 = 36$

$R_{13} = K_2 = 34$

$R_{23} = R_2 = 73$

Jolly-Seber Method

$$B_2 = \frac{M_2 K_2}{R_2} + m_2 \qquad \hat{N}_2 = \frac{B_2 C_2}{M_2}$$

$$B_2 = \frac{(790)(34)}{73} + 36 = 404 \qquad \hat{N}_2 = \frac{(404)(918)}{36} = 10301$$

Bailey's Method

$$\hat{N}_2 = \frac{M_2 (C_2+1)(R_{13})}{(R_{12}+1)(R_{23}+1)} = \frac{(790)(919)(34)}{(31)(74)} = 9016$$

$$\hat{V}(N_2) = N_2^2 - \frac{M_2^2 (C_2+1)(C_2+2) R_{13} (R_{13}-1)}{(R_{12}+1)(R_{12}+2)(R_{23}+1)(R_{23}+2)}$$

$$\hat{V}(N_2) = 9015^2 - \frac{(790)^2(919)(920)(34)(33)}{(37)(38)(74)(75)} = 5399877$$

$$SD = \sqrt{5399877} = 2324 \qquad CI = 4652$$

Legal Size Fish ($\geq 45"$)

$M_1 = 117 \qquad M_2 = 254$

$C_2 = 285 \qquad C_3 = 222$

$R_{12} = m_2 = 3$

$R_{13} = K_2 = 3$

$R_{23} = R_2 = 18$

Jolly-Seber Method

$$B_2 = \frac{254 \times 3}{18} + 3 = 45.3$$

$$\hat{N}_2 = \frac{(45.3)(285)}{3} = 4303.5$$

Bailey's Method

$$\hat{N}_2 = \frac{(254)(286)(3)}{(4)(19)} = 2868$$

$$\hat{V}(N_2) = (2868)^2 - \frac{(254)^2 (286)(287)(3)(2)}{(4)(5)(19)(20)} = 4044685$$

$$SD = \sqrt{4044685} = 2011 \qquad CI = 4022$$

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