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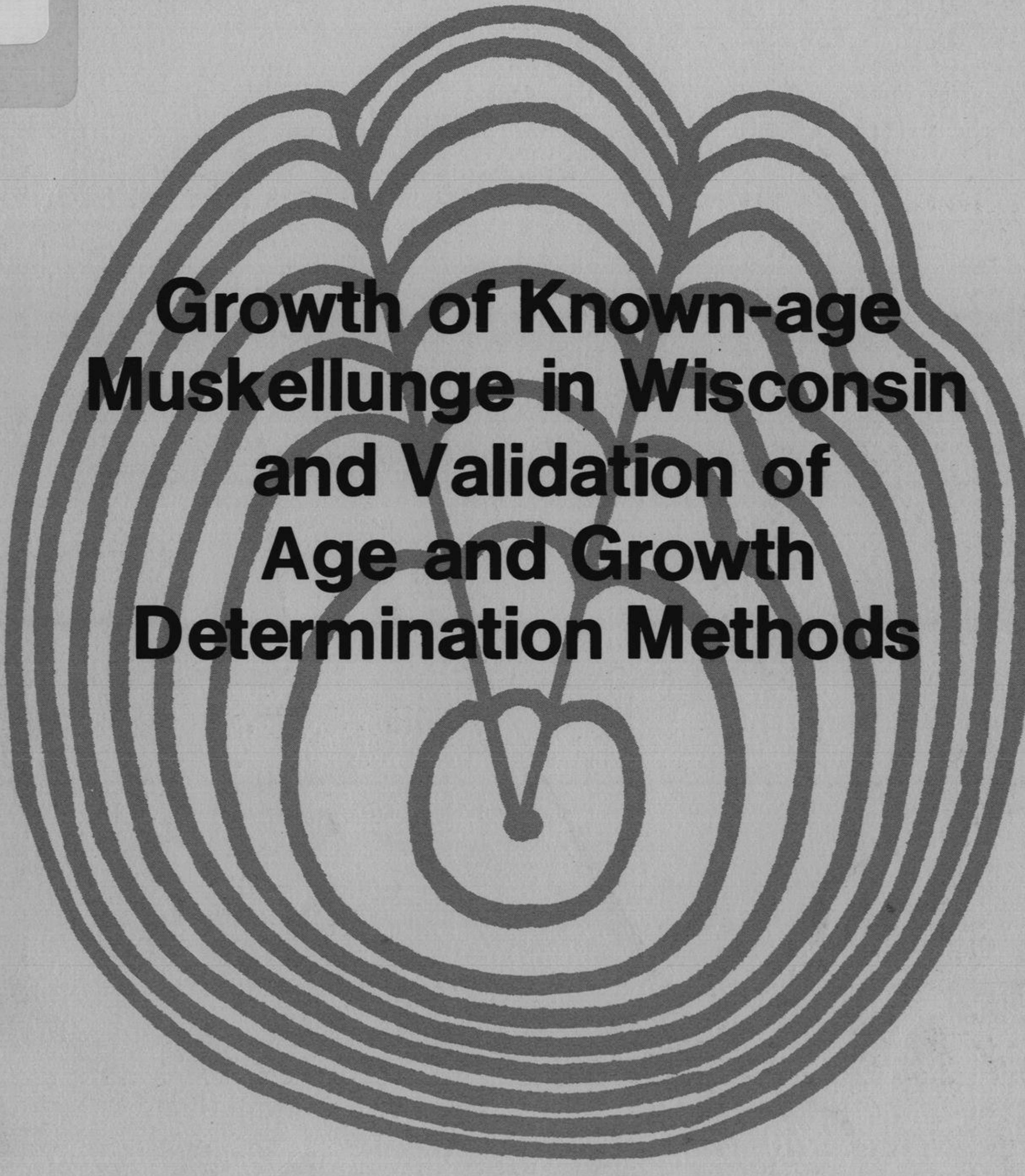
Growth of Known-age Muskellunge in Wisconsin and Validation of Age and Growth Determination Methods



DEPARTMENT OF NATURAL RESOURCES
Madison, Wisconsin 53701
1971

CONTENTS

GROWTH OF KNOWN–AGE MUSKELLUNGE IN WISCONSIN: AND VALIDATION OF AGE AND GROWTH DETERMINATION METHODS

By
Leon D. Johnson

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ABSTRACT

From 1955 to 1969, all muskellunge stocked in Bone Lake, Lac Court Oreilles and Big Spider Lake were finclipped. The presence of this large number of known-age fish provided the opportunity to gather empirical growth data and to compare two widely used methods of determining age and growth. From 1956 through 1968, scale samples and fin sections were taken from 1,734 known-age fish and from 1,468 muskellunge considered to be partially known-age fish.

Through the use of either the scale or fin section method, ages of muskellunge age I through IX could be fairly accurately determined. For fish between ages IX and XI, the fin section method was the more accurate of the two means of determining age. For fish age XII and beyond, outer annuli could not be distinguished and neither method was considered to be accurate.

For making back calculations of growth, however, the scale sample, method was found to be superior. Although most of the lengths calculated by both methods were within an inch of actual measurements made, use of the scale method was more reliable. Application of the fin section method of back calculating growth was found to be very limited due to the arbitrary way in which a correction factor for the growth equation was determined.

On the basis of empirical and calculated data, differential muskellunge growth was found. Fish in Big Spider Lake were slow growing, fish in Lac Court Oreilles were average growing and fish in Bone Lake were fast growing. Although this growth variation was demonstrated, no explanations for this variation were found.

ACKNOWLEDGMENTS

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Credit is also given to James Nehls for the artwork on page 3. Photographs are by the author.

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Edited by Susan Nehls

INTRODUCTION

The muskellunge, *Esox masquinongy* Mitchill, is one of the largest fresh water game fish in Wisconsin. It is important as a trophy fish and is an attraction to all anglers. In 1966, 157,000 fishermen made almost a million muskellunge fishing trips throughout the state and caught 94,000 legal muskellunge, weighing 750,000 pounds (Churchill, 1968). From 1964 through 1967, the yearly catch averaged 101,000 legal muskellunge. From these data, the importance of this species to the sport fishery can be readily recognized.

The proper management of muskellunge populations requires a detailed knowledge of its life history, including rate of growth and age-class structure in normal populations. Although techniques for age and rate of growth determinations have been well worked out for many other species of fish, similar analyses have not been made for the Wisconsin muskellunge. Its extremely large size and apparent old age attained have presented many problems in making positive age determinations.

From 1955 through 1965, all muskellunge over 5 inches long stocked in 80 northern Wisconsin lakes were finclipped to designate the year that they were stocked. After 1965, the stocking of finclipped fish was continued until 1969 only in specially selected study lakes.

The presence of so many known-age muskellunge provided the unique opportunity to validate two standard methods of making age and growth determinations using scale samples and cross-sections of the soft rayed fins. Individual fish were recaptured as often as nine times and each time, increments of growth were measured. Back calculations of growth were made through the use of scale samples and fin sections and were compared to measurements of the actual growth made. Ages were assigned to samples of scales and fin sections and these were compared to known ages, making it possible to test the accuracy of these age determination methods.

In addition to this documentation of calculated growth, recaptures of marked fish provided empirical data on muskellunge growth over a 14-year period. From such data, growth rates of muskellunge were categorized as average growing, slow growing, and rapid growing. For the purposes of this study, three lakes were selected, each one containing muskellunge whose growth rates typified the three representative types.

LAKES STUDIED

Lac Court Oreilles

Located in Sawyer County, this lake is a soft water, 5,038-acre, drainage lake connected to the outlets of Grindstone Lake (3,304 acres) and Whitefish Lake (856 acres) and draining into Little Lac Court Oreilles (189 acres) and the Chippewa River (Table 1). Its fish population consists of the following native species: muskellunge, *Esox masquinongy* Mitchill; walleye, *Stizostedion vitreum vitreum* (Mitchill); largemouth bass, *Micropterus salmoides* (Lacepede); smallmouth bass, *Micropterus dolomieui* Lacepede; rock bass, *Ambloplites rupestris* (Rafinesque); yellow perch, *Perca flavescens* (Mitchill); bluegill, *Lepomis macrochirus* Rafinesque; pumpkinseed, *Lepomis gibbosus* (Linnaeus); black crappie, *Pomoxis nigromaculatus* (LeSueur); white sucker, *Catostomus commersoni* (Lacepede); cisco, *Coregonus* sp.; longnose gar, *Lepisosteus osseus* (Linnaeus); black bullhead, *Ictalurus melas* (Rafinesque); brown bullhead, *Ictalurus nebulosus* (LeSueur). One other species was introduced—lake trout, *Salvelinus namaycush* (Walbaum)—and one species known to be not native—northern pike, *Esox lucius* Linnaeus—was present in the lake at the beginning of the study.

Musky Bay warms up earlier in the spring than the rest of the lake and provides the single important muskellunge spawning area.

Big Spider Lake

This hard water drainage lake (745 acres) is also located in Sawyer County and has a fish population consisting of muskellunge, walleye, largemouth bass, smallmouth bass, panfish and white sucker. Bay areas which warm up earlier in the spring than the rest of the lake tend to concentrate muskellunge spawning activity.

Bone Lake

A hard water drainage lake (1,781 acres), Bone Lake is located in Polk County and has an outlet to Fox Creek. Native fish present include northern pike, largemouth bass, smallmouth bass, bluegill, black crappie, rock bass, pumpkinseed, yellow perch, and bullhead. The muskellunge was introduced to this lake. The entire lake warms to the extent that muskellunge and northern pike spawning areas are not concentrated in any one area. Of the three lakes studied, Bone

METHODS

Lake is the only one that is located outside of the native geographical range of muskellunge.

TABLE 1
Chemical Analyses and Some Physical Characteristics of the Three Study Lakes

Parameter	Lac Court Oreilles	Big Spider Lake	Bone Lake
Physical Features			
Surface Acres	5,038	745	1,781
Shoreline (Miles)	25.4	9.2	12.5
Max. Depth (Feet)	97	60	43
pH	6.9	7.3	8.7
Specific Conduct. (micro-mhos/cm^2 at 25C)	92	102	199
Chemical Features			
Total Alkalinity (mg/l $CaCO_3$)	44	59	122
PO_4(T)	0.09	0.03	0.08
PO_4(D)	Tr	Tr	0.02
NO_3(N)	0.01	0.03	0.04
Cl	2.0	1.5	2.0
Ca	10.0	9.2	21.6
Mg	2.95	3.24	8.45
Na	1.64	1.20	2.28
K	0.56	0.62	1.16
Fe	0.13	0.06	0.02
Zn	0.2	0.2	2.0
Cu	<5.0	<5.0	<5.0
Sr	21	26	13

All measurements are in mg/l except for three elements (Zn, Cu and Sr) which are measured in micro mg/l.

Marking

Finclip

The 5- to 12-inch stocked muskellunge fingerlings were marked with a distinctive finclip to designate the year of stocking. The paired ventral fins were clipped in rotation, beginning with complete removal of the right pectoral fin in 1955, left pectoral in 1956, right pelvic in 1957 and the left pelvic in 1958. The sequence was repeated in 1959 beginning with the right pectoral fin. Urethane and later methyl pentenol were used as a fish anesthetic to aid in handling fingerlings but as we became more adept at finclipping, we discontinued the use of anesthesia.

Muskellunge age was determined accurately through six years by observing which fin was missing or deformed. A four-year size differential between fish with the same finclip enabled us to assign such fish to the proper year. After three to five years, the known–age fish entered the spawning run and those 24 inches and over were tagged so that the old finclip was no longer needed to determine the age of the fish.

External Tags

Maxillary Tag. During the spring spawning periods of 1956 and 1957, an aluminum strap tag was placed around the maxilla of all fish captured in the study lakes except for those stocked as finclipped fingerlings in previous years. Remaining intact over 12 years, these tags provided growth data on older and larger fish. The use of maxillary tags was discontinued after 1957 because it was felt that these tags might possibly interfere with the growth of the fish.

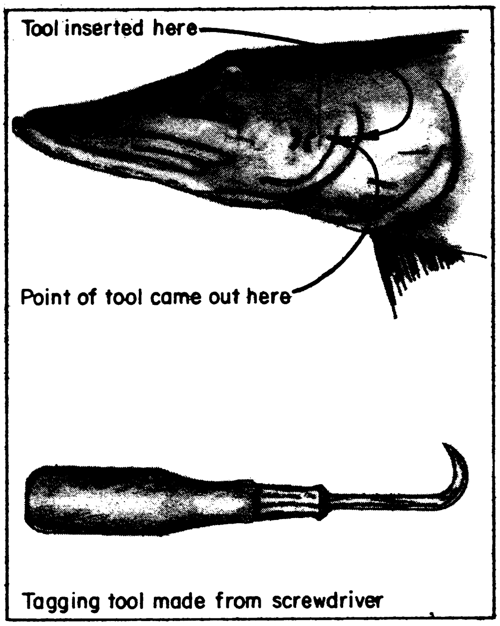
Vinyl Dart Tag. In 1958, a vinyl dart type tag was constructed from No. 20 vinyl plastic tubing and nylon barbs. The dart tags were inserted into the fish with a special tagging needle constructed from No. 304 seamless stainless steel hypodermic tubing which had an outside diameter of 0.109 inch and a wall thickness of 0.012 inch. Pre-incision with a scalpel was required for insertion of the tag. On all fish an attempt was made to anchor the barb between the neural bones of the dorsal fin.

In 1958, 263 vinyl dart tags were inserted in this fashion. Over the next 3 years, only 21 tags were recovered and all of these had become loose. On 49 other fish recaptured, eroded holes were found indicating that the vinyl tags had been lost. Areas of necrosis up to ½ inch in diameter surrounded the point of insertion of the vinyl tubing. On those 21 tags that were recovered, diatom deposits made the numerals almost illegible.

Preopercle Tag. During the 1959 spring spawning season and in the years thereafter, muskellunge were marked with an aluminum strap tag locked around the preopercle. A special tool was made to prepuncture the tagging site. The tool was made from a small, plastic-handled screw driver with the blade ground to a thin double-edged knife and bent into a hook shape (Fig. 1).

The 5-mm-wide preopercle tag was anchored loosely around bone and remained secure over nine years of observations. When some tag numbers became worn down or an occasional tag became unlocked, the defective tag was replaced with a new tag. On all tagged fish recovered, the tagging site showed some sign of inflamation or necrosis but no penetration into the gill chamber or erosion of gills was found. Crossman (1956) found that within 3 years, preopercle disc tags were lost, probably as a result of the migration of the monofilament through the bone of tagged muskellunge.

FIGURE 1
Tagging site and tool used for prepuncturing around the preopercle.



Measurements

Fingerlings and yearlings were measured on a measuring board to the nearest tenth of an inch (total length). Larger muskellunge were measured in a square-end tank containing only three to four inches of water where the fish remained quiet as long as they were not tipped to one side. This tank was narrow, so that most muskellunge could not turn around. The jaws of the muskellunge were pushed against one end of the tank and measurements were made to the tip of the extended tail with a ruler attached to the tank. In many cases these were multiple measurements of the same fish recaptured year after year.

Weights of fingerlings and yearlings were measured on a Harvard trip, double beam balance to the nearest gram. In order to minimize handling, all larger fish were weighed individually in a wet dip net as they were removed from the fyke nets. The muskellunge and dip nets were hung on a dairy spring scale with a 60-pound capacity and weighed as one unit. A movable pointer on the scales was set to zero to compensate for the wet dip net. This allowed for a direct reading of fish weighing two to six pounds and a reading to the nearest one-quarter pound for larger muskellunge. For some small fish, gram weights were converted to tenths of a pound. All measurements in pounds were later converted to tenths of a pound.

Holding tank used to keep larger muskellunge quiet until they were weighed, measured, tagged and released.

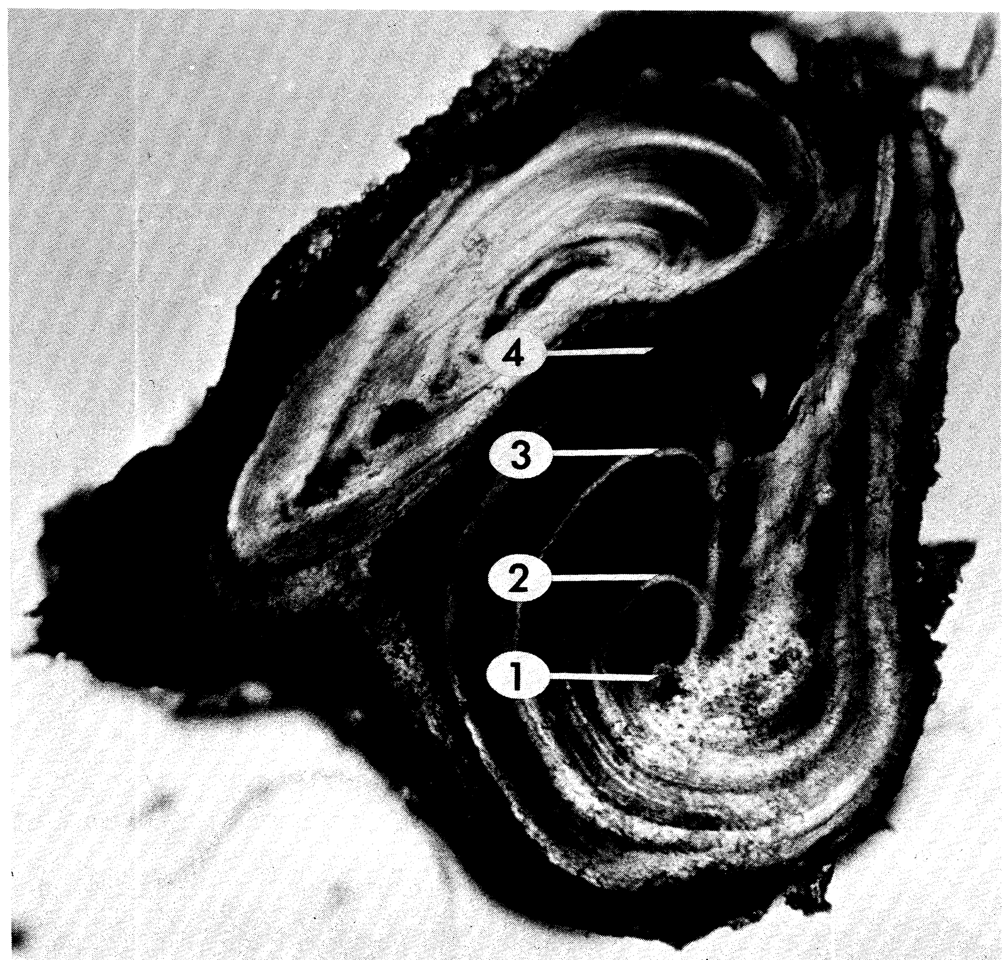
Age and Growth Determinations

Collection and Treatment

Scale Samples. From 1956 to 1968, scales were obtained from muskellunge trapped in fyke nets during the spring spawning period which usually extended from the last week in April through the first week in May. Five to 10 scales were removed from every fish in a key area immediately below the anterior insertion of the dorsal fin and midway to the lateral line. This key area, rather than key scales, was used because scales were often removed from the same fish in subsequent years. Repeated recaptures of individual fish sometimes made it necessary to use both sides of the body for scale collection in order to avoid collection of regenerated scales. By means of a heated hydraulic press, scales were impressed on cellulose acetate slides which were 0.03 inch thick (Greenbank and O'Donnell, 1948).

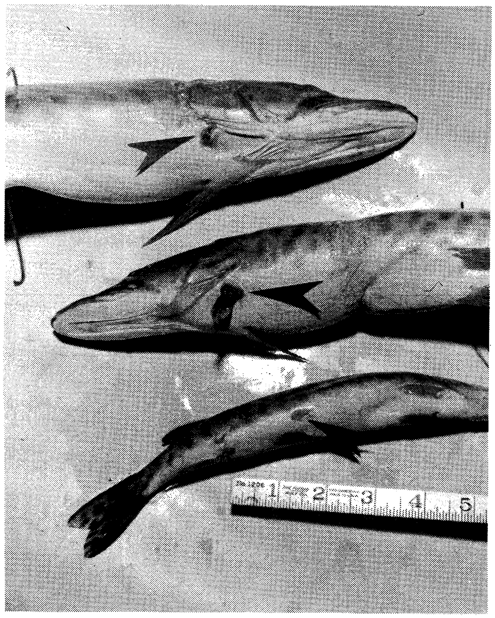
This study was based on the examination of prepared slides of scales and fin sections from 1,734 known-age fish and from 1,468 muskellunge considered to be "partially known-age" fish. The latter were unmarked muskellunge which were captured and presumably aged correctly at age IV, V, or VI; these fish were tagged and were then followed through 6 to 13 years of subsequent known-age growth.

Almost half of the slides of scale samples and fin sections used in this study were taken from "partially known-age" fish. These were fish that had been captured between the ages of IV and VI. Because ages could be so accurately assigned to fish in this age range (as shown by the accompanying picture), these fish were included in the known-age samples.

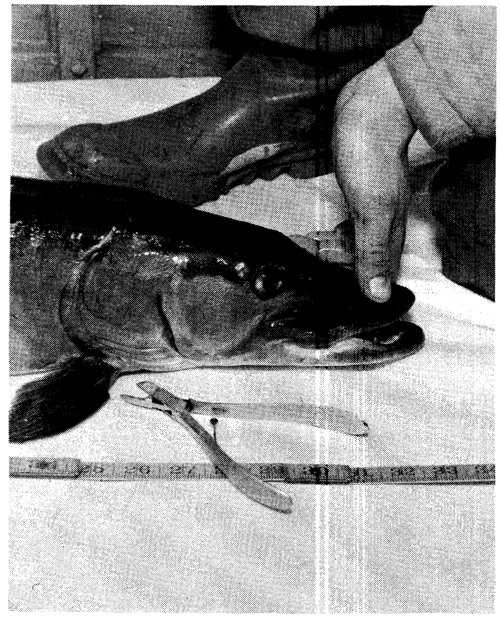


The examination and measurements of scales were made by means of a micro-projector at a magnification of 43.7 times their normal size. One scale which was free from defects and seemed to display the clearest annuli was selected from each slide impression for measurements. The length of this scale and the distance from the focus to each annulus were measured along the anterior radius and recorded to the nearest 0.1 inch. All fish were taken in the spring before growth had started so a virtual annulus was assigned to the edge of the scale.

The method of collecting scales from a key area presented the possibility that different sized scales might be removed from the same fish; these scale sizes would then influence the age determination and measurements for back calculations. Scales were, therefore, removed from other locations on several fish to check on the possible effects of divergent scale sizes in computations.



Arrows indicate regeneration of clipped fins

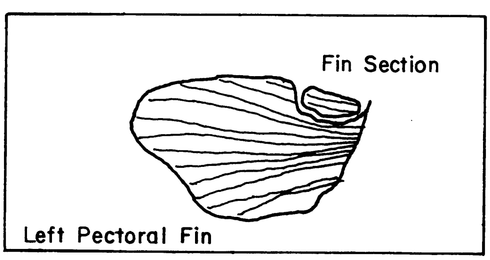


For use in aging and back calculating growth, fin sections were taken from the edge of the pectoral fin as close to the body of the fish as possible.

Fin Sections. Fin sections for age determinations were collected from all known-age muskellunge. A section was removed from the leading edge of the pectoral fin as close to the body as possible (Fig. 2). Each section varied from roughly 1/4 to 1/2 inch in length and 1/8 to 1/4 inch in width and contained the leading edge, in addition to one or two adjacent rays. There was no subsequent regeneration of fin rays; however, adjacent fin rays enlarged, strengthened the fin and compensated for the injury. If individual fish were recaptured, fin sections were taken from a pectoral fin section or other ventral fin section that had not been previously removed.

After fin sections from all ventral fins had been removed over a period of years, it was possible to make a deeper cut, removing undamaged fin rays for futher age determinations. These fin sections, however, were unsuitable for back calculations of growth, because they compensated for growth which was not reflected in the growth in length of the fish.

FIGURE 2
Removal of a fin section for age determination.



Fin notching which resulted from the removal of a fin section served as another means of marking muskellunge without removal of the entire fin. This mark was noticeable on all ages of muskellunge over a period of 12 years. The mark could be seen or felt by experienced personnel, but was not apt to be noticed by anglers.

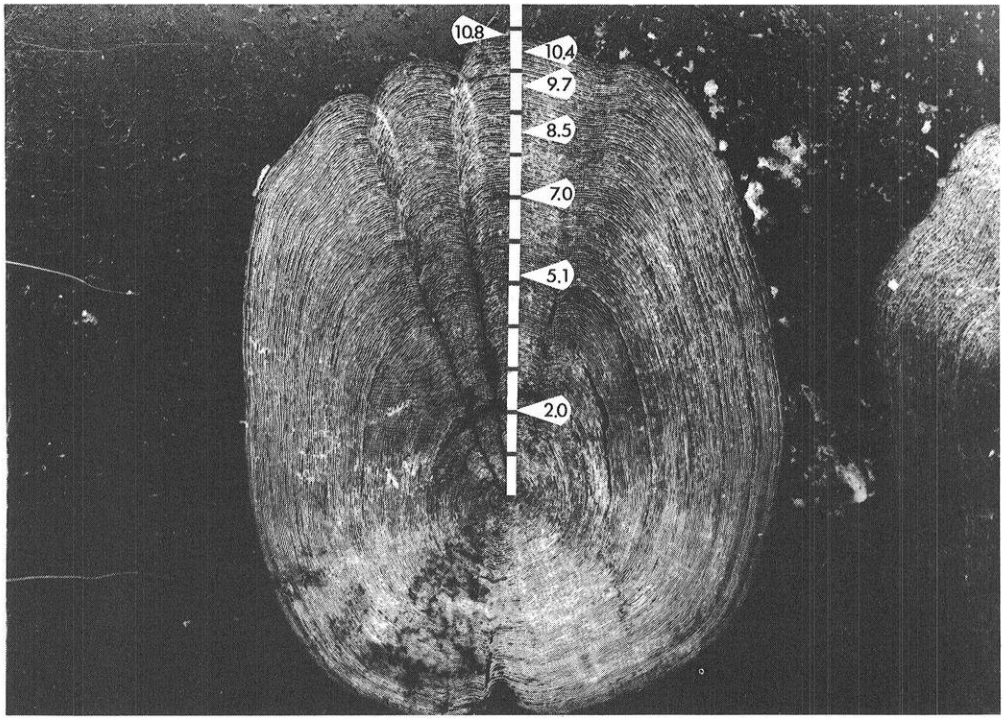
Since some muskellunge were recaptured 4 or more times, there were often no ventral fins that could be sectioned for accurate back calculations of growth. For these fish, right or left maxillaries were clipped at mid-point for age and growth determinations. All maxillary sections were collected and mounted on slides in the same way that fin sections were. Maxillary clips were recognizable as a distinct mark in later years.

Thin cross sections (0.5 mm or less) were cut from the larger end of the dried fin sections with a fine-toothed jeweler's saw. Fin sections could be sawed in either the fresh or dried state, but annuli were not recognized until the cross sections dried. The method was similar to methods used for sectioning the bony marginal pectoral fin ray of sturgeon (Probst and Cooper, 1955) and the pectoral fin rays of the white sucker (Scidmore and Glass, 1953). Delicate fin sections of young fish were glued between cellulose acetate slides with cellulose acetate cement and the whole slide containing the fin sections was sawed. All cross sections were attached with a drop of solvent acetone to one end of each slide containing the scale impressions for that fish.

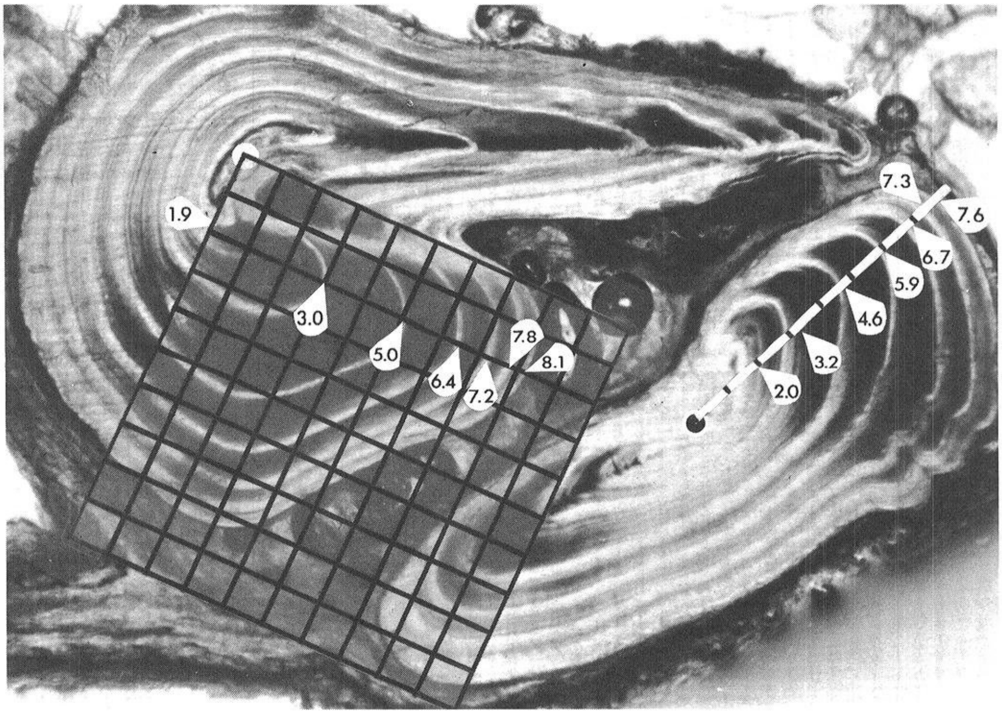
Examination of the fin sections was made with a binocular compound microscope. Appearance of the sections was similar to that described for other fish species (Boyko, 1950; Sneed, 1951 and Scidmore and Glass, 1953). A drop of mineral oil applied to the section increased the differentiation of hyaline and opaque zones. Counts of hyaline rings (annuli) were made along the line of best visibility which varied among the different fins.

For use in back calculations of growth based on fin sections, annuli would ideally be measured along a straight line from the focus to the edge of the section. For the majority of the fin sections, it was possible to make these measurements with an eyepiece micrometer disc. The uneven configuration of the fin section, however, usually required that the eyepiece micrometer be turned and the section moved several times before the measurements could be completed. The movement of either the fin section or the micrometer impaired the accuracy of the measurement. Thus, a Whipple's micrometer disc was used to measure some fin sections. Divided into squares instead of ruled points on a scale, this disc allowed measurements to be made with only one setting of the instrument. Since the squares in the Whipple's disc were not assigned numerical values, measurements for back calculations were made as whole and fractional parts of the square cell units. There was no need for correlation to the actual values because these were proportional measurements having real meaning only when the total length of the fish was known.

A few difficulties were encountered with the reading of fin sections. Occasionally sections were cut at an oblique angle which made the sections appear opaque and annuli not visible until the slide was tipped under the microscope. Two slides in the entire series were so translucent that annuli could not be seen.



Use of scale samples and fin sections to back calculate muskellunge growth. Measurements were made along a straight line for scale samples (above) and through the use of a whipple cell for fin sections (below). At each annulus, the number of arbitrary units is given from the focus to that point.



Test of Age Reliability

Tests were made on the accuracy of aging muskellunge from scales and fin sections. A series of 500 slides containing both scale imprints and fin sections from known-age muskellunge were selected for reading. Independent readings of the fin sections and scales were made by three persons who had had experience and special training in reading scales and fins. Age determinations were made without clues such as knowledge of fish lengths, weights, fin clip marks, tag numbers and sex. Each of the different readers used the same binocular compound microscope.

Length Determination

Two methods were used to determine muskellunge length at the time of scale formation. The first of these involved a measurement of the preserved skins of fingerling muskellunge. The second involved the calculation of body-scale relationships for muskellunge representing age groups III through XII.

Length at Scale Formation

A series of forty fingerlings from 1.9 to 4.2 inches long were collected from Spooner hatchery rearing ponds and preserved in ten-percent formalin. Later, the skin of each fish was stripped from the region between the lateral line and the anterior edge of the dorsal fin. The skin was stained in alizarin red according to the method of Franklin and Smith (1960) and examined under a microscope.

Scalation of each of the muskellunge examined was similar to that reported for northern pike (Franklin and Smith, 1960). On 14 fish 2.5 inches and less in total length no scales had formed in the region from which scales were taken on other muskellunge for back calculation. On 4 fish, the scales first appeared in this region when the fish had reached total lengths of 2.5 inches. On 22 fish, the scales first appeared by the time the fish were 2.8 to 3.5 inches in length. For use in making back calculations of growth from scale samples, the length of the muskellunge at the time of scale formation was rounded off to 3 inches.

Calculation of Body–Scale Relationship

Calculation of Body-Scale Relationship

A series of 1,468 fish ranging in size from 20 to 43 inches were collected from the three lakes studied. The total length of each fish was plotted against the length of the anterior scale radius (See Fig. 12 in the appendix). The solution to the least square equation was:

$$L= 4.17 + 2.71\ S$$

where L equals the total length of the fish in inches and S equals the length in millimeters of the anterior scale radius, modified to 43.7 times its normal size.

Solutions to the equations differed between lakes. In Lac Court Oreilles, the length of the fish at the time of scale formation was 4.92 inches, compared to 7.76 inches for Bone Lake and 9.87 for Big Spider Lake. No explanations for the differences between these solutions were found.

Solutions to the equations did indicate that the body-scale relationship was of little use in determining the length of muskellunge at the time of scale formation. All lengths calculated by this method were greater than the actual lengths when muskellunge began to lay down scales, as determined by the measurement of fingerling skins. However, the solutions were useful in establishing a straight line relationship between the length of a fish and the length of its anterior scale radius. Such a relationship verifies the use of scale samples to back calculate growth of muskellunge.

Collection of Other Data

While the muskellunge lay submersed in the holding tanks, finclips were noted, tag numbers were read, fin sections and scales were removed for aging and the sex of mature fish was determined by stripping eggs or milt from the fish. (Sex of young muskellunge fingerlings, yearlings and other immature fish was determined later when these fish were recaptured as mature muskellunge.)

RESULTS

Validation of Methods

Age Determination

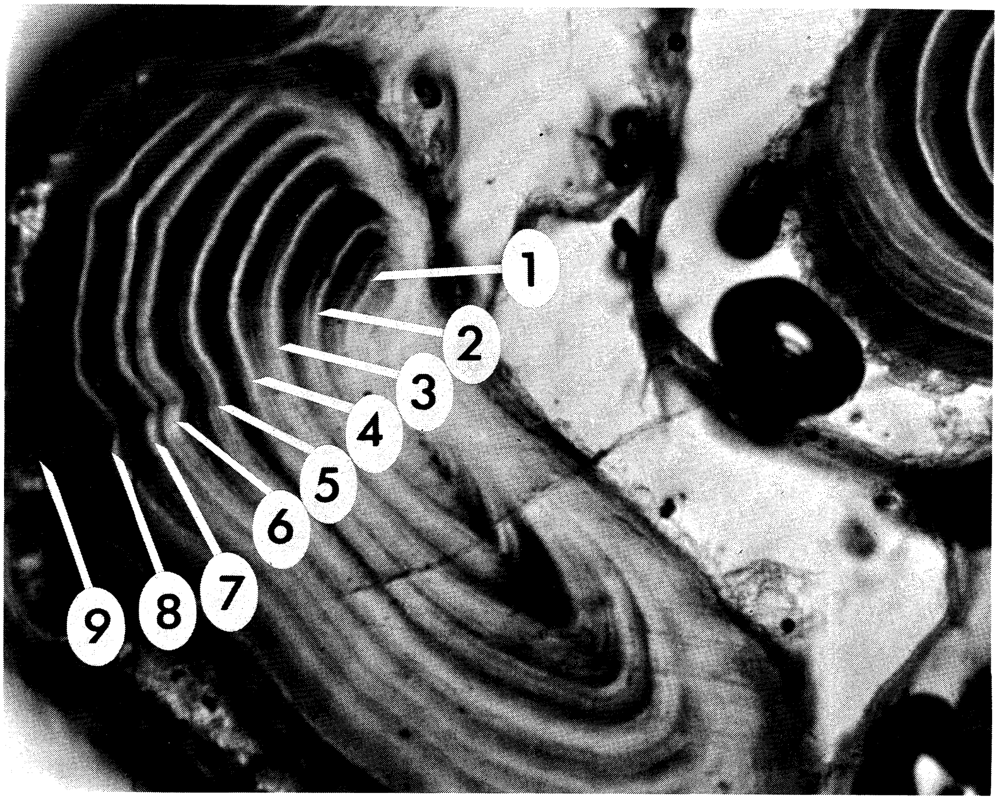
Comparison was made between the percentage of correct ages assigned by those persons reading scale samples and the correct percentage assigned by those persons reading fin sections. The validation of each method was based on a total of 1,500 readings, with each of three persons reading 500 known-age samples.

Ages were quite accurately assigned for muskellunge through age V--91 percent correct by the fin section method and 76 percent correct by the scale sample method (Figs. 3 and 4). For muskellunge ages I through VI, readers tended to overage the samples by counting false annuli as year marks. For muskellunge ages VII through XIII, readers tended to underage the samples by counting fewer annuli than should have been present. By the time the fish attained an age of XII, the outside edges of fin sections were so translucent and scale edges were so eroded that outer annuli could not be distinguished and both means of aging the muskellunge were inaccurate.

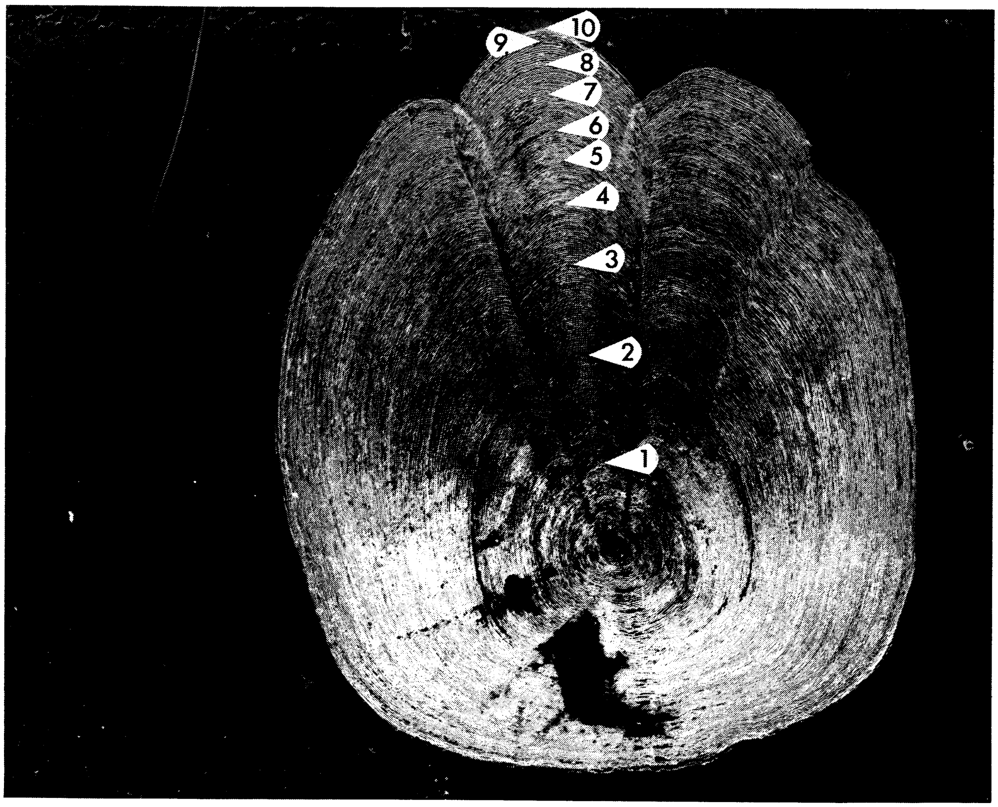
The amplitudes of the errors in ages assigned has been further represented in figures 5 and 6, and in tables 2 and 3 in the appendix. Ages of age I through age IX muskellunge could be fairly accurately determined by both methods. When 95 percent confidence limits were placed around the mean ages assigned, the aging errors reflected in figures 3 and 4 were apparently not great enough to be important. By means of the scale method, muskellunge ages X and older could no longer be accurately aged. The 95 percent confidence limits around the assigned ages no longer encompassed the true ages of the fish, decreasing the accuracy of age determination by this method to the point that only the highest age estimates were occasionally correct. By means of the fin section method, however, ages assigned to muskellunge beyond 9 years were still relatively accurate (Fig. 6). Confidence limits around ages assigned to these older fish approached the true ages of the fish closer than did the ages assigned by the scale method.

Determination of Growth Rates

Use of Scale Samples. Back calculations of the growth of the known-age muskellunge were made from the projected scale image and the recorded distances from the focus to



By means of either the fin section method (above) or the scale sample method (below), ages could be fairly accurately assigned to muskellunge ages I through IX.



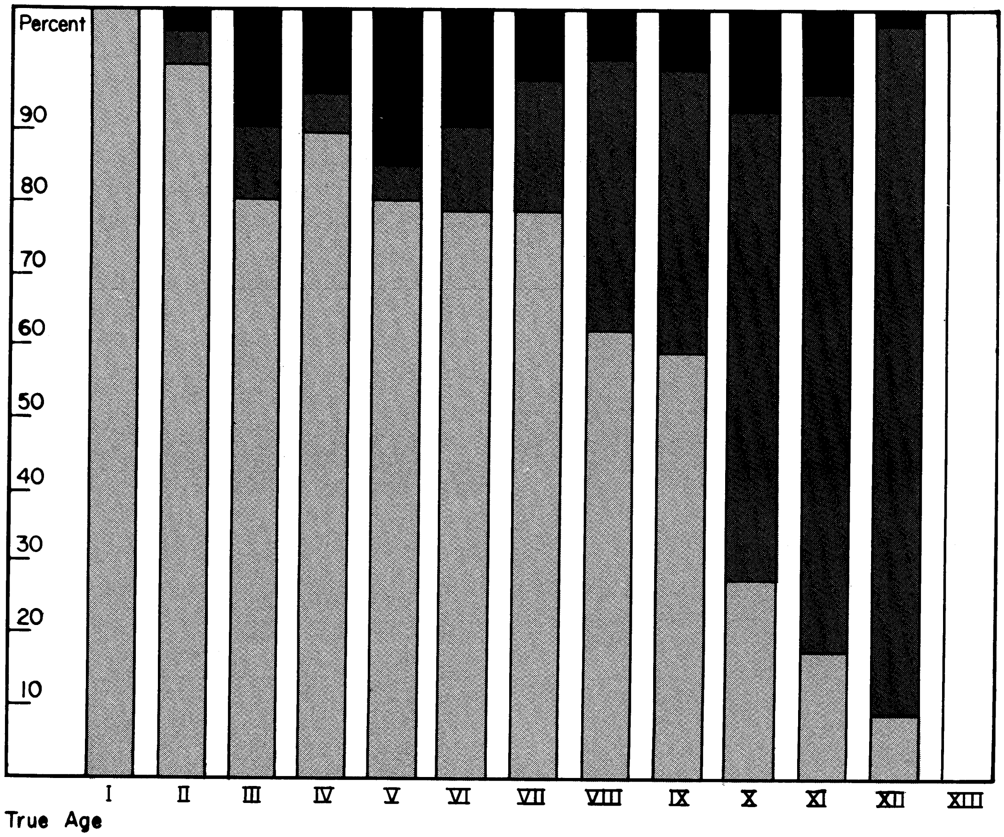


FIGURE 3
Percent of muskellunge correctly aged by the scale sample method, 1960-68.

Aged higher than true age
Aged lower than true age
Aged correctly

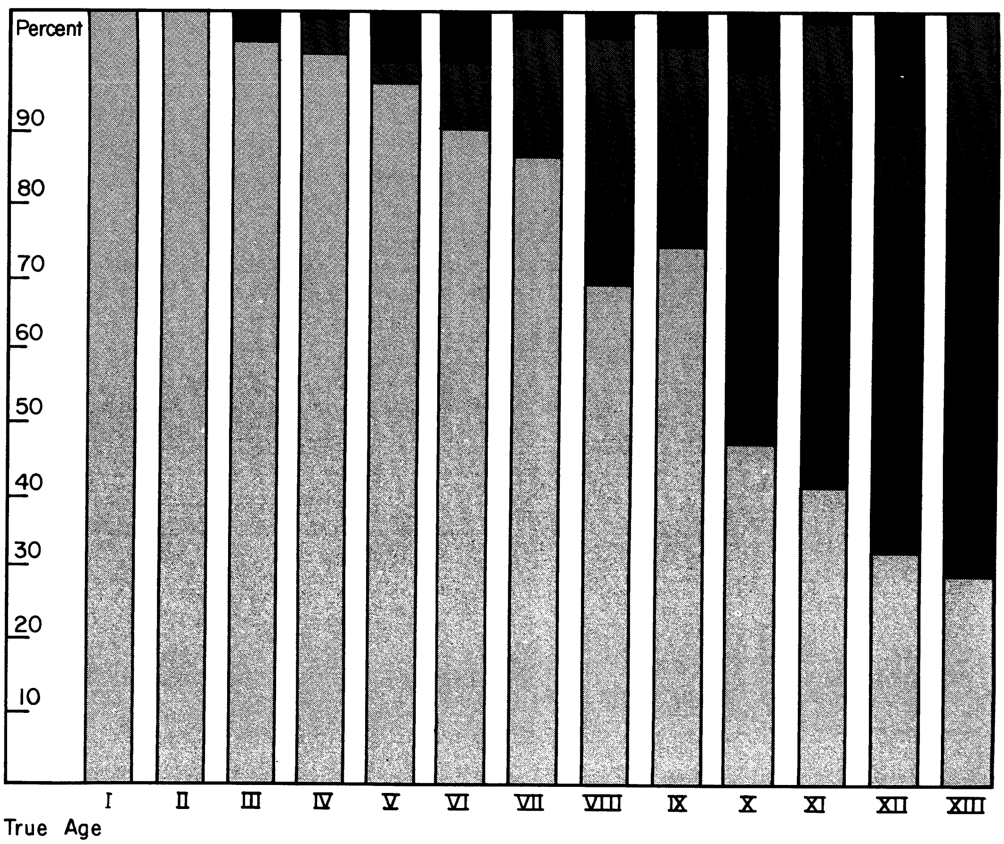


FIGURE 4
Percent of muskellunge correctly aged by the fin section method, 1960-68.

Aged higher than true age
Aged lower than true age
Aged correctly

TABLE 4
Use of Scale Samples to Calculate Total Length for Individual Muskellunge*

Age Group	Calculated Length at End of Year of Life: Young Fish (Tag No. 2616) 2	3	4	5	6	7	Old Fish (Tag No. 3705) 5	6	7	8	9	10
II	(15.5)											
III	15.6	(17.5)										
IV												
V	18.0	22.7	25.2	(26.4)			(32.5)					
VI							33.4	(34.5)				
VII	16.7	22.7	24.6	26.7	29.2	(29.8)	32.4	35.2	(36.3)			
VIII							33.9	35.4	36.9	(38.0)		
IX							33.9	35.8	37.5	39.3	(39.8)	
X							35.5	36.8	37.8	38.8	40.1	(40.2)

*Both fish were taken from Lac Court Oreilles. Numbers in parenthesis are measurements of actual length.

TABLE 5
Use of Scale Samples to Calculate Average Total Length of Known-age Fish, 1955-1968*

Age Group	No. Fish	Total Length at End of Year (In Inches) 1	2	3	4	5	6	7	8	9	10	11
I	12	(11.2)										
II	2	9.2	(16.2)									
III	15	8.8	17.3	(22.5)								
IV	50	9.1	15.8	22.0	(25.9)							
V	104	8.9	15.7	21.3	25.6	(28.4)						
VI	122	8.7	15.7	20.9	25.3	28.4	(30.0)					
VII	92	8.4	14.7	19.9	24.8	27.7	30.0	(31.1)				
VIII	74	8.1	14.7	19.8	24.4	24.8	30.0	31.7	(32.6)			
IX	53	8.4	14.9	19.4	23.7	27.0	29.6	31.6	32.9	(33.0)		
X	27	8.3	14.7	19.4	23.6	27.5	29.2	31.4	33.0		(33.6)	
XI	1	8.2	10.9	15.8	23.1	28.2	31.9	33.6	35.8	36.4	36.7	(37.0)
Average		8.6	15.3	20.5	24.8	27.2	29.8	31.6	33.0	36.4	36.7	(37.0)

*Based on 552 fish from Lac Court Oreilles. Numbers in parenthesis are averages of actual length measurements made.

TABLE 6
Lengths of One Muskellunge Back Calculated From Scales Taken From Seven Different Locations*

Scale Location	I	II	III	IV	V
Key Area	9.1	13.7	20.9	(24.4)	27.9
Caudal					
Ventral	9.1	13.6	20.2	24.9	27.9
Dorsal	8.7	14.9	20.9	26.5	28.1
Mid-					
Ventral	9.0	13.5	22.4	25.2	27.9
Dorsal	8.5	14.3	20.3	25.7	27.7
Cephalad					
Ventral	9.0	14.0	19.3	24.1	27.8
Dorsal	7.2	12.7	19.1	25.5	27.9

*Lengths of fish are given in inches and were calculated from a 6-year-old, 28.7-inch fish taken in 1962. All calculations are based on a correction factor of 3 inches. The length in parenthesis is an actual measurement.

the annuli. The following equation was used to determine the growth rates of the fish:

$$L' = C + \frac{S'}{S}(L-C)$$

where L' equals the length of the fish at the time of each annulus formation, C equals the correction factor of 3 inches representing length of the fish at the time of scale formation, S' equals the length of the anterior radius of the scale at each annulus, S equals the length of the anterior radius at the time of capture and L equals the total length of the fish at the time of capture.

The calculated lengths of two randomly selected individual muskellunge are shown in table 4. These fish were originally finclipped and stocked as fingerlings in September of each year; at the time of stocking, they were approximately 5 months old and were 8 to 11 inches long. The calculated lengths compared closely (i.e., most of them are within an inch of the true length) with the actual lengths of these same fish when they were caught and measured in earlier years.

Average calculated lengths are also given for a group of muskellunge from Lac Court Oreilles (Table 5). Averages were also calculated for muskellunge from the other two study lakes and were basically the same as the ones presented in table 5. Thus the fact that one group of muskellunge was fast growing and the other was slow growing does not affect the accuracy of back calculations of growth.

Average calculated growth appears to be even closer to the average true growth than calculated growth is to the true growth for individual fish. For muskellunge up to about 4 years of age, however, there was some evidence of Lee's phenomenon--a tendency for calculated lengths to be smaller at a given age when these lengths are computed from the scales of older fish (Tesch, 1968).

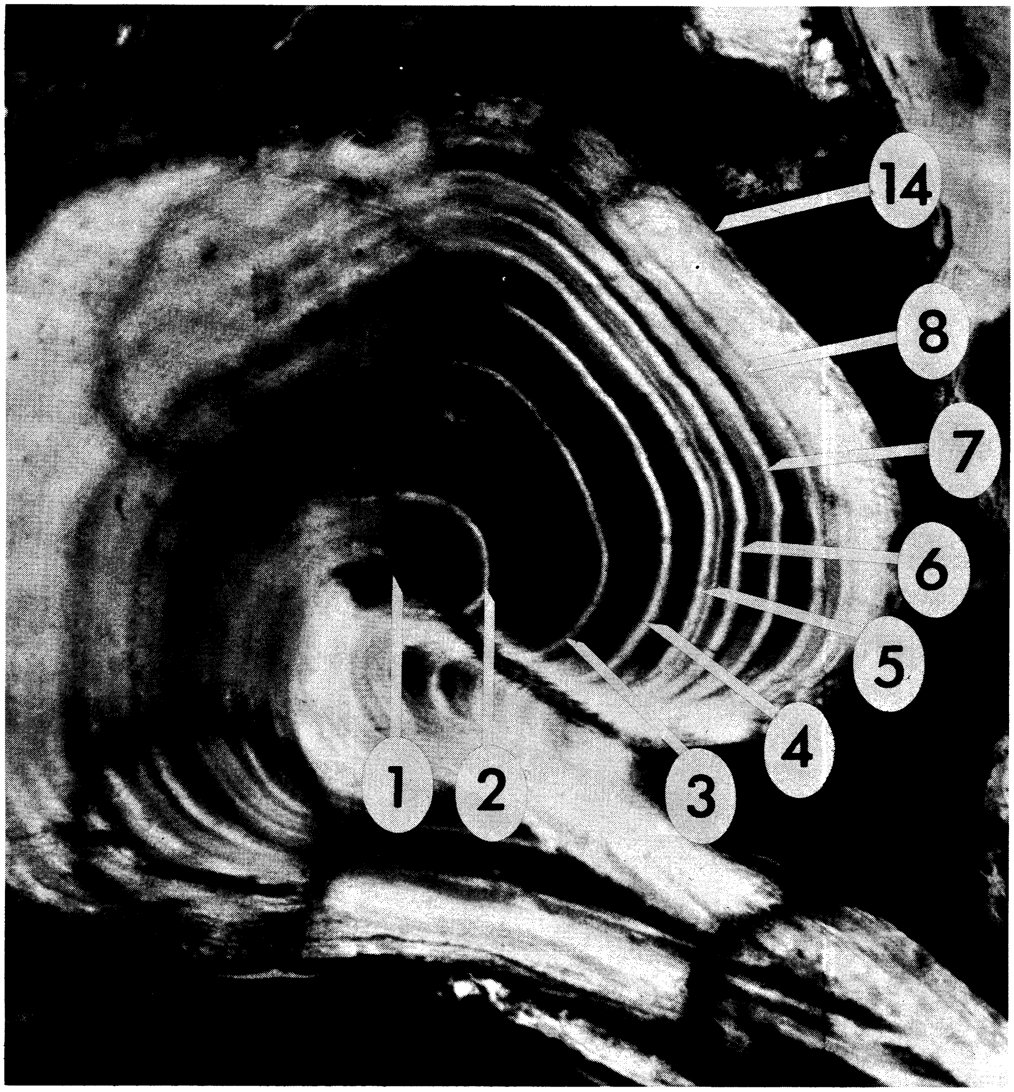
The use of varying sizes of scales was felt to be a possible cause of some of these discrepancies between calculated and actual lengths. To test this hypothesis, scales were collected from the key area and from six other areas on the same muskellunge. Lengths of muskellunge as calculated by means of the scales from the six other areas were similar to those lengths calculated from the key area scales (Table 6). These data indicated that scale size did not affect the growth increments calculated and that scales from a confined key area can be reliably used by other researches for back calculations of muskellunge growth. *

Scale size was therefore not the presumed cause of the discrepancies existing between calculated lengths and actual measurements. Although no other explanation was found, the differences may be the result of rounding off the correction factor used in the growth calculations.

Use of Fin Sections. Back calculations of the growth of known-age muskellunge were made by measuring the distance between annuli on cross sections of fins with a Whipple eyepiece micrometer, as observed in a compound microscope. Measurements were made anywhere on the fin section since through the use of the Whipple cell, distances between annuli were the same no matter where on the fin section the cell was placed. The use of the Whipple cell had a further advantage in that proportional measurements could be made easily and in different directions with only one setting of the instrument.

Calculations of musky length and growth rates from fin sections were made using the same basic equation as was used to calculate growth rates from scale samples. The only alteration in the equation involved the substitution of a correction factor of 7 inches. This factor was determined largely by trial and error; factors ranging from 0 to 7 inches were proposed as the theoretical lengths of the fish at the time of first fin development. The correction factor of 7 inches was used because it brought the calculated values nearest the true values and because it took into account the often disproportionate small size of the annuli of younger fish.

Back calculated lengths were made from a series of fin sections from known-age muskellunge (Table 7). These calculated lengths compared closely with the actual measurements of the fish. As was found for length calculations based on the use of scale samples, most of the lengths calculated from fin sections were within an inch of the true lengths. No evidence of Lee's phenomenon was found (i.e., the tendency of computed



Ages assigned to a known–age muskellunge, illustrating the difficulty of counting outside annuli on very old fish.

*Other researchers should not interpret these conclusions to mean that scales from different areas can be used to calculate fish length. The scales from these areas varied in size and therefore would not be reliable indicators of length unless a correction factor other than 3 inches were determined for scales from the different areas.

TABLE 7
Use of Fin Sections to Calculate Average Total Length of Known-age Fish, 1955-1968*

Age Group	No. Fish	Total Length at End of Year (in Inches) 1	2	3	4	5	6	7	8	9	10
II	1	11.8	(15.5)								
III	9	10.8	16.9	(23.5)							
IV	27	11.0	17.6	22.9	(26.9)						
V	27	11.0	16.6	22.7	27.1	(30.2)					
VI	22	10.8	16.5	22.1	26.1	29.3	(31.7)				
VII	15	10.4	16.4	21.5	25.6	28.9	31.0	(32.8)			
VIII	8	11.0	16.2	22.1	26.7	30.3	33.1	35.3	(36.7)		
IX	5	10.6	16.1	20.9	25.1	28.5	30.5	32.9	35.1	(36.7)	
X	3	11.2	18.5	22.8	27.0	30.0	33.1	35.7	37.8	39.3	(40.8)
Average		10.9	16.8	22.3	26.3	29.3	31.7	34.6	36.1	39.3	(40.8)

*Based on 117 fish from Lac Court Oreilles. Numbers in parenthesis are averages of actual length measurements made.

TABLE 8
Calculations of Average Lengths (in Inches) From Scales and Different Fins From Two Age Groups of Muskellunge, 1960-1968*

Age Group and Sample Type	No. Fish	Lengths Assigned for Various Age Groups I	II	III	IV	V	VI
Age Group V							
Scales	5	9.6	16.5	22.7	26.6	(29.6)	
Fins							
R. Pectoral	5	11.7	18.2	23.3	27.0	(29.6)	
L. Pectoral	5	10.6	15.2	21.7	26.3	(29.6)	
R. Ventral	4	9.8	16.3	21.5	25.8	(29.6)	
L. Ventral	4	11.6	16.5	22.2	25.8	(29.6)	
Dorsal	2	12.6	19.0	24.3	27.1	(29.6)	
Age Group VI							
Scales	7	8.4	15.7	23.0	26.5	29.5	(31.4)
Maxillary	3	9.6	16.2	21.4	26.4	29.9	(31.4)
Fins							
R. Pectoral	7	10.3	15.1	20.2	25.4	28.4	(31.4)
L. Pectoral	7	10.4	16.7	23.3	26.8	30.0	(31.4)
R. Ventral	6	10.0	15.9	21.7	27.0	29.6	(31.4)
L. Ventral	6	10.3	16.4	21.3	26.8	29.9	(31.4)
Dorsal	4	12.4	17.9	22.5	26.7	29.5	(31.4)

*Calculations of length from scales samples were based on a correction factor of 3 inches, while calculations from fin sections were based on a correction factor of 7 inches. Numbers in parenthesis are measurements of actual length.

lengths to be smaller when calculated from the fin sections of older fish.)

Small differences were, of course, present between the actual lengths of the fish and those calculated from the fin sections. The taking of sections from different fins of the muskellunge appeared to be the most obvious cause of these differences. Because of the necessity of taking fin sections from all of the ventral fins on a rotation basis and sometimes from the dorsal fin and the maxillary bone as well, sections from all of these areas were removed from two age groups (V and VI). Lengths calculated from scale samples and from the six different fin sections were compared. The calculated mean lengths (Table 8) indicated reasonable agreement between the lengths calculated from different areas and by different methods.

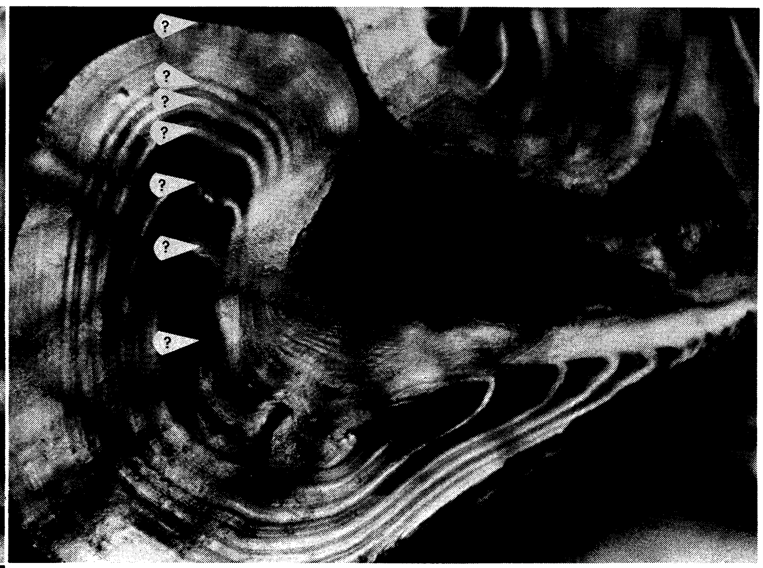
The fact that fin sections had to be taken from different parts of the muskellunge in different years therefore had nothing to do with the differences found between calculated lengths and actual measurements. More probable explanations for these differences were as follows: (1) Although the use of the Whipple cell overcame many of the standard difficulties encountered in measuring distances between annuli, erratic measurements still occurred because of the irregular shapes of the various sections taken from the different fins and because of the necessity for counting annuli where they can be seen. (2) The distances between some annuli were falsified due to the way in which fin sections of large fish were taken. On small fish, sections could be cut out of the fin close to the body of the fish, but on large fish, the fin sections had to be taken farther out on the fin. Such sections showed annuli at younger ages that were smaller than they should have been for those ages; on some fin sections examined, these annuli were completely missing.

Use of Both Methods. Comparison was made between lengths calculated from fin sections, lengths calculated from scale samples and actual measurements of total length, with each of the three lengths being from the same fish (Table 9). No statistically significant difference was found between actual lengths and either of the calculated lengths. In fact, calculated lengths differed from each other as much as either one differed from actual lengths.

TABLE 9
Comparison of Lengths Calculated by Scale Samples and by Fin Sections with Actual Lengths, 1955-1968*

Length (In Inches)	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Calculated Lengths											
From Scale Samples	9.2	16.1	22.3	26.7	30.1	32.9	35.2	36.7	37.4	36.9	--
From Fin Sections	11.5	17.1	22.5	26.7	30.0	32.7	34.9	36.4	38.0	--	--
Actual Lengths	--	15.5	23.2	26.8	29.5	32.6	34.2	36.9	37.0	38.5	37.0

*Averages are based on the same 32 known-age muskellunge.



For all fin sections, it was important to take the section as close to the body as possible. The three fin sections on this page were all taken from the pectoral fin of an 18–year–old muskellunge. On the section taken close to the body (top, left), annuli 1-10 were easily recognizable; beyond that, the fin was too translucent for annuli to be counted. On the section sawed from the midpoint of the same fin (above), some annuli could be counted but no ages could be assigned. On the section taken from the outermost part of the fin (lower left), even fewer annuli could be identified.

Differential Growth

Empirical Data

In order to establish the different growth rates for muskellunge from each lake, two comparisons were made: age-length and age-weight. These comparisons showed that fish of the same age in each lake had different weights and lengths.

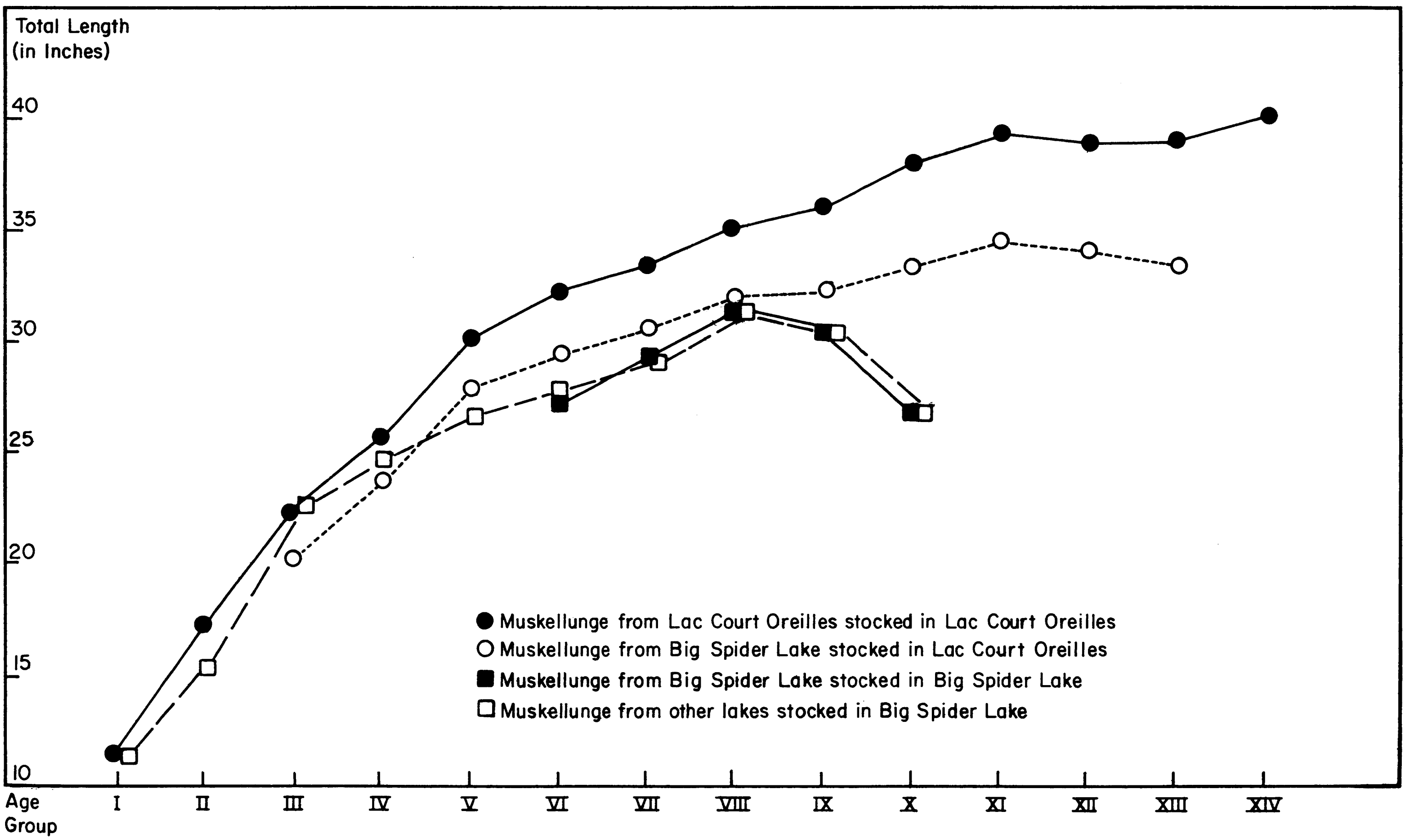
Age-Length. Essentially, the known-age muskellunge in the three lakes were derived from Lac Court Oreilles brood fish. Even muskellunge spawned from Bone Lake in later years were from this strain, because the initial introductions had been from Lac Court Oreilles. The single exception occurred in 1956 when most of the fingerlings stocked were derived from a slow-growing population of muskellunge from Big Spider Lake.

Growth rates of the various year classes in Lac Court Oreilles were relatively stable during the fourteen-year period. At least five years were required for a muskellunge to attain the legal 30-inch size. A leveling off in growth began at about age group X as the fish approached 40 inches in length.

The 1956 year class of muskellunge fingerling stocked in Lac Court Oreilles grew slower than all other year classes. These fish actually distorted the combined average lengths for males and females by their slow growth and exceptional survival. In seven years, they reached legal size having attained an average length of 30 inches. Because the growth of the 1956 year class was so markedly different from the growth of any other year class in Lac Court Oreilles, an explanation was sought for the slow growth of this year class.

Two factors were investigated but were found not to affect growth of the 1956 year class: (1) Marking technique. The means by which the fingerlings were marked did not affect their growth. Fingerlings in 1956 and 1960 were both marked by a left pectoral finclip. Since the 1960 year class subsequently exhibited fast growth, clipping of the left pectoral fin was apparently not a factor inhibiting the growth of either year class. (2) Lake characteristics. To test whether or not there were inherent lake features that inhibited the growth of fish in Big Spider Lake and Lac Court Oreilles, comparison was made between the growth of 4 groups of fish (Fig. 7). Through age 4, there was no significant difference in growth rates between fish in either lake. Thereafter, Lac Court Oreilles muskellunge stocked in Lac Court Oreilles grew at the highest rate. Growth of these fish was significantly better at the 0.01 level than the growth of Big Spider Lake fish stocked in Lac Court Oreilles. Slowest growth was exhibited by Big Spider Lake muskellunge stocked with Big Spider Lake brood stock and with muskellunge from other lakes. There was thus no significant difference between the

FIGURE 7
Comparison of the growth of Lac Court Oreilles muskellunge with the growth of Big Spider Lake muskellunge, 1955-1969.



mean growth rate of fish in Big Spider Lake and the mean growth rate of Big Spider Lake muskellunge stocked elsewhere.

Aside from the influence of the 1956 year class, the muskellunge in Lac Court Oreilles exhibited average growth (Fig. 8). The slowest growth was shown by Big Spider Lake fish which took between 7 and 10 years to attain legal size. Muskellunge from Bone Lake had the fastest growth rates with many fish attaining the 30-inch legal size in 4 years.

Rates of growth seem to be closely related to the age at which muskellunge in each of the three lakes mature. In Big Spider Lake where muskies exhibited slow growth, maturity was delayed several years after the onset of maturity in Bone Lake muskellunge which grew faster. Some males in all lakes were mature spawners at age III and some females were mature at age IV (Table 10). In Bone Lake, more males were mature at 3 years and more females at 4 years than in any other lake. All male muskellunge were mature at age IV and all females were mature at age V. The smallest mature male was 19.5 inches long and the smallest mature female was 22.0, both from Big Spider Lake.

The growth rate varies considerably among individual muskellunge of all ages in the three lake types studied (Fig. 9). The vertical line representing the minimum and maximum sizes of muskellunge collected in each of the age groups shows a large overlap. No overlap of the 95 percent confidence limits occurs in average growth of fish in Lac Court Oreilles until the muskellunge reach an age of 9 at which time their growth rate begins to decrease. Overlap of 95 percent confidence limits for slow-growing muskellunge in Big Spider Lake and also for fast-growing muskellunge in Bone Lake occurs at about 5 years. There were no detectable differences in growth rates due to sex through age class III. After age V, the growth rate of males in each of the 3 lakes was significantly slower than that for females.

Comparison was made between growth of muskellunge in the present study with that reported for other waters. Gammon and Hasler (1965) and Schmitz and Hetfeld (1965) found that muskellunge from two Wisconsin lakes grew slower than muskellunge in Big Spider Lake did (Fig. 10). This was undoubtedly due to predation which almost eliminated the age II and older yellow perch, creating a shortage of forage.

FIGURE 8
Average size of muskellunge in the three lakes studied, 1955-1969.

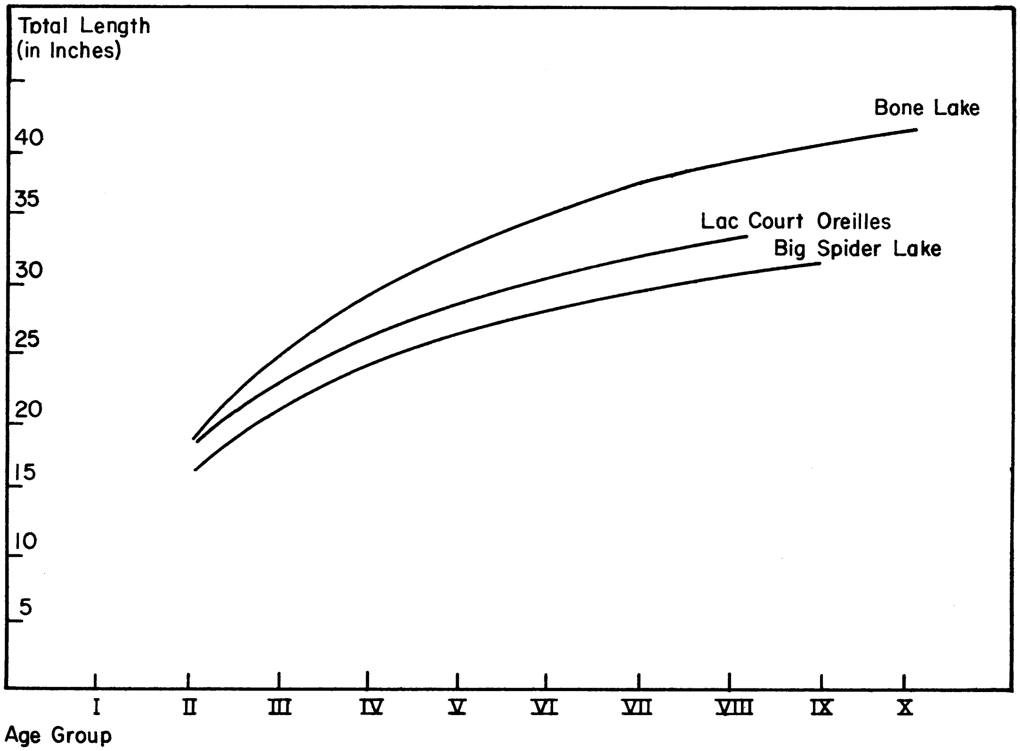
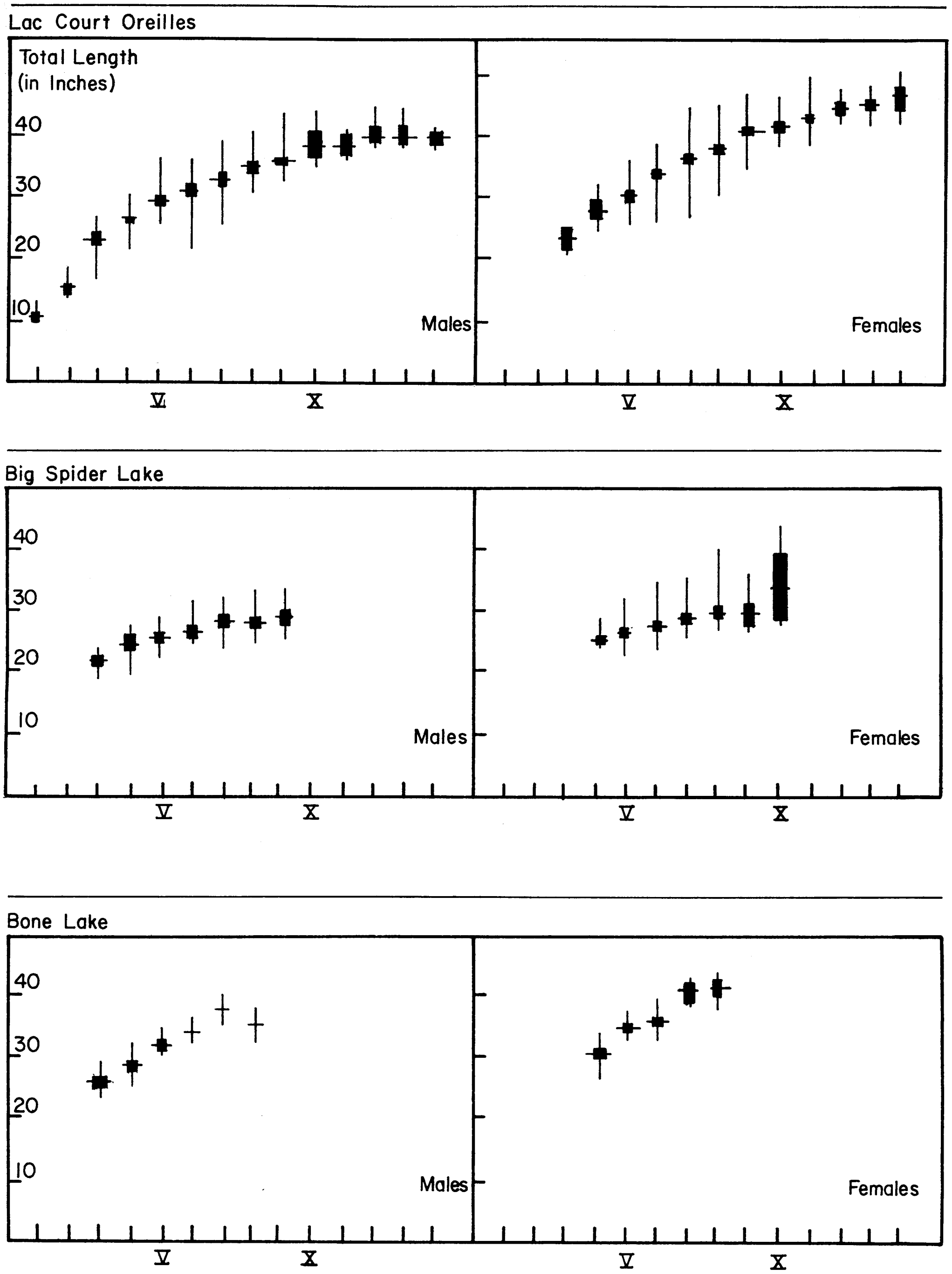


TABLE 10
Relationship of Differential Growth Rates to Maturation and Attainment of Legal Size, 1955-1969

Lake Studied	No. Years Required to Attain Legal Size		Percent Mature		Avg. Length at Maturity (in Inches)	
	Males	Females	At 3 Years (Males)	At 4 Years (Females)	Males	Females
Big Spider Lake	10+	7	14	24	22.7	24.8
Lac Court Oreilles	5	5	10	8	22.5	26.5
Bone Lake	4	4	81	98	26.1	30.6

FIGURE 9
Statistical analyses of the total lengths of known–age and partially known–age fish, 1955-1969.



Growth rates faster than those found in the present study were reported for muskellunge in Pennsylvania and Ohio lakes where warmer water temperatures may have created a more fertile lake environment than that found in northern Wisconsin (Buss, 1961 and Erickson, 1961). Growth rates reported by other researchers fell within the growth limits set by Bone Lake and Big Spider Lake muskellunge (Hourston, 1952; Muir, 1960; Crossman 1956 and Harkness, 1945).

Age Weight. Age-weight relations were compared for known-age muskellunge females and males in the three study lakes. A log equation was used to denote any curvilinear relationships between age and weight. Only spawned-out females were included in these data to nullify the possible influence of the extra weight of eggs. The equation was:

$$\log W = \log c + \log n (\log A)$$

where W equals the weight of the fish in pounds, c and n are constants and A equals the age of the fish in years.

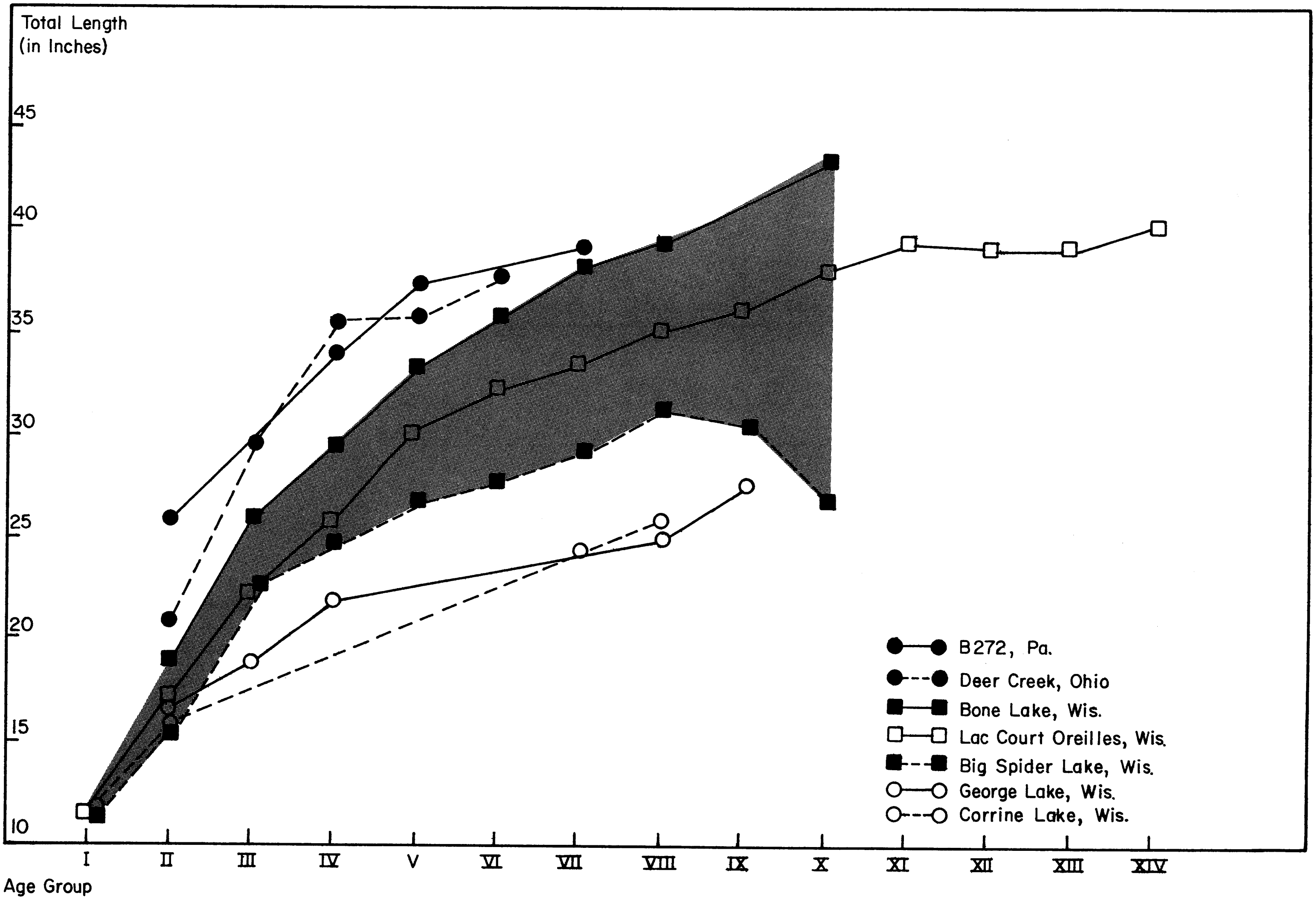
Although the amounts of weight increase varied widely between muskellunge in the different lakes, there was a general trend of increased weight for both sexes through 13 years, at which time data on known-age fish was no longer available.

Differences in weight increases between lakes corresponded to similar differences in growth rates. In Bone Lake, the increases in weight corresponded with rapid growth in length (Fig. 11). in Lac Court Oreilles, average increases in weight corresponded to average growth in length, and in Big Spider Lake, slow weight increases corresponded to slow growth in length.

Calculated Data

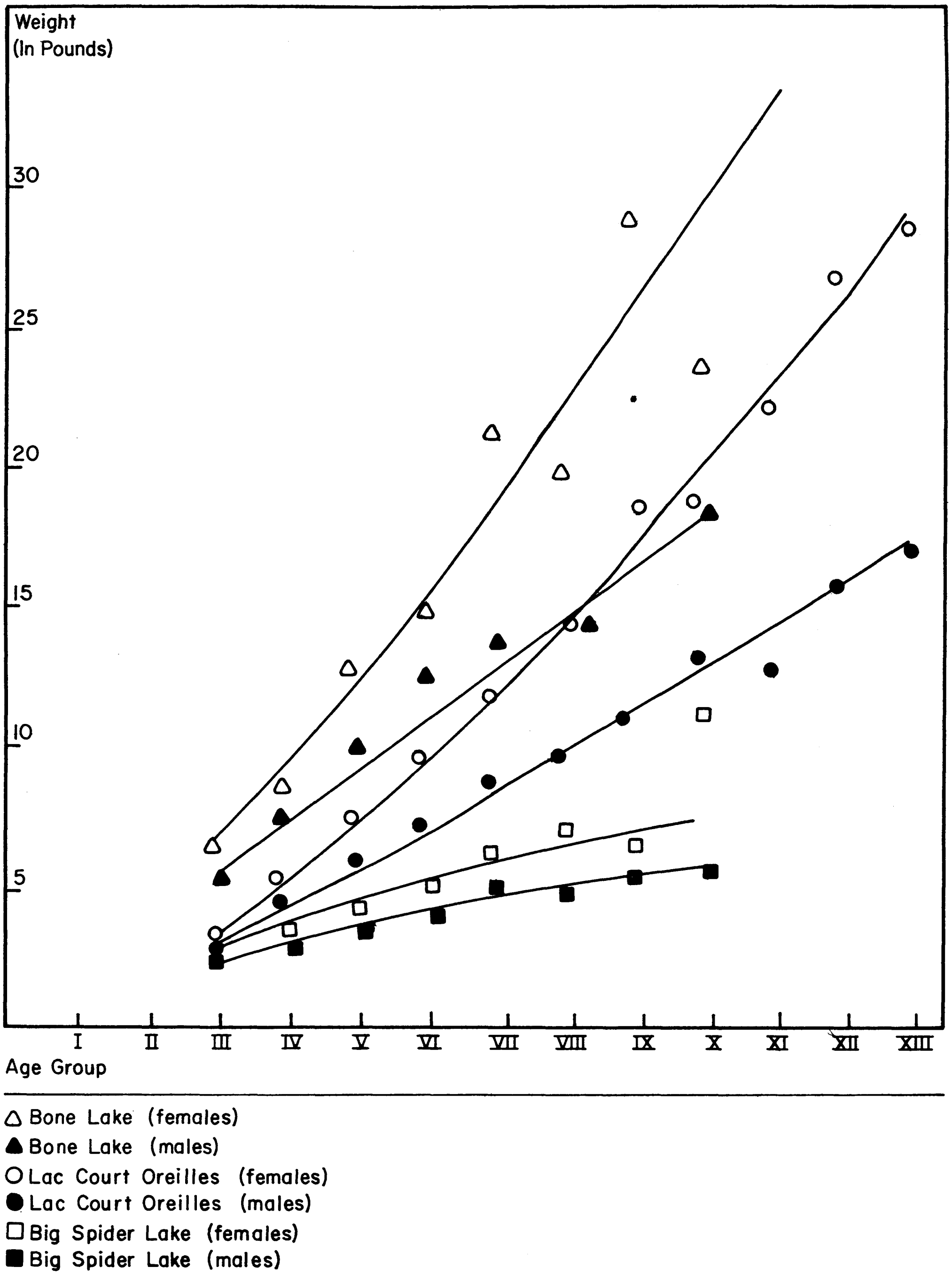
Use of scale samples and fin sections also reflect the growth differences found in the comparisons of empirical data in the previous section (See tables 11 and 12 in the appendix). For all ages where comparable data is present from each lake (for ages IV through VIII), lengths calculated from fin sections most accurately reflect the differential growth pattern for muskellunge from each lake.

FIGURE 10
Relationship of the growth rates of muskellunge in the three study lakes, 1955-1969, to the growth rates of the slowest growing and fastest growing muskellunge reported in the literature.



DISCUSSION AND CONCLUSIONS

FIGURE 11
Relationship of age to weight for males and females from each lake, 1955-1969.



Methods Evaluation

Through the use of both the scale sample and fin section methods of age determination, ages of age I through age IX muskellunge were correctly assigned. This accuracy through 9 years is adequate for any fish management purpose in view of the facts that muskies rarely attain extreme old age and few muskies older than 9 years of age are present in any lake. For any individual muskellunge, especially for the occasional old one, the fin section method of age determination is generally superior to and more accurate than the scale sample method.

For back calculating growth, however, the scale sample method is superior. In spite of the fact that Lee's phenomenon showed up when lengths were calculated from scale samples, but did not show up when fin sections were used, the scale sample method still has advantages: (1) Although a straight line relationship between fin section size and fish length was found, a better, more statistically sound relationship was found between scale size and fish length. (2) The use of fin sections to back calculate growth is further limited by the arbitrary way in which the correction factor of 7 inches was determined. Because of the large number of known-age muskellunge studied, different correction factors were plugged into the growth equation in order to find the one that brought calculated lengths nearest the actual lengths of the known-age fish. Other biologists who are not working with so many known-age fish will find an appropriate correction factor difficult to determine. Again, the use of scale samples to back calculate growth seems to be the more reliable of the two methods since the correction factor of 3 inches used in calculating lengths from scales was determined from empirical data.

Evaluation of Growth Rates

The majority of the known-age muskellunge in the three lakes were derived from the same group of fish—Lac Court Oreilles brood stock. These brood fish exhibited average growth in Lac Court Oreilles. When stocked into Bone Lake, they grew faster largely because of the abundant forage there. Fast growth rates for Bone Lake muskellunge are probably also related to the fact that the lake is a highly productive one and is located on a temperature isotherm that is

APPENDIX

warmer than that for either of the other lakes studied.

Big Spider Lake, on the other hand, has low productivity and lack of forage--factors which undoubtedly cause the slow growth of muskellunge found in this lake. The fact that Big Spider Lake muskellunge stocked in Lac Court Oreilles, a lake with adequate forage, still exhibited slow growth, indicates that some unknown hereditary factor may be inhibiting the growth of Big Spider Lake muskellunge.

Although growth variation does occur, precise explanations for this variation are not known. For this reason, there appears to be no way to predict what type of musky growth rate is likely to occur in other waters. Biologists studying muskellunge populations in other lakes could, however, compare the growth shown by the fish they are studying with either the empirical or calculated growth data for muskellunge in the present study. From such a comparison, the biologist could make a generalization as to whether or not the muskellunge he was studying were exhibiting slow, average or fast growth.

FIGURE 5
Relationship of true ages to mean ages assigned by the scale sample method, 1960-68. (The rectangle around the last 5 means represents the 95 percent confidence limits.)

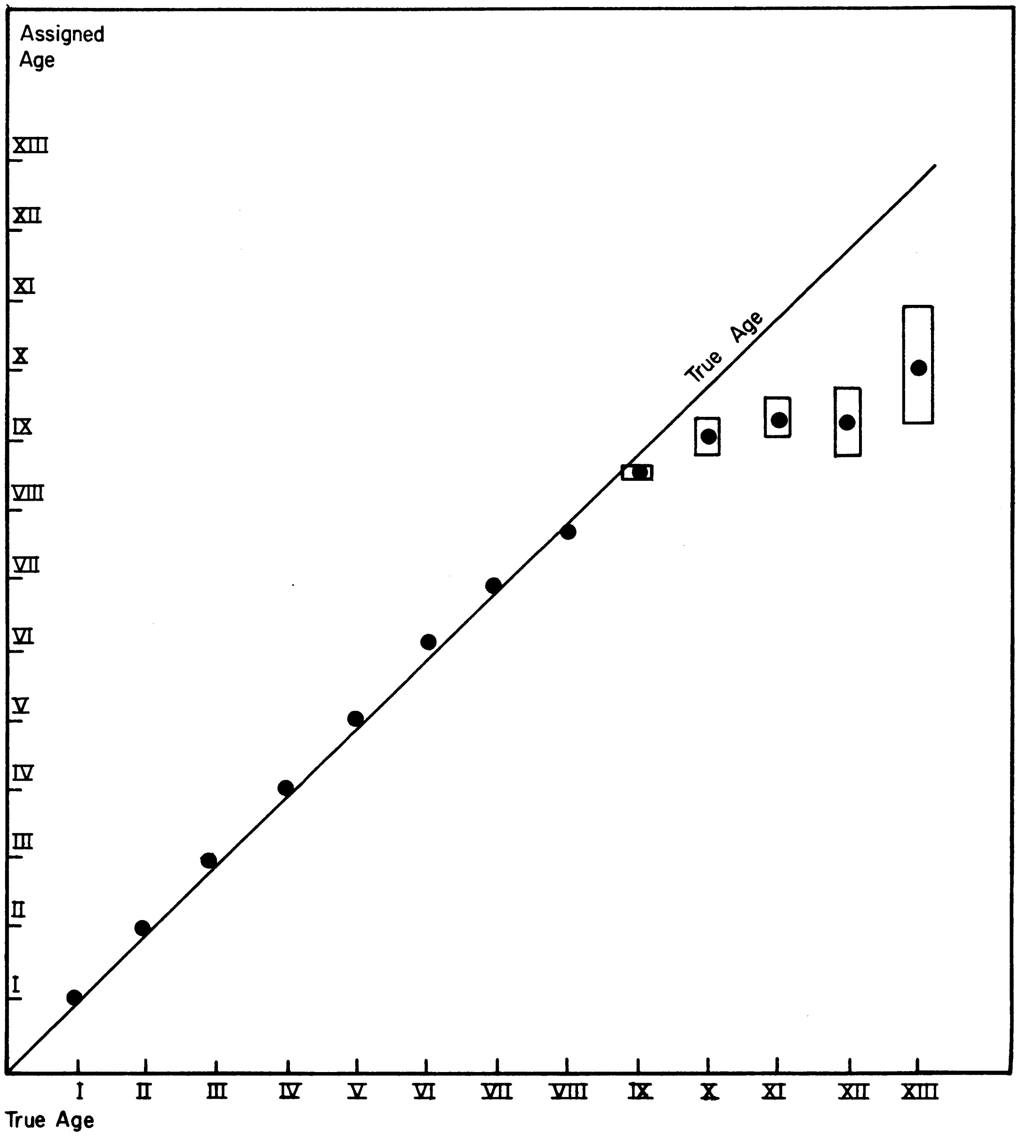


TABLE 2
Statistical Evaluations of the Use of Scale Samples to Make Age Determinations, 1955-1968*

True Age	Assigned Age Mean	Assigned Age Range	Tests of Reliability of Assigned Ages: Confidence Limits (95 Percent)	Standard Deviation	Standard Error	No. Readings
I	1	1				9
II	2	2				18
III	3	3- 4				45
IV	4	3- 5				138
V	5	4- 7				318
VI	6.1	4-10	6.08- 6.12	0.20	0.01	393
VII	6.9	5-10	6.87- 6.93	0.20	0.01	246
VIII	7.7	6- 9	7.65- 7.75	0.23	0.02	120
IX	8.6	6-11	8.54- 8.66	0.29	0.03	81
X	9.1	5-12	8.79- 9.41	1.35	0.15	51
XI	9.4	6-14	9.09- 9.71	1.66	0.16	54
XII	9.3	4-13	8.83- 9.77	1.90	0.23	15
XIII	10.1	6-12	9.25-10.95	1.66	0.40	12

*Based on the ages assigned by 3 persons each reading 500 known-age scales.

TABLE 3
Statistical Evaluations of the Use of Fin Sections to Make Age Determinations, 1955-1968*

True Age	Assigned Age Mean	Assigned Age Range	Tests of Reliability of Assigned Ages: Confidence Limits (95 Percent)	Standard Deviation	Standard Error	No. Readings
I	1	1				9
II	2	1- 3				18
III	3	2- 6				45
IV	4	2- 6				138
V	5	4- 7				318
VI	6.0	4- 8	5.99- 6.01	0.14	0.01	393
VII	6.9	4- 8	6.88- 6.92	0.15	0.01	246
VIII	7.7	6- 9	7.67- 7.73	0.18	0.01	120
IX	8.6	6-10	8.54- 8.66	0.27	0.03	81
X	9.4	7-11	9.36- 9.44	0.29	0.04	51
XI	9.9	5-12	9.5-10.3	1.39	0.19	54
XII	11.3	9-14	10.5-12.1	1.38	0.38	15
XIII	11.3	9-13	10.3-12.3	1.49	0.45	12

*Based on the ages assigned by 3 persons each reading 500 known-age fin sections.

FIGURE 6
Relationship of true ages to mean ages assigned by the fin section method, 1960-68. (The rectangle around the last 4 means represents the 95 percent confidence limits.)

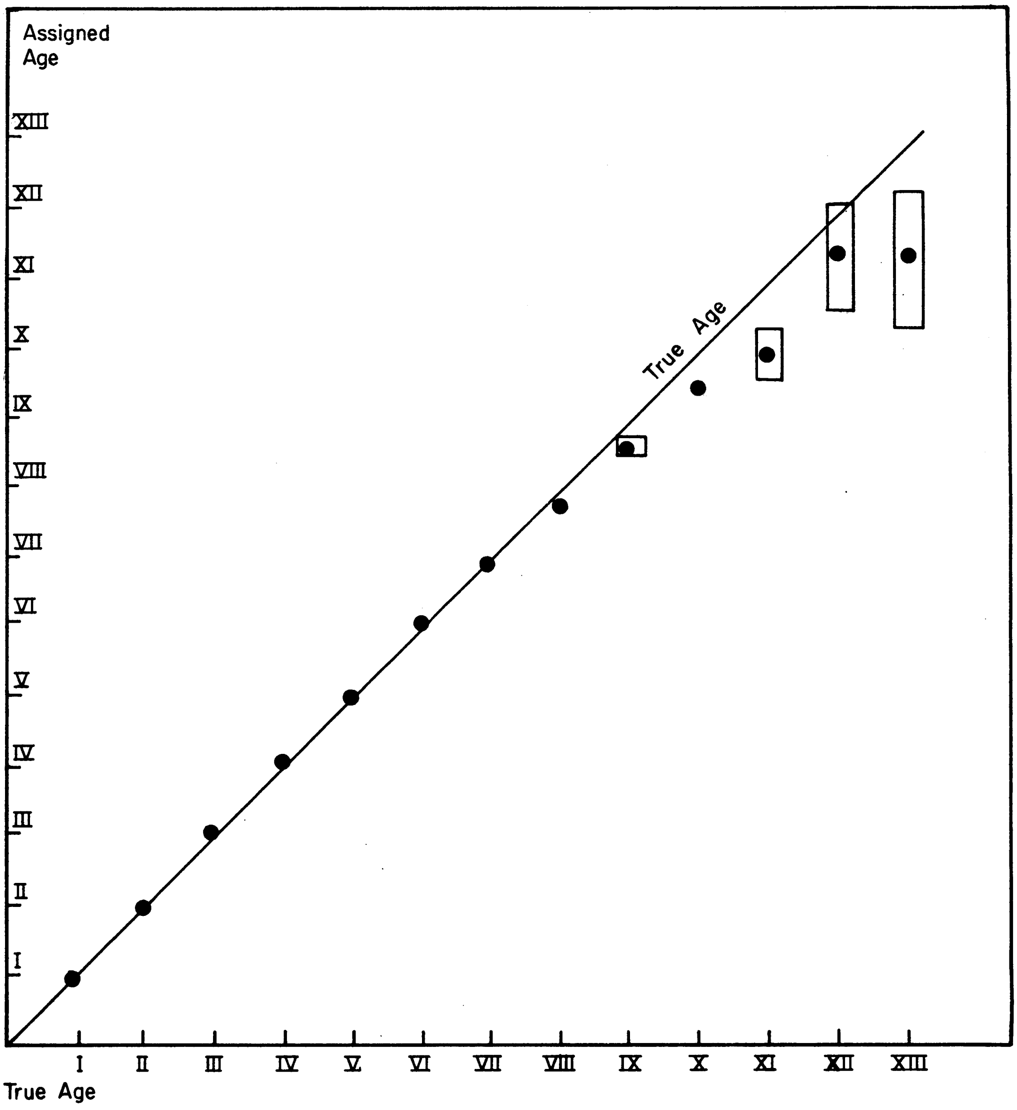


TABLE 11
Use of Scale Samples to Calculate Total Length of Fish From Each of the Three Study Lakes, 1955-1968*

	Bone Lake			Lac Court Oreilles**			Big Spider Lake		
		Calculated Length			Calculated Length			Calculated Length	
Age Group	Actual Length	Avg. Increment	Sum of Increments	Actual Length	Avg. Increment	Sum of Increments	Actual Length	Avg. Increment	Sum of Increments
I	--	10.1	10.1 --	11.2(12)	8.6	8.6(552)	11.4(2)	10.0	10.0(71)
II	19.0(1)	8.5	18.6(246)	16.2(2)	6.7	15.3(540)	15.3(4)	6.2	16.2(69)
III	26.1(57)	7.3	25.9(245)	22.5(15)	5.3	20.6(538)	22.6(2)	5.6	21.8(65)
IV	29.8(108)	4.4	30.3(188)	25.9(50)	4.4	25.0(523)	24.8(7)	3.8	25.6(63)
V	33.4(37)	3.0	33.3(80)	28.4(104)	2.6	27.6(473)	26.2(13)	2.1	27.7(56)
VI	35.7(17)	2.0	35.3(43)	30.0(122)	2.7	30.3(369)	28.1(25)	1.7	29.4(43)
VII	39.2(9)	1.4	36.7(26)	31.1(92)	1.6	31.9(247)	29.4(11)	1.2	30.6(18)
VIII	39.5(14)	2.0	38.7(17)	32.6(74)	1.2	33.1(155)	33.1(4)	--	--
IX	--	1.6	40.3(3)	33.0(53)	0.1	33.2(81)	30.6(2)	--	--
X	43.5(3)	0.2	40.5(3)	33.6(27)	0.3	33.5(28)	27.0(1)	--	--
XI	--	--	--	37.0(1)	0.3	33.8(1)	--	--	--

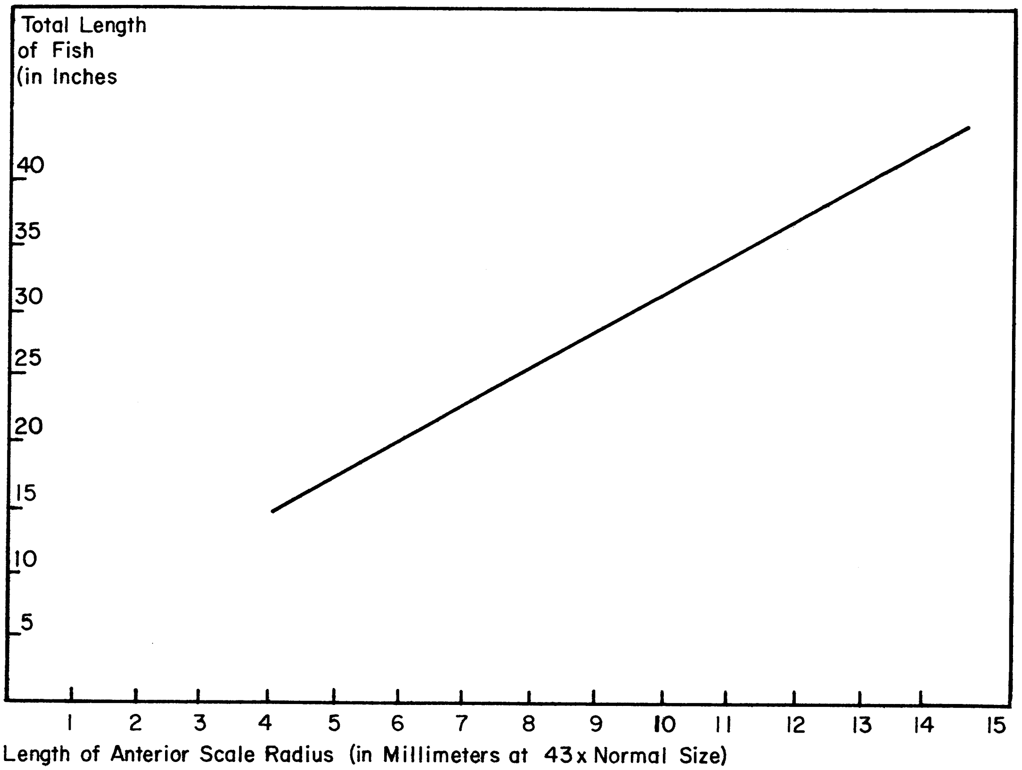
*Numbers in parenthesis indicate the number of fish on which actual or calculated lengths are based.
**Averages exclude the slow growing 1956 year class.

TABLE 12
Use of Fin Sections to Calculate Total Length of Fish From Each of the Three Study Lakes, 1955-1968*

	Bone Lake			Lac Court Oreilles**			Big Spider Lake		
		Calculated Length			Calculated Length			Calculated Length	
Age Group	Actual Length	Avg. Increment	Sum of Increments	Actual Length	Avg. Increment	Sum of Increments	Actual Length	Avg. Increment	Sum of Increments
II				15.5(1)	5.9	16.8(117)			
III	26.1(48)	6.8	25.8(202)	23.5(9)	5.6	22.4(116)			
IV	29.9(102)	4.5	30.3(154)	26.9(27)	4.2	26.6(107)	24.9(7)	3.4	25.4(40)
V	33.6(29)	3.0	33.3(52)	30.2(27)	3.2	29.8(80)	26.9(12)	1.9	27.3(33)
VI	35.8(13)	2.2	35.5(23)	31.7(22)	2.4	32.2(53)	29.2(12)	1.5	28.8(21)
VII	39.8(5)	1.2	36.7(10)	32.8(15)	2.1	34.3(31)	29.6(5)	1.6	30.4(9)
VIII	40.5(5)	0.8	37.5(5)	36.7(8)	1.8	36.1(16)	32.4(3)	1.4	31.8(4)
IX				36.7(5)	1.6	37.8(8)	36.0(1)	1.1	32.9(1)
X				40.8(3)	0.5	38.3(3)			

*Numbers in parenthesis indicate the number of fish on which actual or calculated lengths are based.
**Averages exclude the slow growing 1956 year class.

FIGURE 12
Relationship of the length of the anterior scale radius to the total length of the muskellunge.



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