DISTRIBUTION AND GROWTH OF IMMATURE HATCHERY - REARED LAKE TROUT, SALVELINUS NAMAYCUSH, IN LAKE MICHIGAN

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ABSTRACT

DISTRIBUTION AND GROWTH OF IMMATURE HATCHERY-REARED LAKE TROUT, *SALVELINUS NAMAYCUSH*, IN LAKE MICHIGAN

by John L. Hesse

Lake trout monitoring data from Michigan and Wisconsin waters of Lake Michigan were analyzed for the period of 1965 through 1967. The study is based upon 20,642 recoveries of juvenile hatchery-reared lake trout. The objectives were to determine the bathymetric distribution, the movement or dispersal patterns, and the growth rate of the planted lake trout during their first three years at liberty.

The greatest concentrations of juvenile lake trout were at 20-29 fathoms during the spring, summer, and fall seasons, and at 40-49 in the winter.

Dispersal patterns away from planting sites are described for each of nine groups of marked lake trout. The majority of the hatchery-reared trout remained within the general areas of release even after three years at liberty. However, some extensive movement did occur. Movement away from the planting areas was generally parallel to the shoreline. No pattern of clockwise or counter-clockwise movement was evident. Extensive offshore movement was limited to statistical district MM 3.

The average lengths at capture for age groups I, II, and III were 7.9, 11.3, and 15.7 inches, respectively. Back-calculated lengths at the first three annuli were 6.43, 10.34, and 14.34 inches. Compared to previous reports of lake trout growth in Lake Michigan, the lake trout of the present study exhibited increased growth rates and were more robust.

Lamprey scarring rates are presented and discussed. Gear selectivity of commercial gear types is reported. Reference is also made to the limitations in using commercial fishery data for biological analyses.

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By

[illegible]

John L. Hesse

A THESIS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURES PAGE

INTRODUCTION

No studies have been conducted on the bathymetric distribution, geographic distribution, or growth rate of juvenile lake trout, *Salvelinus namaycush* (Walbaum), in Lake Michigan since their reintroduction in 1965. In light of drastic ecological changes which have occurred in the Great Lakes since the 1940's, new studies in these areas should be conducted and all previous available information be used as a yardstick of comparison. Van Oosten and Eschmeyer (1956) reported briefly on the bathymetric distribution of small lake trout collected during 1930-32. Smith and Van Oosten (1940) conducted a study of geographic movement patterns, and studies by Cable (1956), Van Oosten and Eschmeyer (1956) and Smith and Van Oosten (1940) provide documentation of the growth rates of juvenile lake trout in Lake Michigan prior to 1946.

Before the mid-1940's, the lake trout had long been a species of primary importance to the Lake Michigan fishery. Commercial catch records show a commercial take of 4 to 9 million pounds annually for the period of 1885 to 1945 (Buettner, 1965). Beginning in 1946, the stability of the fishery broke and production dropped catastrophically to 342,000 pounds by 1949 (Hile, Eschmeyer, and Lunger, 1951). Smith (1968) has attributed the decline to a combination of increased predation by the sea lamprey, *Petromyzon marinus*, and to over-exploitation by the commercial fishery in the period just before the decline. By the mid-1950's, the population had reached near extinction (Eschmeyer, 1957). A similar crash had been already experienced in Lake Huron (Hile and Buettner, 1954), and it was also evident that the stocks in Lake Superior were being severely reduced (Buettner, 1965).

As the lake trout stocks declined, the commercial fishery was forced to switch its emphasis to chubs (Leucichthys sp.). At the same time, the lamprey, with its supply of lake trout becoming limited, began preying heavily upon the larger species of chubs. Subsequent abrupt changes in the deepwater fish fauna of the Great Lakes resulted (Moffett, 1957; Smith, 1964, 1968) and culminated with the invasion and population explosion of a marine species, the alewife, Alosa pseudoharengus. According to Smith, (1968) the Great Lakes had reached a state of biological instability by the mid-1960's that is almost unparalleled in the history of fishery science.

Attempts to restore a useful fishery balance in the upper Great Lakes have been undertaken and the progress being made is encouraging. A massive effort to control the sea lamprey using a toxicant that selectively destroys sea lamprey larvae in tributary streams has met with good success. A State and Federal restoration program of re-establishing predatory species in Lake Michigan was begun in 1965 with the planting of 1.3 million fin-clipped yearling lake trout. This has been increased to over 2 million annually and will be continued until natural reproduction is re-established. In addition to the lake trout, plantings of steelhead trout (Salmo gairdnerii) have been increased and coho (Oncorhynchus kisutch) and chinook salmon (Oncorhynchus tshawytscha) have been introduced from the west coast.

Following the reintroduction of lake trout in Lake Michigan, research is needed to learn something of their habits and to appraise the success of the stocking program. A study of the feeding habits has been completed by Wright (1968). The objectives of the present study were to: 1) determine bathymetric distribution of planted lake trout; 2) gain knowledge of the movement or dispersal patterns during their first three years in the lake; and 3) estimate and compare the growth rates to those of juvenile lake trout in Lake Michigan previous to the population decline.

MATERIALS AND METHODS

Statistical Districts

For convenience and standardization in tabulation of fishery data, the Great Lakes and related waters have been subdivided into statistical districts (Smith, Buettner, and Hile. 1961). Districts for Lake Michigan and Green Bay are shown in Figure 1. The author has conformed to these boundaries throughout this study. However, certain of the statistical districts have been grouped into general lake regions closely comparable to areas as described by Cable (1956). Three general regions were formed and are defined as follows:

Upper Lake Michigan . . . The area included within Statistical Districts MM 1 through MM 5, inclusive.

Lower Lake Michigan . . . The area included within Statistical Districts MM 6 through MM 8, inclusive.

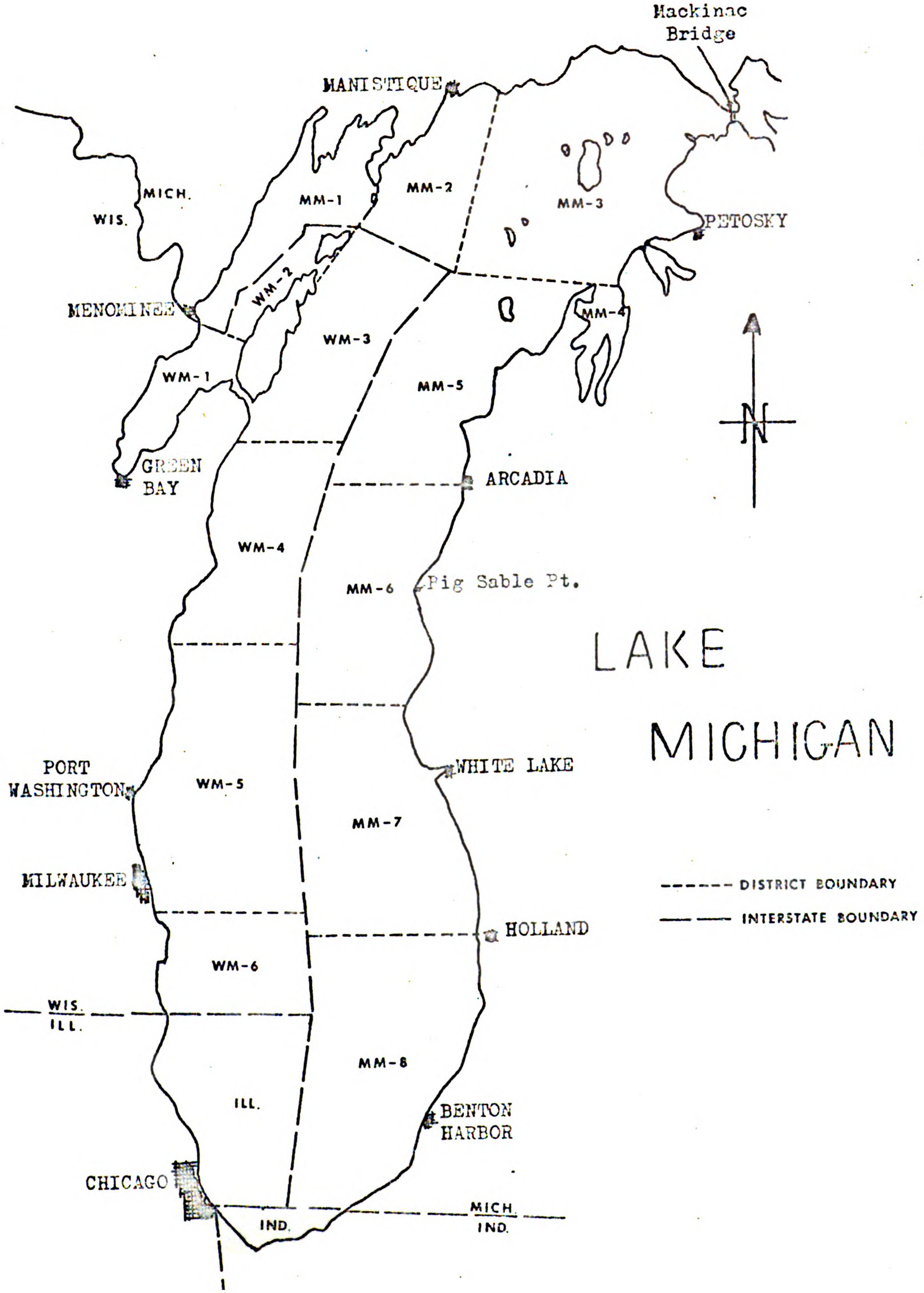
Wisconsin Waters. . . . . The entire area within Wisconsin state boundaries of Lake Michigan, WM 1 through WM 6, inclusive.

Indiana and Illinois districts were not included in this study because data was not available from these waters.

Release of Marked Lake Trout

Planting of hatchery-reared lake trout into the Great Lakes has been conducted under the direction of the Great Lakes Fishery

Figure 1. Statistical districts of Lake Michigan


Mackinac Bridge
MANISTIQUE
MICH.
WIS.
MM-1
MM-2
MM-3
PETOSKY
WM-2
MENOMINEE
WM-3
MM-4
WM-1
MM-5
GREEN BAY
ARCADIA
WM-4
MM-6
Big Sable Pt.
LAKE MICHIGAN
PORT WASHINGTON
WM-5
WHITE LAKE
MM-7
MILWAUKEE
DISTRICT BOUNDARY
INTERSTATE BOUNDARY
HOLLAND
WM-6
WIS.
ILL.
MM-8
ILL.
BENTON HARBOR
CHICAGO
IND.
MICH.
IND.
N

Commission. Pertinent data on the marking and release of the young lake trout are shown in Table 1 for the years of 1965, 1966, and 1967. The number of lake trout released during these three years totaled 5,415,108.

Marking was accomplished by removal of fins. A study by Shetter (1951) has indicated that this method does not seriously affect the survival or growth of lake trout. No clips were repeated in consecutive years and, in most cases, plantings of individual clips were restricted to localized areas of the lake.

Collection of Data

The data for this study were collected through the efforts of the Michigan and Wisconsin Conservation Departments and loaned to the author for analysis. Data analyzed were for the two-year period from January 1, 1966 through December 31, 1967.

The majority of the lake trout recovery information came from the commercial fishery as voluntary reports to the Conservation Departments, or from either dock or onboard inspections by Department Personnel of commercial fish catches. Each licensed fisherman has been required to submit to the Department of Conservation a weekly report of incidental catches of lake trout in his gear, since season closure, October 1, 1965. Although the fishermen were allowed to keep legal sized lake trout which died in the nets, all live or sublegal ($<$17.0 inches) lake trout were to be returned to the water.

Table 1. Marked lake trout in Lake Michigan (1965-1967).

Mark (fin removed)	Year Class	Date of Release	Number Released	Average Weight (fish/lb.)	Age (months)	Place of Release
Adipose (Ad)	1964	May 11-13, 1965	101,600	27.0	15	10 miles offshore Kewaunee, Wisconsin WM 4
"	1964	May 20, 25, 1965	103,000	24.2	15	Door Peninsula - Northport Dock, Gills Rock WM 2
Left Ventral (LV)	1964	July 12, Aug. 11, 12, Sept. 9, 10, 1965	314,997	14.7	17-19	Epoufette MM 3
"	1964	July 14, 15, Aug. 9, Sept. 7, 8, 1965	313,970	15.0	17-19	Gulliver MM 3
"	1964	July 13, 16, Aug. 13, 16, Sept. 13, 1965	237,811	15.7	17-19	Naubinway MM 3
Right Ventral (RV)	1964	May 2, 3, 1965	100,500	30.0	15	West Grand Traverse Bay MM 4
Dorsal (D)	1964	June 8-11, 1965	102,000	21.0	15	Reef and Island Area MM 3
Both Ventrals (BV)	1965	June 1, 6, 16, 1966	201,530	25.8	15-16	Milwaukee Reef MM 7

Table 1. *Marked* lake trout in Lake Michigan (1965-1967), continued.

Mark (fin removed)	Year Class	Date of Release	Number Released	Average Weight (fish/lb.)	Age (months)	Place of Release
Right Pectoral (RP)	1965	July 19, 1966	83,800	16.0	17	Naubinway MM 3
"	1965	July 18, 1966	83,500	15.8	17	Epoufette MM 3
"	1965	Sept. 12, 13, 1966	185,000	13.2	18	Petosky MM 3
"	1965	May 4, 1966	75,400	27.8	16	Charlevoix MM 3
"	1965	May 2, 1966	49,000	23.8	15	Bowers Harbor - West Grand Traverse Bay MM 4
"	1965	May 2, 1966	48,900	23.8	15	Old Mission - East Bay MM 4
"	1965	July 14, 1966	65,400	15.7	17	Grelickville - West Bay MM 4
"	1965	May 3, 1966	100,000	24.6	15	Leland MM 5
"	1965	July 17, 1966	99,900	17.3	16	West Olive MM 7
Dorsal and Left Ventral (DLV)	1965	June 8, 15, 17, 1966	190,300	24.2	15-16	Green Bay (3 miles offshore Sherwood Pt. light) WM 1
Dorsal and Right Ventral (DRV)	1965	April 27, July 11, 1966	164,990	20.9	14-16	Ludington (3-5 miles SW) MM 6

Table 1. Marked lake trout in Lake Michigan (1965-1967), continued.

Mark (fin removed)	Year Class	Date of Release	Number Released	Average Weight (fish/lb.)	Age (months)	Place of Release
Left Pectoral (LP)	1965	May 25, June 17, 22, 1966	148,200	22.0	16-17	Sturgeon Bay Canal WM 3
"	1965	June 12, 1966	100,500	26.2	15	Rowleys Bay WM 3
"	1965	May 12, 23, 1966	120,400	24.4	15-16	Kewaunee, Wisconsin WM 4
Adipose and Left Pectoral (AdLP)	1966	May 31, 1967	80,567	21.3	16	Bowers Harbor - Grand Traverse Bay MM 4
"	1966	May 29, 1967	80,938	22.0	16	Acme - Grand Traverse Bay MM 4
"	1966	June 28, 1967	102,157	18.2	17	Petosky MM 3
"	1966	June 29, 1967	98,211	17.8	17	Charlevoix MM 3
Adipose and Right Pectoral (AdRP)	1966	May 8, 1967	101,410	26.4	15	Ludington (from ferry) MM 6
"	1966	May 15, 1967	101,735	22.9	15	New Buffalo MM 8
"	1966	June 27, 1967	102,400	18.7	16	Leland MM 5

Table 1. *Marked lake trout in Lake Michigan* (1965-1967), continued.

Mark (fin removed)	Year Class	Date of Release	Number Released	Average Weight (fish/lb.)	Age (months)	Place of Release
Adipose and Right Pectoral (AdRP)	1966	July 6, 8, 1967	165,083	17.8	17	Port Sheldon MM 7
Dorsal (D)	1967	Sept. 28, 1967	285,000	75.7	8	Ludington to Manistee (ferry) MM 6
Adipose and Left Ventral (AdLV)	1966	May 23, 1967	101,277	22.8	16	Sand Bay WM 3
"	1966	May 26, June 2, 1967	202,280	21.5	17	Kewaunee (ferry) WM 4
"	1966	June 6, 22, 1967	540,950	21.5	17	Sturgeon Bay (ferry) WM 3
Dorsal (D)	1967	Oct. 7, 1967	284,600	80.2	8	Sheboygan to Port Washington (ferry) WM 5
Adipose and Right Ventral (AdRV)	1966	May 10, 1967	90,425	24.7	16	Great Lakes Naval Dock, Illinois
"	1966	May 18, 1967	87,377	23.8	16	Bethlehem Steel Pier, Portage, Indiana IND.

The remainder of the lake trout samples were obtained directly by the Conservation Department through experimental gill netting and trawling.

Gear used by the commercial fishery consisted of gill nets, trap nets, pound nets and trawls. Gill net sizes ranged from 2.5 to 5.0-inch mesh and were set primarily for the Great Lakes bloater (*Leucichthys hoyi*) and the Great Lakes whitefish (*Coregonus clupeaformis*). In Lake Michigan, the minimum legal mesh size of gill nets set for whitefish is 4 1/2 inches (stretched measure). This was the most commonly used size, although some 4 9/16 and 4 3/4 inch mesh nets occasionally were fished. The gill nets used in the chub fishery are limited from 2 1/2 to 2 3/4 inch stretched measure. Because the mesh size used for these two species are quite standard, the data are generally categorized as large mesh (≥ 4 1/2 inch stretched measure) or small mesh (< 4 1/2 inch stretched measure) gill nets. Impoundment gear (trap nets and pound nets) was used almost exclusively for taking of whitefish, while trawls were used for the commercial harvest of alewife and chubs.

Departmental gill nets ranged in size from 2.0 to 5.5 inches (stretched measure). The experimental trawling was executed with a 39-foot otter trawl.

Each lake trout caught was measured (total length in inches) and examined for fin-clips and lamprey scars. When possible, fish were also weighed and sexed. Scale samples were taken from a representative size range of the population. In addition, the amount of gear fished, and the location and depth of the set were recorded for each lift.

Analysis of Data

Specific analyses used are described in detail in each of the appropriate sections. The large amount of data available for this study made the aid of a computer a necessity. The computer system was a Control Data Corporation (CDC) 3600, available through the Computer Science Center, Michigan State University. In addition to standard pre-written computer programs used, several new programs had to be developed specifically for this study. Program source decks can be made available by request to the author or to the Department of Fisheries and Wildlife, Michigan State University, East Lansing, Michigan.

GEAR SELECTIVITY

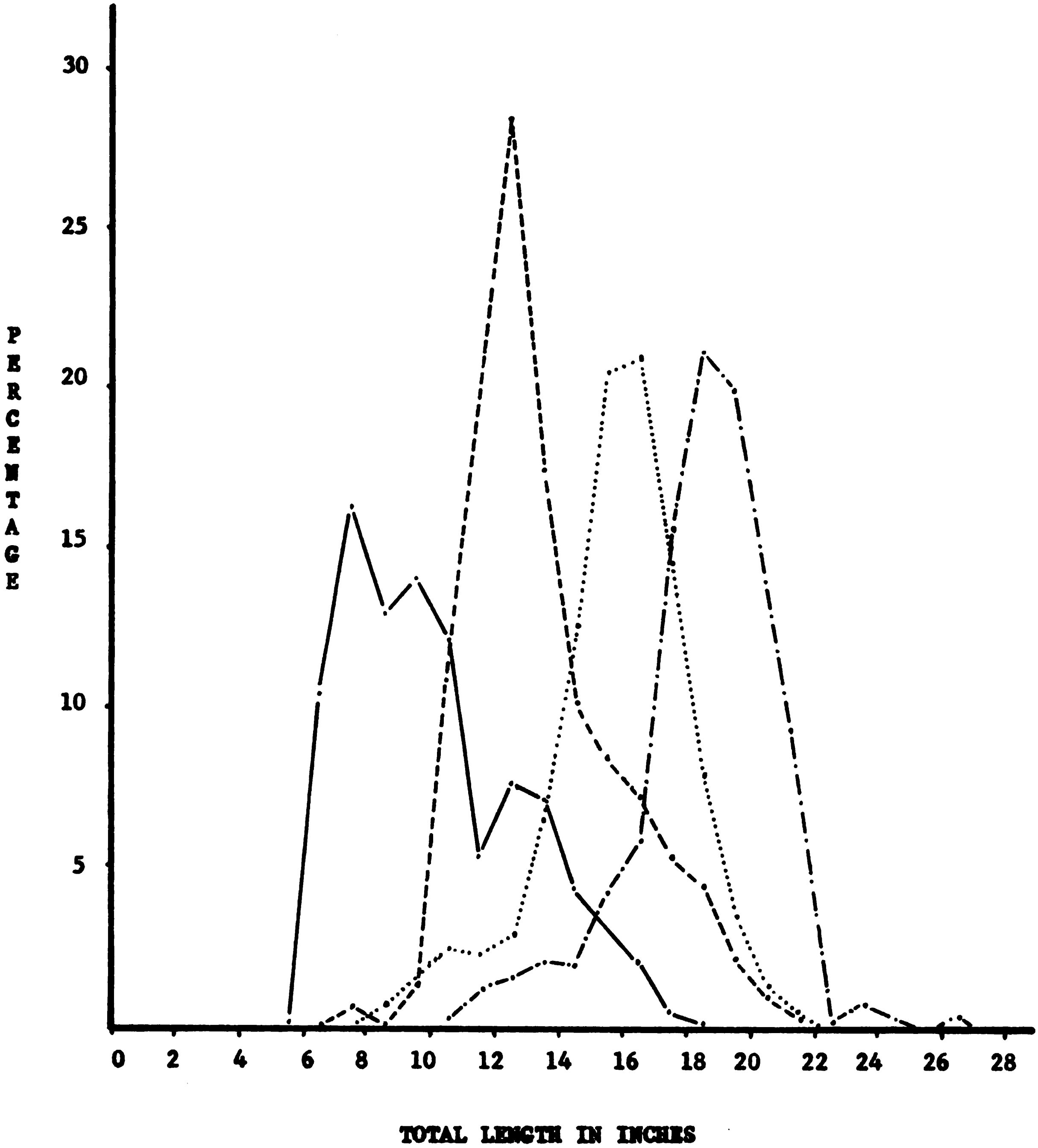
Commercial catch records provide a basis for determining the size frequency of lake trout taken by general gear types. The length distributions of 20,551 lake trout caught in large mesh gill nets, small mesh gill nets, trawls, and trap and pound nets are given in Table 2, and the percentage distributions are shown in Figure 2.

Figure 2 clearly suggests a size specific selectivity of the four gear classifications. The indication is that planted lake trout of yearling size first become vulnerable to the trawl fishery, then to small-mesh gill nets, large-mesh gill nets, and lastly, impoundment gear. The average lengths at capture for age groups I, II and III were found to be 7.9, 11.3, and 15.7 inches, respectively. These averages coincide almost perfectly with the peaks of the catch distribution curves for trawls, small-mesh gill nets, and large-mesh gill nets, indicating a probable corresponding age selectivity for these three gears. Impoundment gear, on the other hand, shows an apparent selectivity for the largest fish of the population, in that the average size of fish reported was approximately 2 inches greater than the average length of age group III fish. The larger size of lake trout reported in trap and pound nets may be due largely to the fact that impoundment gear does not generally kill the entrapped fish, and consequently most sublegal sized fish are returned to the water.

Table 2. Length distributions of 20,551 lake trout caught in large mesh gill nets, small mesh gill nets, trawls, and trap and pound nets, 1966-1967.

Total Length (inches)	Gear Type				
	Large Mesh Gill Nets	Small Mesh Gill Nets	Trawls	Trap and Pound Nets	Totals
5.0 - 5.9	—	1	21	—	22
6.0 - 6.9	11	5	137	—	153
7.0 - 7.9	37	22	208	—	267
8.0 - 8.9	131	6	166	—	303
9.0 - 9.9	282	41	180	—	503
10.0 - 10.9	425	310	156	1	892
11.0 - 11.9	394	802	70	3	1269
12.0 - 12.9	486	501	99	4	1090
13.0 - 13.9	1072	290	92	5	1459
14.0 - 14.9	2056	241	57	5	2359
15.0 - 15.9	3347	209	39	10	3605
16.0 - 16.9	3426	155	28	14	3623
17.0 - 17.9	2390	128	7	37	2562
18.0 - 18.9	1291	62	4	50	1407
19.0 - 19.9	580	30	1	49	660
20.0 - 20.9	219	11	—	33	263
21.0 - 21.9	68	3	1	19	91
22.0 - 22.9	10	1	—	1	12
23.0 - 23.9	4	—	—	2	6
24.0 - 24.9	—	—	1	1	2
25.0 - 25.9	—	1	—	—	1
26.0 - 26.9	—	—	—	1	1
27.0 - 27.9	1	—	—	—	1
Totals	16230	2819	1267	235	20551

Figure 2. Percentage length distribution of lake trout caught in large mesh gill nets (dotted line ......), small mesh gill nets (dashed line -----), trawls (solid line _______), and impoundment gear (dash-dot -.-.-.).


PERCENTAGE
30
25
20
15
10
5
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
TOTAL LENGTH IN INCHES

BATHYMETRIC DISTRIBUTION

Because researchers generally lack the vessels and gear for the large scale fishing which is required to study bathymetric distribution, few studies on this important aspect of a fish's life history have been undertaken.

In the absence of adequate experimental gear, the author felt that extensive data from a commercial fishery could be useful in studying the depth distribution of a species such as the lake trout which is not open to the fishery but which occupies the ranges of other species which are being exploited, the whitefish and chubs.

Reports from the commercial fishermen which contained no lake trout were not available to the author and so were ignored in the analyses. Consequently, because of the incomplete records of fishing pressure, values pertaining to catch per unit effort (CPE) were modified to "catch per unit of effective effort" as described in Hile (1962). Hile supports the use of effective fishing effort for fisheries in which most nets are set with the intent and expectation of taking several species simultaneously. By Hile's definition, all the gear lifted by a fisherman on a particular day is charged to a species if that species is found present in any amount. The author felt that, in the Great Lakes where no effort was being exerted directly toward the taking of juvenile lake trout (they were taken incidentally in gear set for other species), the use of "catch per unit of effective effort" is justifiable and would provide the best possible estimate which could be made with incomplete records of fishing pressure.

The units of effort used in computation of effective CPE values throughout this paper conform to those described by Hile (1962). One unit of effort is defined for each of the following gears as:

Gill nets . . . . The lift of 1,000 linear feet of gill netting.

Impoundment gear (pound nets and trap nets) . . . . .
The lift of one net.

Trawls. . . . . . One hour of actual dragging.

Table 3 presents the data on bathymetric distribution for 18,342 young lake trout (age groups I, II, and III) captured in Lake Michigan during 1966 and 1967. Effort has been limited to that effort exerted by gill nets. Data from large and small-mesh gill nets have been combined to provide the widest possible range in depths from which samples were obtained. The depth of water to which the nets were assigned was determined by the mean of the depths at the end of each gang. Catches are grouped by 10-fathom intervals, from 0 to 79 fathoms.

Because Hile (1962) reported that the length of time nets are fished does not significantly affect catch per unit effort, the time factor was not adjusted for in this study. Data from the three

Table 3. The average number of lake trout caught per 1,000 feet of gill nets at different depths in Lake Michigan, during various seasons in 1966-1967.

	Depth of Water (fathoms)							
Season	10	10-19	20-29	30-39	40-49	50-59	60-69	70-79
Spring	0.81	1.17	2.71	1.34	0.74	1.04	0.30	0.19
Summer	0.13	0.56	0.87	0.39	0.09	—	—	—
Fall	—	0.67	2.03	0.88	0.33	0.23	0.25	0.11
Winter	—	0.71	0.34	0.65	1.01	0.51	—	0.08
All Seasons	0.44	0.78	2.48	1.07	0.62	0.58	0.26	0.12
Thousands of feet of net lifted								
Spring	27.0	2840.3	3646.5	553.3	350.1	98.4	23.6	12.0
Summer	31.6	5114.5	194.2	48.6	45.5	0.0	0.0	0.0
Fall	0.0	153.0	63.7	10.2	304.6	80.0	75.1	9.0
Winter	0.0	16.8	233.9	266.1	186.7	254.2	0.0	13.2
Totals	58.6	8124.6	4138.3	878.2	886.9	432.6	98.7	34.2

regions of the lake were combined but were segregated according to season in order to show any seasonal changes in the depth distribution.

The greatest concentration of young lake trout occurred at the depth of 20-29 fathoms during the spring, summer, and fall seasons. There is some indication that the trout move to deeper water in the winter months with the highest concentration at 40-49 fathoms during that period. Lake trout were captured over the widest range of depths during the spring (0-79 fathoms).

With seasons combined, the data show that the lake trout, on an annual basis, are found in greatest concentrations at the 20-29 fathom interval and that there were also more at 30-39 fathoms than at 10-19.

The present depth distribution appears to differ somewhat from the distribution that had been described by Van Oosten and Eschmeyer (1956) for young native lake trout of the early 1930's. Their study, based on data collected aboard the Bureau of Commercial Fisheries research vessel _Fulmar_ during 1930-32, showed the greatest concentration of small lake trout (mostly 12-15 inches) at depths of 40-59 fathoms for the southern end of Lake Michigan below a line from Kewaunee, Wisconsin to Frankfort, Michigan. Above this line, along the north and northeast shores, the greatest abundance was found to be at 30-39 fathoms.

The results of the present study are more closely comparable to those of Dryer (1966) for lake trout in the Apostle Island region of Lake Superior and to the depth distribution of age group I and II lake trout along the southern shore of Lake Superior as reported by Eschmeyer (1956) where the trout were shown to be most plentiful at 20-34 fathoms.

Data were analyzed according to depth for 1,548 lake trout which had been sexed. Although males outnumbered females for all but one of the depth intervals, χ^2 values with $\alpha = .01$ (Siegel, 1956) indicated that the differences were not significant; males and females apparently have the same depth distribution. Considering that the entire sample was composed of immature fish, there is probably no biological reason for any differences to occur.

GEOGRAPHICAL MOVEMENTS

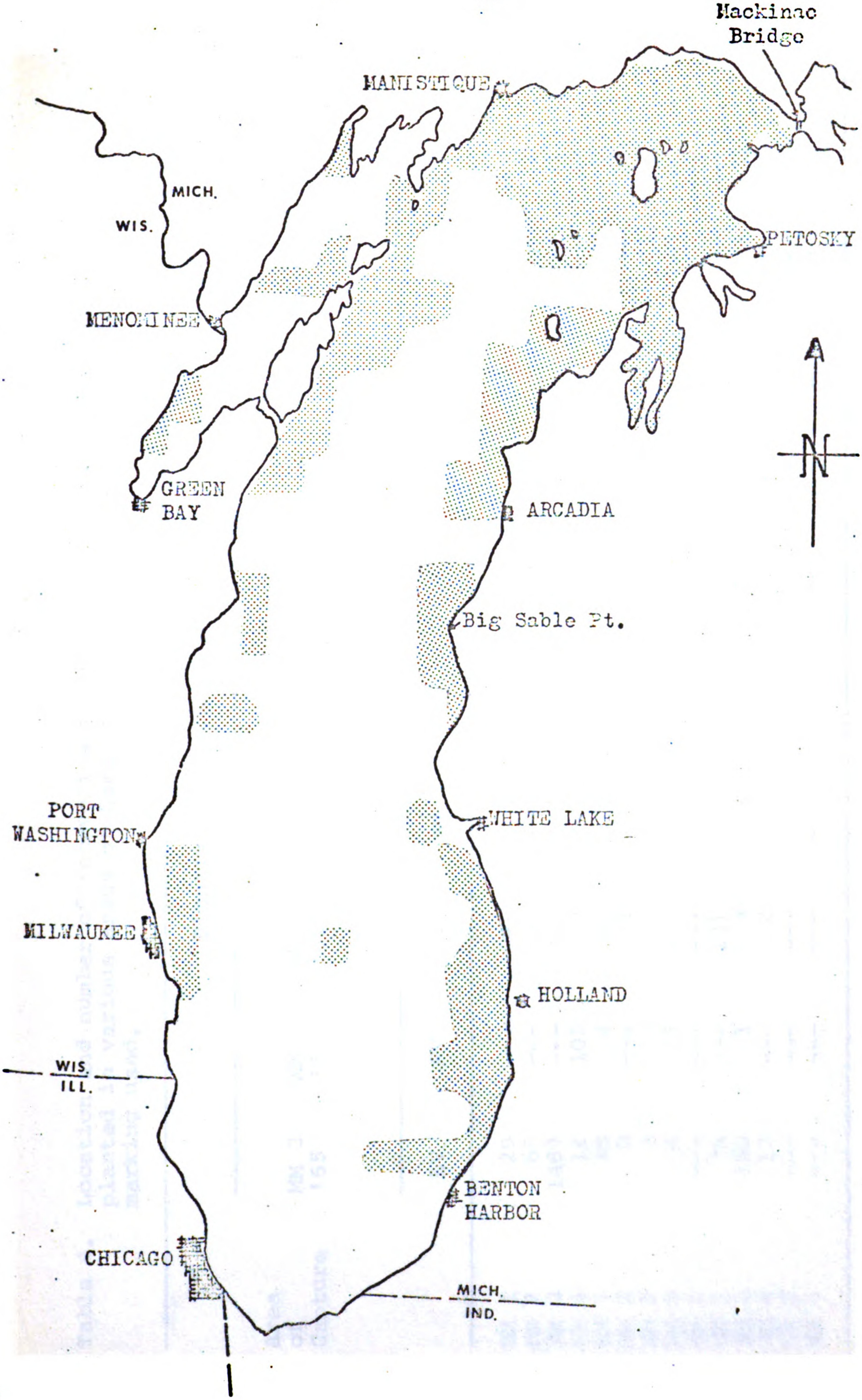
Just as knowledge of bathymetric distribution of planted lake trout is important for evaluation and wise management during a rehabilitation program, so is an understanding of the lake trout's dispersal or geographic movement patterns. The extent and direction of movement away from a planting site will aid in determining where future plants are to be made. Such knowledge is also necessary in estimation of survival of the various plants.

Pycha, Dryer, and King (1965) presented extensive data on the movements of hatchery-reared lake trout in Lake Superior. No comparable study has been made for Lake Michigan.

The present study of movement is based upon 20,642 lake trout recaptured in 1965-1967. Figure 3 shows the areas from which samples of lake trout were obtained. No recaptures of lake trout planted in 1967 were reported, thus limiting the study to recoveries of the 1965 and 1966 plants (for specific planting information, refer to Table 1, pages 8-11).

One direct method of showing where fish move is by total returns, from the various sampling areas, of marked fish planted in a single area. Tables 4 and 5 give the localities and number of recoveries by fin-clip and statistical district for the 20,576 lake trout captures in 1966 and 1967. Only 66 recoveries were made in 1965, the year the stocking program began.

Figure 3. Areas of Lake Michigan from which samples were obtained, 1965-1967.


Mackinac
Bridge
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MENOMINEE
N
GREEN
BAY
ARCADIA
Big Sable Pt.
PORT
WASHINGTON
WHITE LAKE
MILWAUKEE
HOLLAND
WIS.
ILL.
BENTON
HARBOR
CHICAGO
MICH.
IND.

Table 4. Location and number of recoveries in 1966 of hatchery-reared lake trout planted in various areas of Lake Michigan. Also year of planting and marking used.

Area of Capture	Planting Area, Date, and Marking Used										
	MM 3 '65	MM 4 '65	MM 3 '65	WM 2 WM 4 '65	MM 3 MM 4 MM 5 MM 7 '66	MM 6 '66	WM 1 '66	WM 3 WM 4 '66	MM 7 '66		
	LV	RV	D	Ad	RP	D-RV	D-LV	LP	BV	[3]	Totals
MM 1	29	---	---	4	---	---	---	---	---	---	33
MM 2	68	---	---	---	---	---	3	---	---	1	72
MM 3	1469	---	260	3	18	---	5	---	---	21	1776
MM 4	12	105	8	---	2	---	---	---	---	10	137
MM 5	38	4	36	5	6	1	2	1	---	7	100
MM 6	8	---	4	3	3	150	2	1	---	14	185
MM 7	3	5	1	1	51	38	---	---	9	4	112
MM 8	4	17	---	2	347	12	---	2	12	35	431
WM 1	---	---	---	---	---	---	13	---	---	---	13
WM 2	74	---	131	---	---	---	---	---	---	---	205
WM 3	150	1	3	112	---	---	---	4	---	2	272
WM 4	13	---	2	167	---	---	---	47	---	4	233
WM 5	---	---	---	5	1	---	---	1	---	---	7
WM 6	---	---	---	---	---	---	---	---	---	---	0
Totals	1868	132	312	433	428	201	25	56	21	98	3576

[3] Lake trout captured which had clips of unknown origin or no clip information available.

Table 5. Location and number of recoveries in 1967 of hatchery-reared lake trout planted in various areas of Lake Michigan. Also year of planting and marking used.

Area of Capture	Planting Area, Date, and Marking Used										
	MM 3 '65	MM 4 '65	MM 3 '65	WM 2 WM 4 '65	MM 3 MM 4 MM 5 MM 7 '66	MM 6 '66	WM 1 '66	WM 3 WM 4 '66	MM 7 '66		
	LV	RV	D	Ad	RP	D-RV	D-LV	LP	BV	[3]	Totals
MM 1	31	1	---	10	---	---	276	1	---	3	322
MM 2	132	1	4	2	4	2	---	---	---	5	150
MM 3	13,606	17	263	11	303	5	2	13	2	449	14,671
MM 4	39	421	17	1	70	---	---	4	---	20	572
MM 5	34	11	17	2	172	128	---	3	4	10	381
MM 6	1	6	5	---	8	67	---	---	1	2	90
MM 7	4	3	---	---	34	45	---	3	20	5	114
MM 8	4	4	---	3	41	8	---	11	3	6	80
WM 1	---	---	---	---	---	---	---	---	---	---	0
WM 2	24	---	---	186	---	---	---	---	---	1	211
WM 3	51	---	3	17	---	---	---	31	---	3	105
WM 4	30	1	1	44	1	---	1	214	---	2	294
WM 5	6	---	---	3	---	---	---	1	---	---	9
WM 6	---	---	---	---	---	---	---	---	---	---	0
Totals	13,962	465	310	279	633	255	279	281	30	506	17,000

[3] Lake trout captured which had clips of unknown origin or no clip information available.

Variations in fishing intensity and the rates of movement and survival determine how many fish actually are recovered from the different areas. A measure of relative abundance, comparable in all sampling areas, is needed. Catch per unit of effort values, computed for fish recaptured from a given planting that had been at liberty the same number of years, provide such a measure (Pycha, et al., 1965). CPE values were not used in the present study, however, because effort was too low in the majority of the sampling areas to provide reliable results and because lake trout were taken only as incidental catches in nets set for other species.

Bearing in mind that differential fishing intensity and fish survival among areas will have an effect upon the total numbers caught, total catch data alone can still be suggestive of trends of movement. Figures 4-12 show the locations of all returns and probable directions of movement for each of nine fin-clip designations.

Percentages of the recaptures according to statistical district for each of the fin-clips were computed and are presented in Tables 6 and 7.

"LV" Clip - North Shore Plant

Yearling lake trout having the "LV" (left ventral) clip were released from three locations along the north shore in 1965. The total number planted amounted to 866,778, representing the largest

Table 6. Percentage of recaptures according to statistical district for each of the fin-clips, 1966. Also total number of each fin-clip recovered.

	Areas of Planting								
Area of Capture	MM 3	MM 4	MM 3	WM 2 WM 4	MM 3 MM 4 MM 5 MM 7	MM 6	WM 1	WM 3 WM 4	MM 7
	LV	RV	D	Ad	RP	D-RV	D-LV	LP	BV
MM 1	1.55	---	---	0.92	---	---	---	---	---
MM 2	3.64	---	---	---	---	---	12.00	---	---
MM 3	78.64	---	82.80	0.69	4.21	---	20.00	---	---
MM 4	0.64	79.55	2.55	---	0.47	---	---	---	---
MM 5	2.03	3.03	11.46	1.15	1.40	0.50	8.00	1.79	---
MM 6	0.43	---	1.27	0.69	0.70	74.63	8.00	1.79	---
MM 7	0.16	3.79	0.32	0.23	11.92	18.91	---	---	42.86
MM 8	0.21	12.88	---	0.46	81.07	5.98	---	3.57	57.14
WM 1	---	---	---	---	---	---	52.00	---	---
WM 2	3.96	---	---	30.25	---	---	---	---	---
WM 3	8.03	0.76	0.96	25.87	---	---	---	7.41	---
WM 4	0.70	---	0.64	38.57	---	---	---	83.93	---
WM 5	---	---	---	1.15	0.23	---	---	1.79	---
Number of Recaptures	1868	132	314	433	428	201	25	56	21

Table 7. Percentage of recaptures according to statistical district for each of the fin-clips, 1967. Also total number of each fin-clip recovered.

Area of Capture	Areas of Planting								
	MM 3	MM 4	MM 3	WM 2 WM 4	MM 3 MM 4 MM 5 MM 7	MM 6	WM 1	WM 3 WM 4	MM 7
	LV	RV	D	Ad	RP	D-RV	D-LV	LP	BV
MM 1	0.22	0.22	---	3.58	---	---	98.92	0.36	---
MM 2	0.95	0.22	1.29	0.72	0.63	0.78	---	---	---
MM 3	97.45	3.66	84.84	3.94	47.87	1.96	0.72	4.63	6.67
MM 4	0.28	90.54	5.48	0.36	11.06	---	---	1.42	---
MM 5	0.24	2.37	5.48	0.72	27.17	50.20	---	1.07	13.33
MM 6	0.01	1.29	1.61	---	1.26	26.27	---	---	3.33
MM 7	0.03	0.85	---	---	5.37	17.65	---	1.07	66.66
MM 8	0.03	0.86	---	1.08	6.48	3.14	---	3.91	10.00
WM 1	---	---	---	---	---	---	---	---	---
WM 2	0.17	---	---	66.67	---	---	---	---	---
WM 3	0.37	---	0.97	6.09	---	---	---	11.03	---
WM 4	0.21	0.22	0.32	15.77	0.16	---	0.36	76.16	---
WM 5	0.04	---	---	1.08	---	---	---	0.36	---
Number of Recaptures	13,962	465	310	279	633	255	279	281	30

planting of any fin-clip. Returns from this plant have been extremely high with 41 recoveries in 1965, 1,868 in 1966, and 13,962 in 1967.

Although distribution of the recaptures (Figure 4; Tables 6-7) indicate that the majority of returns came within the general area of planting, a small percentage of the fish have shown extensive movement. The fact that MM 3 received the greatest fishing intensity of any area in Lake Michigan could significantly bias estimates of relative abundance based solely upon returns for the various sampling areas.

Fish of this clip have been recaptured throughout Grand Traverse Bay and all along the eastern shoreline as far south as Benton Harbor. On the western shoreline, the LV clip was recaptured as far south as Milwaukee. Returns from Green Bay show a substantial amount of movement also into that area.

"D" Clip - Reef and Island Area

The "D" (dorsal) clip was represented by a single plant of 102,000 lake trout released from a ferry off the eastern shore of Beaver Island in 1965. As with the returns from the north shore plant, the majority of the recaptures came within MM 3 (Figure 5; Tables 6 and 7). The fish became well distributed throughout the district. Some moved southward and infiltrated into both arms of Grand Traverse Bay. Still others moved further south along the Michigan

Figure 4. Localities and number of returns of hatchery-reared lake trout having the "LV" clip. Black circles are planting localities and open rectangles give the number of fish caught in each area; arrows indicate probable direction of movement.

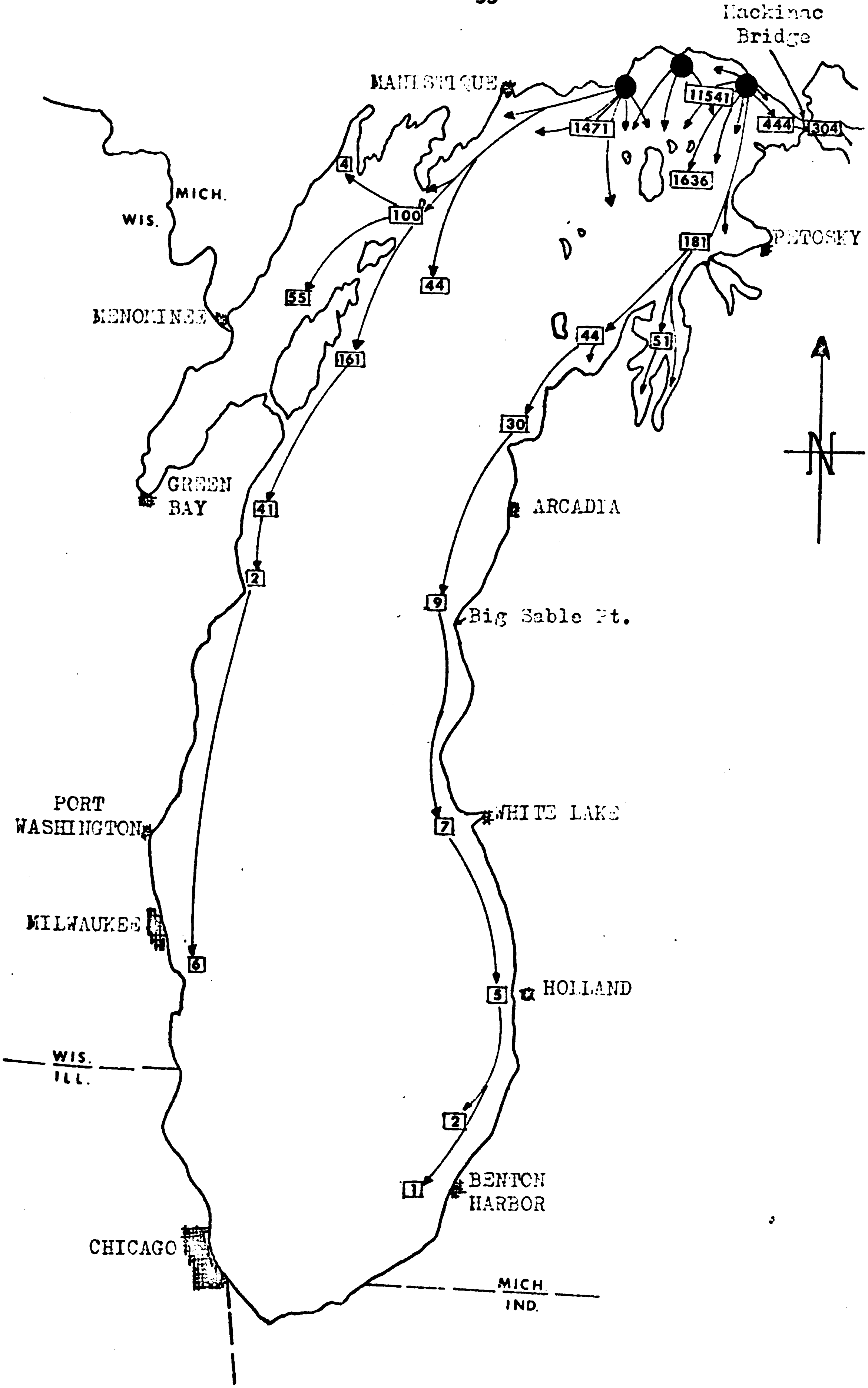
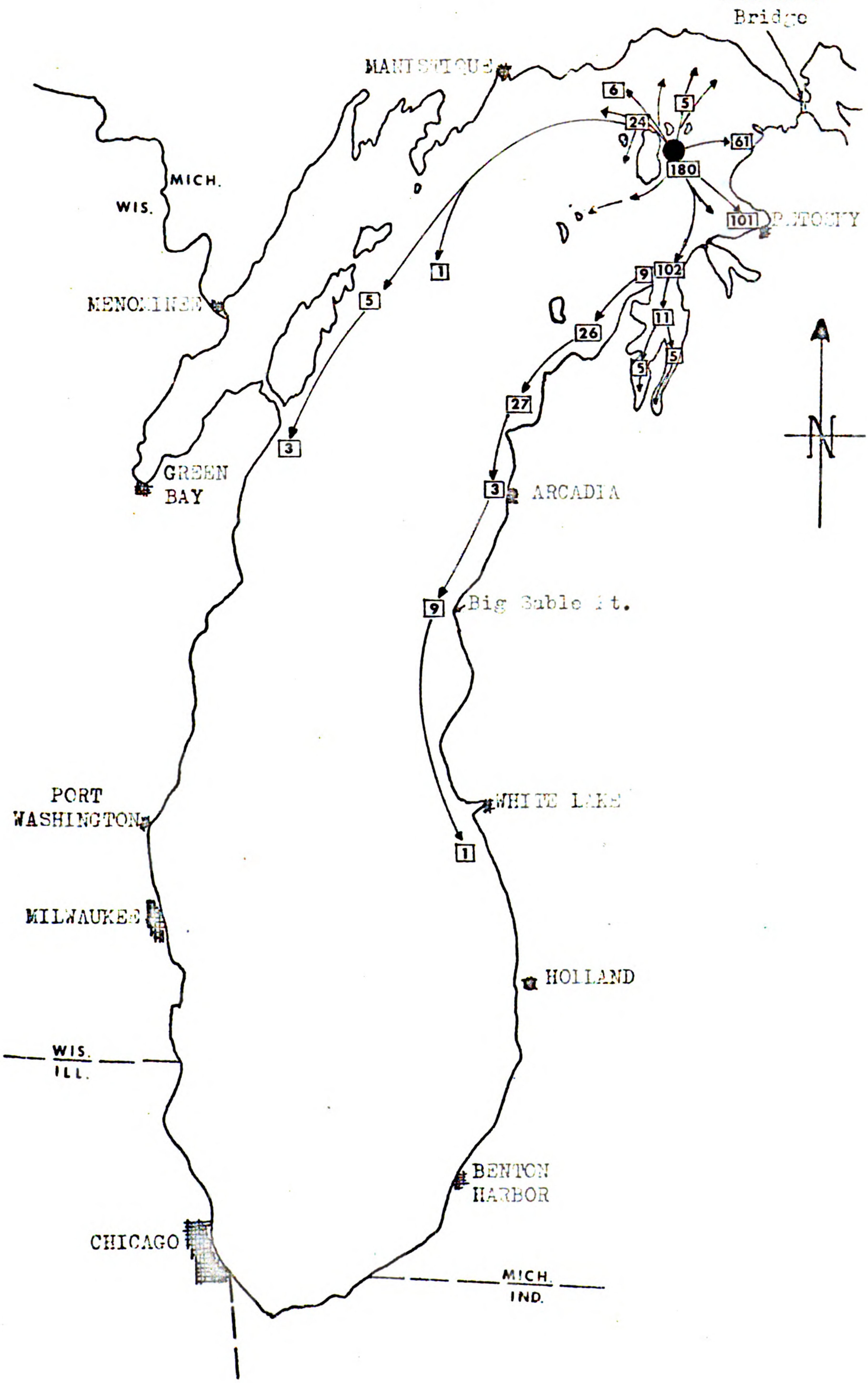

Mackinac Bridge
MANISTIQUE
1471
11541
444
304
1636
4
100
MICH.
WIS.
PETOSKY
181
55
44
MENOMINEE
44
51
161
30
GREEN BAY
41
ARCADIA
N
2
9
Big Sable Pt.
PORT WASHINGTON
7
WHITE LAKE
MILWAUKEE
6
5
HOLLAND
WIS.
ILL.
2
1
BENTON HARBOR
CHICAGO
MICH.
IND.

Figure 5. Localities and number of returns of hatchery-reared lake trout having the "D" clip. Black circles are planting localities and open rectangles give the number of fish caught in each area; arrows indicate probable direction of movement.


Mackinac Bridge
MANISTIQUE
MICH.
WIS.
MENOMINEE
GREEN BAY
6
24
5
61
180
101
PETOSKY
1
5
3
9
102
26
11
5
5
27
3
ARCADIA
9
Big Sable Pt.
WHITE LAKE
1
PORT WASHINGTON
MILWAUKEE
HOLLAND
WIS.
ILL.
BENTON HARBOR
CHICAGO
MICH.
IND.
N

shoreline as far as Muskegon. Westward movement appeared to be less extensive with only nine recoveries within Wisconsin waters. These were taken as far south as Algoma. Five recoveries were made in 1965, the year of planting. Two of these had traveled outside the MM 3 boundary into MM 5.

"RV" Clip - Grand Traverse Bay

The "RV" (right ventral) clip was represented by 100,500 lake trout planted in the west arm of Grand Traverse Bay in 1965 (Figure 6). Twelve recoveries were made in 1965, all within Grand Traverse Bay. In 1966, 79.55 per cent of the recaptures were within Grand Traverse Bay. With the exception of a single recovery in Wisconsin waters (Table 4) the remainder were taken southward along the Michigan shoreline to just below Holland. Although in 1967, the number recaptured within Grand Traverse Bay had increased to 90.5 per cent, there were recoveries reported within every statistical district in Michigan waters.

"RP" Clip - Multiple Locations

The "RP" (right pectoral) clip, was represented by 790,000 lake trout released in 1966 from eight locations. Apparently there was very little movement into Wisconsin waters. Because these planting sites ranged over a widely scattered area (Figure 7), very little else can be said about the dispersal patterns.

"D-RV" Clip - Ludington

The "D-RV" (dorsal and right ventral) clip was represented by 164,990 lake trout planted from a ferry three to five miles

Figure 6. Localities and number of returns of hatchery-reared lake trout having the "RV" clip. Black circles are planting localities and open rectangles give the number of fish caught in each area; arrows indicate probable direction of movement.

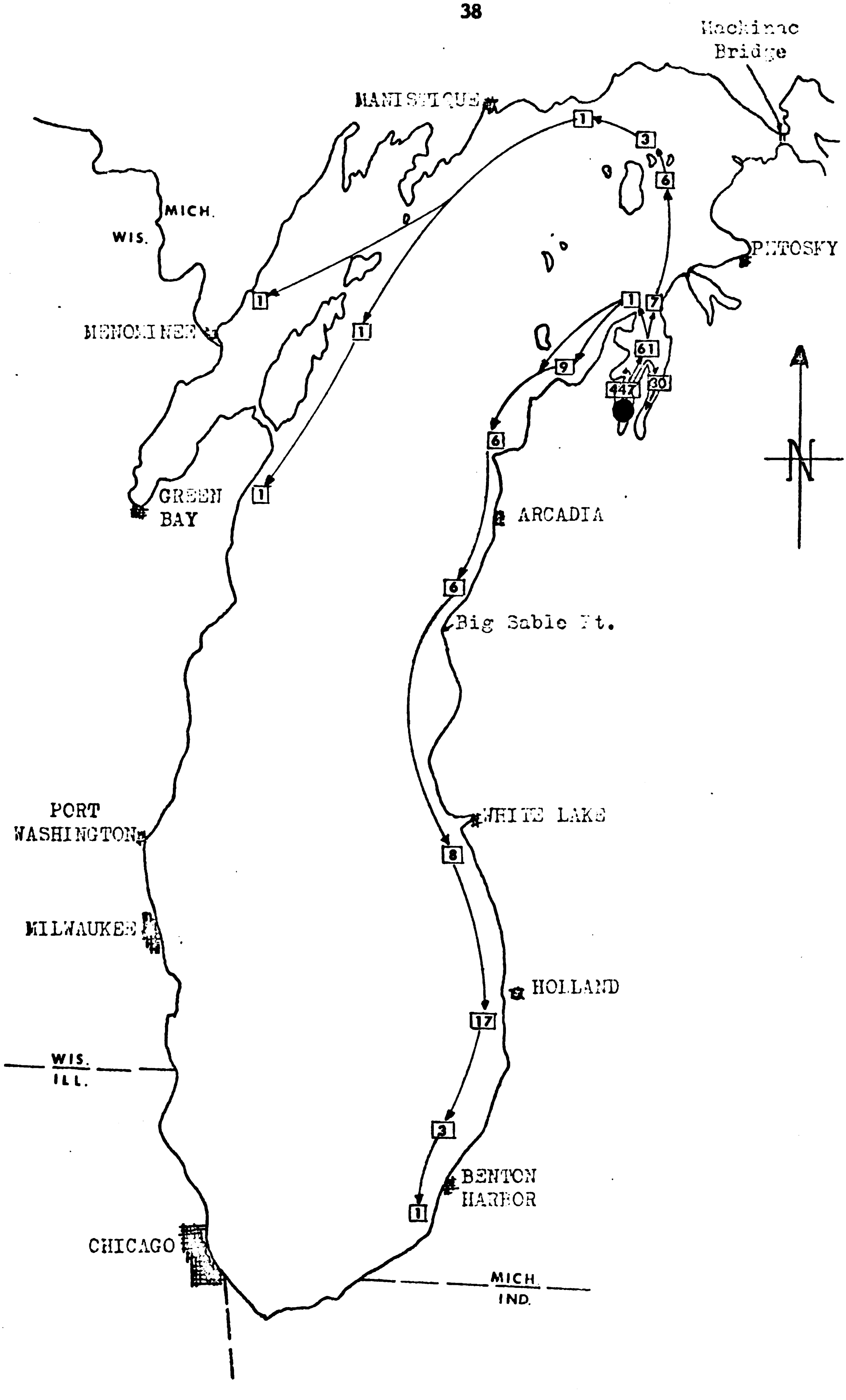
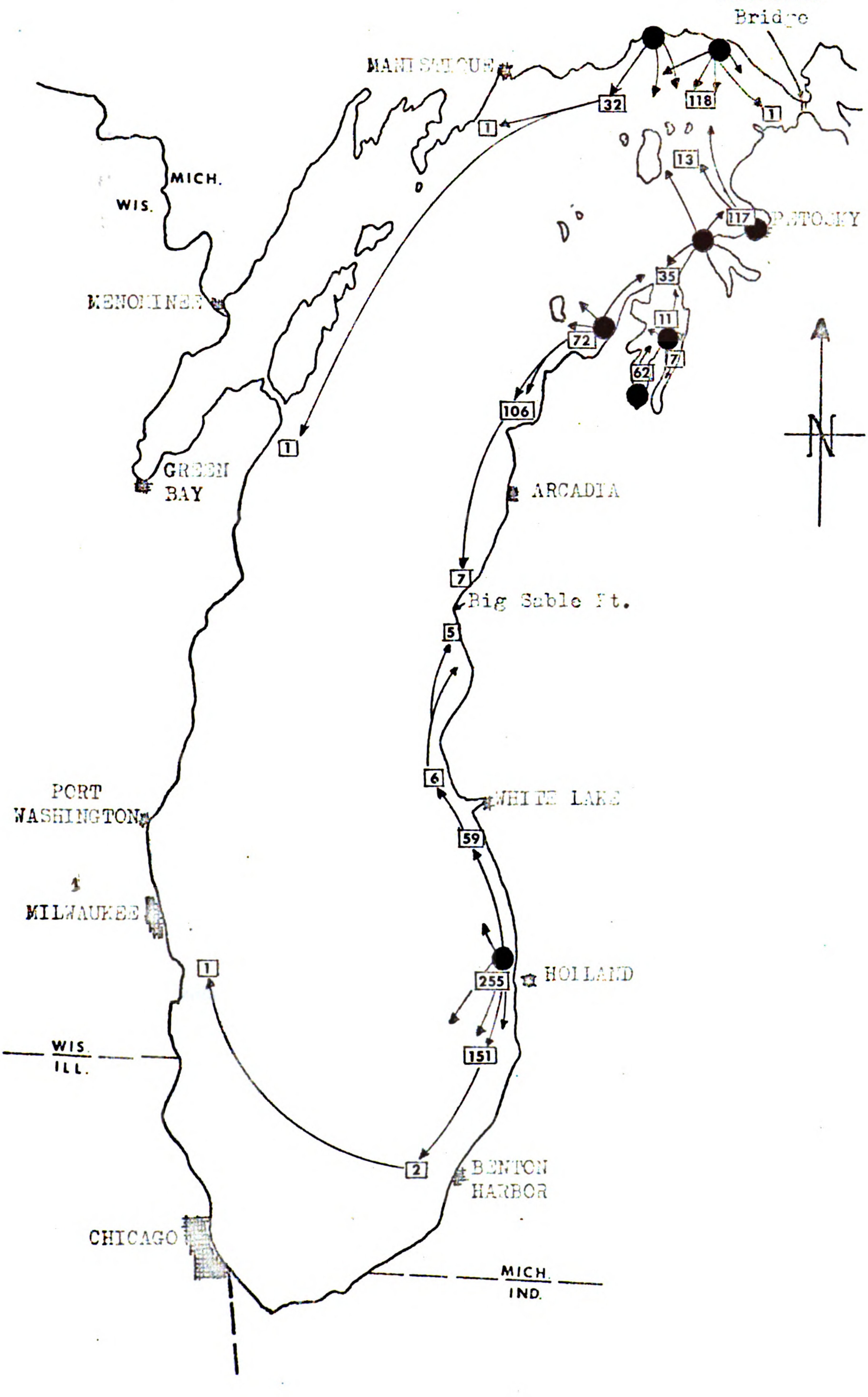

Mackinac Bridge
MANISTIQUE
1
3
6
MICH.
WIS.
PETOSKY
1
1
7
MENOMINEE
1
61
9
447
30
6
1
GREEN BAY
ARCADIA
N
6
Big Sable Pt.
PORT WASHINGTON
WHITE LAKE
8
MILWAUKEE
HOLLAND
17
WIS.
ILL.
3
BENTON HARBOR
1
CHICAGO
MICH.
IND.

Figure 7. Localities and number of returns of hatchery-reared lake trout having the "RP" clip. Black circles are planting localities and open rectangles give the number of fish caught in each area; arrows indicate probable direction of movement.


Mackinac Bridge
MANISTIQUE
32
118
1
1
13
117
PETOSKY
35
11
72
17
62
106
MICH.
WIS.
MENOMINEE
1
GREEN BAY
ARCADIA
N
7
Big Sable Pt.
5
6
WHITE LAKE
59
PORT WASHINGTON
MILWAUKEE
1
255
HOLLAND
151
WIS.
ILL.
2
BENTON HARBOR
CHICAGO
MICH.
IND.

southwest of Ludington. Movements show a trend of even dispersal both north and south along the shore (Figure 8). Of the total recaptures for the two years combined, 29.8 per cent were recovered in statistical districts north of MM 6 while 22.6 per cent were taken south of MM 6. The difference may be due only to differential fishing intensity.

"BV" Clip - Milwaukee Reef

The "BV" (both ventrals) clip was represented by a plant of 201,530 yearling lake trout released in 1966 from a ferry in mid-lake near the interstate boundary (Figure 9). Fishing pressure in the area of planting was slight. Only 51 recoveries of this clip were reported. The principal movement out of the area was eastward and then northward along the Michigan shoreline. No recoveries were reported in Wisconsin waters.

"Ad" Clip - Door Peninsula and Kewaunee

The "Ad" (adipose) clip was represented by 204,600 lake trout released in 1965 from two Wisconsin locations. Fish from these plantings were recaptured in every district sampled with exception of WM 1 and WM 6. The majority of the recaptures were in the vicinity of the two planting sites. Figure 10 indicates that movement was probably in both directions - north into Michigan waters and Green Bay, and south along the Wisconsin shore.

Figure 8. Localities and number of returns of hatchery-reared lake trout having the "D-RV" clip. Black circles are planting localities and open rectangles give the number of fish caught in each area; arrows indicate probable direction of movement.

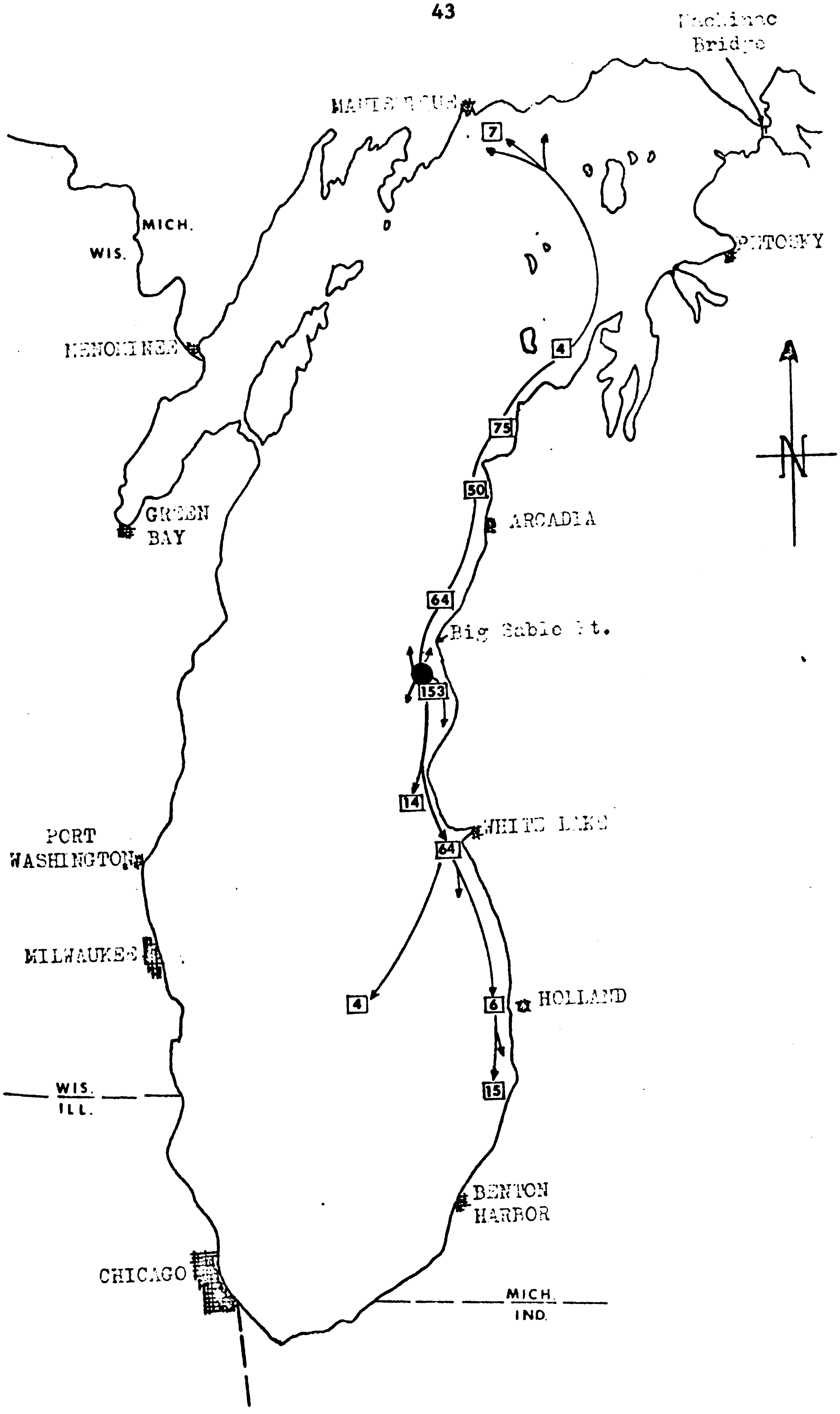

Mackinac Bridge
MANISTIQUE
7
PETOSKEY
MICH.
WIS.
MENOMINEE
4
75
50
GREEN BAY
ARCADIA
N
64
Big Sable Pt.
153
14
WHITE LAKE
64
PORT WASHINGTON
MILWAUKEE
4
6
HOLLAND
15
WIS.
ILL.
BENTON HARBOR
CHICAGO
MICH.
IND.

Figure 9. Localities and number of returns of hatchery-reared lake trout having the "BV" clip. Black circles are planting localities and open rectangles give the number of fish caught in each area; arrows indicate probable direction of movement.

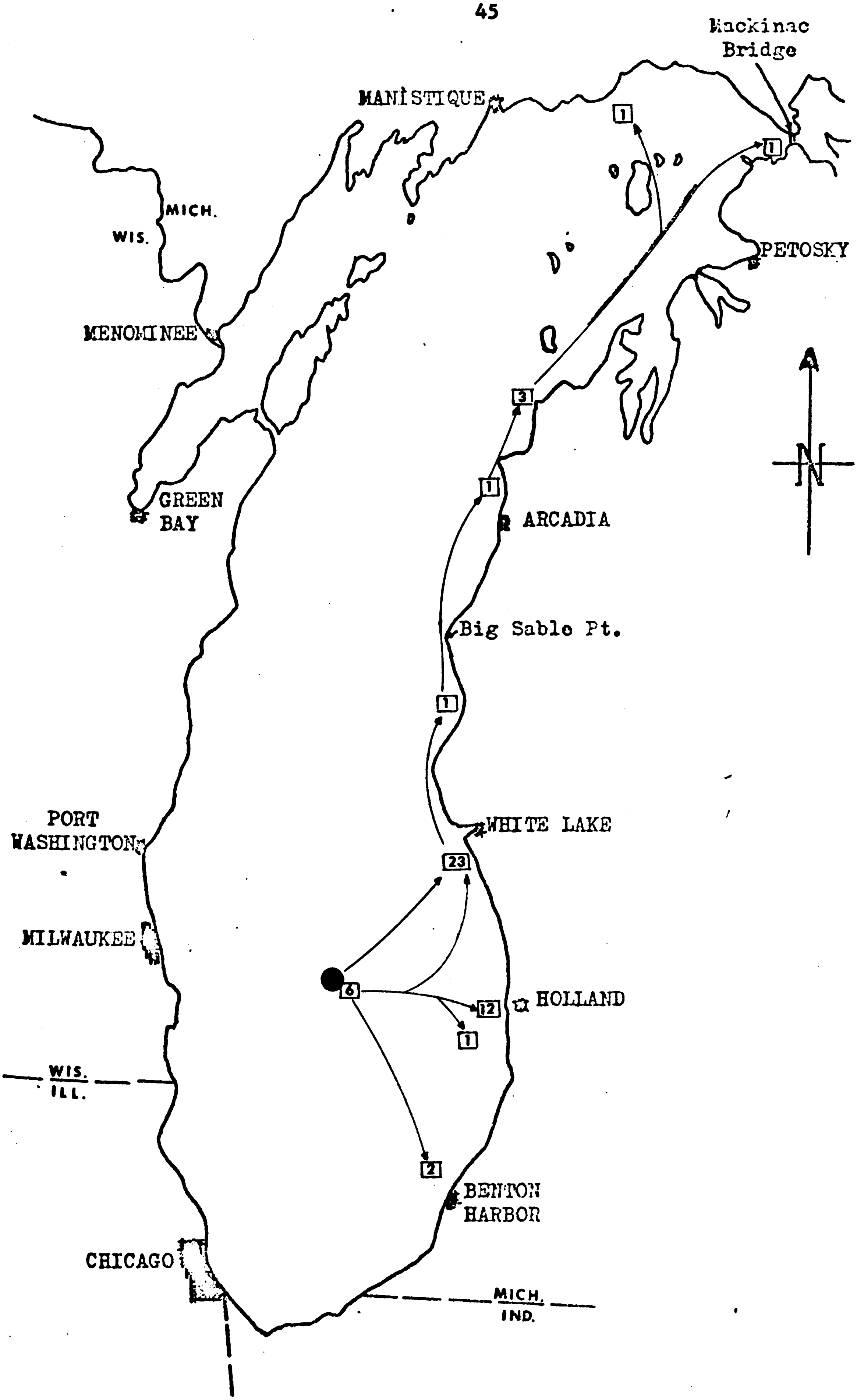
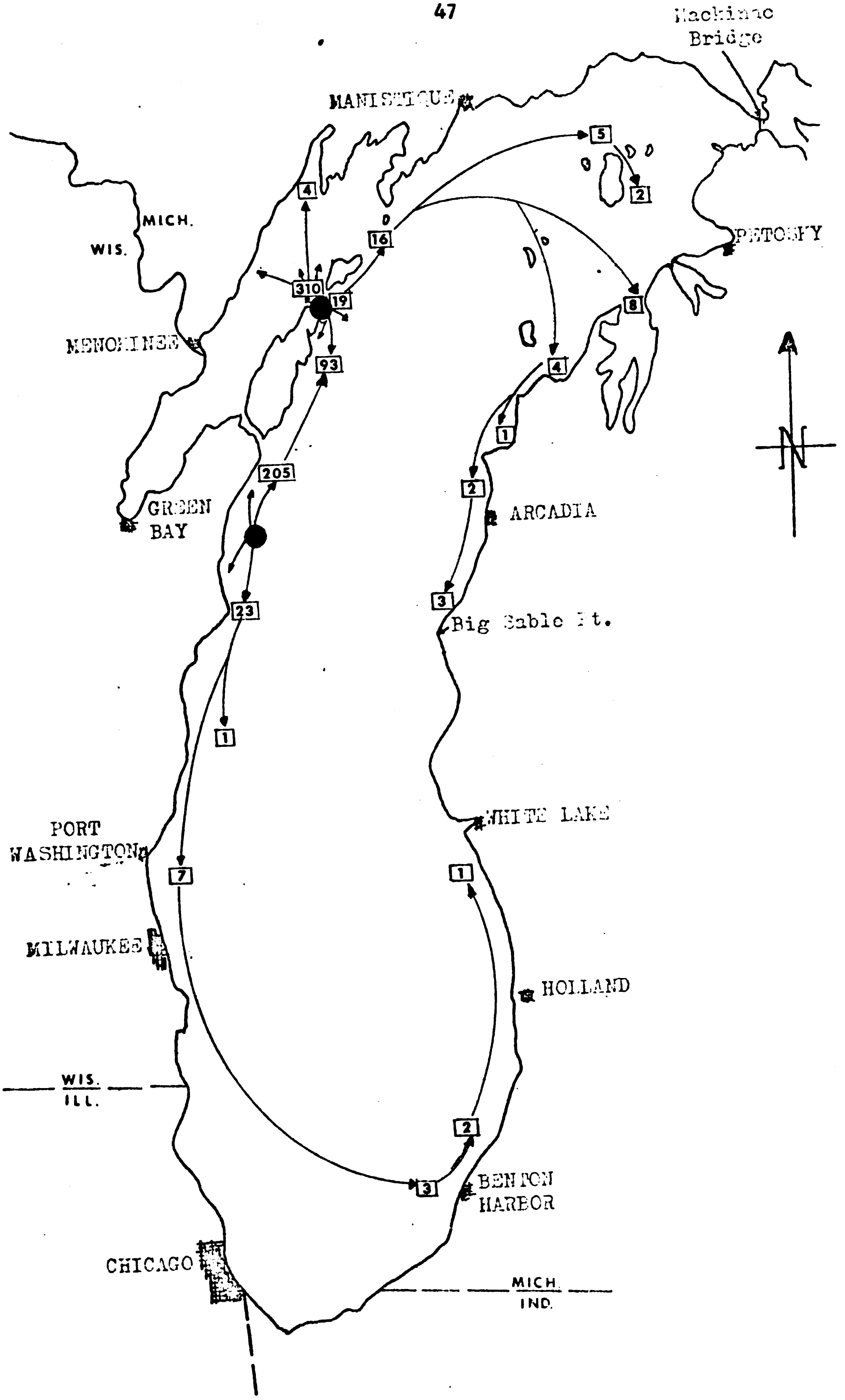

Mackinac Bridge
MANISTIQUE
1
1
MICH.
WIS.
PETOSKY
MENOMINEE
3
GREEN BAY
1
ARCADIA
Big Sable Pt.
1
PORT WASHINGTON
WHITE LAKE
23
MILWAUKEE
6
12
HOLLAND
1
WIS.
ILL.
2
BENTON HARBOR
CHICAGO
MICH.
IND.
N

Figure 10. Localities and number of returns of hatchery-reared lake trout having the "Ad" clip. Black circles are planting localities and open rectangles give the number of fish caught in each area; arrows indicate probable direction of movement.


Mackinac Bridge
MANISTIQUE
MICH.
WIS.
MENOMINEE
GREEN BAY
PETOSKY
ARCADIA
Big Sable Pt.
WHITE LAKE
HOLLAND
PORT WASHINGTON
MILWAUKEE
WIS.
ILL.
BENTON HARBOR
CHICAGO
MICH.
IND.
N
4
310
19
16
93
205
23
1
7
5
2
8
4
1
2
3
1
2
3

"LP" Clip - Door Peninsula and Kewaunee

The "LP" (left pectoral) clip was represented by 369,100 lake trout released in 1966 from two sites along the Door Peninsula and a third site at Kewaunee, Wisconsin (Figure 11). Distribution of recoveries was very similar to lake trout having the "Ad" clip. The majority of samples were recovered in the localities of the planting sites. A few fish had moved into Michigan waters, apparently following the shoreline around both ends of the lake. In contrast to the "Ad" clip, very few fish of this group dispersed into waters of Green Bay.

"D-LV" Clip - Green Bay

The "D-LV" (dorsal-left ventral) clip was represented by 190,300 yearing lake trout released in Green Bay in 1966. Recovery data from this plant indicate a northward trend of movement, with the majority of recaptures made within MM 1. Small numbers moved along the northern shore into Michigan waters (Figure 12).

There was little evidence that the lake trout moved southward along the Wisconsin shoreline. In general, dispersal appeared to be slight, with only 16 recoveries outside of Green Bay waters.

Discussion of Movements

Previous documentation of lake trout movement patterns in Lake Michigan is limited. A study by Smith and Van Oosten (1940), based on 1416 tagged native lake trout averaging 12.8 inches, indicated

Figure 11. Localities and number of returns of hatchery-reared lake trout having the "LP" clip. Black circles are planting localities and open rectangles give the number of fish caught in each area; arrows indicate probable direction of movement.

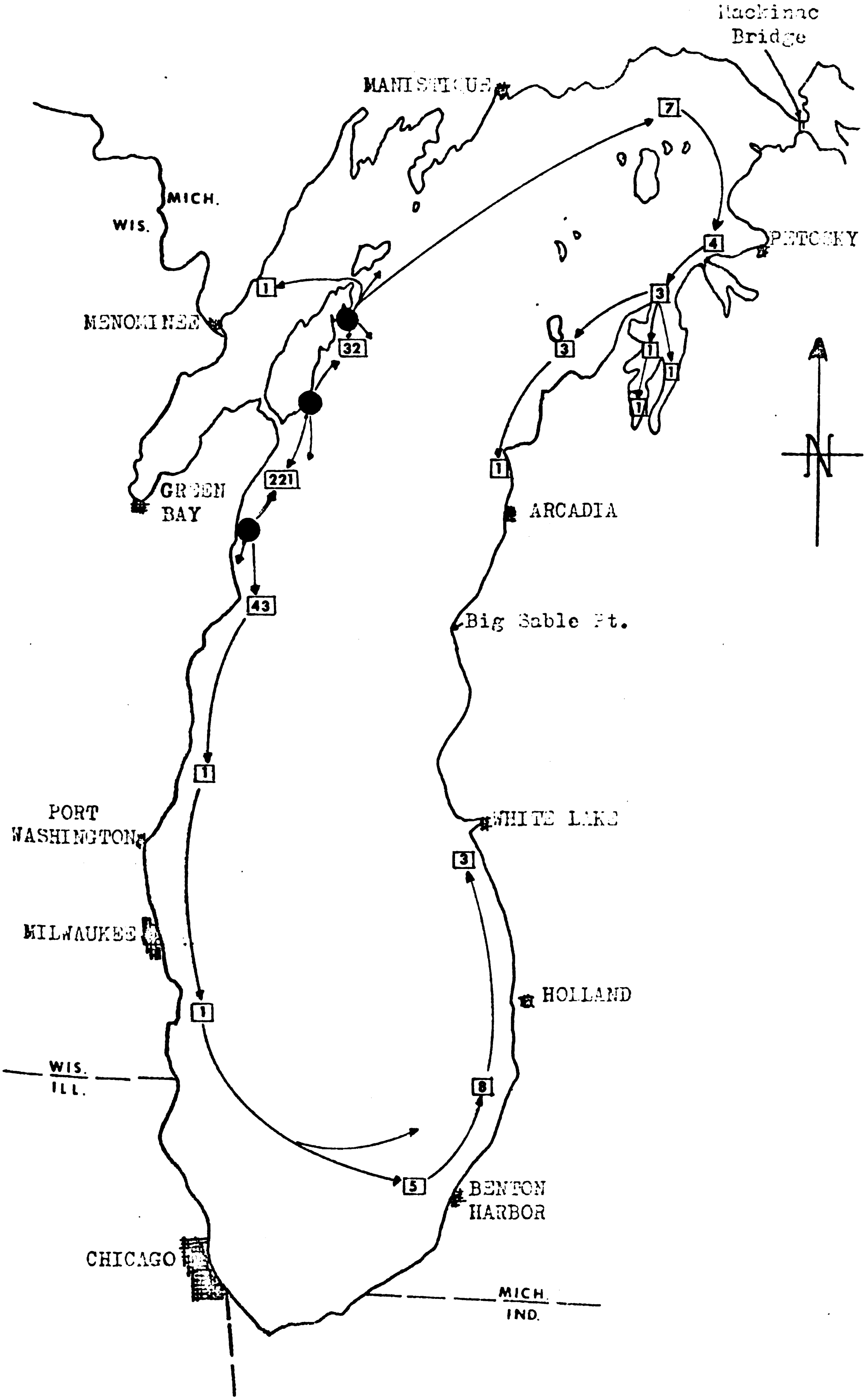
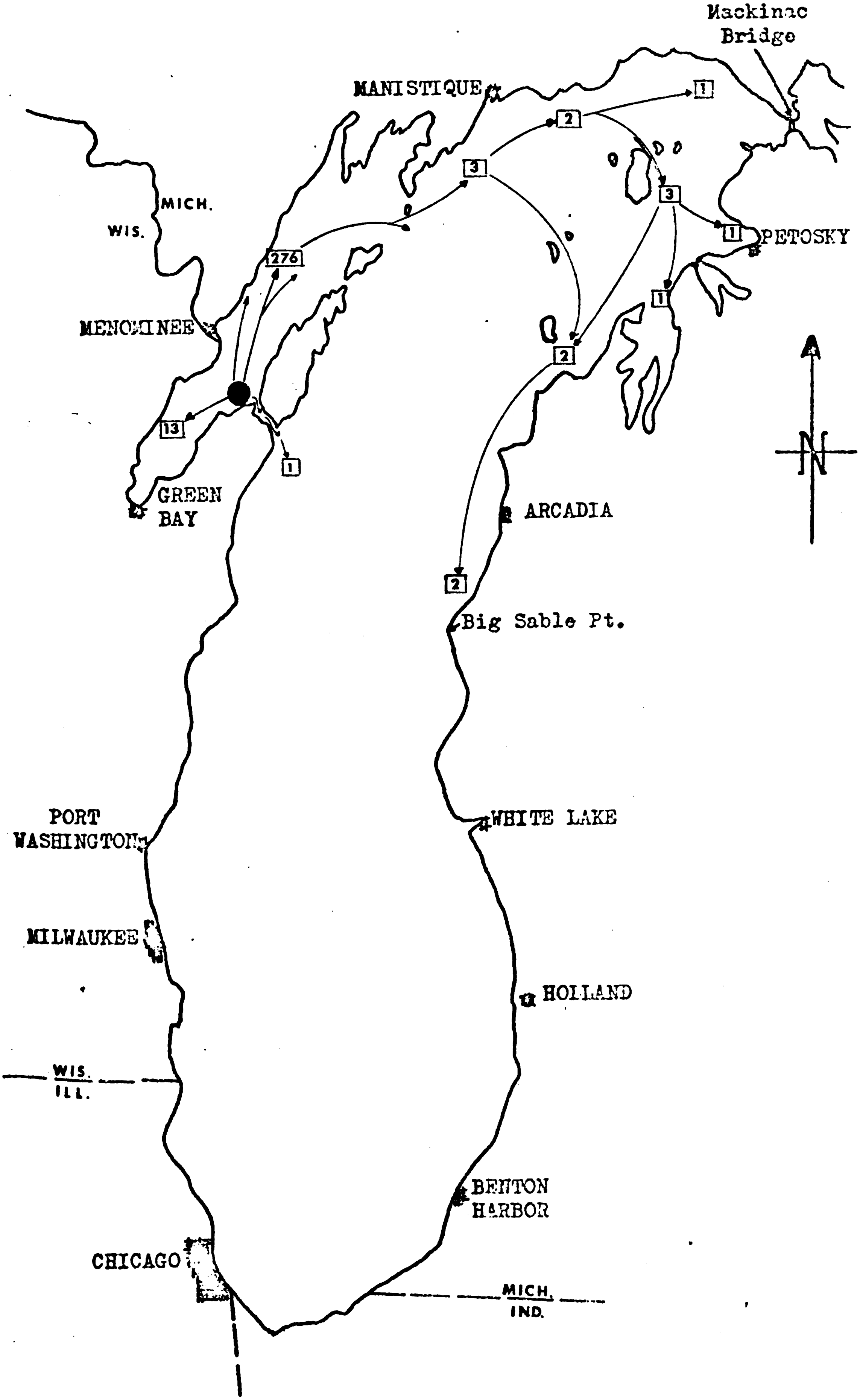

Mackinac Bridge
MANISTIQUE
7
MICH.
WIS.
PETOSKY
4
1
3
MENOMINEE
32
3
1
1
1
221
1
GREEN BAY
ARCADIA
43
Big Sable Pt.
1
PORT WASHINGTON
WHITE LAKE
3
MILWAUKEE
HOLLAND
1
WIS.
ILL.
8
5
BENTON HARBOR
CHICAGO
MICH.
IND.
N

Figure 12. Localities and numbers of returns of hatchery-reared lake trout having the "D-LV" clip. Black circles are planting localities and open rectangles give the number of fish caught in each area; arrows indicate probable direction of movement.


Mackinac Bridge
MANISTIQUE
1
2
3
3
1
PETOSKY
1
MICH.
WIS.
276
MENOMINEE
2
13
1
GREEN BAY
ARCADIA
2
Big Sable Pt.
N
PORT WASHINGTON
WHITE LAKE
MILWAUKEE
HOLLAND
WIS.
ILL.
BENTON HARBOR
CHICAGO
MICH.
IND.

that after one year of liberty 73 per cent of the recaptures were still within 25 miles of the release site. In the present study, the majority of immature hatchery-reared lake trout appear to have remained in the general areas of release even after three years at liberty. However, movement which did occur away from planting sites was very extensive with distances as great as 290 miles between point of release and point of recapture.

Movement away from planting sites tends to be a gradual dispersal in directions along preferred depth contours; movement to offshore waters was limited. The one case where offshore movement was exhibited was the north shore plant (MM 3) which showed dispersal to nearly all areas within the district, both along the shore and offshore. Immature lake trout tend to inhabit water depths of 10-50 fathoms (range of greatest abundance: 20-29 fathoms); they were seldom taken in depths greater than 60 fathoms (Table 3, page 20). Water depth in MM 3 is relatively shallow (approximately 90 per cent of the area is less than 40 fathoms), whereas the majority of the other districts have depths of 10-50 fathoms only near the shore. Pycha, et al., (1965) found concentrations of planted lake trout in Lake Superior also limited to the areas along the shoreline or at least in waters of less than 50 fathoms. It appears that depth preferences are important in geographic distribution.

The contribution of Michigan planted trout to Wisconsin's total catch appears to be substantial, accounting for 36.5 per cent of

Wisconsin's total recaptures. Wisconsin releases made a lesser contribution to the total catch of fish within Michigan waters amounting to only 2.0 per cent. Total recaptures were much greater in Michigan waters, however. The total releases in Michigan waters were 2,226,698 during 1965 and 1966 while only 764,000 were released in Wisconsin.

SIZE AT CAPTURE

With information about the fin-clip and the date of recapture, each fish can be assigned to an age group. Table 8 presents the length distribution by age groups for 20,015 recaptured lake trout having fin-clips that corresponded to specific plantings during 1965 and 1966.

Each age group represents fish of a wide range of lengths. This wide range can be largely explained by the sampling season being extended throughout the year of growth. Some of the extremely large fish assigned to age groups I and II may be the result of recaptures of marked fish from a few experimental plants made during the years of 1960-1962. LV, RV, LP, and RP are clips which had been used in these earlier plants and duplicated in either 1965 or 1966. The analysis was executed by a computer program with no means of detecting and eliminating these larger fish.

Because of errors in reporting, and occasional mis-clipping in the hatcheries, one would not expect this method of assigning ages to fish to be completely accurate. However, the extreme values should not significantly bias average lengths at time of capture for the individual age groups.

The average lengths for age groups I, II, and III were 7.93 inches, 11.28 inches, and 15.68 inches showing increments of 3.35 and 4.40 inches for the second and third years, respectively. These

Table 8. Length distribution of the age groups of marked lake trout recaptured in Lake Michigan, 1966 and 1967.

Total Length (inches)	Age Group[1]			
	I	II	III	Totals
5.0 - 5.9	26	1		27
6.0 - 6.9	154	12		166
7.0 - 7.9	219	53	2	274
8.0 - 8.9	142	161	2	305
9.0 - 9.9	93	385	10	488
10.0 - 10.9	79	762	33	874
11.0 - 11.9	49	1083	110	1242
12.0 - 12.9	11	731	319	1061
13.0 - 13.9	9	461	966	1436
14.0 - 14.9	7	287	2017	2311
15.0 - 15.9	1	148	3352	3501
16.0 - 16.9	1	55	3457	3513
17.0 - 17.9		33	2428	2461
18.0 - 18.9		13	1341	1359
19.0 - 19.9	2	6	628	636
20.0 - 29.9		4	250	254
21.0 - 21.9		2	83	85
22.0 - 22.9			11	11
23.0 - 23.9			6	6
24.0 - 24.9			1	1
24.0 - 25.9	2			2
26.0 - 26.9	1			1
27.0 - 27.9		1		1
Totals	796	4203	15016	20015

---

[1] Some of the extreme values for age groups I and II may be the result of recaptures of marked fish of experimental plants of 1960-1962. LV, RV, LP, and RP are clips which had been used in these earlier releases.

increments compare quite closely to values to be brought out in a later discussion of computed growth.

GROWTH

Cable (1956) confirmed the validity of the reading of annuli on scales as a method of aging lake trout. As a check on the use or marks on planted lake trout for determining age and for back-calculations of length, scale samples were collected from 402 lake trout captured in Michigan waters of Lake Michigan. These fish were captured in a variety of gears. Of the total, 184 (45.8 per cent) were taken in small-mesh gill nets, 141 (35.1 per cent) in large-mesh gill nets, 66 (16.4 per cent) in trawls, 9 (2.2 per cent), in impoundment gears, and 2 (0.5 per cent) in an unknown gear type. Samples were combined to minimize bias due to gear selectivity and to provide the widest possible range of lengths.

The total length of each fish was determined to the nearest 0.1 inch. The length composition of the lake trout used in the growth study is given in Table 9 for each of the five statistical districts from which samples were obtained.

Body-Scale Relation and Calculation of Growth

The scales for the growth study were taken from the area below the origin of the dorsal fin and just above the lateral line. Cellulose acetate impressions were made of all scales using a scale press of the type described by Smith (1954). The impressions were magnified 80X and projected onto a frosted glass screen by an Eberbach micro-projector. For each of the scales, the total scale diameter and the

Table 9. Length distribution and area of capture for 402 lake trout from which scale samples were obtained.

Length Interval (inches)	Statistical District					
	MM 3	MM 4	MM 5	MM 7	MM 8	Totals
5.0 - 5.9						
6.0 - 6.9	1				1	2
7.0 - 7.9	5				12	17
8.0 - 8.9	16				16	32
9.0 - 9.9	5			1	20	26
10.0 - 10.9	19		1	4	3	27
11.0 - 11.9	39	4	2	11	4	60
12.0 - 12.9	25	4	2	7		38
13.0 - 13.9	40	4		5	1	50
14.0 - 14.9	42	2				44
15.0 - 15.9	18	2				20
16.0 - 16.9	18	2				20
17.0 - 17.9	28					28
18.0 - 18.9	21					21
19.0 - 19.9	9	2				11
20.0 - 20.9	2	2				4
21.0 - 21.9		1				1
22.0 - 22.9						
23.0 - 23.9		1				1
Totals	288	24	5	28	57	402

diameters at each of the annuli were measured to the nearest millimeter along an imaginary line that passed through the focus and bisected the anterior and posterior fields.

The body-scale relation was determined from the average diameters of two scales from each of 392 fish. Ten samples (2.5 per cent) were discarded because of poorly defined annuli or too few scales.

Van Oosten and Eschmeyer (1956) and Cable (1956) supported the use of scale diameters rather than scale radii for lake trout growth calculations. Van Oosten and Eschmeyer state that lengths computed from radial measurements have been found to be too low in nearly all species of fish. In addition, diameters tend to be less variable than either the anterior or posterior radii (Van Oosten, 1929).

Rahrer (1967), also using scale diameters rather than scale radii, found the body-scale relationship for lake trout in Lake Superior to be curvilinear. The least-squares technique showed the relationship in the present study to be more strongly linear than curvilinear with simple correlation coefficients of 0.9278 and 0.9095, respectively. The linear equation describing the means of magnified scale diameters to the total body length was found to be:

$$L = 0.538 + 0.0788\ S$$

where L is total length in inches, S is the magnified scale diameter in millimeters, 0.0788 is the slope of the regression, and 0.538 is the y-intercept value.

Back-calculated lengths were derived from the direct proportion equation:

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

where L' equals the body length when annulus x was formed, S' is the field within annulus x, S is the total scale diameter, L is the body length at capture, and C is the y-intercept (alpha) from the total length-scale diameter equation above.

The average lengths at capture and back-calculated lengths for age groups I, II, and III (year classes combined) are shown in Table 10. Growth data were analyzed separately for the upper and lower regions of Lake Michigan; computations were also made with all samples combined. The upper region is represented by samples from Statistical Districts MM 3, MM 4, and MM 5. The lower region had fish from MM 7 and MM 8.

Note that calculated lengths for age groups I and II from the lower region were considerably smaller than corresponding lengths for the upper region. These differences may be a result of gear selectivity rather than actual differences in growth rates. As evidence of this, one would expect the length at the end of the first year of life to be approximately the same for both regions as a result of nearly identical rearing histories prior to planting. Because no age group III fish were represented in samples from the lower region, no comparisons of growth histories can be made between the two regions for this age group.

Table 10. Total length at capture and lengths calculated by direct proportion from diameters of annuli on the scales of marked lake trout; age groups I, II, and III. Year classes are combined; lengths are in inches.

Age Group	Area	Number of Specimens	Average Length at Capture	Calculated length at end of year of life		
				1	2	3
I	Upper	20	8.27	6.66		
	Lower	51	8.72	5.72		
	Combined	71	8.59	5.93		
II	Upper	184	12.75	6.31	10.11	
	Lower	34	11.76	5.88	9.25	
	Combined	218	12.60	6.24	9.98	
III	Upper	103	17.16	7.15	11.19	15.19
	Lower	---	---	---	---	---
	Combined	103	17.16	7.15	11.19	15.19
Number of Specimens				392	321	103
Mean increment of growth in length				6.43	3.91	4.00
Length from summation of increments				6.43	10.34	14.34

The data show that with all samples combined, the calculated lengths for a particular year of life become progressively higher with increasing age. Such an occurrence is the inverse of what is commonly described as "Lee's phenomenon." Back-calculated lengths computed by Cable (1956) showed decreasing values with increasing age (Lee's phenomenon) for age groups III to VI. This was explained to be the result of selective mortality for the larger individuals by both the sea lamprey and the commercial fishery. In contrast, age groups I, II, and III in the present study are not being subjected greatly to either of these selective factors because they are still too small for heavy lamprey predation and are not being exploited by the fishery. The inverse of Lee's phenomenon, then, might be exhibited in these samples because of selectivity by gears. The majority of age group I fish were obtained by trawls while groups II and III fish were captured in gill nets (refer to earlier section for the selective action of these gears). Gill nets would tend to select for faster growing fish of these lower age groups than do trawls.

In view of the above factors, the author believed the best overall estimate of growth rate for juvenile planted lake trout to be the mean increments of growth for each year of life as are given in the lower portion of Table 10. This method shows the mean annual increments of growth for the first three years of life to be 6.43, 3.91, and 4.00 inches. Cable (1956) reported increments of 5.9, 2.8, and 2.5 inches for age groups I, II, and III while Van Oosten and Eschmeyer's (1956) data indicated corresponding values of 3.4, 3.7, and 3.0. Fish studies by Cable were principally recoveries from plantings of hatchery-reared fingerlings; data from Van Oosten and Eschmeyer were for native lake trout.

The mean lengths at the end of successive years of growth were obtained by the summation of mean calculated increments of length. Table 11 compares the mean lengths of the present study to those of Cable and Van Oosten and Eschmeyer. For areas combined, lengths were greater for each year of life during the present study than for either of the previous reports (for a graphic illustration of this comparison, see Figure 13).

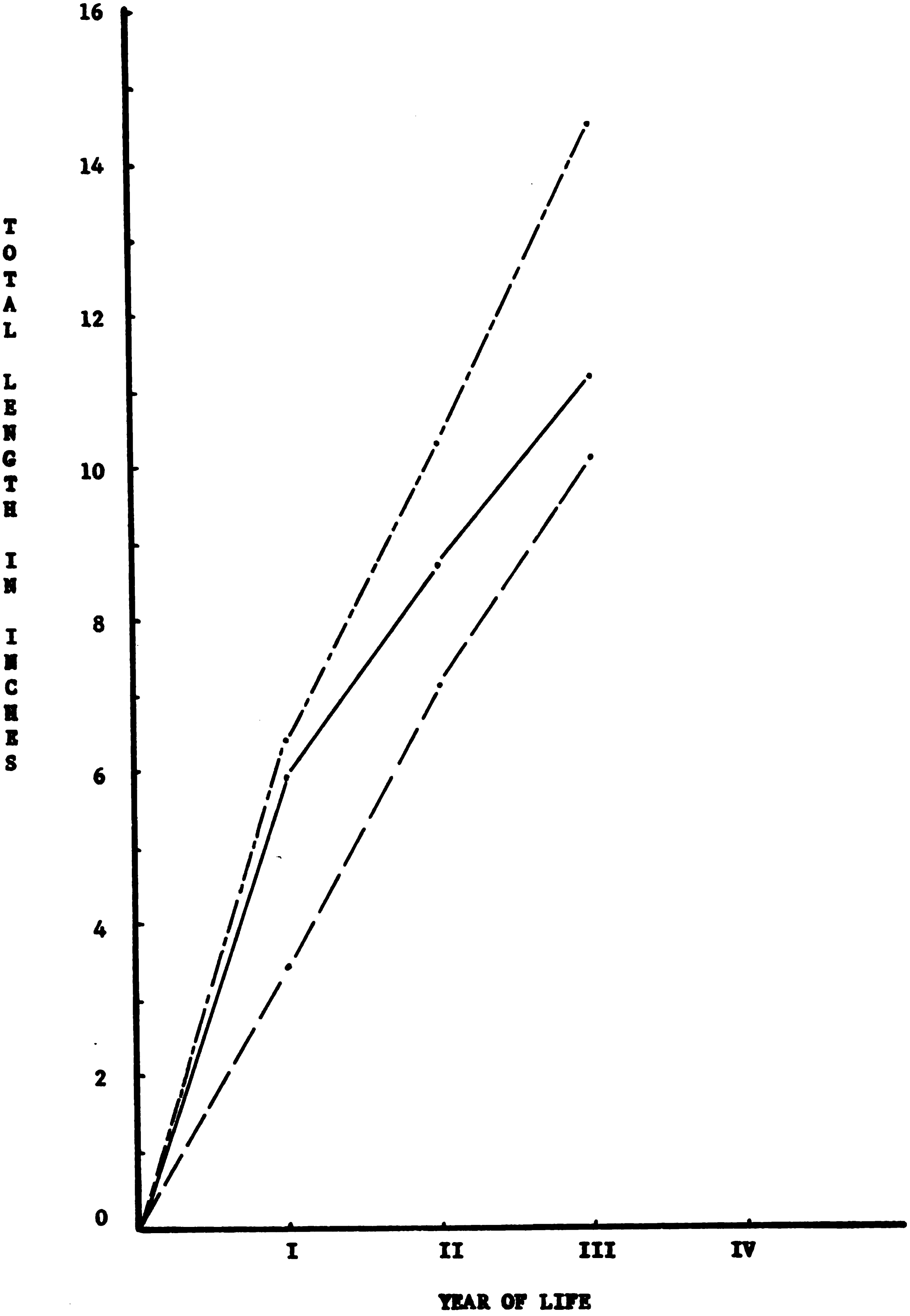
The increased rate of growth exhibited by lake trout of the present study over growth rates in the 1920's and 1940's may reflect an advantage attained by the longer period of hatchery growth and the subsequent increased length at age I. This advantage obviously carries over into later years as is evidenced by the differences at age III.

While the differences in length at age I can be explained by hatchery growth, the increased increments of growth for the second and third years shown by the current study over previous periods may be due partially to other factors. Low lake trout population levels during the present study period could result in less intraspecific competition than occurred during earlier periods before the decline

Table 11. Growth of lake trout for northern Lake Michigan, southern Lake Michigan, and areas combined. All values are from grand average increments based on calculated lengths at the end of the indicated years of life.

Area and Author	Year Classes	Total Length (inches) from Summation of Increments		
		1	2	3
Northern L. Michigan				
Cable (1956) MM 4-6	'44-'46	6.9	10.0	12.8
Hesse (present report) MM 3, 4, and 5	'64-'66	6.8	10.7	14.7
Southern L. Michigan				
Cable (1956) MM 7-8	'44-'46	5.6	8.8	12.1
Hesse (present report) MM 7-8	'64-'66	5.8	9.2	____
All Areas				
Van Oosten and Eschmeyer (1956)	'22-'30	3.4	7.1	10.1
Cable (1956) MM 4-8	'44-'46	5.9	8.7	11.2
Hesse (present report) MM 3, 4, 5, 7, and 8	'64-'66	6.4	10.3	14.3

Figure 13. Calculated growth in length (from summation of increments) for the present study (dash-dot line), from Cable (1956) (solid line), and from Van Oosten and Eschmeyer (1956) (dashed line).


16
14
12
10
8
6
4
2
0
TOTAL LENGTH IN INCHES
I
II
III
IV
YEAR OF LIFE

of the stocks. Other drastic ecological changes which have taken place in Lake Michigan such as the severe changes in species composition (Smith, 1968) undoubtedly affect present lake trout growth.

LENGTH-WEIGHT RELATION

Data on both length and weight were obtained for a total of 2,253 lake trout over the period of study. These samples were collected with a variety of gear types and include recaptures during each of the seasons. Lengths and weights were taken by Department personnel either during on-board and dock inspections of commercial fishing vessels or were obtained after the samples had been brought to the laboratory.

The equation used to express the length-weight relation in fishes is:

$$\mathrm{Log}_{10}W = \mathrm{Log}_{10}c + n\ \mathrm{Log}_{10}L$$

where W is weight in ounces, L is total length in inches, c is the y-intercept, and n is the slope of the regression.

Equations describing the relationship for the three general lake regions of Lake Michigan and for the total sample are presented in Table 12.

The equation found for the upper Lake Michigan sample compared very closely to the equation reported by Cable (1956) for a sample of 1,197 planted lake trout from northern Lake Michigan:

$$\mathrm{Log}_{10}W = -2.4698 + 3.1125\ \mathrm{Log}_{10}L$$

The study by Cable was of planted fish of year classes 1944, 1945 and 1946. Recoveries of these plantings were made between the years of 1947 and 1952, a period characterized by the crash of the lake

Table 12. Length-weight relationships for lake trout in the upper region, lower region, and Wisconsin waters of Lake Michigan; also for regions combined. R = correlation coefficient.

Area	Number of Fish	Length-weight Relation	R
Upper Lake	1583	$Log_{10}W = -2.4484 + 3.1727\ Log_{10}L$	0.9711
Lower Lake	616	$Log_{10}W = -2.4622 + 3.2034\ Log_{10}L$	0.9652
Wisconsin	54	$Log_{10}W = -2.1141 + 2.8224\ Log_{10}L$	0.9772
Combined Regions	2253	$Log_{10}W = -2.4007 + 3.1309\ Log_{10}L$	0.9829

trout stocks in Lake Michigan.

An earlier study by Eschmeyer and Van Oosten (1956) provides an estimate of the relationship during the pre-lamprey period. Data for the study were from lake trout collected during the years of 1930-32. The resulting equation was as follows:

$$\mathrm{Log}_{10}W = -5.4652 + 3.1377\ \mathrm{Log}_{10}L$$

where W is weight in grams, and L is total length in millimeters. Samples were collected from extensive regions of Lake Michigan. Figure 14 shows a comparison of the above relationship to the relationship presented in the current study for regions combined. The curves indicate that the lake trout planted in Lake Michigan since 1965 are more robust throughout the length range sampled than the native lake trout of the earlier study of Van Oosten and Eschmeyer.

The relationships for the three lake regions in the present study show a marked difference between fish collected in Michigan waters as compared to fish from Wisconsin waters of Lake Michigan. Note that the value of "n" is greater than 3 for sampled from the upper and lower regions, indicating that these fish became progressively more robust with increase in length. The Wisconsin sample, on the other hand, has an "n" value of 2.8224. This shows that these lake trout are neither as robust as lake trout of the other two regions nor do they conform to the "cube law." The differences may result from the smaller sample size (54 observations) from which the relationship was computed for the Wisconsin region. Further study is

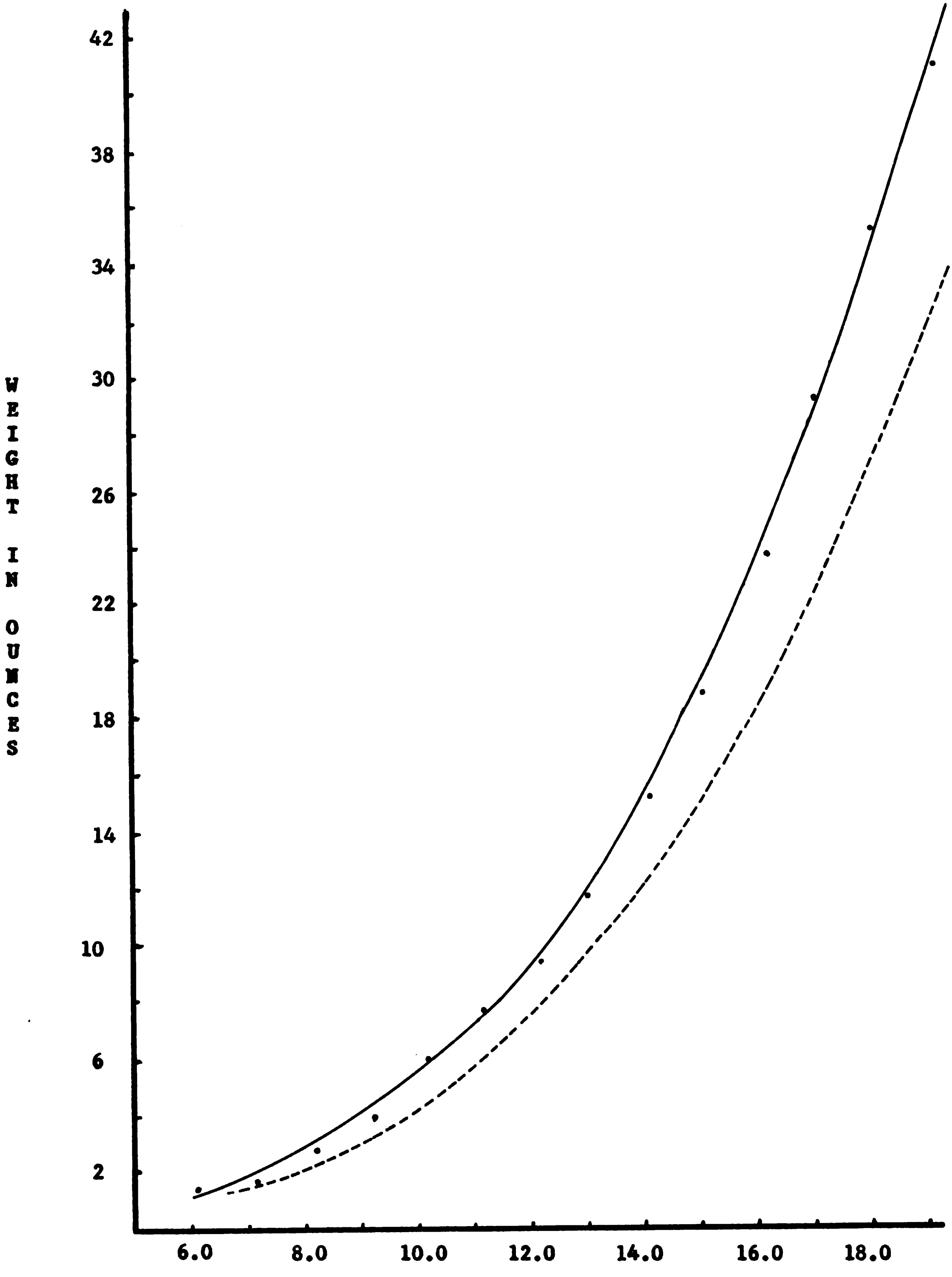
Figure 14. Length-weight relations of lake trout of Lake Michigan. The solid line represents the relation presented in the present study for regions combined:

$$\mathrm{Log}_{10}W = -2.4007 + 3.1309\ \mathrm{Log}_{10}L$$

The dots about that line show the empirical weights. The dashed line describes the relation presented by Van Oosten and Eschmeyer (1956):

$$\mathrm{Log}_{10}W = -5.4652 + 3.1377\ \mathrm{Log}_{10}L$$

(The upper equation was based on length in inches and weight in ounces; the second equation was in millimeters and grams.)


WEIGHT IN OUNCES
42
38
34
30
26
22
18
14
10
6
2
6.0
8.0
10.0
12.0
14.0
16.0
18.0
TOTAL LENGTH IN INCHES

necessary to determine more specific explanations for the differences. Smith (1956) points out that the relation between length and weight in a population can vary with respect to sex, season, method of capture, and year of capture. In order to segregate the data according to all of these variables, much larger sample sizes would be necessary.

PREDATION BY SEA LAMPREYS

Predation by the sea lamprey, Petromyzon marinus, was one of the primary causes of the decline of the lake trout fishery in the 1940's. In order to evaluate the success of the lamprey control program which began in Lake Michigan in 1960, close attention has been given to the incidence of lamprey scarring in all samples of lake trout since their reintroduction in 1965.

Tables 13a, 13b, and 13c summarize the lamprey wounding rates for 20,541 lake trout collected during 1966 and 1967. The data are presented according to total length of fish (1-inch intervals) for each year by regions of the lake. No attempt was made to distinguish between fresh and old scars.

Records from upper Lake Michigan showed the heaviest scarring rates of the three lake regions for both years, with overall rate of 1.4 per cent in 1966 and 4.5 per cent in 1967. In each of these years there appeared to be a gradual increase in the rate of scarring with an increase in the length of the fish. In 1966, however, lake trout as small as 9.0 inches showed lamprey scars, while in 1967, no scarring was reported on fish less than 11.0 inches. The average size of lake trout present in the lake in 1966 was less than in 1967, thus possibly indicating that the lampreys only attack the smaller individuals when there is an absence or shortage of larger lake trout.

Table **13a.** Incidence of lamprey scarring on lake trout captured in upper Lake Michigan, 1966 and 1967. Data are analyzed according to 1-inch length intervals.

Length Interval (inches)	1966			1967		
	Number of Fish	Number with Scars	Per Cent with Scars	Number of Fish	Number with Scars	Per Cent with Scars
5.0 - 5.9	7	0	0.0	---	---	---
6.0 - 6.9	24	0	0.0	---	---	---
7.0 - 7.9	41	0	0.0	4	0	0.0
8.0 - 8.9	123	0	0.0	27	0	0.0
9.0 - 9.9	246	2	0.8	117	0	0.0
10.0 - 10.9	372	3	0.8	168	0	0.0
11.0 - 11.9	365	5	1.4	356	1	0.3
12.0 - 12.9	358	4	1.1	529	7	1.3
13.0 - 13.9	279	5	1.8	1083	17	1.6
14.0 - 14.9	170	4	2.4	2101	61	2.9
15.0 - 15.9	72	5	6.9	3445	134	3.9
16.0 - 16.9	19	1	5.3	3546	200	5.6
17.0 - 17.9	10	1	10.0	2491	161	6.5
18.0 - 18.9	5	0	0.0	1319	83	6.3
19.0 - 19.9	3	0	0.0	599	40	6.7
20.0 - 20.9	1	0	0.0	219	16	7.3
21.0 - 21.9	---	---	---	67	5	7.5
22.0 - 22.9	---	---	---	10	1	10.0
23.0 - 23.9	---	---	---	4	0	0.0
24.0 - 24.9	---	---	---	1	0	0.0
25.0 - 25.9	---	---	---	---	---	---
26.0 - 26.9	---	---	---	---	---	---
Totals	2095	30	1.4	16086	726	4.5

Table **13b.** Incidence of lamprey scarring on lake trout captured in lower Lake Michigan, 1966 and 1967. Data are analyzed according to 1-inch length intervals.

Length Interval (inches)	1966			1967		
	Number of Fish	Number with Scars	Per Cent with Scars	Number of Fish	Number with Scars	Per Cent with Scars
5.0 - 5.9	12	0	0.0	---	---	---
6.0 - 6.9	126	0	0.0	---	---	---
7.0 - 7.9	204	1	0.5	6	0	0.0
8.0 - 8.9	117	0	0.0	4	0	0.0
9.0 - 9.9	87	0	0.0	11	0	0.0
10.0 - 10.9	83	0	0.0	37	0	0.0
11.0 - 11.9	59	1	1.7	110	0	0.0
12.0 - 12.9	16	0	0.0	77	0	0.0
13.0 - 13.9	5	0	0.0	17	0	0.0
14.0 - 14.9	6	0	0.0	7	0	0.0
15.0 - 15.9	5	0	0.0	2	0	0.0
16.0 - 16.9	4	0	0.0	4	0	0.0
17.0 - 17.9	---	---	---	4	0	0.0
18.0 - 18.9	1	0	0.0	2	0	0.0
19.0 - 19.9	---	---	---	1	0	0.0
20.0 - 20.9	---	---	---	---	---	---
21.0 - 21.9	---	---	---	---	---	---
22.0 - 22.9	1	0	0.0	---	---	---
23.0 - 23.9	---	---	---	---	---	---
24.0 - 24.9	---	---	---	---	---	---
25.0 - 25.9	2	2	100.0	---	---	---
26.0 - 26.9	1	1	100.0	---	---	---
Totals	729	5	0.7	282	0	0.0

Table **13c.** Incidence of lamprey scarring on lake trout captured in Wisconsin waters of Lake Michigan, 1966 and 1967. Data are analyzed according to 1-inch length intervals.

Length Interval (inches)	1966			1967		
	Number of Fish	Number with Scars	Per Cent with Scars	Number of Fish	Number with Scars	Per Cent with Scars
5.0 - 5.9	2	0	0.0	1	0	0.0
6.0 - 6.9	8	0	0.0	---	---	---
7.0 - 7.9	12	0	0.0	1	0	0.0
8.0 - 8.9	31	0	0.0	1	0	0.0
9.0 - 9.9	35	0	0.0	7	0	0.0
10.0 - 10.9	112	0	0.0	113	0	0.0
11.0 - 11.9	252	0	0.0	117	0	0.0
12.0 - 12.9	94	0	0.0	17	0	0.0
13.0 - 13.9	61	3	4.9	14	0	0.0
14.0 - 14.9	48	0	0.0	27	0	0.0
15.0 - 15.9	40	1	2.5	41	2	4.9
16.0 - 16.9	16	3	18.8	34	2	5.9
17.0 - 17.9	11	0	0.0	46	0	0.0
18.0 - 18.9	6	0	0.0	74	1	1.4
19.0 - 19.9	1	0	0.0	56	1	1.8
20.0 - 20.9	---	---	---	43	2	4.7
21.0 - 21.9	---	---	---	24	2	8.3
22.0 - 22.9	---	---	---	1	0	0.0
23.0 - 23.9	---	---	---	2	0	0.0
24.0 - 24.9	---	---	---	1	0	0.0
25.0 - 25.9	---	---	---	---	---	---
26.0 - 26.9	---	---	---	---	---	---
Totals	729	7	1.0	620	10	1.6

Although the sample size was small for each of the years in lower Lake Michigan, scarring appeared to be very light. The overall scarring rate was 0.7 per cent in 1966 and 0.0 in 1967. However, the average size of fish captured was also considerably less than in the upper region.

Data from Wisconsin waters of Lake Michigan also indicated very light scarring in 1966 and 1967, with 1.0 and 1.6 per cent, respectively. In 1966, no lake trout smaller than 13.0 inches bore lamprey scars, and in 1967, no scars were reported on trout smaller than 15.0 inches. For the larger sized fish, however, scarring rates were quite comparable to rates for the same length intervals reported for the upper region.

Combining the lake regions and years, sublegal sized lake trout (<17.0 inches) showed a scarring rate of 3.0 per cent, while legal sized trout had a rate of 6.3 per cent. According to Crowe (pers. comm.), the scarring rate of the legal-sized lake trout at the time of the population crash was approximately 25-30 per cent. Even though the present data indicate a scarring rate much lower than this, no definite conclusions can be drawn as to the effectiveness of the lamprey control program in Lake Michigan until more of the fish reach a size which is vulnerable to predation.

SUMMARY AND CONCLUSIONS

The study was based upon recoveries of 20,642 juvenile lake trout during 1965 through 1967. The majority of the data came from reports of incidental catches of lake trout in commercial gear set for other species. Because complete information was not always available as to type or amount of gear used, depth of recovery, fin-clip designation, weight, sex, or lamprey scarring data, the total numbers of fish used in the various analyses differed from one analysis to another. A summary of sample sizes is as follows: Gear selectivity, 20,551; Bathymetric distribution, 18,342; Geographic movement, 20,642; Size at capture by age group, 20,015; Back-calculated growth, 402; Length-weight relation, 2,253; Predation by sea lampreys, 20,541.

1. The size frequency distributions of incidental catches of lake trout in four commercial gear types show a definite size specific selectivity. Impoundment gears took the largest lake trout; large-mesh gill nets, small-mesh gill nets, and trawls took progressively smaller fish. There appeared to be a corresponding age selectivity for the latter three gears.

2. The depth distribution was computed according to season by 10-fathom intervals based upon effective CPE in commercial gill nets. Lake trout were recaptured throughout a range of 0-79 fathoms. The greatest concentration during spring, summer, and fall seasons occurred at 20-29 fathoms. In the winter, the greatest concentration

was at 40-49 fathoms. Bathymetric distribution was not significantly different between males and females (χ^2values; $\alpha = .01$).

3. Geographical movement away from planting sites was a gradual dispersal in directions along preferred depth contours with very little movement to offshore waters. Movement did not appear to be either clockwise or counterclockwise. The majority of lake trout remained within the general areas of release even after three years at liberty. However, movement which did occur away from planting sites was very extensive with distances as great as 290 miles between point of release and point of recapture.

4. Michigan planted trout accounted for 36.5 per cent of Wisconsin's total recaptures while Wisconsin releases contributed only 2.0 per cent of the recoveries within Michigan waters. However, far greater numbers of trout have been planted in Michigan waters than in Wisconsin waters.

5. The length distribution of the age groups I, II, and III show a wide range within an age group and substantial overlap between age groups. This was probably due to the combining of samples over the entire growing season. The average lengths at capture were 7.93, 11.28, and 15.68 inches for the three age groups.

6. The body length-scale diameter relationship was described by the linear equation: $L = 0.538 + 0.0788\ S$. This provided the y-intercept value of 0.538 inches to be used as the correction factor in the back-calculation of growth. The mean calculated increments of growth for the first three years of life were found to be 6.43,

3.91, and 4.00 inches. Summation of these increments yielded total back-calculated lengths of 6.43, 10.34, and 14.34 inches. Compared to growth rates during periods of pre-lamprey and lamprey abundance, the present growth rate was considerably greater. The author believes that the increased growth is probably due to a combination of factors: 1) advantages gained during a longer hatchery existence, 2) less interspecific and intraspecific competition than occurred prior to the decline of the lake trout stocks, and 3) to extreme changes in species composition within the Great Lakes.

7. A length-weight relationship based on samples from upper Lake Michigan compared closely to a relationship described by Cable (1956) for lake trout in that area during the 1940's. The equation based on the entire sample of fish for which length and weight had been recorded indicated that lake trout planted in Lake Michigan since 1965 are more robust throughout the length range sampled than were native lake trout of the 1920's. Fish recaptured in Michigan waters appeared to be more robust than those from Wisconsin waters.

8. Incidence of lamprey scarring was slight for all samples. Sublegal sized lake trout (<17.0 inches) showed a scarring rate of 3.0 per cent, while legal trout had a rate of 6.3 per cent.

The author wishes to present several inherent problems researchers encounter when using commercial fisheries data for biological analyses:

a. Fishing intensity is not equal among geographical areas.

b. Sampling is limited to established fishing grounds of commercial fishermen.

c. Gear types used in the various areas vary with the species being harvested. Because of unequal vulnerability to the different gear types, data becomes difficult to interpret.

d. Use of incidental catch data, such as for the lake trout, may not be as reliable as if the species under study was being specifically sought. Commercial fishermen fish their gears in areas of greatest abundance of the particular species they desire. This may or may not be within the optimum range of the species taken incidentally.

e. Data reported by lay people may tend to lack the accuracy, consistency, and completeness that can be attained by trained personnel.

Even though the above factors limit the interpretation of commercial data, the fact that the commercial fishery provides a readily available and economical means of sampling extensive areas far overshadows the negative aspects. On the other hand, the limitations illustrate the need for increased systematic sampling through the use of well-equipped research vessels.

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