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LIFE HISTORY STUDIES OF THE LONGNOSE SUCKER, *CATOSTOMUS CATOSTOMUS*, AND THE WHITE SUCKER, *CATOSTOMUS COMMERSONI*, IN NEARSHORE EASTERN LAKE MICHIGAN NEAR LUDINGTON, MICHIGAN

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Fred E. Koehler

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By

Fred E. Koehler

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
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ABSTRACT

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Longnose suckers and white suckers taken with gill nets and trawls provided seasonal data on age, growth, maturity, fecundity, food habits, and distribution. Ages of mature fish were best determined from sections of the pectoral fin rays, while ages of immature fish were best determined from scales. The growth rate of both species approached the fastest reported in previous investigations. Suckers generally matured faster and at larger sizes in Lake Michigan than in other waters. Regression equations were developed for fecundity vs. length and weight. Suckers are bottom feeders and the most important food items of both species were chironomids, cladocerans, and amphipods. Multiple regression analysis identified water temperature, depth, photoperiod, and substrate type as important factors in explaining longnose sucker gill net catches. Multiple regression analysis also identified water temperature, depth, photoperiod, light penetration, barometric pressure, and substrate type as factors significant in explaining white sucker catches.

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TABLE OF CONTENTS

LIST OF TABLES

PART I. THE LIFE HISTORY OF THE LONGNOSE SUCKER, *CATOSTOMUS CATOSTOMUS*, IN NEARSHORE EASTERN LAKE MICHIGAN

PART II. THE LIFE HISTORY OF THE WHITE SUCKER, *CATOSTOMUS COMMERSONI*, IN NEARSHORE EASTERN LAKE MICHIGAN

LIST OF TABLES (Continued)

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INTRODUCTION

The Great Lakes area has been intensively settled by man and many of the native fishes have been reduced by selective exploitation, pollution, and competition from exotic species. The longnose sucker, *Catostomus catostomus*, has maintained considerable populations in the Great Lakes despite these factors. Recently, the possibility of commercially harvesting suckers on a large scale has been examined (Galloway and Kevern 1976). The proper management of this fishery requires more biological information than is currently available. Bailey's (1969) study of the age and growth of longnose suckers in western Lake Superior is the only widely available published data on Great Lakes longnose sucker populations.

The accuracy of the scale method for determination of age for longnose suckers has been questioned, because of difficulty in discerning annuli, particularly in older individuals (Geen et al. 1966; Falk and Gillman 1975). Age determination by examination of annual marks on pectoral fin ray sections is currently used on mature white suckers (*Catostomus commersoni*). This aging method has been proven to be more accurate than the scale method for white suckers (Beamish and Harvey 1969; Beamish 1973). There are no studies that have used this aging technique on longnose suckers. The present study is an investigation of the biology of the longnose sucker, including a comparison of the two aging methods.

METHODS

The year was divided into three periods that coincided with climatic changes at the study area: spring, 1 April - 14 June; summer, 15 June - 31 August; fall, 1 September - 14 November. Suckers were collected three times monthly in Lake Michigan from 14 April to 13 November 1977 with nylon gill nets in conjunction with an environmental study of the Ludington Pumped Storage Project (Liston and Tack 1973). The experimental gill nets consisted of seven 15.2 m x 1.8 m panels of 25, 51, 63, 76, 102, 114, and 178 mm stretched mesh. Nets were set on the bottom for 24 hours at six stations 7.5 - 15 km south of Ludington, Michigan. The gill net stations were established at the 6, 8 12 (2), 14, and 24 m depth contours.

Trawling stations were established 7.5 km and 15 km south of Ludington, Michigan. Five minute hauls at five knots were made monthly after sunset. The 1.5, 3.0, and 4.5 m depth contours were sampled at each station. The semibaloon otter trawl had a 7.6 m head rope, 38 mm stretch mesh body, and 3 mm bar mesh in the cod end liner.

During the spring, additional longnose suckers used for aging were taken in gill nets adjacent to the jetties of the Ludington Pumped Storage Power Plant. These fish were not used in other analyses. A few additional fish were collected in beach seines and gill net sets along the beach.

The bottom of the sampling area consisted largely of sand with areas of gravel, rocks, clayey silt, large rocks, and occasional clay outcropping (Lechel 1974). A gill net station's substrate type was determined for statistical analysis by assignment of a value based on the presence of clay, sand, gravel, and rocks in the sediment.

Benthic macroinvertebrates were collected at the gill net stations seasonally. A standard ponar dredge enclosing an area of 529 cm^2 was used in three replicate casts taken randomly at all six stations. Each replicate was strained through a standard #30 (.0234 inch per mesh) sieve, and the organisms were removed, separated by major taxa, counted, and preserved. Seasonal counts of amphipods and chironomids were converted to biomass/m^2 and combined to obtain a prey level at each station for statistical analysis.

Bottom water temperatures were 2 - 4° C in April, warmed to 19 - 21° C in August, and cooled to 6 - 8° C in November. Secchi disc values, a measure of light penetration, ranged from less than 1 m to greater than 9 m. The values were generally greater at the deeper stations. Turbidity generally decreased from shore, with values of 1.0 - 4.8 ntu in the shallow areas and 0.9 - 3.4 ntu at the deeper stations. Ranges for other recorded chemical parameters in a previous study of the area were: pH, 7.7 - 8.8; alkalinity, 108 - 124 ppm; dissolved solids, 170 - 200 (Liston et al. 1976). Air temperatures ($^{\circ}$C), barometric pressure (inches), wind direction (22° increments) and velocity (mph) were obtained from the Ludington Coast Guard Station. Photoperiod (hours) was calculated from times of sunrise and sunset for Muskegon, Michigan, approximately 85 km south of the sampling area.

In the laboratory, a random sample no greater than twenty individuals with each mesh size of the gill nets represented in proportion to its yield was taken from each station. Total length (nearest mm), weight (nearest g below 1,100 g; nearest 10 g above 1,100 g), sex, and condition of gonads were recorded. Ovaries were removed from fish taken in the sampling area from 1975 through 1977, wrapped in cheesecloth and fixed in Gilson's fluid (Pennak 1978). Scales were taken from all specimens, and the right pectoral fin was removed from 432 longnose suckers. Stomachs were taken from 203 fish captured between 17 May and 13 November 1977. The anterior one-third of the digestive tract was removed from the fish and preserved in 10% formalin.

Scales were removed from the left side of the longnose sucker in the area above the lateral line and below the dorsal fin. Scales were viewed directly and aged using a scale projector. Pectoral fins were cut as close to the body as possible using bone cutters. The fins were rinsed and dried for several days, before being cleaned and coated with clear epoxy. In the spring, the fins were held in a fly tier's vice and a jeweler's saw was used to cut transverse sections of the first 3 to 6 rays. Different blades (4/0, 6/0, and 8/0) were used depending on the size of the fin. Fins taken during the summer and fall were sectioned using a "microtone", because of time savings. In this device, the fin was held by a graduated vice and cut by a Dremel Moto Tool (blade 406). The sections were about 0.5 mm thick and the best sections were usually obtained closer to the base of the fin. Three sections were generally taken from each fish, but on some occasions more were needed to age the fish. The sections were washed in xylene and mounted in a media composed of three parts permount and one part xylene. The sections were aged with a microscope and annuli identified at 200X.

The digestive tracts were opened and the contents filtered in a Buuchner funnel. Wet weights were taken for large food items and the total contents of the stomach. Organisms were identified and ennumerated under a disecting scope. The presence of algae and aquatic plants was noted for each stomach. Biomass of amphipods, chironomids, gastropods, pelecypods, and oligochaetes were determined seasonally from the benthos samples. Wet weights of cladocerans and copepods were estimated from

dry weights reported by Hall et al. (1970). Weights of other organisms were determined for the entire sampling period from food items encountered in the stomachs or benthos samples.

Fecundity was determined for 24 longnose suckers taken prior to spawning in April and May. The volumetric technique of water displacement was used to estimate the number of eggs in both ovaries. Three 1 ml aliquots comprised of eggs arbitrarily selected from different portions of the ovaries were counted for each fish. Based on the tissue volume of 20 longnose sucker ovaries, 2.0% was subtracted from the total volume of the ovaries to account for exterior tissue.

Longnose sucker yields from 120 gill net samples were compared to climatic parameters, water condition variables, physical variables, and food availability by multiple regression models. In these models, it was assumed that the longnose suckers collected in the investigation represented a single population, or different populations that were equally subject to capture. Gill net catches are not normally distributed, but are characterized by many zero or small values and also other larger values. A log (yield + 1) transformation was performed on the catch data to approximate a normal distribution.

In the initial analysis, the following linear regression model was assumed: $y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6 + b_7x_7 + b_8x_8 + b_9x_9 + b_{10}x_{10} + b_{11}x_{11} + e$, where y is the log (yield + 1), a is a constant, b's are regression coefficients, x_1 is depth, x_2 is prey biomass, x_3 is water temperature, x_4 is light penetration, x_5 is turbidity, x_6 is wind direction x_7 is wind velocity, x_8 is air temperature, x_9 is the barometric pressure, x_{10} is photoperiod, x_{11} is substrate type and e is the random residual corresponding to y. The model in matrix notation

$\underline{y} = \underline{Xb} + \underline{e}$ has expectations $E(\underline{e}) = \underline{0}$, $E(\underline{y}) = \underline{Xb}$, variance ($\sigma^2$) equal in all samples, and covariance equal to zero.

The stepwise addition procedure was used to choose the most important variables in the fitted equation. In this procedure, variables are added singly to the regression equation. The variable that is selected for entry into the equation is that variable that explains the greatest amount of unexplained variance. This selection is based on the partial F values of the variables at that point. After a variable is added to the equation, the partial F values of all of the independent variables in the equation are examined. If a variable no longer provides a significant contribution to the regression equation, it is removed from the equation. A five percent level was used for all tests of significance and as a stopping criterion.

In a second model, independent variables describing joint effects (cross products) of all possible pairs of original independent variables were added to the linear variables in the first model for consideration in the equation. The second model failed to contain the same variables as the first model, so a third model was composed of variables found to be significant in the first two models. The first three models all used data pooled from all the stations. In a fourth regression equation, the yield from individual stations was compared to the variables that were significant in the second model.

RESULTS AND DISCUSSION

Aging Methods

The annulus on the fin rays is recognized as an area of less optical density. In transmitted light, the annulus appears as a light mark on the darker background of the section. Annuli form on the fin rays before the scales. This irregularity has also been observed on white sucker fins and scales (Beamish and Harvey 1969). To avoid confusion, a year was added to each fish's age on January first, even though the annulus didn't form until later. The annuli on the sections of the pectoral fin rays are easier to read than annuli on the scales, but the scales require less effort to prepare than the sections. It is also difficult to obtain sections of the pectoral fin rays in young-of-the-year and age I fish because the small rays are fragile and splinter easily.

The ages determined by the two methods agreed well until age V (Table 1). There was some agreement of the results up to age VIII, but ages determined from the sections were greater than ages determined from the scales in the majority of the fish examined. Differences between ages determined by the two methods ranged up to eight years and were not predictable at an age.

The maximum age determined by the scale method in this investigation was 10 years. Harris (1962) aged longnose suckers from Great Slave Lake to age XIX by scales, but Bailey (1969) found a maximum scale age of 11 years in western Lake Superior longnose suckers.

Geen et al. (1966) aged longnose suckers by scales and discovered that recaptured fish didn't always have as many new annuli as they should have. This finding and studies of the white sucker (Ovchynnyk 1965; Beamish and Harvey 1969; Beamish 1973) indicate that ages of older

Table 1. Comparison of longnose sucker ages determined by examination of scales and transverse sections of pectoral fin rays.

Fin ray age	Number of fish	Percentage ray > scale	Percentage ray = scale
0	1	0	100
1	7	0	100
2[a]	97	2	96
3	68	4	96
4[a]	27	0	89
5	44	20	80
6	26	42	58
7	35	86	14
8	31	87	13
9	32	100	0
10	14	100	0
11	4	100	0
12	7	100	0
13	8	100	0
14	9	100	0
15	3	100	0
16	1	100	0
17	2	100	0

[a]This age group contained fish having a scale age greater than their ray age.

fish are a more accurate measure of true age if they are determined from sections of the pectoral fin rays. In the present study, scale ages of fish age IV or older were considered inaccurate.

Age and Length Composition

Of 573 longnose suckers captured in the gill nets and aged during the study period, age II and III fish were 27.5% and 18.8%, respectively, of the total number. Ages IV through IX contributed most of the remaining fish, but the exact strength of each older age class could not be estimated because not all older fish were aged by the fin ray method. Fish captured ranged from age 0 to age XVII. The age 0 and I longnose suckers were not adequately sampled by the gill nets, and consequently, these ages represented only 2.3% and 2.1%, respectively, of the total number. In the trawls age 0 and I fish comprised 31.4% and 19.6%, respectively, of the 51 longnose suckers captured. A combination of the two sampling methods results in collection of all age groups, but eliminates quantification of age structure of the population.

The total lengths at ages of longnose suckers taken in the study are presented in Table 2. Age IV and older fish were included in this table only if they were aged from transverse sections of pectoral fin rays. Lake Michigan suckers display a phenomenal rate of growth in the first three years of their life. The longest young-of-the-year (146 mm) was captured on 28 September, and consequently, more growth would have occurred during its first year. As the fish reach maturity, the growth rate decreases and incremental growth after age VI is relatively small.

Harris (1969) reported that longnose suckers from Great Slave Lake approached the size of Lake Michigan fish, but the fish did not grow as fast during their younger years. He also described a northern popu-

Table 2. Average total lengths (mm) at capture of longnose suckers by age and sex (1977).

Age	Immature			Male			Female		
	Mean length (range)	Number	Standard deviation	Mean length (range)	Number	Standard deviation	Mean length (range)	Number	Standard deviation
0	118(76-146)	29	16.8						
1	204(109-264)	22	41.1						
2	277(153-348)	179	32.5	309(304-313)	2	6.4	322(316-329)	4	5.5
3	333(250-400)	74	23.9	354(303-394)	22	22.2	348(312-372)	18	16.7
4	382(358-402)	3	22.4	398(374-418)	14	13.6	402(363-428)	10	16.7
5				415(386-438)	19	14.8	429(390-463)	25	19.1
6				430(418-444)	8	9.4	454(387-491)	18	27.2
7				445(430-464)	14	10.7	469(439-513)	21	20.9
8				449(431-472)	5	16.5	476(413-524)	26	28.1
9				446(413-468)	6	20.2	483(446-526)	26	23.0
10				458(430-484)	7	21.6	495(480-540)	7	26.1
11				435	1		497(475-515)	3	20.4
12				441(393-465)	3	41.3	510(485-534)	4	22.0
13							510(474-541)	8	20.9
14				455(444-462)	3	9.6	520(503-541)	6	14.0
15							522(503-543)	3	20.1
16							498	1	
17							547(505-588)	2	58.7

lation that grew slower than a southern population. Longnose suckers from western Lake Superior were smaller at all ages than Lake Michigan fish (Bailey 1969).

Female and male suckers were separated in Table 2 because the females of an age class were generally longer than the males. Brown and Graham (1954) observed that longnose sucker females grew faster than males in Yellowstone Lake. Bailey (1969) or Harris (1962), however, fail to mention differential growth rates between the sexes.

Female longnose suckers lived longer than males in this area of Lake Michigan. All of the fish of ages XV, XVI, and XVII were females and most of the older age classes were dominated by females. Most of the older members of the longnose sucker populations in western Lake Superior were also females (Bailey 1969).

Maturity and Fecundity

Some longnose suckers of both sexes matured during the third summer of their lives. Hayes (1956) has reported spawning by males of two years and females of three years in a Colorado reservoir. Other authors report the youngest mature fish to be ages IV, V, and VII (Brown and Graham 1954; Harris 1962; Geen et al. 1966; Bailey 1969). Although some Lake Michigan suckers did mature at age II, the majority matured later. During the study, 3.2% of age II, 35.1% of age III, 88.9% of age IV, and 100% of age V longnose suckers captured were mature. In previous sampling in this area, 100% maturity wasn't reached until age VI (Unpublished data, Michigan State University, Ludington Research Laboratory), and Bailey (1969) reported that immature longnose suckers ranged up to age IX in western Lake Superior.

Brown and Graham (1954), Hayes (1956), and Bailey (1969) have reported that male longnose suckers will mature a year or more earlier

than females. The majority of mature age III and IV Lake Michigan fish were males, indicating that they generally mature earlier than females. Individual females did, however, mature as early as males.

Longnose sucker fecundity ranged from 11,629 (419 mm, 888 g) to 69,320 (543 mm, 1,770 g). Fecundity plotted against total length and weight produced linear relationships with good line fit ($r^2 = 0.72$ and 0.75 respectively). Fecundity plotted against total length yielded the following equation: $y = 114,217 + 314x$, where y is the number of eggs and x is the total length in millimeters. Fecundity plotted against weight led to the development of the equation: $y = 20,939 + 46X$, where y is the number of eggs and x is the weight in grams.

Lake Michigan longnose suckers have similar egg production to eight longnose suckers examined by Bailey (1969) from Lake Superior, but since only a mean and range was published, further comparison between the two populations is impossible. Longnose suckers from Great Slave Lake had lower fecundities at given sizes than Lake Michigan suckers, but the small sample size prevents rigorous comparison (Harris 1962).

Length-Weight Relationships

The relationships were developed using the equation: $W = aL^n$, where W is the weight in g and L is the length in mm (Carlander 1953). Relationships were developed by the least squares method for groups caught in different seasons, of different sexes, and spawning conditions. A t test described by Gill (1978) was used to examine differences between the slope values of different relationships. This test performed on slope values of pre- and post-spawning male and female spring fish revealed only non-significant differences, and consequently, all members of a sex were combined for the spring period. No spawning was observed

in the sampling area and fish may have recovered any weight lost in spawning before returning to this area.

Significant differences did exist between sexes and seasons, so those groups were kept separate (Table 3). Longnose suckers taken in the fall had a higher slope than those taken in the other seasons, while summer suckers had a higher slope than spring suckers. Differences in slopes between sexes varied depending on the season. The above differences may be attributed to food availability, gonadal development, or an interaction of these two factors. A lowered food intake during winter and the spring spawning period results in lower weight at a length. As the fish feed and the gonads develop in the summer and fall, the weight at any length increases.

An overall length-weight relationship was determined to be: log W = -5.20 + 3.09 Log L. Longnose suckers in Shadow Mountain Reservoir in Colorado were slightly lighter at all lengths greater than 100 mm (Hayes 1956). Mature Longnose suckers captured by Falk and Gillman (1975) in Great Slave Lake had a similar length-weight relationship to Lake Michigan suckers, but the use of a fork length in their study prevents detailed comparison.

Food Habits

The longnose sucker is an opportunistic bottom feeder that consumes a variety of benthic invertebrates and algae. The results of the food habits analysis are listed for seasonal periods in Table 4. Amphipods (*Pontoporeia hoyi* and *Gammarus* sp.), chironomids (larvae and pupae), and cladocerans (*Chydorus sphaericus* and *Alona* sp.) were the most important food items in the diet of the longnose suckers, contributing 14.3%, 38.9%, and 44.5% of the total number of food items respectively.

Table 3. Total length-weight relationships for longnose suckers by sex and season (1977).

Sex	Spring	Summer	Fall
Immature	$\log W = -5.10 + 3.05 \log L$	$\log W = -5.19 + 3.09 \log L$	$\log W = -5.25 + 3.11 \log L$
Male	$\log W = -4.34 + 2.76 \log L$	$\log W = -4.74 + 2.92 \log L$	$\log W = -5.70 + 3.28 \log L$
Female	$\log W = -3.40 + 2.40 \log L$	$\log W = -5.00 + 3.02 \log L$	$\log W = -5.40 + 3.17 \log L$
All Sexes	$\log W = -4.73 + 2.90 \log L$	$\log W = -5.21 + 3.10 \log L$	$\log W = -5.29 + 3.13 \log L$

Table 4. Summary of seasonal food habits of longnose suckers taken from Lake Michigan in 1977. FO-frequency of occurrence; TW-percentage of total weight; TN-percentage of total number; tr-less than 0.1.

Food Item	Spring			Summer			Fall		
	FO	TW	TN	FO	TW	TN	FO	TW	TN
Amphipoda	73.7	33.6	49.8	40.5	1.0	5.2	82.6	3.1	15.3
Chironomidae	100.0	2.1	44.5	94.9	9.6	72.3	85.9	0.6	11.9
Cladocera	52.6	tr	1.3	57.0	0.1	19.1	15.2	0.1	71.7
Pelecypoda	21.1	0.1	0.2	5.1	0.4	0.5	8.7	tr	0.1
Gastropoda				2.5	0.1	0.1	15.2	0.1	0.3
Trichoptera	26.3	0.2	0.2	6.3	tr	tr	16.3	0.1	0.1
Insecta (Terrestrial)	5.3	tr	tr	6.3	0.2	0.3	6.5	tr	tr
Oligochaeta	21.1	tr	0.3	13.9	tr	0.3	10.9	tr	0.1
Fish eggs				2.5	tr	tr	13.0	1.0	0.3
Nematoda	57.9	tr	3.0	29.1	tr	1.7	3.3	tr	tr
Ostracoda	36.8	tr	0.4	15.2	tr	0.3	5.4	tr	tr
Hydracarina	10.5	tr	0.1	21.5	tr	0.1	4.3	tr	tr
Copepoda	5.3	tr	tr				2.2	tr	0.1
Miscellaneous[a]	10.5	tr	tr	3.8	tr	tr	20.7	tr	0.1
Algae	63.2			43.0			21.7		
Aquatic plants							3.3		
Detritus[b]		63.9			88.5			94.8	
Stomachs examined		19			85			99	
Stomachs with food		19			79			92	
Total weight of contents		63.9			153.2			449.4	
Total number of animals		6,116			27,225			34,971	

[a]Includes fish scales, Isopoda, *Mysis* sp. and Simulidae.

[b]Includes unidentified material, congealed digestive juices, algae, aquatic plants, and sand.

Rawson and Elsey (1948) reported that amphipods and chironomids dominated the food of large longnose suckers in Pyramid and Patricia Lakes, Alberta, and that cladocerans constituted 66% of the food of young suckers. Hayes (1956) also reported that cladocerans were the primary food item of longnose suckers in Shadow Mountain Reservoir, Colorado.

Cladocerans were found in large numbers, but they contributed only 0.1% of the total stomach content weight, when all seasons were combined. The large numbers of cladocerans in the fall period was due to heavy predation by a few small suckers on *Chydorus spaericus*. Cladocerans were more important to the smaller longnose suckers. They contributed 77.2% of the total number of food items in small fish (0-250 mm), 18.5% in medium size fish (251-400 mm), and 1.6% in large fish (401 mm and longer). Rawson and Elsey (1948) also reported this pattern of cladocerna usage by longnose suckers in Pyramid Lake.

Amphipods increased in importance with increasing fish size. Amphipods composed 58% of the total number of food items of the largest fish. Medium and small size fish contained 14.3% and 0.3% amphipods, respectively. The larger fish also consumed gastropods and pelecypods, which were not found in the small fish. This trend toward increased use of larger food items by larger fish was also described by Rawson and Elsey (1948).

Chironomids were important to longnose suckers of all size classes. They appear to be more important during the spring and summer, but are still prevalent in fall stomachs. Fish eggs comprised a small portion of the total longnose sucker diet in eastern Lake Michigan. The longnose sucker has been reported as a predator on game fish eggs in previous studies (Simpson 1939; Stenton 1951). A few large eggs (Salmonidae) were found in fall stomachs and eggs of other sizes were occasionally found in Lake Michigan sucker stomachs. The importance of this predation on game fish populations was recently concluded to be minor (Holey et al. 1979).

Algae was found more often in large fish (31.6%) than medium (13.0%), or small fish (11.5%). It was found in 34.7% of the longnose suckers examined in this study. Algae was found more often in spring and summer fish than in fall fish (Table 4). Brown and Graham (1953) reported that algae was found in 69% of the longnose suckers that were examined from tributaries to Yellowstone Lake, Wyoming, and constituted one-third of the food volume. Other authors working in lakes have reported algae to be of lesser or no importance (Rawson and Elsey 1948; Hayes 1956).

Detritus, which included unidentified material, sand, algae, aquatic plants, stomach lining, and congealed digestive juices, constituted 90.4% of the stomach contents of all longnose suckers by weight. Considerable volumes of items in this category are reported by Brown and Graham (1953) and Hayes (1956), but no other investigators have weighed the food items. A considerable portion of this weight is due to the stomach lining and digestive juices. Because of this, the weight percentages presented in Table 4 should be interpreted with caution.

Distribution and Yield

The longnose sucker prefers the shallow waters of lakes, but is commonly found in deeper waters. The majority of longnose suckers captured in gill nets were taken at the shallow stations (6-8 m), but several fish were captured at the deepest station (24 m). The catch

per unit effort (CPE) was 6.6 at 6 - 8 m stations, 3.7 at the 13 - 14 m stations, and 1.0 at the 24 m station. Considerable variation in the total catch of longnose suckers existed between the two stations of the same depth. One 12 m station had a CPE of 5.3, while the CPE of the other 12 m station was only 2.6.

Spring catches of longnose suckers were relatively small. Suckers occurred in 56.3% of the spring gill net sets, and CPE was only 2.0. In April and May, longnose suckers were captured with green, ripe and spent gonads. The small spring catches reflected movements of the fish out of the sampling area for spawning purposes. Longnose suckers may spawn in tributaries of lakes or on shallow reefs (Rawson and Elsey 1948; Geen et al. 1966). Summer catches of longnose suckers were substantial in the study area. They occurred in 81.0% of the samples, and CPE was 7.2. Summer yields at the deepest station were considerably larger than spring or fall catches, indicating that the fish will move into deeper waters with the right conditions. During the fall, CPE of longnose suckers declined slightly from the summer value. CPE was 3.8 in the fall, and suckers occurred in 70.8% of the samples.

The multiple regression of yield and the independant variables resulted in the development of the regression equations that are described in Table 5. The first equation in Table 5 is the result of the initial analysis and describes 43% of the variation ($\bar{R}^2$) in the longnose sucker gill net yields. Inclusion of the joint effect terms, which describe two way interaction in the multiple regression analysis led to the development of the second fitted equation. This operational model describes 45% of the variation ($\bar{R}^2$) in the longnose sucker gill net yield.

Table 5. Results of multiple regression of log (yield + 1) with independent variables, including parameter coefficients, their standard errors, and standardized coefficients.

Parameter	Regression coefficient	Standard error	Standardized coefficient
$y = a + b_3x_3 + b_1x_1 + b_{11}x_{11}$			
x_3=Water Temperature (^oC)	0.0404	0.0057	0.5020
x_1=Depth (m)	-0.0340	0.0069	-0.4548
x_{11}=Substrate (ave.)[a]	-0.0186	0.0070	-0.2391
Constant	0.940		
$y = a + b_1x_3x_{10} + b_2x_1x_{11}$			
x_3x_{10}=Water Temperature x Photoperiod (hours)	0.0030	0.0004	0.5334
x_1x_{11}=Depth x Substrate	-0.0017	0.0003	-0.3334
Constant	0.5305		

[a]Substrate values are unitless averages based on size of sediment types at the stations.

A third regression equation was formulated that included all the independent variables found significant in the first two regression equations. All variables were entered in the regression equation, regardless of the significance of their partial F values. This regression equation explained 44% of the variation ($\bar{R}^2$) in the longnose sucker yields. The variables important in the first model exhibited very small partial F values and contributed little to the explanation of variation in this model. The inclusion of these variables resulted in the lower adjusted multiple correlation coefficient ($\bar{R}^2$), and consequently, the second model contains the variables that explain longnose sucker yields the best. The presence of joint effect terms in the operational model illustrates the complex relationships between gill net yields and environmental variables. The yields not only reflect abundance, but also susceptibility of the fish to capture, and consequently, interpretation of these results in terms of an individual variable's net effect is difficult.

The four factors important in explaining longnose sucker catches in gill nets were water temperature, depth, substrate type, and photoperiod. An increase in water temperature or photoperiod resulted in greater sucker yields, while an increase in depth or sediment size resulted in smaller catches of suckers. The depth x substrate term is constant at individual stations, and consequently, it describes differences between stations. Within station differences are accounted for by the water temperature x photoperiod interaction term. This interaction term was significant at 4 ($p = 0.05$) or 5 ($p = 0.1$) stations when the yield was regressed against it, indicating the importance of these factors in different areas.

Water temperature is a controlling factor in sucker movement. It has been identified as an important factor in determining the time of the spawning migration of longnose suckers by several authors (Brown and Graham 1953; Harris 1962; Geen et al. 1966; Bailey 1969). Warmer water temperatures also cause greater movement and feeding activity that increase the opportunity for capture by the collection technique used.

Sampling from several years in this area indicates that longnose sucker abundance decreases with increasing depth (Brazo and Liston 1979). This parameter is second only to water temperature in importance in determining sucker yields. Longnose suckers prefer the shallow waters, but are not restricted to them, and were captured in deeper waters under the right conditions.

Substrate and photoperiod are of lesser importance in explaining longnose sucker yield. The length of the photoperiod may affect movement of the fish into feeding or spawning areas. Bailey (1969) reported, however, that movement of longnose suckers into streams was more dependent on water temperature than photoperiod. The joint effect of photoperiod and water temperature was important in explaining longnose sucker yield suggesting that a combination of these factors rather than one factor is important in explaining sucker movement.

The importance of substrate type on longnose sucker yield appears to be related to prey abundance. Larger catches of suckers occurred at the gill net stations with a smaller substrate type. Cole and Weigmann (1977) found that populations of macrobenthos were larger in areas of small sediment size. These areas, thus, would provide easier feeding for the fish than areas characterized by larger sediment types.

The variation in the yield that remained unexplained after the operational model was fit may be due to non-linear functions of investigated independent variables or other variables not quantified. Competition

for space and food with other bottom dwelling fish, such as the white sucker and round whitefish (*Prosopium cylindraceum*), is a factor that is important in controlling longnose sucker distribution, but is difficult to quantify. The water currents at the stations may also affect longnose sucker yield, but were not measured in this study. Joint effects of three or more factors may also be important in explaining longnose sucker yields. Individual factors may best explain yield in non-linear expressions, but these types of factors were also not tested in this investigation.

SUMMARY AND CONCLUSIONS

As stated earlier, one of the objectives of this investigation was to provide data comparing the scale and ray-section methods of age determination. The data indicate that scales are valid for young fish, and in addition, scales are easier to prepare than the sections. The sections, however, are a more accurate indicator of age in older fish than scales. In future studies, it is recommended that immature fish be aged by scales, while the mature fish be aged by sections. This method has been used on white suckers with success (Beamish 1973).

The early age of maturity and exceptional growth rate in younger years by Lake Michigan longnose suckers indicate that this habitat is among the most favorable that has been investigated. Suckers reached similar sizes in Great Slave Lake, but the growth rate in early years was lower (Harris 1962). The impact of commercial harvest on population numbers and biomass remains open to speculation. The longevity of a large proportion of this unexploited population suggests that the age structure would change considerably. Brazo and Liston (1979) noted the importance of certain year classes in maintaining catch levels in experimental gill nets set in the study area for several years.

Populations of longnose suckers in other areas of Lake Michigan will have similar biologies, but variation has been found in growth of fish in different areas of the same lake (Harris 1962; Bailey 1969). The food habits of longnose suckers vary depending on the composition of the benthos. Factors important in controlling sucker distribution other than at spawning haven't been investigated in other areas and consequently comparisons are difficult to make. It is expected that topics such as this will receive more attention as this underutilized fish becomes more important to man.

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THE LIFE HISTORY OF THE WHITE SUCKER,

CATOSTOMUS COMMERSONI, IN

NEARSHORE EASTERN LAKE MICHIGAN

By

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INTRODUCTION

The white sucker (*Catostomus commersoni*) is common throughout the United States and Canada. This fish is reported to be a genetically plastic animal, and differences in appearance, counts and the presence of dwarf populations have led to this species being given several names. In the Great Lakes region, this fish is generally considered to be an underutilized species, and recently interest has been focused on the possibility of enlarging the commercial fishery of this species (Galloway and Kevern 1976; O'Neal 1978). White suckers make up the majority of the commercial catch, but longnose suckers and redhorse suckers are also included in the available commercial catch data. In 1970 the commercial production of suckers from Lake Michigan was nearly a million pounds. In the past, commercial production of suckers from Lake Michigan ranged up to four million pounds annually (Wells and McLain 1973). A sport fishery also currently exists during the spawning migration of this fish into the tributaries of Lake Michigan. The white sucker, however, is generally not sought at other times of the year by sport fishermen.

Biological information on the white sucker in the Great Lakes is meager. Coble (1967) studied the white sucker population in a large bay in Lake Huron, and Vondracek (1977) studied the age and growth of spawning populations of white suckers in tributaries to western Lake Michigan. Recent information has shown that the widely used scale method of age determination is not accurate for older fish. It has been found that

ages determined from transverse sections of pectoral fin rays are more reflective of true age than scale ages (Beamish and Harvey 1969; Beamish 1973). Due to variability of this species and doubtful validity of older age and growth studies, more biological information would be useful in understanding the life history of this fish. The present study is an investigation of the life history of the white sucker in nearshore Lake Michigan waters.

METHODS

The year was divided into three periods that coincided with climatic changes at the study area: spring, 1 April - 14 June; summer, 15 June - 31 August; fall, 1 September - 14 November. Suckers were collected three times monthly in Lake Michigan from 14 April to 13 November 1977 with nylon gill nets in conjunction with an environmental study of the Ludington Pumped Storage Project (Liston and Tack 1973). The experimental gill nets consisted of seven 15.2 m x 1.8 m panels of 25, 51, 63, 76, 102, 114 and 178 mm stretched mesh. Nets were set on the bottom for 24 hours at six stations 7.5 - 15 km south of Ludington, Michigan. The gill net stations were established at the 6, 8, 12 (2), 14, and 24 m depth contours.

Trawling stations were established 7.5 km and 15 km south of Ludington, Michigan. Five minute hauls at five knots were made monthly after sunset. The 1.5, 3.0, and 4.5 m depth contours were sampled at each station. The semiballoon otter trawl had a 7.6 m head rope, 38 mm stretch mesh body, and 3 mm bar mesh in the cod end liner.

During the spring, additional fish used for aging were taken in gill nets adjacent to the jetties of the Ludington pumped storage power plant. A few additional fish were collected in beach seines and gill net sets along the beach. These fish were not used in analyses other than aging.

The bottom of the sampling area consisted largely of sand with areas of gravel, rocks, clayey silt, large rocks, and occasional clay outcroppings (Lechel 1974). A gill net station's substrate type was determined for statistical analysis as an average of values assigned for the presence of clay, sand, gravel, and rocks in the sediment.

Benthic macroinvertebrates were collected at the gill net stations seasonally. A standard ponar dredge enclosing an area of 529 cm^2 was used in three replicate casts taken randomly at all six stations. Each replicate was strained through a standard #30 (.0234 inch per mesh) sieve, the organisms removed, separated by major taxa, counted, and preserved. Seasonal counts of amphipods and chironomids were converted to biomass/m^2 and combined to obtain a prey level at each station for statistical analysis.

Bottom water temperatures were 2 - 4° C in April, warmed to 19 - 21° C in August, and cooled to 6 - 8° C in November. Secchi disc values, a measure of light penetration, ranged from less than 1 m to greater than 9 m. The values were generally greater at the deeper stations. Turbidity generally decreased from shore, with values of 1.0 - 4.8 ntu in the shallow water stations and 0.9 - 3.4 ntu at the deeper stations. Ranges for other recorded chemical parameters in a previous study of the area were: pH, 717 - 8.8; alkalinity, 108 - 124 ppm; dissolved solids, 170 - 200 (Liston et al. 1976). Air temperature ($^{\circ}$C), barometric pressure (inches), wind direction (22° increments) and wind velocity (mph) were obtained from the Ludington Coast Guard Station. Photoperiod (hours) was calculated from times of sunrise and sunset at Muskegon, Michigan, approximately 85 km south of the sampling area.

In the laboratory, a random sample no greater than twenty individuals with each mesh size of the gill nets represented in proportion to its yield was taken from each station. Total length (nearest mm), weight (nearest g below 1,100 g; nearest 10 g above 1,100 g), sex, and condition of gonads were recorded. Ovaries were removed from the fish taken in the sampling area from 1975 through 1976, wrapped in cheesecloth and fixed in Gilson's fluid (Pennak 1978). Scales were taken from all specimens, and the right pectoral fin was removed from 381 white suckers. Stomachs

were removed from 174 fish captured between 17 May and 13 November 1977. The anterior one-third of the digestive tract was removed from the fish and preserved in 10% formalin.

Scales were removed from the left side of the fish in the area above the lateral line and below the dorsal fin. Scales were viewed directly and aged using a scale projector. Pectoral fins were cut as close to the body as possible, using bone cutters. The fins were rinsed and dried for several days, before being cleaned and coated with clear epoxy. In the spring, the fins were held in a fly tier's vice and a jeweler's saw was used to cut transverse sections of the first 3 to 6 rays. Different blades (4/0, 6/0, and 8/0) were used depending on the size of the fin. Fins of fish taken during the summer and fall were sectioned using a "microtone", because of time savings. In this device, the fin was held in a graduated vice and cut by a Dremel Moto Tool (blade 406). The sections were roughly 0.5 mm thick and the best sections were usually obtained close to the base of the fin. Three sections were generally taken from each fish, but on some occasions, more were needed to age the fish. The sections were washed in xylene and mounted in media composed of three parts permount and one part xylene. The sections were aged with a microscope and annuli identified at 200X.

The digestive tracts were opened and the contents filtered in a Buuchner funnel. Wet weights were recorded for large food items and the total contents of the stomach. Organisms were identified and ennumerated under a disecting scope. The presence of algae and aquatic plants was noted for each stomach. Biomass of amphipods, chironomids, gastropods, pelecypods, and oligochaetes were determined seasonally from the benthos collections. Wet weights of cladocerans and copepods were estimated from dry weights reported by Hall et al. (1970). Weights of other organisms were recorded for the entire sampling period from stomach contents or benthos collections.

Fecundity was determined for 37 white suckers taken prior to spawning in April and May. The total number of eggs was estimated from measurement of the total volume of both ovaries by water displacement. Three 1 ml aliquotes consisting of eggs arbitrarily selected from different portions of the ovaries were counted for each fish. Based on the tissue volume of 17 white sucker ovaries, 1.5% was subtracted from the total volume of the ovaries for exterior tissue.

White sucker yields from 120 gill net samples were compared to climatic parameters, water condition variables, physical variables, and food level by multiple regression models. In these models, it was assumed that the white suckers collected represented either a single population or different populations that were equally subject to capture. Gill net catches are not normally distributed, but are characterized by many zero or small values and also other larger values. In order to approximate a normal distribution a log (yield + 1) transformation was performed on the catch data.

In the initial analysis, the following linear regression model was assumed: $Y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6 + b_7x_7 + b_8x_8 + b_9x_9 + b_{10}x_{10} + b_{11}x_{11} + e$, where y is the log (yield + 1), a is a constant, b's are regression coefficients, x_1 is depth, x_2 is prey biomass, x_3 is water temperature, x_4 is light penetration, x_5 is turbidity, x_6 is wind direction, x_7 is wind velocity, x_8 is air temperature, x_9 is barometric pressure, x_{10} is photoperiod, x_{11} is substrate type and e is the random residual corresponding to y. The model in matrix notation,

$\underline{y} = \underline{Xb} + \underline{e}$, has expectations $E(\underline{e}) = \underline{0}$, $E(\underline{y}) = \underline{Xb}$, an equal variance ($\sigma^2$) in all collections, and no covariance.

The stepwise addition procedure was used to choose the most important variables in the fitted equation. In this procedure, variables are added to the regression equation one at a time. The variable that is considered for selection into the equation is the one that explains the greatest amount of the variance that is unexplained by the equation at that point. The selection of a variable is based on the partial F values of the variables not in the equation at that point. After a variable is added to the equation, the partial F values of the independent variables in the equation are examined. If a variable no longer provides a significant contribution to the fitted equation, it is removed. A five percent level was used for all tests of significance and as a stopping criterion.

In a second model, independent variables describing joint effects (cross products) of all possible pairs of original independent variables were added to the linear variables in the first model for consideration in the fitted equation. The second model failed to contain the same variables as the first model, so a third model composed of variables found to be significant in the first two models was tested. The first three models all used data pooled from all the stations. In a fourth regression equation, the yield from individual stations was compared to the variables that were found significant in the second model.

RESULTS AND DISCUSSION

Aging Methods

Scidmore and Glass (1953) first suggested the use of sections of the pectoral fin rays for aging white suckers. Ovchynnyk (1965) reported that ages determined by scales and various bones differed. He also concluded that ages determined from pectoral fin rays were more accurate than ages determined by scales. Recently, it was demonstrated in a very complete analysis that ages determined by pectoral ray sections are more accurate for older white suckers than ages determined by scales (Beamish and Harvey 1969; Beamish 1973).

The annulus on the fin rays is recognized as an area of less optical density. In transmitted light, the annulus appears as a light mark on the darker background of the rest of the section. Annuli form in the spring on the fin rays before the scales. Beamish and Harvey (1969) also reported that this phenomenon occurred in white suckers from George Lake, Ontario. To avoid confusion, a year was added to each fish's age on January first, even though the annulus didn't form until later. The annuli on the sections were easier to read than scales but the sections required more time to prepare and sections were difficult to obtain in very young fish with the methods used.

The ages determined by the two methods agreed well until age V (Table 1). Agreement existed up to age X, but the majority of older fish were aged to greater ages by fin sections. Differences between ages determined by the two methods range up to seven years. Beamish (1973) reported differences between the two ages to be up to five years in white suckers from Ontario. Due to these results, fish in the present investigation found to be age IV or older by scales alone were considered as inaccurately aged.

Table 1. Comparison of white sucker ages determined by examination of scales and transverse sections of pectoral fin rays.

Fin ray age	Number of fish	Percentage ray > scale	Percentage ray = scale
0	0	0	0
1[a]	10	0	80
2[a]	84	0	98
3	39	0	100
4[a]	30	3	93
5[a]	42	19	79
6	34	47	53
7	15	60	40
8	26	96	4
9	31	100	0
10	14	93	7
11	15	100	0
12	15	100	0
13	4	100	0
14	2	100	0

[a]These age groups contained fish having a scale age greater than their ray section age.

Age and Length Composition

Of 463 white suckers captured in the gill nets and aged during the study period, age II and III fish constituted 22.5% and 13.4%, respectively, of the total number. Ages IV-XIV contributed most of the remaining fish, but the exact strength of these year classes couldn't be estimated because not all fish were aged by sections of the pectoral fin rays. No age 0 fish were taken in the gill nets and age I fish constituted only 2.6% of the catch. In the trawls, age 0 and I fish accounted for 8.7% and 10.9%, respectively, of the 46 white suckers collected. The absence of many age 0 fish in the trawl catches indicates that they were not in the sampling area. In Shadow Mountain Reservoir, Colorado, white sucker fry were collected in the shallow weed beds (Hayes 1956). A large number of white suckers were also taken by electroshocking in tributaries of Lake Michigan near the study area (Unpublished data), indicating that some white sucker young-of-the-year may stay in the tributaries for an extended period.

The average total lengths at capture of age groups are presented in Table 2. Age IV and older fish were included in this table only if they were aged by sections from their pectoral fins. White suckers in eastern Lake Michigan grow very rapidly in the first three years of their lives. The growth rate declines after the fish mature and after age VI incremental growth is only 5 to 10 mm per year. In western Lake Michigan, Vondracek (1977) has reported that white suckers exhibit a similar growth pattern. White suckers in George Lake, Ontario (Beamish 1973), and Hamell Lake, Saskatchewan, (McFarlane and Franzin 1978) have similar growth rates to Lake Michigan fish. In most locations, however, the white sucker grows at a slower rate than Lake Michigan (Stewart 1926;

Table 2. Total length (mm) at capture of white suckers by age and sex (1977).

Age	Immature			Male			Female		
	Mean length (range)	Number	Standard deviation	Mean length (range)	Number	Standard deviation	Mean length (range)	Number	Standard deviation
0	100(81-144)	4	30.1						
1	225(131-277)	19	40.9						
2	273(152-347)	123	40.2	321(298-346)	9	16.5	314(296-336)	4	16.8
3	316(208-385)	35	41.7	353(312-383)	18	18.6	352(304-383)	20	19.5
4	357(351-366)	3	7.8	378(353-419)	11	19.8	404(369-445)	16	22.5
5	408	1		415(363-475)	22	27.3	440(411-470)	19	15.9
6	416(378-454)	2	53.7	438(404-476)	9	26.5	460(430-492)	23	18.9
7	426(413-439)	2	18.4	439(428-458)	4	13.7	455(402-483)	9	24.9
8	452	1		452(409-516)	10	36.0	484(441-514)	15	22.3
9	419	1		444(420-485)	17	16.8	490(450-530)	13	23.2
10				467(447-491)	6	17.2	505(487-539)	8	16.4
11				446(445-447)	2	1.4	510(470-540)	13	23.6
12				453(432-471)	8	15.2	517(481-551)	7	23.5
13				465(454-476)	2	15.6	507(502-512)	2	7.1
14				477	1		530	1	

Spoor 1938; Dence 1948; Kathrein 1950; Hayes 1956; Lalancette 1976; Priegel 1976; Verdon and Magnin 1977).

Sexes were separated in Table 2 because females were larger at a given age than males. This trend has been previously observed in Lake Michigan (Vondracek 1977) and other habitats (Hayes 1956; Lalancette 1976; Verdon and Magnin 1977). In eastern Lake Michigan, female white suckers did't outlive males as observed in Wolf Lake, New York, (Beamish and Crossman 1977).

Maturity and Fecundity

In the third summer of life, the first eastern Lake Michigan white suckers of both sexes matured and most fish were mature by age IV. In tributaries to western Lake Michigan, Vondracek (1977) reported mature males at age II and mature females at age III. Most of these lake run fish were mature by age IV. Priegel (1976) observed that in Lake Winnebago, Wisconsin, most white suckers of both sexes were mature at age II, and all fish were mature at age III. Lalancette (1976) also reported that white suckers in Gamelin Lake, Quebec, matured at ages II and III. In other investigations, maturity occurred later, at ages IV, V, and VI (Spoor 1938; Raney and Webster 1942; Geen et al. 1966).

Most authors have found that males mature before females, but Spoor (1938) found spawning females younger than any males observed. In the present study, more age II mature fish were male, but the sexes were equally represented in mature age III fish.

White suckers in eastern Lake Michigan matured at a large size. The shortest mature fish was 296 mm in total length, and most fish were mature by 400 mm. Hayes (1956) found mature males as short as 150 mm total length, and Stewart (1926) reported mature fish as small as 152 mm.

In eastern Lake Michigan, a few undeveloped or immature fish were found as old as age IX. Spoor (1938) also observed individuals that failed to develop until the end of the eighth year of life. Geen et al. (1966) suggested that a major portion of the white sucker population fails to spawn each year, but he didn't investigate the development of these fish.

In the white sucker, fecundity ranged from 14,933 (424 mm, 819 g) to 54,417 (505 mm, 1,450 g). White sucker fecundity plotted against total length and weight produced general trends that demonstrated poor line fit (r^2 = 0.36 and 0.40 respectively). The most adequate relationship of fecundity and total length was linear and yielded the following equation: $y = -39{,}132 + 151x$, where y is the number of eggs and x is the total length. Fecundity plotted against weight produced a curvelinear relationship best described by the logarithmic equation: $\log y = 1.918 + 0.837 \log x$, where y is the number of eggs and x is the weight.

Raney and Webster (1942) used the volumetric method to estimate fecundities in eight white suckers from Skaneateles Lake Inlet, New York. Among the largest white suckers (above 470 mm) they found fecundities greater than the Lake Michigan fish, but medium and smaller size fish had comparable fecundities. They also reported much larger egg size than was found in Lake Michigan fish, but this may reflect the method of preservation.

Length-Weight Relationships

Length-weight relationships were developed using the equation: $W = aL^n$, where W is the weight in grams and L is the length in millimeters (Carlander 1953). Relationships were calculated by the least squares method, for different sexes and seasons (Table 3). These groups

Table 3. Total length-weight relationships for white suckers by sex and season (1977).

Sex	Spring	Summer	Fall
Immature	$\log W = -4.97 + 2.98 \log L$	$\log W = -5.17 + 3.09 \log L$	$\log W = -5.41 + 3.19 \log L$
Male	$\log W = -4.42 + 2.78 \log L$	$\log W = -4.72 + 2.91 \log L$	$\log W = -4.13 + 2.70 \log L$
Female	$\log W = -4.24 + 2.72 \log L$	$\log W = -4.74 + 2.92 \log L$	$\log W = -5.21 + 3.11 \log L$
All sexes	$\log W = -4.98 + 2.99 \log L$	$\log W = -5.04 + 3.04 \log L$	$\log W = -5.22 + 3.11 \log L$

were separated because this relationship varies with sex and time of year (Bassett 1956; Lalancette 1976; Vondracek 1977).

Large white suckers of both sexes increased in weight as the year progressed. This may reflect growth in weight during the summer and development of the gonads for the next year's spawning. Bassett (1957) found that large white suckers in Shadow Mountain Reservoir were heavier in the winter than summer and attributed the weight to the development of the gonads. Vondracek (1977) observed that the length-weight relationships of female white suckers were different before and after spawning, and Raney and Webster (1942) found that females taken before spawning were significantly heavier than post-spawning individuals.

Male white suckers taken by Raney and Webster (1942) showed no significant difference in weight between pre- and post-spawning individuals. Vondracek (1977) also combined pre- and post-spawning males in the development of length-weight relationships. The increase in weight exhibited by the males in eastern Lake Michigan probably largely reflects body growth, while the increase in weight exhibited by the females reflects gonadal development and body growth.

Vondracek (1977) has proven that length-weight relationships can vary in areas very close to one another. The length-weight relationships of eastern Lake Michigan white suckers in the spring are similar to those in western Lake Michigan (Vondracek 1977), but are significantly different from populations of individual areas. For comparison to other areas, the following total length-weight relationship was developed: $\log W = -4.95 + 3.00 \log L$, where W is the weight in g and L is the length in mm. Lake Michigan suckers were heavier than suckers taken by Lalancette (1976) in Gamelin Lake, Quebec. The length-weight relation-

ship of Lake Michigan white suckers, however, was similar to white suckers in Lake Huron (Coble 1967) and Shadow Mountain Reservoir (Hayes 1956).

Food Habits

The white sucker is an opportunistic bottom feeder that consumes a variety of invertebrates, bottom material, aquatic plants and algae. The results of the food habits analysis are listed for seasonal periods in Table 4. The periods were separated because white sucker diet varies with seasons (Bassett 1957; Beamish 1974; Lalancette 1977).

Chironomids (larvae and pupae) are the dominant food item in the diet of white suckers in eastern Lake Michigan. They occurred in 93.8% of the fish examined, and they accounted for 52.0% of the total food items of the fish examined. They were important in every season that was studied and utilized by all sizes of fish. They constituted 28.5% of the food items of small fish (0-250 mm), 49.4% of the food items in medium size fish (251-400 mm), and 59.4% of the food items in large fish (401 mm and longer). Chironomids have been identified as an important food item to white suckers in other areas (Stewart 1926; Bassett 1957; Beamish 1974; Eder and Carlson 1977).

Cladocerans (*Alona* sp.) were important as a food of young suckers. They were largely found in small fish (0-250 mm) taken during the summer. They accounted for 70.2% of the food items in small fish, 35.9% of the food items in medium size fish, and 22.0% of the food items in large fish. Cladocerans have been noted to be an important food item of smaller white suckers in Shadow Mountain Reservoir, Colorado (Hayes 1956).

Whereas cladocerans decrease in importance with increasing fish size, amphipods increase in importance. Amphipods, including *Pontoporeia*

Table 4. Summary of seasonal food habits of white suckers taken from Lake Michigan in 1977. FO-frequency of occurrence; TW-percentage of total weight; TN-percentage of total number; tr less than 0.1.

Food Item	Spring			Summer			Fall		
	FO	TW	TN	FO	TW	TN	FO	TW	TN
Chironomidae	97.6	1.4	60.8	94.9	6.2	49.9	88.4	1.0	49.2
Amphipoda	53.7	5.4	16.3	60.3	1.1	6.1	69.8	2.9	34.9
Cladocera	12.2	tr	15.5	74.4	0.2	40.9	18.6	tr	0.7
Gastropoda	29.3	0.7	1.9	17.9	0.6	0.8	44.2	1.5	8.4
Pelecypoda	17.1	0.6	2.5	15.4	0.7	1.0	30.2	0.6	3.7
Nematoda	31.7	tr	1.7	23.1	tr	0.3	20.8	tr	0.7
Fish eggs	7.3	0.1	0.3	5.1	0.4	0.3	2.3	0.2	0.1
Tricoptera	9.8	tr	tr	7.7	tr	tr	16.3	0.5	1.4
Oligochaeta	22.0	tr	0.5	15.4	tr	0.1	16.3	tr	0.3
Insecta (Terrestrial)	4.9	tr	tr	11.5	0.4	0.2	4.7	tr	0.1
Hydracarina	22.0	tr	0.2	7.7	tr	tr			
Ostracoda	9.8	tr	0.1	7.7	tr	0.3			
Decapoda				1.3	0.9	tr			
Miscellaneous[a]	9.8	tr	0.1	14.1	tr	0.1	18.6	0.1	0.4
Aquatic plants	4.9			1.3					
Algae	63.4			55.1			20.9		
Detritus[b]		91.6			89.3			93.2	
Stomachs examined		41			81			52	
Stomachs with food		41			78			43	
Total weight of contents		194.7			211.4			115.7	
Total number of animals		9,215			35,122			3,633	

[a]Includes fish scales, Copepoda, *Mysis* sp., and unknown invertebrates.

[b]Includes unidentified material, congealed digestive juices, algae, aquatic plants, and sand.

hoyi and *Gammarus* sp., accounted for only 0.2% of the food items in small fish, but were 11.2% and 11.9%, respectively, of the food items in medium and large fish. Amphipods were most important in the diet of spring and fall fish. Bassett (1957) also found that white suckers in Shadow Mountain Reservoir consumed more amphipods in the winter than the summer. Many of the amphipods taken in the summer by Lake Michigan white suckers are young, accounting for their small importance in the weight of the stomach contents.

Pelecypods and gastropods also were more important to larger fish. Together, they constituted 0.1%, 1.4%, and 5.0%, respectively, of the food of small, medium and large fish. The absence of these items in the food of young suckers has also been observed by Hayes (1956).

Fish eggs comprised a small portion of the white sucker diet in eastern Lake Michigan. Until recently, the white sucker was considered a major egg predator (Holey et al. 1979), but eggs only comprised 0.3% of the total number of food items in all fish examined. Of these, only three eggs were considered large enough to be eggs of the family Salmonidae, an important group of sport fish in Lake Michigan.

Algae was found in 48.1% of the white suckers that were examined. It was found in all sizes of fish, but was mainly observed in fish taken during the spring and summer. Algae was also considered a significant portion of the stomach contents of white suckers from the South Platte and St. Vrain rivers (Eder and Carlson 1977).

Detritus, which included unidentified material, sand, algae, aquatic plants and congealed digestive fluids, comprised 91% of the total weight of all the white suckers examined. Detritus has been identified as a major portion of the stomach contents of white suckers (Eder and Carlson

1977), but its significance as a food item is unclear. A major portion of this material is composed of digestive juices, and consequently, the percentage weight of food items other than detritus are biased downwards. Therefore, the weight percentages presented in Table 4 must be interpreted with caution.

Distribution and Yield

The white sucker is restricted to the shallow waters of eastern Lake Michigan. The majority of white suckers captured in the gill nets were taken at the shallowest stations and only one fish was captured at the deepest station. Nets set along the beach also occasionally captured large numbers of suckers (Unpublished data). The catch per unit effort (CPE) was 7.3 at the 6 - 8 m stations, 3.0 at the 12 - 14 m stations, and less than 0.1 at the 24 m station. There was considerable variation in yield between stations of the same depth. One 12 m station had a CPE of 4.8, while the other 12 m station had a CPE of only 2.2.

Spring catches of the white sucker in the gill nets were small. Fish occurred in 43.8% of the spring samples, and the CPE was only 1.8. In the spring months, fish were captured in the gonadal conditions of green, ripe, and spent. The small spring catches of white suckers probably reflect little movement because of low water temperatures and also movement of the fish out of the sampling area into spawning areas. Various authors (Stewart 1926; Raney and Webster 1942; Dence 1948; Hayes 1956; Olson and Scidmore 1963; Coble 1967; Vondracek 1977) have reported that white suckers migrate into streams to spawn, and Hayes (1956) reported that white suckers may also spawn on the shallow reefs of lakes.

Summer catches of white suckers were larger than the spring yields. White suckers occurred in 64.3% of the samples, and CPE was 7.2. During

the fall, white suckers occurred in 54.2% of the samples and had a CPE of 3.3. In the fall, white suckers were not as restricted to the shallow water stations. The two shallow stations accounted for only 46.3% of the sucker yield in the fall, while they contributed 69.8% and 64.0% of the total yield in the spring and summer, respectively.

In an attempt to identify factors that were important in explaining white sucker gill net yields, multiple regression analysis was conducted between yield and various independent variables. This analysis resulted in the regression equations that are described in Table 5. The first equation in Table 5 is the result of the initial analysis and describes 60% of the variation ($\bar{R}^2$) in the white sucker yield. Inclusion of joint effects terms, describing two way interaction, led to the development of the second fitted equation in Table 5. This regression equation describes 61% of the variation in the white sucker yields.

A third regression equation was constructed of all the variables found significant in the first two equations. The variables that were significant as part of a joint effect term were also included in this reduced model. All variables were entered in this reduced model, regardless of the significance of their partial F values. This regression equation explained 60% of the variation in the white sucker yields and the terms found important in the second model were most important in this model. The variables important in the first model exhibited very small partial F values and contributed little to the explanation of variation in this model. The inclusion of these variables resulted in the lower adjusted multiple correlation coefficient ($\bar{R}^2$), and consequently, the second regression equation contains the variables that explain white sucker gill net yields the best.

Table 5. Results of multiple regression of log (yield + 1) with independent variables, including parameter coefficients, their standard errors, and standardized coefficients.

Parameter	Regression coefficient	Standard error	Standardized coefficient
$y = a + b_3x_3 + b_1x_1 + b_{10}x_{10} + b_4x_4$			
x_3=Water Temperature (^oC)	0.0520	0.0054	0.5794
x_1=Depth (m)	-0.0240	0.0054	-0.2870
x_{10}=Photoperiod (hours)	0.0690	0.0199	0.2131
x_4=Light penetration (m)[a]	-0.0565	0.0211	-0.1766
Constant	-0.4258		
$y = a + b_1x_3x_{11} + b_2x_1x_{11} + b_3x_{10}x_9 + b_4x_{10}x_4$			
x_3x_{11}=Water Temperature x Substrate (ave.)[b]	0.0020	0.0002	0.6230
x_1x_{11}=Depth x Substrate	-0.0016	0.0003	-0.2854
$x_{10}x_9$=Photoperiod x Barometric Pressure (inches)	0.0027	0.0007	0.2528
$x_{10}x_4$=Photoperiod x Light Penetration	-0.0035	0.0014	-0.1719
Constant	-0.5290		

[a]Secchi disc values.

[b]Substrate values are unitless averages based on size of sediment types at the station.

The inclusion of joint effect terms in the best or operational model illustrates the complex relationships between gill net yields and environmental variables. Gill net catches may reflect susceptibility of the fish to capture as well as abundance, and consequently, interpretation of these results in terms of an individual variable's net effect is difficult.

The six factors important in explaining white sucker gill net yields were water temperature, depth, photoperiod, light penetration, substrate, and barometric pressure. Increases in the water temperature or substrate size are reflected in a larger joint effect term, and consequently, a greater white sucker yield. The water temperature x substrate joint effect term described differences in gill net yield within stations. This joint effect term was significant at all stations when yield was regressed against it, indicating the importance of these factors regardless of the area sampled. An increase in the depth x substrate size term resulted in a decrease in the white sucker yield. This joint effect term is constant at a station, and consequently, describes differences between stations.

An increase in the photoperiod x barometric pressure term resulted in larger catches of white suckers. This joint effect term was significant in explaining the catch at one station when the yield of individual stations was regressed with the best independent variables. This indicates that this term explains differences both within and between stations. An increase in the photoperiod x light penetration term resulted in a smaller catch of white suckers. When the yield of individual stations was regressed against the best set of independent variables, this term was never significant, indicating that it explains differences between stations.

Water temperature is the most important factor identified in the explanation of white sucker gill net yields. Temperature has been found to be important in movement of white suckers in other investigations. It has been identified as a controlling factor in spawning migrations (Raney and Webster 1942; Dence 1948; Geen et al. 1966), and surface swimming and jumping has been observed in white suckers at 12 C (Stewart 1926). In eastern Lake Michigan, white suckers were taken more frequently in warm waters. Young suckers have been observed to move into the shallow waters of lakes and streams (Reighard 1915; Huntsman 1935), and the young white suckers were found to grow best at close to 27 C (McCormick et al. 1977). This temperature exceeded any recorded in the study, and therefore, it appears that white suckers congregated in the warmest area available. The increase in temperature may also make the fish more susceptible to capture because of increased movement and feeding activity.

Increase in depth resulted in lower white sucker yield, with only one fish being captured at the deepest station. Spoor and Schloemer (1938) reported that white suckers exhibit diurnal movement in Muskellunge Lake, Wisconsin. At night, the fish moved into shallow water, but during the day, the peak catches occurred in deeper water. The 6-8 m stations would lie in the path of these daily movements if they occur in Lake Michigan. Gill net sets along the shore indicate that such a movement is likely (Unpublished data). The depth from which the suckers will migrate is unknown, and if the fish in the deeper areas don't migrate as extensively as the fish in shallow waters, then they would be less subject to capture. It is also widely believed that the major portion of the white sucker population is located between depths of

7 and 10 m (Galloway and Kevern 1976). This would also explain the large yields of white suckers at the 6 and 8 m stations.

The length of photoperiod was important in explaining sucker yields. In the operational model, an increase in photoperiod could result in an increase or decrease in the white sucker yield, depending on the barometric pressure and light penetration. In the initial model, an increase in the photoperiod resulted in an increase in white sucker yields. A nightly migration of white suckers into depths less than 6 m would reduce the gill net yield, and consequently, the longer the photoperiod, the greater the chance of capture, given the depths sampled in this investigation.

An increase in light penetration resulted in lower sucker yields. This is probably related to the fish's ability to see the gill net. Spoor and Schloemer (1938) concluded that this was not a major factor in their gill net catches, but didn't consider light penetration as a minor but contributing factor to gill net yields. In Lake Michigan, light penetration is not the most important factor in determining white sucker yields, but it does play a significant role.

The substrate type based on size was important in joint effect terms with water temperature and depth. The importance of this factor is difficult to discern because in one term an increase in substrate size explains an increase in yield, while in another term, it explains a decrease in yield. Cole and Weigmann (1977) found that sediments of smaller size in Lake Erie contained more macrobenthos on which the white suckers rely for food. Prey may, however, be easier to capture over larger substrate types, so the effect of this factor is masked.

An increase in barometric pressure resulted in an increase in sucker yields. It has been found in a previous investigation of the study area that barometric pressure was the most significant factor in explaining yellow perch yields (Lechel 1974). High barometric pressure usually accompanies fair weather and the white suckers may increase movement at these times to adjust for little movement during the many periods of inclement weather at this site.

The variation in the white sucker yield that remained unexplained after the best regression equation was fit may be due to several factors. Non-linear functions of the factors investigated may more accurately explain yield. Joint effects of three or more terms could also explain more variation in the yield. One environmental factor that was not measured that may explain white sucker behavior was current. In streams white suckers are mainly bottom dwellers, and experience more trouble maintaining equilibrium in fast currents than other fish (Symons 1976). Kelso (1976) has also observed that white sucker behavior is altered in lakes when the fish are subjected to current. Currents in the sampling area were produced by winds and were occasionally observed to be substantial at the surface. Longshore currents in the sampling area were also considerable at times. Competition for space and food with other bottom dwelling species such as the longnose sucker (*Catostomus catostomus*) and the round whitefish (*Prosopium cylindraceum*) also affects white sucker distribution, but is difficult to quantify. Movements associated with spawning may also be important in the abundance and susceptibility of these fish to capture. Olson and Scidmore (1963) have described these movements as quite extensive.

SUMMARY AND CONCLUSIONS

One of the major objectives of this study was to provide new age and growth data on Lake Michigan white suckers. The aging analysis demonstrated that past investigations have underestimated the age of mature white suckers. The immature fish are accurately and easily aged by the scale method, but older fish should be aged by sections of their pectoral fins.

White suckers from eastern Lake Michigan display a rate of growth comparable to the fastest reported in the literature. Lake Michigan white suckers reach maturity at an earlier age and greater size than most other populations of this fish. This habitat appears to be beneficial to the growth of white suckers, but the biology of the young in this area may be important in sustaining viable populations of this fish. McFarlane and Franzin (1978) demonstrated that adult suckers may grow rapidly in habitats that stress the young and inhibit population growth.

The food habits of the white sucker vary with the composition of the benthos. They are mainly bottom browsers, and consequently, their stomach contents reflect the composition of the benthos. In this way they are selective, but selection within the benthos was not investigated statistically because of the presence of cladocerans in the sucker stomachs. Little information is available on the populations of the microbenthos and they are important to the white sucker. Larger white suckers will select larger food items in Lake Michigan as well as other areas (Lalancette 1977). This results in selection of the type of food due to the different sizes attained by different prey organisms.

Environmental factors were found to be important in describing white

sucker gill net yields by multiple regression. Factors identified as important were water temperature, depth, light penetration, substrate size, photoperiod, and barometric pressure. Joint effect terms of these factors led to the best explanation of the variation in the gill net yields. The presence of joint effect terms in the best fitted equation illustrates the complexity of interactions between an organism and its environment.

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