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MICHIGAN SUCKERS THEIR LIFE HISTORIES, ABUNDANCE AND POTENTIAL FOR HARVEST

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Dr. N.R. Kevern, Professor and Chairman of the Department of Fisheries and Wildlife, Michigan State University, was Mr. Galloway's major professor and principal investigator of the project of which this study was a part.

PREFACE

In the spring of 1973 officers of the Michigan Fish Producers Association asked the Department of Fisheries and Wildlife, Michigan State University for assistance in developing information on the economic impact of the Michigan commercial fishery. That request led to an involvement of several faculty and graduate students not only in Fisheries and Wildlife but also in the areas of food science and marketing. We have tried to work closely with the fishermen and with the management agency, the Michigan Department of Natural Resources, Fish Division, to provide information that would relieve the economic plight of the fishermen. This publication represents one of a series that is intended to contribute that information.

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ABSTRACT

Concurrent with recent increases in protein demand, the yield of traditionally high value species of Great Lakes fish has declined. Filling the void left by this decline makes harvest of new species desirable. Before the harvest of additional species is implemented, it is advisable to compile relevant information concerning their life history and abundance in the region.

Life history data on white suckers (*Catostomus commersoni*), longnose suckers (*Catostomus catostomus*), silver redhorse (*Moxostoma anisurum*), northern redhorse (*Moxostoma macrolepidotum*), and golden redhorse (*Moxostoma erythrurum*) are compiled from the available literature. Data on the past commercial catch of suckers from Michigan waters of the Great Lakes are compiled. Indications of natural fluctuations in spawning run intensity, and correlations between time of spawning and water temperature were obtained from U.S. Fish and Wildlife Service lamprey assessment weir records.

Growth rates for the species studied are dependent upon the richness of the environment. Sufficient data are not available to predict growth rates in the Great Lakes, but rates are expected to vary significantly. Lamprey weir data indicate maximum spawning migrations for large white suckers when temperatures are about 11-15 C. Weir records show no definite trends in annual numbers of spawning suckers over the years of weir operation. These records are not useful in determining the total number of migrating fish entering a stream.

Commercial catch records reveal an erratic decreasing trend in annual yield beginning as early as the late 19th century. Some fluctuations in catch correlate with shifts in fishing pressure due to gear changes and the invasion of the sea lamprey. Accurate assessment of stocks is not possible from commercial records as suckers were not actively pursued in most areas.

Limited data from Michigan Department of Natural Resources index stations indicate white suckers are the most abundant sucker species in Michigan waters, and in some regions of the Great Lakes are one of the most abundant of all fish species.

Commercial harvesting of these species is desirable but government aid may be necessary to initiate such a fishery. After inception of a fishery, careful regulation will be required to obtain maximum sustainable yields.

INTRODUCTION

Selective exploitation of fish in the Great Lakes has been responsible in part for the wide fluctuation in abundance of preferred species. It is reasonable to assume that the optimum maximum sustained yield of both preferred species and all fish can only be achieved if exploitation is balanced so all niches are maintained at high levels of productivity, and preferred species are never placed at a competitive disadvantage. Both of these criteria require the management of more species of fish than those presently considered preferred.

Historically, the most economical means of management of a species has been controlled harvest. The exploitation of currently underutilized species therefore would not only immediately increase the productivity of lakes, but would provide an additional tool for the management of the fishery resource as a whole. In an industry such as the commercial fisheries of the United States, where exploitation of a species is entirely dependent upon the economic advantage involved, the only way to create a fishery for a species is to increase the profit margin. This is most easily done by creating demand in the form of a desirable product. Frozen fish patties, where the identity of the fish need not be prominently displayed, may be the product required to maintain a stable, profitable market for species generally unaccepted by the public. However, it is necessary to estimate future production before processing plants for such a product can be developed.

The purpose of this study was to gather the available information on the life histories, abundance, and commercial exploitation of some of the common members of the sucker family in Michigan. Hopefully this will provide useful background information on which future decisions concerning the commercial exploitation of the several species can be based.

Life history data on white suckers (Catostomus commersoni), longnose suckers (Catostomus catostomus), silver redhorse (Moxostoma anisurum), northern redhorse (Moxostoma macrolepidotum), and golden redhorse (Moxostoma erythrurum) were compiled from the available literature. These data reveal similar habits for the species but wide differences in growth rates within each species depending upon the richness of the environment.

Indications of abundance were obtained from U.S. Fish and Wildlife Service lamprey assessment weirs and Michigan Department of Natural Resources index stations. These sources suggest the sucker family is currently underexploited and has the potential of becoming a useful commercial species. Accurate assessment of sucker stocks was not possible from commercial catch records as suckers were not actively pursued in most areas.

Commercial catch records dating from before 1900 reveal an erratic decreasing trend in annual yield beginning as early as the late 19th century. Some fluctuations in catch correlate with shifts in fishing pressure due to gear change and the invasion of the sea lamprey, and others seem to reflect changes in the quality of the environment.

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Service for their aid in obtaining records for the lamprey assessment weirs and the commercial fisheries respectively. Buck LaVallee and Roy Jensen provided personal accounts of the history of the sucker fishery in the Bay De Noc area, and Vern Applegate commented upon the effect of the sea lamprey on the relative abundance of the sucker species.

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LIFE HISTORIES

White Sucker (*Catostomus commersoni*)

The white sucker is fairly common throughout most of the United States and Canada, with the Great Lakes region being nearly centrally located within its distribution. Scott and Crossman (1973) describe it as an extremely 'plastic' species with drastically varying characteristics according to its habitat. The species is known to show a slight north-south cline in its meristic characters, and a tendency to evolve dwarf populations. Metcalfe (1966) suggests that this combination of plasticity, varying meristics, and dwarf populations, may be responsible for the single species being given a variety of names across its range.

The white sucker is usually found in warm shallow lakes or bays, or in the tributary rivers of larger lakes. They are generally taken in water with depths up to 7 or 10 m, showing some tendency to move offshore with increased size and age. Because adults of the species tend to avoid light, individuals are most active in shallow water in the evening, tending to move inshore during the afternoon, and offshore in early morning (Lawler, 1969).

The importance of this species in the biological community depends upon its interaction with the other species present. In most situations, this species does not constitute serious competition in terms of food or space for other browsing species (Scott and Crossman, 1973). Evidence that white suckers do extensive damage on the spawning grounds of other species is inconclusive, and in all probability less damage is done than is usually supposed. The common use of young suckers as baitfish suggests that the species is probably important as forage in many areas. In some situations, however, the sucker does seem to compete with more desirable species, and is not used extensively as forage. This type of situation was reported by Burrows (1969) in regards to the walleye and white sucker in infertile northern lakes.

Stewart (1926) suggests that the white sucker may be a host for numerous parasites; Hoffman (1967) confirms this, listing 94 species which infect this fish (others have since been added to the list by Dechtiar, 1969).

This species is used in some localities as a baitfish, and as a food for humans and other animals. It is not considered a prime commercial species, but has been harvested when more desirable species were scarce. When marketed in the Great Lakes region, it is often labeled as 'mullet' and not distinguished from other suckers.

Reproduction

Age at sexual maturity varies greatly with location. Campbell (1935) found Waskesiu Lake, Saskatchewan males maturing at ages VI and VII, and females maturing at ages VI to IX. Hayes (1956) reported that in Colorado male *C. c. suckleyi* matured at age II, and females at age IV. Spoor (1938) found females in Wisconsin spawning younger than males at ages III and IV respectively, but most authors agree that males generally spawn earlier than females. Size at first spawning is small in some areas. Hayes found males spawning at 150 mm total length (T.L.) and females at 267 mm T.L., while Stewart (1926) referred to spawners as small as 152 mm to 178 mm in New York.

Spawning generally occurs in shallow streams with gravel bottoms, but white suckers will sometimes spawn in the shallow areas along the margin of a lake. Much of the research on this species has been conducted in conjunction with the upstream spawning run due to the ease with which specimens can be obtained at this time.

Various sources report the onset of spawning by the white sucker to occur from early May (Scott and Crossman, 1973) to mid June (Spoor, 1938), depending upon water temperatures. Geen et al. (1966) report spawning runs begin when stream temperatures reach 10 C, which seems to correlate well with the description of breeding activities given by Stewart (1926). Spawning is reported by Trautman (1957) at temperatures as high as 20 C.

The early segment of the upstream run is composed primarily of males in most years, with females following slightly later (Geen et al., 1966). The daily magnitude of a run in a particular stream seems to be linked to the increase in stream temperature above what it was on the previous day, with larger temperature rises provoking greater run intensities (Geen et al., 1966). Geen et al. also report that yearly run magnitude may be affected by stream levels, as only the largest individuals seem to migrate in years when stream flow is minimal.

Data from Sixteenmile Lake, British Columbia, suggest that only 25-50% of the adult population spawns in any one year (Geen et al., 1966). What factors, other than stream level, affect the number of spawners was not discussed, but Geen et al. did show that some individuals spawn in successive years, while others skip years in their spawning activities. Over the six year period of the study, they found 50-80% of those fish marked in a year returned to spawn one additional year, 10-30% two additional years, and less than 3% three additional years. From this, it can be seen that even though individuals may spawn over a period of several years, it is unusual for an individual to spawn more than four times (lake spawning was not considered as a possibility in these conclusions by Geen et al. apparently because it was felt there was no suitable substrate on which this could occur). They also found that roughly 20-40% of the fish spawned two successive years, and less than 10% three successive years. Some fish were recovered as long as seven years after being marked, indicating a rather low mortality for adult white suckers. Dence (1948) reported similar first year return rates for the dwarf sucker, *C. commersoni utawana*, but found second year rates to be much lower, indicating perhaps higher mortality rates for this subspecies.

Olson and Scidmore (1963) investigated repeat spawning in terms of homing tendency and concluded that in Many Point Lake, Minnesota, there was a lake-wide tendency for individuals to return to the spawning stream in which they were originally marked despite being randomly distributed throughout the lake at other times of the year.

Scott and Crossman (1973), and Stewart (1926) report that on the spawning grounds two to four males often crowd around one female during spawning acts which lasts only 3-4 seconds and may occur as often as 40 times in an hour. Egg number has been reported as high as 140,000 (Slastenenko, 1958) with Scott and Crossman (1973) suggesting the usual number is 20,000-50,000. Campbell (1935) calculated that there were approximately 24,604 eggs per kilogram of body weight in individuals from Waskesiu Lake, Saskatchewan. Eggs are simply scattered and adhere to gravel or drift downstream and adhere to substrates in quieter areas.

Adult spawning mortality is low as would be expected from the high number of repeat spawners. Geen et al. (1966) estimated that mortality at most was 16-20%, and attributed this low figure to the lack of aggressiveness displayed by males during spawning. Scott and Crossman (1973) indicate Geen's figures are typical for the north and west, but are high for the eastern portion of the species' range.

The downstream migration of adults commences about 10-14 days after the onset of the upstream migration, with females generally returning to the lake prior to males (Geen et al., 1966). Geen's data also indicate that the earlier an individual fish migrated upstream, the more variable its time of return. He found in some cases a fish marked on the first day of the upstream run would be recovered on the last day of the return migration, while individuals migrating upstream late returned more immediately, many without spawning. Scott and Crossman (1973) indicate that in some populations migration without spawning followed by lake spawning is common. Downstream migration of spent suckers showed a daily peak during or shortly after the period of highest water temperature, and ceased when stream temperature fell to the daily minimum (Geen et al., 1966).

Egg incubation periods have been reported from 4 to 15 days under various conditions (Slastenenko, 1958; Geen et al., 1966; Hale, 1970; Oseid and Smith, 1971). Geen et al. report the young remain in the gravel for 1 to 2 weeks after hatching, and Geen et al. and Hale (1970) both record the fry as being 12-14 mm after this period. According to Clifford (1972), downstream movement of the fry in a brown water stream of Alberta occurs almost entirely at night, their nocturnal drift pattern being more pronounced than any of the drifting invertebrates. Clifford (1972) notes that as the fry become larger they move closer to the stream surface. This behavior suggested to Clifford that the smaller fry move passively while the older ones move more actively.

Geen et al. (1966) reported most movement occurred between dusk and dawn. They hypothesize this migration pattern to be due to loss of orientation in the dark which results in drifting, or to a light avoidance response which causes fry to hide in the gravel during daylight and avoid the current. Their findings, that increased water level and turbidity also resulted in more downstream movement, seem to agree with this hypothesis. Using data from both longnose and white suckers, Geen et al. (1966) roughly estimated the survival rate of eggs to migrant fry to be only 0.3%.

Food

Stewart (1926) provided a detailed account of the feeding habits of white suckers throughout their life cycle. The initial stage, the 'yolk-food period', ends with the beginning of what Stewart calls the 'top feeding period' when the fish are approximately 12 mm long and 9 days old. During this period, the mouth is terminal, but is in the process of becoming inferior, and the fish feeds close to the surface on floating organisms as shown in Table 1. Following the 'top feeding period' is the 'critical period' when the transition from top to bottom feeding takes place. This period covers about 9 days during which the fry make occasional trips to the bottom and take mouthfuls of sand. The 'fingerling period' (18-75 mm) which follows may last a period of years over which the fish is limited by the size and position of its mouth to consuming small bottom organisms. During this stage the fish is not capable of separating these organisms from the sand and must consume both. Beyond 75 mm in length, Stewart considered the fish to be in the 'adult feeding period'. During this period, the fish are characteristically shy, avoiding most light, and feeding most actively at dusk and dawn. The major differences between the diet of the adult and fingerling are due to the increased mouth size, and the ability of the fish to separate food from sand.

Carlander (1969) cited several authors who listed the following foods for young white suckers: entomostracans, small insects, rotifers, and algae. Larger and adult suckers were said to feed on chironomids, entomostraca, amphipods, fingernail clams, snails, and detritus. Campbell (1935) examined the food of adults of this species (217-244 mm) and cited the following ranges for percentage composition of gut contents: Chironomidae 5-90%, Trichoptera 2-70%, Mollusca 5-85%, Entomostraca 5-98%, Chaoborus 0-50%.

Reports of the white sucker being a threat to other species through egg predation are largely unsubstantiated. Ellis and Roe (1917) reported that individuals may consume as many as 500 log perch eggs per day, but Campbell (1935) found no eggs in 100 white sucker stomachs taken on whitefish spawning grounds, and Stewart (1926) found no eggs in the stomachs of suckers he found in brook trout spawning grounds.

Table 1. Percent volume of stomach contents from white suckers of various sizes.[a]

Feeding Period	Top-feeding		Critical	Fingerling	Adult
Size	12 - 16 mm		16 - 18 mm	18 - 75 mm	75 mm+
Location	Pond	Stream	Pond	Unspecified	Unspecified
No. of Fish	9	23	9	57	52
Chironomid Larvae	15.0	62.0	19.0	28.0	30.0
Entomostraca	37.0	4.0	15.0	3.0	5.0
Diatoms and desmids	1.3	8.0	10.0	22.0	3.6
Protozoa	27.0	6.0	2.0	9.0	0.1
Rotifera	18.0	7.0	20.0	4.0	0.0
Arthopod fragments	0.0	7.0	0.0	1.0	5.4
Sand	0.0	0.0	27.0	21.0	0.9
Algae	0.0	0.0	2.0	2.0	2.4
Larger Insects	0.0	0.0	0.0	0.0	31.0
Other	1.7	6.0	5.0	10.0	21.6

[a]After data of Stewart, 1926.

Age and Growth

Reliable age-growth data are scarce, as most of the authors who dealt with this relationship determined age by counting scale annuli, and this process is now considered unreliable for fish over five years old (Beamish and Harvey, 1969). From the data available, it is apparent that large variations in annual rates of growth do occur in different locations (Table 2). These variations may be due to genetic differences among populations, but are more likely due to the length of the growing season and level of enrichment of the body of water which the fish inhabit. Roland and Cumming (1969) reported that an increase in the hardness of the water of an impoundment significantly increased the growth rates of white suckers in the southeastern United States. Eddy and Carlander (1940) found that growth in Minnesota was correlated with total dissolved solids, total carbohydrates, pH, plankton abundance, bottom fauna and length of growing season. Parker (1958) found thinning of all of the fish populations in Flora Lake, Wisconsin increased the growth of the white sucker.

Growth rates for adult suckers have been calculated by three authors using methods other than scale reading. The results of Beamish (1970), using pectoral fin ray sections, Coble (1967) using tags, and Geen et al. (1966) using length frequency distribution, were similar. In Ontario, Beamish found an average annual growth rate of 20 mm at age VI and slower growth at ages of more than VI (Table 2). The work of Coble (1967) in South Bay, Lake Huron showed tagged adult fish recaptured later in the same year having an average growth of 7-12 mm for the summer, but fish captured up to 5 years later showed an average annual growth rate of only 7.6 mm. Geen et al. (1966) obtained an estimated annual growth of only 10-20 mm for the population they studied in Sixteenmile Lake. The drastic difference between these estimates and those of Beamish for fish under 6 or 7 years of age exemplify the variance of growth rates possible by this species at different ages. Differences in growth rates for younger individuals at different locations can be seen in Table 2.

Preliminary results of student studies on white suckers from Lake Michigan, near Ludington, Michigan, show calculated total lengths similar to the Minnesota studies (Table 2) at ages I and II, similar to Beamish's study at age III, and slightly larger than Beamish's study at ages V-VII (Tack, personal communication). The work of Beamish (1973) suggests in some studies errors in age and growth determinations may have resulted from interpreting a false annulus as the first true annulus. Such an error would have resulted in underestimations of size at any age.

Growth rate differences also appear between males and females. Spoor (1938) found for the first 4 or 5 years of life both sexes increase in length at about the same rate, but from then on the females increase more rapidly than the males. He also reported that although the average annual increment in length decreases with age, the average annual increment in weight increases, the rate being the same per unit of length for males and females.

Table 2. Average calculated total length (mm) of white suckers at each annulus.

Authors	Eddy & Carlander (1942)[a] Smith & Moe (1949)[a]	Kuehn (1949)[a] Moyle & Burrows (1954)[a]	Montana Fish & Game Dept. (1964)		Spoor (1938)[c]	Kath-rein (1951)	Beamish (1970)[b]
Place	Minnesota	Minnesota	Montana Streams	Montana Lakes	Wis-consin	Mon-tana	Ontario
No. of fish	2,655	1,065	163	282	2,990	223	
Age							
I	109	94	53	53	71	66	179
II	206	180	135	147	117	135	274
III	295	259	198	229	163	208	336
IV	351	333	254	295	203	257	387
V	401	378	277	328	231	310	424
VI	424	424	302	378	262	348	452
VII	437	460	328	391	290	358	472
VIII	490	495	333	417	310	386	487
IX	495		378	434	345		499
X			394		335		509
XI							517
XII							524
XIII							529
XIV							533
XV							536

[a]Combined data as taken from Carlander (1969).

[b]Data converted from fork length using a factor of 1.07. Age by fin ray sections.

[c]Data converted from standard length using a factor of 1.18.

Carlander (1969) lists numerous length-weight relationships for this species in various conditions of sexual development. The only Great Lakes population studied was in South Bay, Lake Huron where Coble (1967) determined a relationship of $\log W = -4.679 + 2.92262 \log L$ (W is weight in grams and L is fork length in millimeters) from individuals between 229 and 457 mm. Spoor (1938) and Bassett (1957) found no evidence of a sexual difference in length-weight relation or condition factor. Spoor and others also noted that no change in condition factor with age or length was discernible. The extremes of coefficients of condition (K) based on total length listed by Carlander (1942) were 1.02 and 1.27. These were used as Minnesota standards for fish in poor and excellent conditions.

The maximum length reported for white suckers is 635 mm (2.35 kg) by Trautman (1957) and the maximum weight 3.18 kg (579 mm) by Chambers (1963).

Mortality

Low natural mortality rates for adult white suckers have been reported by several authors. Olson and Scidmore (1963) estimated an annual mortality of 13.1% for adult white suckers in Many Point Lake, Minnesota. Geen et al. (1966) noted the longevity of the adult population as indicated by the high number of repeat spawners, but also pointed out the relatively high mortality of young indicated by the low annual recruitment into the spawning population. Coble (1967) considered the question in more detail and determined a mean annual mortality of 25.7% for the South Bay population which was under predation by sea lampreys. Coble's data also indicate the rate of mortality of fish larger than 380 mm increased with size. Maximum age of this species is about 17 years.

Longnose Sucker (*Catostomus catostomus*)

The distribution of the longnose sucker is somewhat more northern than that of the white sucker. It lives throughout most of the mainland of Canada, and is present in at least parts of all of the states of the United States which border upon Canada. This species is one of the most common in the northwest sections of Canada, and is the only North American sucker which appears in Asia. Scott and Crossman (1973) call it the most successful and widespread cypriniform in the north, stating that it occurs almost everywhere in clear cold water. In general, it is restricted to freshwater lakes or tributary streams, and has been reported to depths of about 200 m (Scott and Crossman, 1973).

As with the white sucker, the longnose does compete to some extent with more favored species for limited food supplies, but this competition in most instances is not considered extensive. Longnose were once thought to be serious egg predators, but evidence of this appears to be scarce and possibly the reputation is unjustified. Like the white sucker, this species is a common host for many parasites. Hoffman (1967) listed 32 commonly occurring parasites, and others have been added by Dechtiar (1969).

The longnose is seldom sought by man commercially, but is sometimes locally sought as a game fish. Its flesh is considered more palatable than that of the white sucker, but is still primarily used only as dog food. The limited amount which is marketed for human consumption is usually labeled as 'mullet'.

Reproduction

The reproductive activities of the longnose sucker are similar to those of the previously discussed white sucker. The longnose sucker spawns primarily in streams or on the shallow reefs of lakes. The onset of the spawning run is influenced by water temperature, the critical temperature for the beginning of the run being reported as 5 C by Geen et al. (1966) with the peak being between 12.2 C and 15.0 C (Brown and Graham, 1954; Harris, 1962). The majority of spawners move upstream between noon and midnight, with maximum movement during the evening hours.

The composition of the spawning run has been reported for several streams by various authors. Geen et al. (1966) noted that the longnose suckers appeared to be smaller than the white suckers during the spawning migration in Frye Creek, and that the males were smaller than the females. Their data, which show lengths ranging from 130-400 mm fork length (F.L.) and estimated ages from 5 to 15 years, also reveal that a large percentage of the migrating longnose suckers were immature whereas almost no immature white suckers were present in the streams during their spawning runs.

Brown and Graham (1954) reported that the males sampled from a spawning run near Yellowstone Lake had total lengths ranging from 269 to 455 mm, while the females ranged from 345 to 510 mm. The youngest mature male found was age IV, and the youngest mature female age VI, with over 51% of the males being age V and 45% of the females age VI. These data indicate a slightly earlier maturation than was found by Bailey (1969). He reported average lengths and ages for the spawning population of the Brule River (Lake Superior) as 386 mm (7.2 years) for males and 422 mm (8.0 years) for females, and minimum lengths of 267 mm and 292 mm respectively. Bailey also estimated over 91% of the males were from age groups VI-VIII, and over 75% of the females were from age groups VII-IX.

The extremes in age at first spawning are those reported by Harris (1962) and Hayes (1956). Harris (1962) found the greatest number of fish to be 11 years old and all fish examined to be between 9 and 15 years of age in Great Slave Lake. Hayes (1956) reported males of 2 years (100-125 mm) and females of 3 years (203 mm) spawning in a Colorado reservoir. The large differences may be due to local differences in maturation rates or to errors in scale reading, as Geen et al. (1966) found that the scales were not reliable for aging mature longnose suckers.

Repeat spawning of longnose suckers is common. Geen et al. (1966) reported 30-60% of those fish marked in one year would spawn again, with 12-24% spawning two additional years, and less than 3% three additional years. They also found 17-48% spawned in successive years. These first-year return figures are higher than those reported by Bailey (1969) for the Brule River (Lake Superior). He found that only 7-18% of the spawners returned in successive years, but did mention that his estimates may have been in error due to escapement, spawning in other streams, or lake spawning.

Geen et al. (1966) observed longnose spawning in a stream 15-30 cm deep with a bottom composed of gravel 0.5 cm in diameter, and a current of 30-45 cm/sec. They reported that during the day males rested upon the bottom and females remained along the banks in areas of still water. To initiate spawning, a female would move out among the males and generally two to four males would crowd around her. The group would thrash about for 3 or 4 seconds during egg deposition. Following this, each of the individuals returned to their previously held position in the stream. Geen et al. also noted that spawning occurred from 6 to 40 times per hour and usually took place between 0600 and 2130 hours.

The total number of eggs laid by a female in one season has been reported to be between 14,000 and 35,000 (averaging 26,000) for the Lake Superior population studied by Bailey (1969), and between 17,000 and 60,000 (averaging 35,000) for the Great Slave Lake population studied by Harris (1962). No aggressive behavior was reported among the male spawners by any of the authors. This seems to be reflected in the low spawning mortality rate (11-28%) for the species reported by Geen et al. (1966) in his studies of Sixteenmile Lake, British Columbia.

The downstream migration of adults follows a daily pattern similar to that of the white sucker, showing a maximum at about the time of highest water temperature and ceasing when stream temperatures fall to the daily minimum (Geen et al., 1966). Geen et al. report that the main downstream movement begins about 5 days after the spawning migration begins, with the females generally leaving the stream first. They estimate the suckers are present in the stream approximately one month, with the first individuals entering the stream being the last to leave. The length of time longnose were present in the stream is consistent with that reported by Brown and Graham (1954), who found individual males present in the tributaries of Yellowstone Lake for 5-39 days (average 17) and individual females present for 14-25 days (average 19) during a single year.

Geen et al. (1966) report that under laboratory conditions longnose eggs require 8 days to hatch at 15 C and 11 days at 10 C. They estimate from these figures that under the natural conditions prevalent in Frye Creek, eggs probably required 2 weeks to hatch. Because fry were not sighted until one month after spawning, Geen et al. also suggest that the larvae remained in the gravel 1-2 weeks prior to their downstream migration.

The downstream migration of fry is poorly documented, being studied by only Geen et al. (1966). They found fry first migrating at 10 to 12 mm in total length, and established these to be longnose sucker by comparison to known specimens. This migration preceded that of white sucker fry, presumably because of an earlier date of spawning. The effect of daylight and turbidity upon migration was the same as that previously described for the white sucker.

Food

The food of this species appears to be highly variable with respect to age and locality. Scott and Crossman (1973) list typical foods in order of frequency of occurrence as amphipods, Trichoptera, chironomid larvae and pupae, Ephemeroptera, ostracods, gastropods, Coleoptera, pelecypods, copepods, cladocerans, and plants. The limited results reported by Rawson and Elsey (1950) indicate some change in diet resulting from growth as shown in Table 3.

Inspection of these data suggests a possible change in feeding habit from midwater to bottom feeding, as occurs in the white sucker. The data of Rawson and Elsey (1950) varies considerably from that of Brown and Graham (1954) at Yellowstone Lake. The latter investigators found that 69% of the fish containing food had algae in their stomachs, and the algae composed about 33% of the stomach volume. Higher plants were found in 40% of the individuals and composed 10% of the stomach volume, their frequency of occurrence exceeding all other stomach contents except algae (69%) and Diptera (55%). Aquatic insects appeared to be much more important to the fish studied by Brown and Graham (1954) than to those studied by Rawson and Elsey (1950). Perhaps this is because the fish examined by Brown and Graham were captured in stream environments, while those studied by Rawson and Elsey were from a lake.

As with the white sucker, the label of egg predator seems to be erroneous. The only report of longnose suckers consuming eggs of a valuable species was by Stenton (1951) who found 6 of the 9 fish he examined had consumed brook trout eggs. He presumed, however, that the consumption was not willful, and that the eggs were probably dead prior to being taken.

Age and Growth

Age and growth determinations have been carried out by numerous investigators. Although the validity of these studies is in question

Table 3. Percent volume of the stomach contents of longnose suckers from Pyramid Lake.[a]

Food Item	25 young fish	100 large fish
Amphipods	1	72
Chironomidae	6	19
Copepods	4	--
Cladocera	66	--
Snails	--	.6
Terrestrial insects	23	--
Other	--	8.4

[a]After data of Rawson and Elsey, 1950.

due to the use of the scale method for aging, the results of some studies are shown in Table 4. Preliminary results from student studies of longnose suckers near Ludington, Michigan indicate growth which is much faster than any presented in Table 4. Calculated total lengths at the first four annuli from these studies are roughly comparable to the lengths observed in the northern population of Great Slave Lake (Table 4) at ages II, IV, VII, and IX (Tack, personal communication).

The study by Harris (1962) was not the only work showing differential growth rates between subpopulations in the same body of water. Bailey (1969) noted that growth rates varied in different localities in western Lake Superior and attributed this variance to differences in the richness of the habitat. Neither Bailey nor Harris reported significant differences between the growth rates of males and females within the populations they studied, but Brown and Graham (1954) found Yellowstone Lake females grew significantly faster than males. This was particularly evident after the first four years of life. Growth in weight was not reported as being related to any factor other than length by any of the investigators.

Length-weight relationships were calculated by several authors including Harris (1962), Bailey (1969) and Hayes (1956). Their results were:

Harris (1962) Great Slave Lake

$$\text{Log } W = -3.60 + 2.88 \text{ Log } S\,L$$

Weight in grams - Standard length in millimeters

Bailey (1969) Western Lake Superior

$$\text{Log } W = -2.5413 + 2.8499 \text{ Log } T\,L$$

Weight in grams - Total length in millimeters

Hayes (1956) Shadow Mountain Lake

$$\text{Log } W = -5.0685 + 3.0225 \text{ Log } T\,L$$

Weight in grams - Total length in millimeters

Bailey noted that fish of particular ages and fish caught in certain areas showed consistent deviations either above or below the values predicted by the length-weight relationship he derived.

The only calculation of coefficient of condition found which was based on over 100 fish was that of Harris (1952), who reported a mean K_{SL} of 1.90 with a range of 1.73 to 2.04.

Mortality rates for this species were revealed to be low by Geen et al. (1966) in their study on longnose and white suckers, but the only quantitative estimate found in the literature was by Harris (1962) who calculated a 55% annual mortality for suckers over 14 years of age. Scott and Crossman (1973) state individuals may be as old as 22-24 years but Keleher (1961) estimated the largest fish on record (642 mm fork length, 3.3 kg) to be only 19 years.

Table 4. Total lengths (mm) of longnose suckers.

	Calculated (at each annulus)				Observed		
	Yellowstone Lake, Brown & Graham (1954)	Missouri R. Kathrein (1951)	Lake Superior Bailey (1969)		Pyramid L. Rawson, Elsey (1950)[a]	Great Slave L. Harris (1962)[a] North	South
No. of fish	575[b]	87[b]	1349[b]	1349[c]			
Age							
I	51	76	81	91	53	---	---
II	122	140	150	137	85	153	180
III	216	206	213	185	108	171	204
IV	297	264	269	234	133	254	240
V	345	312	323	279	153	291	307
VI	401	348	371	328	179	315	309
VII	442	373	399	358	204	331	364
VIII	460	394	424	389	225	373	413
IX				414	245	404	480
X				434	265	434	497
XI				464	316	466	497

[a] Data converted from fork length using formula given by Carlander (1969).

[b] Calculated by direct proportion.

[c] Obtained from empirical curve.

Redhorses (*Moxostoma* spp.)

The group of suckers generally called redhorses consists of the genus *Moxostoma* which have been referred to as one of the most perplexing groups of fishes encountered by American ichthyologists. Because of the uncertain systematic position of the group, little reliable information is available on their life histories (Robins and Raney, 1956).

Both the silver redhorse (*M. anisurum*), and the northern or shorthead redhorse (*M. macrolepidotum*) are known to inhabit some streams on the United States shore of Lake Superior (Moore and Braem, 1965), and the golden redhorse (*M. erythrurum*) is common in some sections of Lake Huron. Each of these species occupies a range significantly smaller than white or longnose suckers. The southern shore of Lake Superior lies on the extreme northern edge of the distribution of silver redhorse with the drainage of the other Great Lakes forming the northeast portion of its boundary. The golden redhorse range borders on the Upper Great Lakes. This species being more commonly reported south from the Lake Erie drainage. The northern redhorse lives as far north as Hudson Bay with the Upper Great Lakes falling in about the center of its range. More detailed definitions of these ranges are available in Scott and Crossman (1973).

Habitat

The habitat requirements for each of these species are somewhat dependent on the population being considered. Meyer (1962) described the northern redhorse as having the strictest habitat requirements of the three.

In the DesMoines River he found this species only in fast moving water, usually over rock, gravel, and rubble bottoms, but occasionally over thick layers of silt behind eroded bank vegetation. Scott and Crossman (1973) note that prior to 1970, when Jenkins (1970) combined four conspecific forms (*M. breuiceps, M. coregonus, M. lachrymale, M. macrolepidotum*) into one, this species was considered more of a lake than a river form. However, the species must now be said to inhabit the shallow clear waters of lakes or rivers. Cross (1967) found *M. macrolepidotum* to be highly tolerant of high temperatures (up to 37 C), but relatively intolerant of chemical pollution and silting.

The silver redhorse was found by Meyer (1962) to frequent slower moving waters in the DesMoines River than the northern redhorse. He reported young silver redhorse congregated over areas with a soft-bottom, but adults showed little preference for bottom types. Scott and Crossman (1973) accept this description of the silver redhorse habitat, and add that the species is more common in streams than in lakes. However, Hackney, Hooper and Webb (1970) found that the fish of the population they studied remained in a reservoir except during spawning, suggesting they preferred the lentic to the lotic environment.

Meyer (1962) found golden redhorse to inhabit areas similar to those inhabited by the silver redhorse, but Martin and Campbell (1953) found them in deeper, faster waters near riffle areas in Missouri. Hall and Jenkins (1953) indicate the golden redhorse is better adapted to river than to lake habitats, but from statements presented by Carlander (1969) it appears that growth increases progressively in more lentic environments, being faster in larger rivers than in headwater streams. Cross (1967) describes the species as sedentary in streams when stream conditions are relatively constant; however, during extended periods of highwater or drought, populations move to areas with more favorable stream conditions.

Scott and Crossman (1973) note that the golden redhorse is one of the few species of suckers whose range has not been recently diminished by habitat changes. This suggests that the golden redhorse may be more tolerant of man-induced environmental changes than other related species.

Ecology

The species of redhorse being considered here interact with their biologic community in much the same way. All are probably highly subject to predation when young, but as adults are only preyed upon by the largest of the piscivorous species. Direct competition for each of the species is limited to other bottom feeding fishes, particularly other suckers, but indirect competition must include to a limited extent all species which depend upon invertebrates spending part of their life cycles on or in the bottom. This would include such high value fishes as the trouts, sunfish, and basses.

The incidence of parasites in these species is not as well documented as for the white and longnose suckers, but it appears that the redhorses are a common host. Hoffman (1967) found only five species of parasites for the silver redhorse and northern redhorse and thirteen species for the golden redhorse, but Dechtiar (1972) reports that by examining only six silver redhorse he found fifteen species of parasites. Fredrickson and Ulmer (1965) found that the northern redhorse along the Iowa, South Dakota border were subject to seasonal infestations of tapeworm which infected as much as 38% of the population.

Reproduction

The spawning activities of the silver, northern, and golden redhorse are similar with the exception of stream type. Scott and Crossman (1973) report that silver redhorse spawning takes place in the main channel of turbid rivers in 0.38-1.0 m of water, over gravel or rubble bottoms, and that the northern redhorse migrates from larger bodies of water into smaller rivers or streams to spawn on gravelly riffles. Gerking (1953) found that the golden redhorse in Indiana preferred to spawn in the riffles of main streams, like the silver redhorse, but would ascend small streams near their home territory.

The onset of the spawning run for each of the species is highly dependent upon water temperatures. Both Meyer (1962) in Iowa, and Hackney et al. (1970) in Alabama, found 13.3 C to be a good estimate of the water temperature at the beginning of the silver redhorse spawning run. The northern redhorse spawns slightly earlier when the water temperature reaches 11.1 C and the golden redhorse slightly later when the stream temperature is 15.0 C (Meyer, 1962). Males of all species congregate on spawning grounds before the females, apparently to defend home territories. Sex ratios (males:females) on the spawning grounds during spawning have been reported for the three species combined as about 2:1 (Meyer, 1962), and for silver redhorse alone as about 4:1 (Hackney et al., 1970). No nest is built by any of the species, and all of the species show highest spawning intensity in early morning and evening. Meyer (1962) found female silver redhorse carrying from 14,910 to 36,340 eggs, female northern redhorse carrying from 13,500 to 27,150 eggs, and female golden redhorse carrying from 6,100 to 23,350 eggs. From a limited number of samples, Meyer arrived at regression equations for the number of eggs per female as (-19.7 + 0.101 TL) 1000 for northern redhorse, (18.8 + 0.103 TL) 1000 for silver redhorse, and (-33.1 + 0.136 TL) 1000 for golden redhorse, where total length was measured in millimeters.

The size of the fish involved in the spawning runs has been reported only by Hackney et al. (1970) from Alabama. They found female silver redhorse ranging from 548 mm upward (with most between 548 mm and 600 mm), and males ranging from 507 mm upward (with most between 510 mm and 530 mm). Their data showed most fish of both sexes becoming mature at age VII with a very few spawners being ages V and VI. Meyer (1962) showed similar results for the silver redhorse in his study in Iowa, and also found that male northern redhorse commonly mature at age III. His data were not sufficient to show the age at which females mature. Scott and Crossman (1973) report ages at maturity of II for female northern redhorse in South Dakota, IV or V for both sexes in Saskatchewan, and III or IV for both sexes in the Great Lakes. Meyer (1962) reported golden redhorse to first mature at age III, with most being mature at age IV.

Food

Each of these redhorse species obtain food exclusively by sucking up bottom material and straining from it a random variety of invertebrates (Scott and Crossman, 1973). Due to this habit, the diet of these species probably varies greatly with habitat. Meyer (1962) reports each of the three species utilized the same foods in the streams he studied. By frequency of occurrence these foods were: immature chironomids (91%), immature Ephemeroptera (62%), immature Trichoptera (18%), and a few small molluscs. Northern redhorse food habits in

Lake Nipigon were reported by Clemens, Dymond, and Bigelow (1924) as consisting of immature forms of Ephemeroptera, Trichoptera, Chironomidae, Tipulidae, Stratiomyidae, Ostracoda, molluscs, Oligochaeta, various crustaceans, Hydracarina, and diatoms.

Age and Growth

Silver redhorse:

Few age and growth studies have been conducted on this species. The results of those which have been published are presented in Table 5.

Meyer (1962) noted that for this species annual gains in weight continue to increase throughout the life of the fish despite decreases in annual length gains. Sexual dimorphism in growth, with the female becoming larger after sexual maturity (age VI), was reported by Hackney et al. (1970), but was not noted by Meyer (1962). The longest fish recorded of this species may be the specimen listed by Trautman (1957) as 635 mm in length and weighing 3.74 kg, however he noted specimens of 4.54 km have been reported from the Ohio River.

Length-weight relationships for this species were calculated by Meyer (1962) using first-degree, second-degree, third-degree, and logarithmic regressions. He found the logarithmic relationship Log W = -4.236 + 3.1243 log TL (W = weight in grams, TL = total length in millimeters) to be the most accurate in describing the length-weight relationship. Meyer also found that the coefficient of condition fluctuated between a high of 1.43 in May prior to spawning, to a low of 1.08 in June.

Northern redhorse:

Age and growth records are more numerous for the northern redhorse than for most of the other redhorse species. Results of those studies using more than 100 fish are presented in Table 6.

Meyer (1962) found that annual weight gains for this species increase through age VI but then decline. It should be noted however, that very few specimens above age VI were used for this determination. Scott and Crossman (1973) state that growth in Saskatchewan is much slower than in Minnesota. This statement, along with the data presented in Table 6 implies that growth is faster in the southern part of the species' range. No sexual dimorphism in growth was reported by any of the investigators cited. The largest specimen noted by Trautman (1957) was 620 mm in length and 1.87 kg in weight, but Meyer (1962) found one age VIII fish of 655 mm, and 3.06 kg.

Length-weight relationships for this species were calculated by several investigators including Greenbank (1950), Purkett (1958), and Meyer (1962). Their results were as follows:

Table 5. Calculated and observed total lengths (mm) of silver redhorse at each annulus.

	Observed mean total length at capture		Calculated mean total length				
	DesMoines R. Iowa Meyer (1962)	Flint R. Alabama Hackney (1970)	DesMoines R. Iowa Meyer (1962)	Flint R. Alabama Hackney (1970)	St.Francis R. Missouri Purkett (1958)	Meramaec R. Missouri Purkett (1958)	Gasconade R. Missouri Purkett (1958)
<u>Age</u>							
I	108	---	109	171	114	94	94
II	168	305	195	296	201	178	170
III	302	---	271	381	269	269	262
IV	349	---	328	451	312	338	333
V	392	484	379	503	351	399	406
VI	452	548	432	537	386	439	455
VII	497	565	470	559	414	467	457
VIII	514	581	505	589	437	---	---
IX	518	603	513	602	455	---	---
X	---	620	---	---	462	---	---

Table 6. Average calculated total length (mm) of northern redhorse at each annulus.

Age Class	Statewide Minnesota Eddy & Carlander (1942)	Illinois R. Oklahoma Hall & Jenkins (1953)	Statewide Missouri Purkett (1958)	DesMoines R. Iowa Meyer (1962)
I	107	79	107	117
II	190	188	193	224
III	264	328	264	293
IV	330	384	305	343
V	381	447	335	417
VI	427	538	371	521
VII	483	---	---	589
VIII	579	---	---	655
IX	615	---	---	---

Greenbank - upper Mississippi River

$$\log W = -3.20 + 2.83 \log TL$$

Purkett - Missouri

$$\log W = -4.887 + 2.958 \log TL$$

Meyer - Iowa

$$\log W = -4.042 + 3.021 \log TL$$

where weight (W) is in grams and total length (TL) in millimeters.

Meyer reported the average condition factor of the northern redhorse to have an annual fluctuation less than that of the silver redhorse. In Iowa, the northern redhorse reached its highest coefficient of condition in October (K_{TL} = 1.11) and its lowest in mid June (K_{TL} = 0.91). Fogle (1961, 1963) reported condition factors (K_{TL}) as high as 1.35 in South Dakota during parts of the annual fluctuation, but noted a condition decrease during the first few years of impoundment of the reservoir he was studying.

Golden redhorse:

The results of the most extensive age and growth studies published concerning golden redhorse are presented in Table 7. From Table 7 no definite north south growth gradient can be determined. Faster growth in slower flowing waters seems evident, but this may reflect stream richness more than the velocity of flow. Sexual dimorphism in growth was not noted in any of the studies cited. Trautman (1957) listed maximum size in Lake Erie as 660 mm and 2.04 kg, with females tending to be slightly heavier.

Length-weight relationships have been reported from Illinois, Missouri, and Iowa as follows (im millimeters and grams):

Lewis and Elder (1953) - Illinois

$$\log W = -4.85 + 3.07 \log SL$$

Purkett (1958) - Missouri

$$\log W = 04.881 + 2.975 \log TL$$

Meyer (1962) - Iowa

$$\log W = 04.202 + 3.098 \log TL$$

Condition factors for this species, as for the other redhorse species, vary greatly throughout the year. Roach (1948) recorded an average K_{TL} of 1.39 in Ohio, while Meyers (1962) recorded monthly mean condition factors (K_{TL}) of from 1.02 in June to 1.19 in May, in Iowa.

Table 7. Average calculated total length (mm) of golden redhorse at each annulus.

Age Class	Missouri (several streams) Purkett (1958)					
	Statewide	Headwater	Middle	Lower	Worst Station	Best Station
I	79	76	79	79	61	86
II	150	147	147	168	119	208
III	218	190	218	262	165	333
IV	272	236	274	333	208	396
V	310	274	307	371	239	419
VI	333	302	330	399	274	434
VII	---	---	---	---	300	445
VIII	---	---	---	---	307	457
IX	---	---	---	---	335	376
X	---	---	---	---	333	404
XI	---	---	---	---	356	366

Table 7 (Contd.)

	(Unspecified Habitat) Ohio	Illinois R. Oklahoma	L. Eucha Oklahoma	Spavinaw L. Oklahoma	DesMoines R. Iowa
Age Class	Roach (1948)	Jenkins, Leonard & Hall (1952)	Jackson (1966)		Meyer (1962)
I	97	94	145	122	124
II	251	218	302	297	188
III	330	305	391	361	264
IV	391	378	434	427	290
V	434	445	490	551	325
VI	---	521	---	---	472
VII	---	579	---	---	488
VIII	---	625	---	---	---
IX	---	---	---	---	---
X	---	---	---	---	---
XI	---	---	---	---	---

Mortality rates for these three species of redhorse were not discovered in the literature, but very few silver redhorse beyond 8 years, and very few golden or northern redhorse beyond 5 years were reported. However, Scott and Crossman (1973) did report northern redhorse from slow growing Canadian populations survived to 12 or 14 years of age.

HISTORY OF THE COMMERCIAL IMPORTANCE OF SUCKERS IN MICHIGAN

The Great Lakes have always provided the major portion of the freshwater fish produced in the United States. The traditionally high value of many of the species resulted in the fishing industry being important to the economy of the Great Lakes States. Unfortunately, the total United States production from the Great Lakes is gradually declining. Total international production from the Great Lakes does not appear to have decreased much since 1920 because of increasing Canadian exploitation throughout this period.

The decline of the United States fishery can be traced to problems originating on the watershed as well as in the water themselves. The increasing population of the United States shores has resulted in areas receiving large quantities of domestic and industrial wastes. Farming practices have led to increased soil erosion and the introduction of fertilizers and pesticides to the lakes. Although these problems may not have drastically altered the main body of water in the lakes, they have degraded many spawning grounds. Catastrophes occurring within the lakes themselves include the collapse of some stocks, presumably due to overfishing (particularly in Lake Erie), the mass mortality of smelt in Lakes Huron and Michigan in 1942-1943, and most importantly, the invasion of the alewife and sea lamprey into the upper Great Lakes (Buettner, 1968).

The species of suckers considered here have been affected by some of these changes as have most other species. Despite their known tolerance to high water temperatures and relatively low oxygen concentrations, most species of suckers are also known to be relatively intolerant to chemical pollutants. This fact would suggest they are sensitive to industrial wastes and pesticide runoff. Most suckers also have highly specific spawning requirements which make them sensitive to the increased silting in streams affected by the erosion of agricultural lands. The sea lamprey is known to have affected the populations of suckers in some areas of the upper Great Lakes (Buettner, 1968). This is particularly true of the white sucker, which is more vulnerable to predation by the sea lamprey than is the longnose sucker. In some areas sea lamprey predation possibly caused a temporary change in the population composition from mostly white to mostly longnose suckers (Applegate, personal communication). One factor which probably has not affected these species is overfishing.

Although suckers, or 'mullet' as they are referred to commercially, have been locally popular as human or animal food, and some are occasionally sought as sport fish, they have never been a widely successful item on the freshwater fish market. Historically the only substantial market for these fish was in the New York area where they were used in 'gefilte fish', but this market was seasonal, and has been gradually decreasing with changes in religious traditions. The loss of this eastern market is probably the major cause for the decrease in the price of suckers relative to other species. As the relative price of suckers decreased, those few fishermen who actively sought them gradually went out of business, and those fishermen who landed suckers as incidental catch, found it unprofitable to continue doing so. Thus suckers, which Buettner (1968) reported as being important in the early shallow water fisheries, have faded from commercial importance.

Lake Erie

Lake Erie is the shallowest and warmest of the Great Lakes. Due to the limited Lake Erie shoreline in Michigan, it is also the least important lake to this state in terms of commercial production.

Buettner (1968) reported the early fishery of the lake consisted largely of blue pike, lake herring, sauger, yellow perch, and walleye; with carp, sheepshead and suckers being abundant but little used. A succession of collapses of the most favored species which seriously affected the fishing industry in this lake are discussed by Buettner (1968). Lake herring was the first major species to show a drastic decline, with the population collapsing in 1925. This decline was followed by the collapse of the sauger stocks in the early 1950's, the blue pike and whitefish in the late 1950's, and the walleye in the mid 1960's. These decreases in catch have greatly affected the total United States production from the lake. In the period 1874-1908 the average annual production was 46.0 million pounds. This declined to 37.7 million in 1914-1929, 30.6 million in 1930-1939, 26.3 million in 1940-1949, 25.2 million in 1950-1959, 15.2 million in 1960-1969, and all the way to 8.9 million in the period from 1970 to 1974.

The total sucker production from the lake was fairly steady prior to 1940, with the annual catch ranging between 0.9 and 1.4 million pounds in all but 7 years. Since that year, however, the United States catch has shown a steady decline and has been below 200,000 pounds since 1965. Michigan's portion of the catch has always been small, but has shown an erratic decreasing trend, seldom being above 50,000 pounds since 1935.

The decline in the catches of the favored species was probably caused by a combination of changing environmental conditions and over-fishing, but the latter of these two factors probably has not affected the sucker. The decreasing sucker catch can probably be attributed to pollution and the blocking of spawning streams, but an additional factor could possibly be a decrease in fishing effort, particularly in shallow waters with seines and trap nets.

Lake Huron

The U. S. Department of Interior report (1969) noted that from 1897-1909 the annual production of six species of Lake Huron fish averaged over 1 million pounds each. These species included lake herring, whitefish, lake trout, suckers, yellow perch, and walleye. No major changes in the production of these species occurred until the late 1930's when the lake trout and whitefish populations began to show the effects of sea lamprey predation. These two species were severely depleted by the mid to late 1940's. The walleye population also began to decline in the Saginaw Bay area after 1943. This decline was probably the result of a combination of changing environmental conditions and sea lamprey predation. In addition to these declines, decreases appeared in the catch of lake herring, yellow perch and suckers in Saginaw Bay. These trends were attributed by the Department of Interior to decreasing fishing effort rather than a lesser abundance of fish, but Buettner (1968) reported that the sea lamprey significantly reduced the sucker population, and the lake herring population fell due to a failure to reproduce successfully.

The commercial production of suckers from Lake Huron was significant in all years prior to 1956, only once dipping below one million pounds during this period. Koelz (1926) reported that in the years from 1893-1922 'mullet' commonly ranked in the top three species in annual U. S. production. Inspection of records extending into the mid 1960's reveal that this ranking was maintained despite falling sucker catches. Historically, the majority of the suckers harvested were captured by trap and pound nets in Saginaw Bay. Other areas of significant catch were north of Cheboygan, where trap nets were commonly used, and in the North Channel, where pound nets were employed.

The effect of the sea lamprey, pollution, and declining numbers of fishermen upon the catch of suckers has been mentioned earlier in this section, but it is difficult to determine the impact of each factor. Throughout the earlier years of the fishery (prior to 1930) the records reveal the sucker catch to be cyclic, reaching a peak about every 12 years (1895, 1906, 1919, 1931). The first two peaks in this cycle are of approximately equal magnitude suggesting the population was fairly stable during this period.

The large drop in catch which occurred between 1906 and 1919 was primarily due to decreases in the Saginaw Bay landings. During this period, the total lakewide production of all species remained farily stable and no clearcut reason for this decline is apparent. Possible factors influencing this decline may have been competition with carp in Saginaw Bay, and the pollution of spawning streams by expanded agricultural and industrial efforts.

The next major drop in production occurred after 1931 and was probably due to three factors. The first of these to occur was the introduction of the deep trap net in 1929. This resulted in a shifting of fishing effort from shallow areas heavily populated by suckers, to deeper offshore areas. The sea lamprey also established itself in the lake during this period and presumably caused a decline in the stocks of suckers in some areas. The third factor, a reduced number of fishermen, is a direct result of the declining stocks of high value species caused by the first two factors mentioned. Continuing decreases in catch are most likely the result of the decreasing effort caused by low prices.

Lake Michigan

The records reported by Buettner (1968) reveal that the early fishery of Lake Michigan was largely supported by yellow perch, chubs, lake herring, lake trout, whitefish, and probably suckers. Buettner (1968) provides fairly complete records for all of these species except the sucker. These records show that the fishery of the lake as a whole for these species was relatively stable prior to the establishment of the sea lamprey.

The lake trout catch was first to be affected by the sea lamprey, declining in 1945 and being almost completely destroyed by 1952. The whitefish catch increased briefly when the lake trout catch first began their decline, but they too began to decline after 1952. The lake herring followed a pattern similar to the whitefish, but did not decline greatly until the late 1950's. Chubs responded to the absence of lake trout predation, and increased fishing pressure by yielding larger catches beginning in the early 1950's. Yellow perch catches have fluctuated widely since 1889, but no definite trend is evident. Sucker records, incomplete on a lakewide basis until 1929, showed a fairly stable catch of close to two million pounds annually until they began to decline in the mid 1940's.

Koelz (1926) reported that in 1925 the catch of suckers ranked 4th in annual poundage, being slightly less than that of whitefish. Suckers were also reported as ranking no lower than 5th in every survey taken since 1890, but fishermen were noted as saying sucker abundance was beginning to decline. The report recorded the largest portion of the catch from Green Bay, while Grand Traverse Bay was noted as supplying the next largest number of fish. The most successful gear used was trap nets.

Sucker catch records for the state of Michigan from the lake reveal a gradually increasing catch through 1907, followed by about a 20-year period of wide fluctuations. This ended with a catch of only about 456,000 pounds in 1928. The annual yield then rapidly increased to over two million pounds in 1935, but this increase was followed by an irregular decrease to only 21,000 pounds in 1968. Since then, the catch has fluctuated between 120,000 and 522,000 pounds annually.

The fluctuations which occurred in the sucker fishery in Lake Michigan are difficult to explain for the years prior to the establishment of the sea lamprey in the area. Declines which occurred after this time can probably be attributed to a combination of decreasing populations, the withdrawal of fishermen from the industry, and the shifting of fishing effort in the Bay DeNoc area to whitefish, which were more valuable and becoming increasingly plentiful (LaValle, personal communication).

Lake Superior

The records of Buettner (1968) reveal that historically, Lake Superior has produced only lake trout, lake herring, and whitefish in large quantities. Whitefish showed significant declines in catch between 1908 and 1913 and have remained at these depressed levels, except for a brief increase from the mid 1940's to mid 1950's. Catches of lake herring showed increases from the turn of the century to the early 1940's. Since then, the catch of this species also has slowly decreased. Lake trout catches were fairly stable and usually in excess of two million pounds until the establishment of the sea lamprey in the lake during the 1950's. The commercial catch steadily declined after that, but never collapsed as entirely as in the other lakes.

Suckers were never extremely abundant in Lake Superior due to the lack of shallow water. Commercial records for these species are incomplete on a lakewide basis until 1929, with the highest recorded catch being 447,000 pounds in 1937. In 1947 the catch dropped to 71,000 pounds and has exceeded that value only six times since then. Michigan's harvest had a high of 378,000 pounds in 1937, and was above 100,000 pounds for most years prior to 1947. In that year it fell to 38,000 pounds, and since then has exceeded 50,000 pounds only three times. The decline of this fishery is believed to be largely the result of declining fishing effort.

Careful inspection of catch data reveals simultaneous variations in catch occurring in at least the three upper lakes. This could suggest simultaneous changes in fishing effort in these lakes as a result of changing economic conditions. Or, these changes could reflect simultaneous changes in spawning success in each of the lakes due to favorable or unfavorable spring weather conditions. The first of the two explanations seems most probable.

LAMPREY WEIR DATA

In the early 1950's electric barriers were installed across many of the streams of the upper Great Lakes in an effort to assess the abundance of the sea lamprey (*Petromyzon marinus*), and to block this species from entering streams to spawn. In order to avoid blocking the spawning runs of indigenous species of fish, traps were incorporated into the barriers. Fish accumulating in these traps during their upstream migration were manually removed, with daily records being kept of the numbers of each species handled, and the physical characteristics of the stream. These records provide information on the run intensity of many fish species in Great Lakes streams, but because they were not designed for this purpose, they have serious limitations.

Four such limitations affect this study. The first is due to the common practice of releasing captured suckers downstream from the barrier rather than upstream. This practice would effectively reduce the available spawning grounds for suckers, as well as make the recapture of individual fish possible. Secondly, the efficiency of the traps would certainly vary over the years studied as the result of changes in the pattern of sedimentation caused by the presence of the weirs. The third factor which may have resulted in some changes in apparent run intensity is the filling of the traps during certain periods by other migrating species (most notably smelt). When the traps are filled, they become inaccessible to suckers, and give the appearance that no migration is occurring. Although this situation was noted in the data, and may have affected the total numbers of fish caught, it is not believed to have affected interpretations concerning the effects of temperature upon spawning. The single factor which probably most influenced the number of fish captured is the tendency for the fish to congregate below the weirs rather than trying to go around them and being captured. This behavior is especially common in the species of the sucker family (Moore, personal communication), and resulted in total sucker captures well below the true number of spawners present.

Records of the number of fish handled (trapped or killed) annually at each of the stream barriers monitored by the United States Fish and Wildlife Service show large annual fluctuations in run intensity. These large fluctuations reveal no well defined patterns over the period of years monitored, but several streams have shown periods when the catch was unusually high or low for successive years. Although in most cases all streams did not fluctuate in the same direction during the same years, the eight barriers still in operation on Lake Superior did show totals of both white and longnose suckers decreasing sharply during the early 1970's. The number of fish handled in 1974 showed a definite increase over those of the earlier 1970's, but totals have not yet reached the former high levels.

Annual totals for each year and stream suggest that extensive fluctuations in run intensities are not unusual for these species.

Although sudden decreases in the number of fish caught between two successive years cannot be completely explained by the data available, in a few instances low or highly variable stream flows may have reduced the number of fish caught in a particular year. In most cases, large increases in the number of large white suckers captured followed years in which there were large numbers of small white suckers reported from the weirs. This pattern suggests that the increases are the result of the maturation of large year classes rather than differences due to mature individuals spawning only in years with the most favorable conditions.

Despite the previously mentioned limitations on the weir data, which greatly restrict their usefulness in relation to the total number of spawners in a stream, reliable data concerning the preferred temperature at spawning can be obtained. The annual spawning runs of both white and longnose suckers for six streams (34 stream-year combinations) were examined according to the date and water temperature at which 10%, 50% and 90% of the total fish handled were recorded. These data reveal that in each situation involving an annual capture of over 100 i-inch or larger white suckers, 10% of them had been captured by the time the stream temperature was 4.4-10.0 C (April 21 - May 25), 50% by the time the temperature was 7.8-17.2 C (May 2 - June 1), and 90% by the time the temperature was 9.4-22.2 C (May 9 - June 17). Smaller white suckers showed wider ranges of temperature for each division, suggesting they may not be as temperature sensitive as larger individuals. Longnose suckers appeared to be slightly more sensitive than either size group of white suckers, 10% being captured by the time the water temperature reached 6.7-15.0 C (April 25 - May 15), 50% by the time the temperature was 8.9-17.8 C (May 4 - May 21), and 90% by the time the temperature was 14.4-20.0 C (May 8 - June 10). Both the 10 C requirement for the onset of spawning of white suckers, and the 12.2-15.0 C optimum spawning range for longnose suckers described in the life history section seem reasonable according to these calculations. However, the wide ranges of temperatures involved, which are the result of rapid irregular fluctuations in stream temperature, limit the usefulness of the data.

In order to reduce the problems caused by high fluctuations in temperature, the average temperature for 5-day periods was calculated, and compiled along with the number of fish handled during that period. Examination of the data for large white suckers reveals that the average temperature for the 5-day period during which the largest number of fish were caught varied from 6.4 C to 16.1 C. The smaller white suckers again displayed less selectivity, with maximum captures being recorded when average temperatures ranged from 3.0 C to 24.4 C. Average temperatures for the 5-day periods in which the largest numbers of longnose were captured ranged between 8.4 C and 16.4 C. Even the ranges arrived at by using this method were rather wide so a qualitative inspection of the original data was used to identify key temperatures.

Inspection of the data for large white suckers indicated most maximum daily catches occurred when water temperatures were between 10.0 C and 14.4 C. It also appeared that consistent temperatures around 7.0 C to 10.0 C induced upstream movement, but rapid rises in temperature usually resulted in readings well above 10 C before movement was recorded. When temperatures were consistently above 15.5 C, movement appeared to cease. This information agrees well with that cited earlier from Geen et al. (1966). Optimal temperature appears to be around 11 - 15 C for large white suckers, but is less consistent and appears slightly higher for smaller individuals. Longnose suckers exhibit temperature preferences very similar to those of the larger white suckers with optimum temperatures appearing to be around 12 - 15 C. This correlates well with the optimum temperatures noted by Brown and Graham (1954) and Harris (1962) of 12.2 - 15 C, however, the temperature first inducing movement is often significantly higher (at 10 - 11 C) than the 5 C noted by Geen et al. (1966). That this species spawns earlier than the white sucker, as reported by other authors (Scott and Crossman, 1973), was not confirmed by this data.

Temperature preferences more specific than those given are not possible to determine due to the rapid changes in temperature exhibited by the streams examined.

MICHIGAN DEPARTMENT OF NATURAL RESOURCES INDEX STATION CATCHES

As well as being a low-value commercial fish, suckers bring a relatively small amount of money into the economy of the state as a sport fish. According to the Michigan DNR Management Report No. 5 (1973) an estimated 2,616,360 suckers were caught by 86,720 fishermen in 1971. Only one of the other 14 species listed had fewer fishermen pursuing them than did the suckers. Due to this low economic value in both the commercial and sport fields, little research has been done by any government agency on the abundance of these fish.

The Michigan Department of Natural Resources has collected data from index stations throughout the Michigan waters of Lakes St. Clair, Erie, Huron and Michigan since 1970. Catch per unit effort (CPE), where unit effort is one trap net lift or 304.8 m of gill nets (graded 63.5 - 152.4 mm mesh), has been calculated for white and longnose suckers at these stations.

Because such a small amount of data exists, only general comparative statements can be made concerning abundance. The data from Lakes St. Clair and Erie indicate that only white suckers are present at the index stations, and they are present in low to moderate numbers, with only 2 sets yielding a CPE of over 10. Catches of white suckers in Lake Huron and Saginaw Bay were, at most stations, significantly higher than those in Lakes St. Clair and Erie. Catches per unit effort at Pinconning and Sand Point in Saginaw Bay were consistently high with catches per unit effort ranging from 17.5 to over 61.5. In the lake proper, the highest concentrations appeared to be along the southern shore of the Upper Penninsula with moderate catches noted in areas close to Saginaw Bay and along the northern shore of the Lower Penninsula. The highest single catches per unit effort were reported at the mouth of the Carp River (58.4) and Forestville (31.9).

In Lake Michigan, the greatest concentration of white suckers is noted around Little Traverse Bay and Beaver Island (CPE of 22.0 - 98.5). Some other stations show high catches per unit effort for single dates, but these were offset by extremely low catches for other dates, or were the result of very small amounts of effort. Moderate catches were recorded for a large number of stations, but little consistency was apparent at those stations sampled in more than one year. Surprisingly few white suckers were taken in Green Bay despite historically high commercial catches of 'mullet' from that area.

In Lake Huron, longnose suckers do not appear in the index records for most of the stations in the southern portion of the lake. Some longnose are recorded for stations at the northern tip of the thumb region, and a few were listed at stations along the eastern shore of the Lower Penninsula, but the highest catches per unit effort appeared along the northern shore of the Lower Penninsula at Hammond Bay (82.0) and Cheyboygan Point (42.4). Longnose suckers were conspicuously absent from the catches of some of the index stations along the southern shore of the Upper Penninsula in this lake.

Lake Michigan catches per unit effort of longnose suckers are not very high for any station where fishing effort was above minimal; the highest CPE coming from Pt. Aux Barques (44.6). The only areas where longnose appeared to be more important than white suckers was northern Green Bay and along the southern shore of the Upper Penninsula. Other areas where moderate catches have been made are scattered along the eastern shore of the lake, but these catches seem to be inconsistent from year to year and season to season.

In general, the records show white suckers being the predominant sucker in the lakes surveyed. Longnose suckers, when present, were more common in the northern regions of the lakes. The available data show higher catches per unit effort for spring periods than for other times of the year. This presumably is due to these species congregating near shore prior to spawning.

DISCUSSION

Close investigation would certainly reveal that the recent decline in the United States Great Lakes fishery is even more serious than indicated by the decrease in weight of the annual catch alone. Many of the high value species have been all but eliminated from the fishery either by a sheer decrease in their numbers, or by legal restrictions designed to protect them. In many areas, only one or two species commonly used for human consumption are still available for commercial harvest. If the Great Lakes commercial fishery is to survive it will be necessary to harvest species which are now relatively unexploited. Increasing the number of species harvested would not only increase total yield, but also provide for better overall management by allowing biologists to control the populations of low value fish which are competing directly, or indirectly, with higher value species. Although the biology of the species considered in this paper suggests that they probably do not compete with high value fish to a large extent under most considerations, their numbers and palatability may make them economically feasible to harvest.

Abundance and Stability of Stocks

The commercial catch records of the Great Lakes bordering upon Michigan show that at least Lakes Huron and Michigan have supported substantial fisheries to 'mullet' in the past. The decline in these fisheries after the invasion of the sea lamprey seems to be due more to an alteration in fishing effort than to the effects of predation, although the sea lamprey did affect sucker stocks. If this is true, it seems reasonable to conclude that in those areas where no large scale environmental changes have occurred (particularly with respect to chemical pollutants and stream alterations), significant populations may still exist. Some evidence is available which suggests this is true.

The Michigan Department of Natural Resources (1974) reports that the Lake Huron catch of suckers reflects demand rather than abundance, suggesting increased effort could substantially increase yield if the demand were there. In Lake Michigan it was reported that longnose and white sucker could be excellent commercial species and that their abundance, as indicated by the catch at index stations, is high relative to other species (Keller, personal communication). In Lake Superior, suckers are reported as being less abundant and more scattered than in the other lakes (Wright, personal communication). This situation would be anticipated from the morphology of the lake basin and the early commercial records.

The biology of the suckers suggests that the areas of most importance to a commercial fishery for them would be the bays and shallow inshore areas of the lakes. Examination of the commercial records show this to have been true in the past with major areas of production being Green Bay, Grand Traverse Bay, and Saginaw Bay. Index station catches show other small bays and river mouths to have abundances equal to these areas at the present time, but estimates of maximum commercial yield from any of the areas are little more than guesses. In terms of environmental changes, it seems that the area most likely to be able to reach former high levels of production would be the Michigan portion of Green Bay, but even here the annual yields estimated by biologists familiar with the area range anywhere from 250,000 to 1,000,000 pounds. This suggests accurate estimates of sucker populations are not available for important areas of potential production.

The available evidence indicates that commercial catches of 'mullet' would consist mostly of white sucker, with significant numbers of longnose being included, but very few redhorse. The biology of all of these species suggests that their contribution to the overall commercial fishery would depend, to a large extent, upon their environment. The literature shows a rather wide variance of growth rates, ages, and sizes at maturity for both the white and longnose suckers. These variances seem to be largely dependent upon the richness of the environment as discussed in the life history section. The most discouraging factors found in the literature are the apparent low annual recruitment and the slow growth rates of adult white suckers, but this would be expected to improve when the adult population was thinned by exploitation.

A situation paralleling commercial exploitation has been observed in South Bay, Lake Huron, during the late 1950's where Coble (1967) studied the effect of sea lamprey predation on white suckers. He found that the white sucker population decreased sharply about the time that the sea lamprey destroyed the lake trout population. The sucker population began to rebound after about five years, but the average size of individuals caught continued to decline from a high of about 39 cm to a low of about 32 cm over the period of study which ended in the mid 1960's. During this period, Coble estimated the total annual mortality of white suckers to be only 25 - 30%, and because of this suggested that even without lamprey predation the population of larger suckers could not have been sustained under moderate fishing pressure. Rawson and Elsey (1950) also found that the removal of larger fish resulted in larger numbers of small individuals appearing in the population. However, commercial catch records support the idea that sucker stocks can be successfully exploited. These records show that under favorable conditions populations of white and longnose suckers have been sustained during long periods of steady commercial exploitation. It seems that the final determination on the feasibility of commercially harvesting suckers must await some sort of trial fishing period.

Management Considerations

Because of current fishery restrictions designed to protect high value species, it is likely that the Michigan sucker fishery would be limited to the use of shallow water impoundment gear as a capture method. This type of gear has not been widely used in recent years, and is fairly expensive. Due to this expense, and the question of market popularity and profit which accompanies any enterprise, there is some question as to the number of fishermen who might be drawn into the fishery. The suggestion has been made by some fishermen that a government agency should initiate the fishing effort in order to estimate stocks of fish and market price, thus giving commercial fishermen something on which to base an investment. Such an approach seems reasonable since a large percentage of the catch will come from small areas of water, and it would allow an accurate stock assessment.

In view of the collapse of the fishery for so many species of Great Lakes fish, such an assessment would appear to be desirable as a management tool in future years. Once economic feasibility was established, commercial fishermen could take over under some management scheme. A limited access fishery based on gear and area restrictions, or a quota system would seem to be a reasonable approach to take in managing these species.

Conclusions

The literature on the biology of suckers reveals that in most situations the mortality and growth rates of adults of these species are low. It also appears that these species are not often important in the food chain, and do not pose serious competition for more favorable species. Such conditions would suggest that the sucker population is relatively static and that establishment of a fishery for these species would not greatly affect the ecosystem as a whole. Unfortunately, not enough information is available to determine if such conditions actually do exist in the Great Lakes.

Commercial catch records, data from lamprey weirs, and index station records all reveal that suckers are widespread in the upper three Great Lakes. The lack of information concerning abundance on a commercial scale arises from the low value of the species and subsequent lack of fishing effort. Substantial data concerning abundance and the effect of fishing upon sucker stocks is likely to be gathered only by the establishment of a fishery.

Because of the lack of solid information about the species, a fishing industry should be established on a small scale and then gradually expanded if it becomes evident that the stocks can support the fishing pressure. Judging from the problems arising in the past in fisheries governed by economics alone, such an approach would probably require a quota system or a limited access fishery.

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