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THE POND-SPAWNING AND FINGERLING PRODUCTION OF MUSKELLUNGE AT THE MINOR E. CLARK HATCHERY, KENTUCKY, DURING 1973

BY

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INTRODUCTION

There are three nominal subspecies of the muskellunge, *Esox masquinongy masquinongy* Mitchill, *Esox m. ohioensis* Kirtland, and *Esox m. immaculatus* Mitchill (Buss, 1960). The muskellunge found in Kentucky, *Esox masquinongy ohioensis*, is a lotic inhabitant, presumably being confined to the Ohio River system. The species has been reported from the Kentucky, Licking, Green, and Little Sandy rivers, and in Kinniconick and Tygarts creeks; also from the South Fork of the Cumberland in Tennessee, but not from the portion of that river drainage which lies in Kentucky (Clay, 1962). Muskellunge have been creeled during recent years from about 27 Kentucky streams, but only 18 of those regularly yield catches to anglers. The largest number of muskellunge streams are located in the eastern portion of the state, whereas, only five of them are situated in south-central Kentucky, near Mammoth Cave (Brewer, 1969).

Although the muskellunge appears to be rather widely distributed throughout Kentucky, it is not particularly abundant anywhere in the state. Furthermore, the muskellunge population has steadily diminished, with much of the decline being attributed to the loss of suitable habitats by the impoundment of former muskellunge streams and because of pollution from coal mining, sawmills, sewage and silt. These factors, combined with the species' relatively low level of natural reproduction in the streams, contribute to a small and decreasing population.

The muskellunge's value to Kentucky's fishery program as a rare, prized trophy fish and as a possible predator for controlling undesirable fish populations, such as gizzard shad (Dorosoma cepedianum LaSueur), warrants any special efforts that may be required to increase the species' numbers in the streams, or perhaps to establish populations in some of the state's reservoirs. In order to protect and maintain the muskellunge, a thorough knowledge of its life history and habits are required, as well as a well-executed propagation and stocking program. At present, all states attempting to manage muskellunge rely heavily on stocking programs, principally based on artificial propagation, to maintain populations.

Consequently, in 1966, Kentucky began a muskellunge program by stocking certain reservoirs with fry received from West Virginia. In 1967, the state initiated a six-year muskellunge project involving a detailed life history study. It was not until 1973, when construction of the Minor E. Clark Fish Hatchery was complete, that Kentucky first attempted to culture muskellunge from native broodstock.

Modeled somewhat after the Woodruff Hatchery in Wisconsin, the Minor E. Clark Hatchery was designed for artificial propagation of several game species. The hatchery's main water supply will be the newly impounded Cave Run Reservoir. The water, which can be drawn from three levels of the lake, will be piped from the dam to the hatchery ponds, as well as to a large building containing complete facilities for the artificial propagation of muskellunge, walleye (Stizostedion vitreum Mitchill), and striped bass (Morone saxatilis Walbaum). There are no large native populations of these three species in Kentucky, so broodstock must be raised from fry or collected from the wild and held in ponds until the spawning season. During the spring, the fish will be removed from the ponds and injected with hormones to promote ripeness. Eggs and milt will be hand-stripped from the gravid fish, and the fertilized eggs placed in plastic incubating jars with continously circulating water. As the fry hatch, they will be carried by gravitational water flow from the overflow trough of the hatching jars to inside concrete tanks and later taken to outside ponds as they start to feed.

A delay in impounding Cave Run Reservoir during 1973 resulted in an insufficient water supply to the main building of the hatchery and made incubating eggs in jars impossible, although an adequate amount of water could be pumped from the Licking River by means of a diesel engine to fill most of the ponds. However, this problem was anticipated and an alternate method for muskellunge-fry production had been planned previously. This method would utilize the muskellunge brood fish already retained at the hatchery for pond spawning and fry production. Hopefully, natural reproduction in the hatchery ponds could be achieved by creating a suitable spawning habitat within the ponds, and by controlling certain external factors, such as predation and water fluctuation, which are known to be limiting to successful natural reproduction. Any fry produced would be raised to fingerling size and stocked in streams that contain known native muskellunge populations. The main objective of this research was to ascertain whether muskellunge-fry production in ponds is feasible. However, the long-term goal of the program is to establish a muskellunge population which will supplement the egg supply of the hatchery brood fish and partially eliminate holding a great number of domestic brood stock.

REVIEW OF THE LITERATURE

Hatchery propagation of esocid species, particularly muskellunge (*Esox masquinongy* Mitchill), dates back as far as 1890 in New York and 1899 in Wisconsin. There was some muskellunge culture in Pennsylvania in the 1890's, but it was discontinued until 1953. By 1953, Ohio had initiated a program, followed by West Virginia and North Dakota (Sorensen, Buss, Bradford, 1966). Today, approximately 11 or 12 states are participating in muskellunge propagation.

Several writers, including Webster (1924), Leach (1927), Mackay and Werner (1934), Johnson (1954), Bishop (1966), and Oehmcke (1969) have described the artificial method of propagating muskellunge. Little success has been recorded for muskellunge fry production from pond spawning, even though this method seems fairly successful for raising northern pike, *Esox lucius* Linnaeus (Brandt, 1948; Clark, 1950; McCarraher, 1957). In 1939, Wisconsin fish culturists attempted to induce ripeness in muskellunge by placing fish captured during the spring migration into shallow ponds, but no eggs were obtained. The following year, the experiment was tried again with half of the collected fish receiving an injection of 50 mg of acetone-dried pituitary gland (carp) before they were introduced into the pond; the second half received no injections. Eggs were taken from the injected fish, while the uninjected controls produced no eggs (Hasler, et al, 1940). Other investigators (Phillips and Graveen, 1973) at a North Dakota hatchery have found that maturation in domestic muskellunge can be achieved without the use of hormonal stimuli. Eggs were taken from each of the females (6) that were held in earthen ponds and allowed to mature without the use of a hormone injection. Ohio biologists experimented for several years to produce muskellunge fry from pond spawning. In 1949, they introduced ten muskellunge into a one-acre pond and created conditions thought to be inducive to spawning. The results were two eight-inch fingerlings, one and one-half years later. A second and third try at production from pond spawning in succeeding years indicated that this method was not practical (Riethmiller, 1956). In more recent years, Clark (1964) reported limited success at the Kincaid Hatchery in Ohio from 1960 through 1962. Muskellunge spawning activities were actually observed several times and a high of 530 fingerlings were produced in 1961.

Muskellunge usually spawn in pairs, one male with one female (Parsons, 1958). Eggs are indiscrimately broadcast in shallow water with no parental care being exercised. In Tennessee, females mature at three to four years of age and 63.5 cm of length, while males mature in three years at 55.9 cm.

Wisconsin and Canadian muskellunge mature at four to six years of age when they measure 57.2 to 74.9 cm (Buss, 1960). Kentucky muskellunge mature when they are four years old and measure 71.1 to 76.2 cm (Brewer, 1970).

The spawning time of muskellunge in natural habitats varies with locality, seasonal temperatures, and possibly genetic strains (Buss, 1960). Spawning activity apparently is not triggered by any single factor, such as water temperature, but a series of factors or stimuli are involved. These stimuli, both internal and external, begin affecting the fish early in the year. Internal stimuli, such as increased gonadal activity and high hormone levels, plus the external stimuli of increasing light intensity and duration, rising water temperatures, presence of vegetation and sight of other fish affect the spawning time (Handy, Unpublished). In Kentucky, the muskellunge spawns anytime between April 1 and May 15, depending on the stream temperature (Brewer, 1970). Optimum water temperatures for spawning are generally between 8.8° C and 13.3° C, but spawning may occur at water temperatures as high as 15.7° C.

Although internal and external stimuli determine the time of spawning, certain environmental factors appear to regulate the success or failure of muskellunge reproduction. Oehmcke, et al., (1958) and Buss (1960), for example, listed several of the factors which may be limiting to muskellunge reproduction in the natural environments. Among them were:

fluctuating water levels and cold water temperatures at spawning time; predation on eggs and fry by other fish and invertebrates; quantity and size of live zooplankton and forage fish for fry; and hybridization of the species with northern pike. Of these external factors, temperature appears to be one of the more important. Buss (1960) and Johnson (1968) reported that when the weather turned cold, and the temperature of the littoral zone dropped below 10° C, that muskellunge spawning became erratic or was discontinued. Usually, a constant temperature above 10° C must be maintained for several weeks before spawning takes place. In Kentucky, the average water temperature at the time of spawning was 13.3° C during a three-year study period (Brewer, 1970). Stable water temperatures not only affected spawning, but also influenced fry and egg development. Fry survival appeared to be dependent upon water temperatures which were high enough to initiate a crop of plankton followed by a successful minnow spawn (Clark, 1964). Sudden depressions in water temperature to 4.4° C or lower from higher ones may be detrimental to muskellunge eggs (Mackay, 1931).

Successful spawning may also be correlated with the presence of suitable spawning sites. Moore (1925), in describing the muskellunge of Chautauqua Lake, stated, "the natural conditions that prevail in Chautauqua Lake are unquestionably favorable to the propagation of the species, and it is important to know the factors contributing to this success. In a general way, it is assumed that favorable conditions are related to the presence of excessive areas of shallow water and the abundance of weedy and muddy bottoms in the lake. Adult fish spawn in such situations and most of them are caught there." Parsons (1958) and Brewer (1970) found, in Tennessee and Kentucky, that muskellunge spawn best in shallow water where there is an abundance of organic matter along the bank. Apparently, in most streams these shallow water spawning sites are associated with low gradient pools and have substrates dominated by rubble and large gravel, although some suspected sites have considerable sand deposits (Brewer, 1970). Wisconsin muskellunge, primarily lake inhabitants, prefer shallow bays in water one to three feet deep for spawning. A muck bottom covered with detritus and dead vegetation is the usual spawning site (Oehmcke, et al, 1958). In Pennsylvania, spawning generally occurs at night in shallow bays on muck bottoms covered with detritus, preferably in an area with sunken stumps and logs (Buss, 1960). In all cases, muskellunge spawn in shallow waters of lakes and streams, usually among logs, stumps, dead brush, and driftwood rather than in flooded marshes or meadows (Karvelis, 1964).

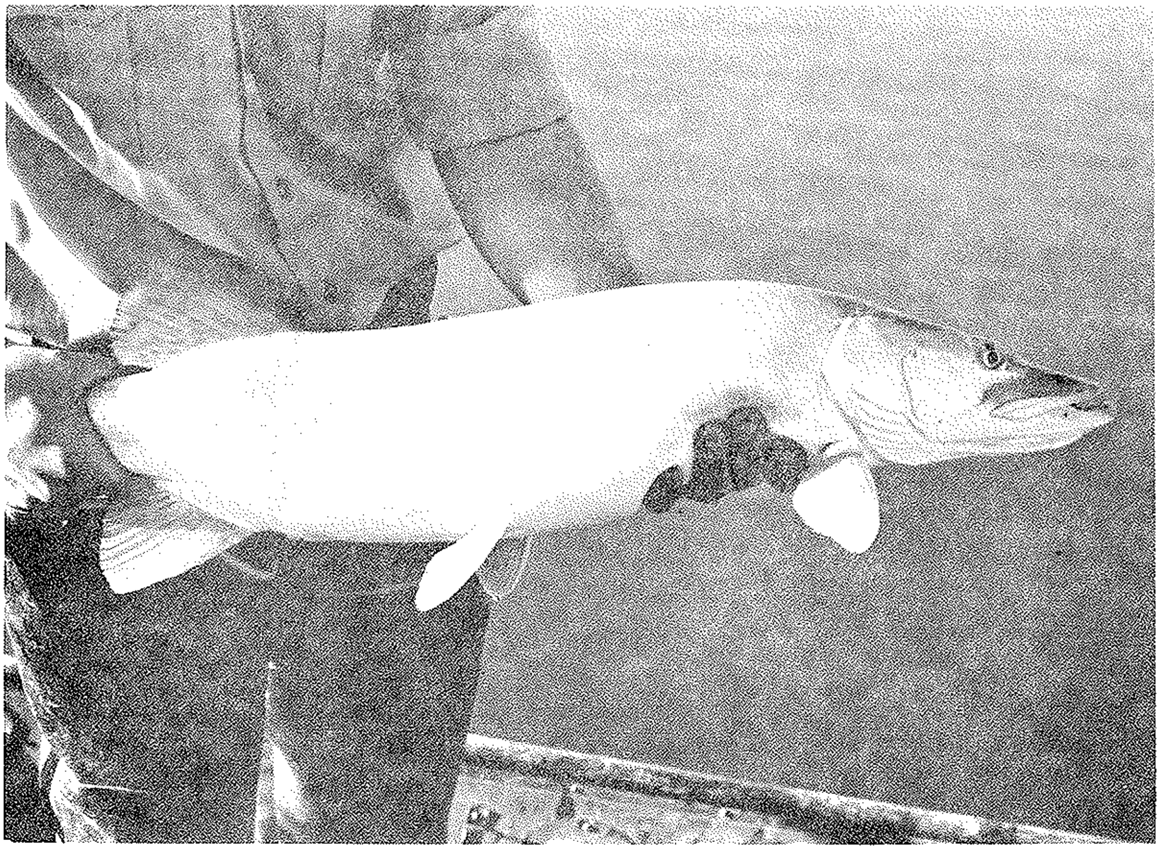
METHODS

Hatchery Broodstock

Forty-one muskellunge (71.1 to 114.3 cm long) were used during the experiment on pond spawning (Fig. 1). Most of the broodstock were collected from streams in the northeastern portion of the state by electrofishing, using a boat equipped with a 230-volt generator and eight electrodes mounted on a boom. Several fish were also captured by means of a winged fyke net fished in local streams during the spring. Twenty-one muskellunge of the total were collected between the fall of 1970 and the fall of 1971. These fish were retained in holding ponds containing bass-bluegill populations until completion of the hatchery. No natural pond reproduction was noted during the previous two and one-half years of captivity. The other twenty muskellunge were collected during the fall of 1972 (2) and through the spring of 1973 (18).

An attempt was made to place the fish in separate spawning ponds according to the year (1970, 1971, 1972, 1973) in which they were collected, although there was some integration of the different year classes. It was felt that the fish

Fig. 1. A typical brood muskellunge (88.9 cm) used in the experiment.



caught in 1973 had a greater chance for spawning in the ponds, since most were caught on their spring run and had achieved some degree of ripeness within the stream.

Ten to 11 muskellunge were introduced into each of the four one-acre spawning ponds, placing approximately 100 pounds of brood fish per acre. Ohio biologists, in their pond spawning experiences, introduced ten brood fish per acre for the purpose of spawning, whereas McCarraher (1957) in his pond spawning investigations with northern pike (*Esox lucius* Linnaeus) stated that there should be no more than five females per acre of spawning ponds. No sex determination was attempted at the time of introduction into the ponds, although the sex of several fish, captured during the spring of 1973, was noted because of freely flowing eggs or milt. The muskellunge collected during 1970 and 1971 were introduced into the spawning ponds on 28 and 29 March, while those muskellunge caught in 1972 and 1973 were placed into spawning ponds between 29 March and 20 April. Those fish introduced into the spawning ponds after 30 March were placed there as they were captured from the streams. Table I lists the number and lengths of the fish in the four ponds, date of capture, and date introduced into the ponds.

Each spawning pond was checked daily, usually in the late afternoon, by walking the banks to observe any spawning activity and/or fry occurrence. The pond temperature was also recorded each day (with a pocket thermometer) in

Table I. Statistics of Spawning Ponds for the Broodstock Muskellunge.

Pond No.	Total Length of Fish (cm)	Date Collected	Date Placed in Spawning Pond
37	76.2	Most Captured During Oct. and Sept. of 1971.	3/29/73
	76.2-81.3		3/29/73
	76.2-83.8		3/29/73
	76.2-83.8		3/29/73
	76.2-83.8		3/29/73
	76.2-91.4		3/29/73
	76.2-91.4		3/29/73
	76.2-91.4		3/29/73
	78.7	10/7/71	3/28/73
	78.7	9/9/71	3/28/73
	88.9	9/9/71	3/28/73
38	71.1	2/28/73	3/29/73
	76.2	2/28/73	3/29/73
	78.7	4/6/73	4/16/73
	80.0	Oct. 1972	3/30/73
	81.3	2/28/73	3/29/73
	83.8	3/7/73	3/29/73
	83.8	4/1/73	4/1/73
	83.8	Oct. 1972	3/30/73
	83.8	4/1/73	4/1/73
	85.1	4/16/73	4/16/73

Table I. (Continued)

Pond No.	Total Length of Fish (cm)	Date Collected	Date Placed in Spawning Pond
43	83.8	Collected in 1970 and 1971.	3/28/73
	83.8		3/28/73
	83.8		3/28/73
	83.8		3/28/73
	87.6		3/28/73
	85.1	7/15/70	3/28/73
	86.4	7/10/70	3/28/73
	86.4	7/15/70	3/28/73
	91.4	7/16/70	3/28/73
	91.4	7/21/70	3/28/73
44	80.0	4/2/73	4/2/73
	82.5	4/2/73	4/2/73
	83.8	4/20/73	4/20/73
	88.9	4/2/73	4/2/73
	88.9	4/13/73	4/13/73
	91.4	4/2/73	4/2/73
	104.1	4/3/73	4/3/73
	104.1	4/13/73	4/13/73
	106.7	4/2/73	4/2/73
	114.3	4/16/73	4/16/73

an attempt to correlate time of spawning with the water temperature.

The broodstock muskellunge were removed from the spawning ponds the first week of May by electrofishing (Fig. 2), after initial attempts to remove the large fish by seining had failed. Removal of the parent fish eliminated any predation which might occur on the offspring, and also served to reintroduce the broodstock to forage. Some of the fish had been in the spawning ponds over a month without food.

Spawning Pond Preparation

Four one-acre ponds (37, 38, 43, 44), designated as muskellunge-spawning ponds, were filled with water from the Licking River during January and February of 1973. A saran bag filter (0.25 mm) was placed over the inflow pipe of each pond to stop wild fish from entering the river. This kept the ponds free of other fish species which might prey on the muskellunge eggs and fry. Each of the four ponds were identical in physical parameters, measuring 132.8 meters long by 30.4 meters wide, ranging in depth from 167.6 cm at the catch basin to 45.7 cm at the opposite end, having a bottom composed of sandy loam, and the banks completely rip-rapped with large crushed limestone rocks (Fig. 3). Each of the ponds could be filled from either the shallow or deep end. A limited flow could be created within the ponds by filling from the shallow end and allowing water to run over the spillway of the kettle. Ponds 43 and 37 contained

Fig. 2. Broodstock removal to forage ponds.

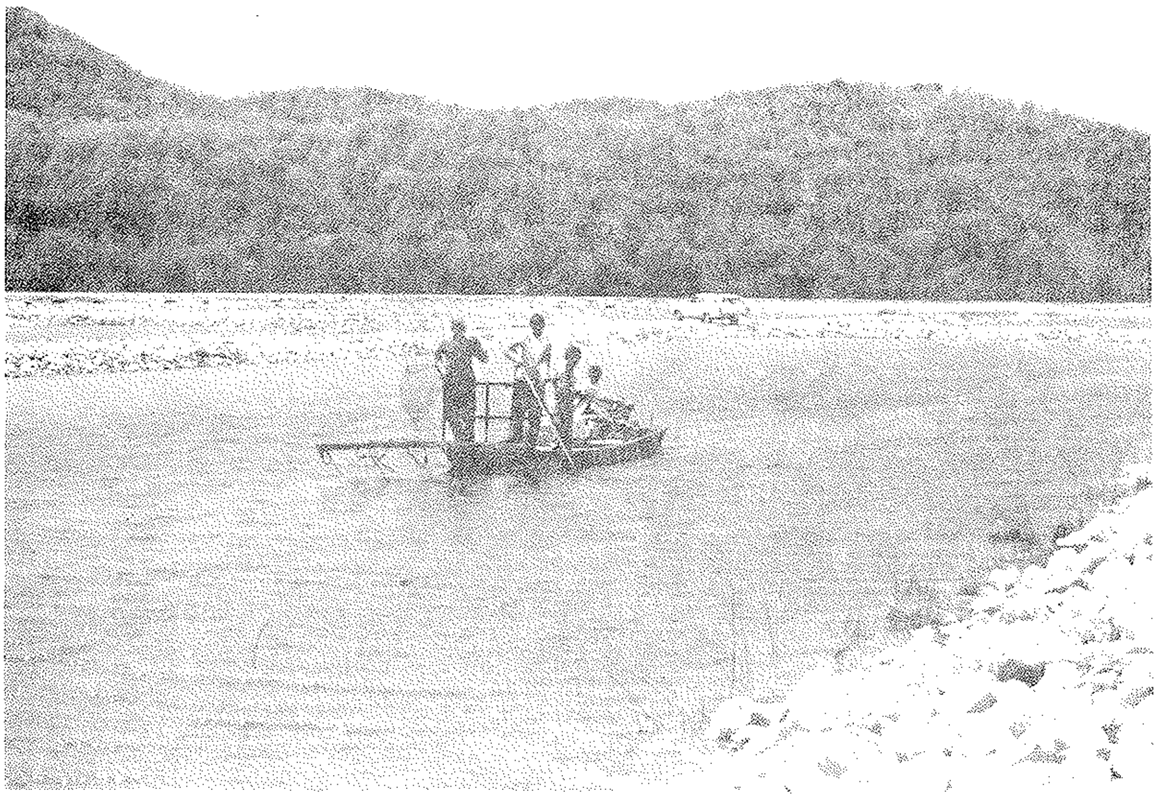
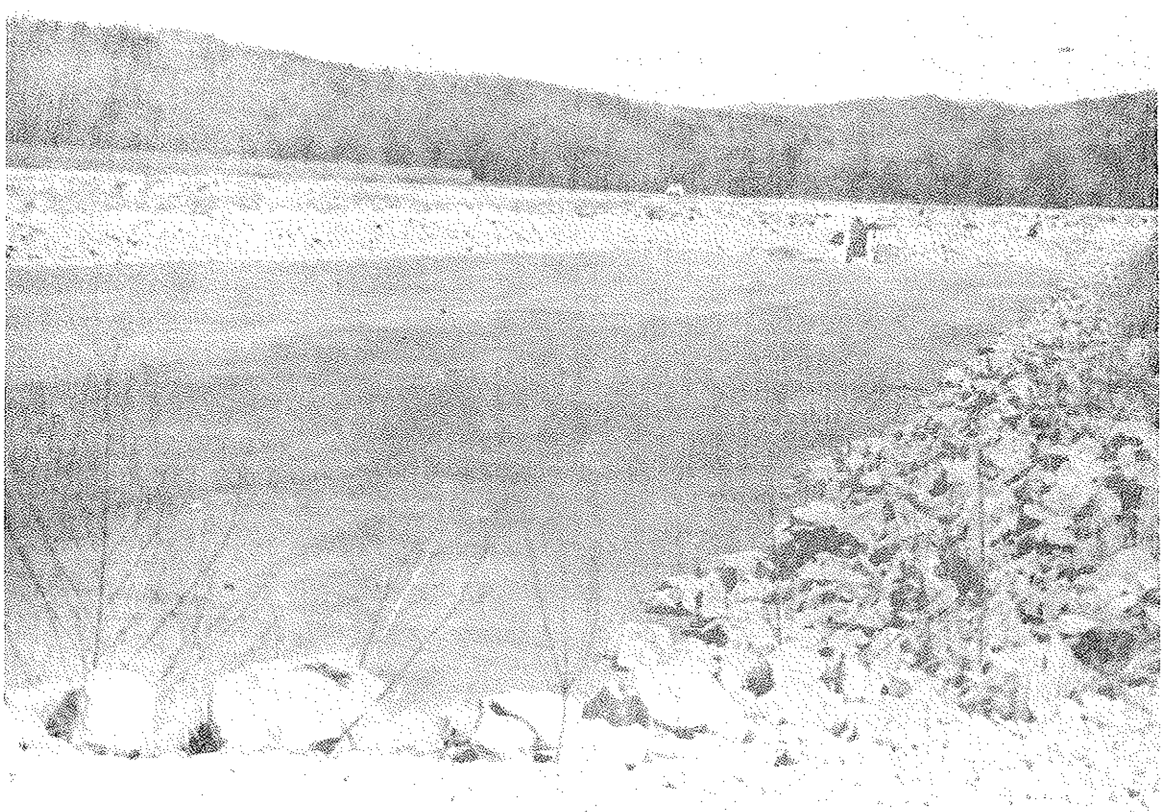


Fig. 3. Spawning pond structure.



muskellunge caught in 1970 and 1971, while ponds 38 and 44 held muskellunge captured in 1972 and 1973.

A total of 20 bales of hay were added to each of the four ponds. Ponds 37 and 38 each received 12 bales of hay two days before broodstock introduction, and 8 additional bales two weeks later. Ponds 43 and 44 each received 8 bales of hay two days before introduction of the broodstock, and 12 additional two weeks later. The hay simulated the organic vegetation usually associated with typical spawning sites, and also created abundant zooplankton that could be used by the muskellunge fry for food.

After a muskellunge spawn was evident, commercial and organic (meat scraps) fertilizers were applied to the ponds to maintain plankton production, and ten pounds of brood-size fathead minnows (*Pimephales promelas* Rafinesque) were added to each of the spawning ponds to reproduce and furnish food for the muskellunge fry and fingerlings. To prevent predacious invertebrates from preying on muskellunge eggs and fry, each pond received a treatment of four gallons of diesel fuel every two weeks starting with the first week of April.

Water level fluctuation, caused by soil seepage, was remedied by periodic backfilling with river water. Water was also introduced into the ponds from the shallow end for a two-day period during the last part of April, in an attempt to trigger spawning in those muskellunge which had failed to reproduce.

Fry Transfer

A large number of the fry, produced in the spawning ponds, were transferred to rearing ponds containing goldfish (*Carrassius auratus* Linnaeus) or fathead minnows (*Pimephales promelas* Rafinesque). It was hoped that these fish would spawn and furnish food for the muskellunge fry, while removal of part of the fry from the spawning ponds also served to reduce cannibalism.

Transferal of muskellunge fry from the spawning ponds was first attempted by dipping from the bank with aquarium nets, and later by seining with a net made of Swiss silk bolting cloth (No. 6). Both methods proved ineffective and tedious. Finally, a sealed beam light, powered by a 12-volt battery and surrounded by styrofoam, was attached to a 106.7 cm net handle and extended over the kettle on the deep end of the ponds. The fry were attracted to the light at night and were easily dipped with a large aquarium net. An estimated fry count was made for each dip and sample counts were taken periodically to assure accuracy.

RESULTS

Spawning

Three to four days after introduction into the spawning ponds, the muskellunge began to cruise the banks. On 1 April, a pair of muskellunge in pond 38 were observed swimming in a typical spawning position, but it was impossible to see whether eggs were actually being deposited. The water temperature was 15.5° C and had been increasing daily since broodstock introduction. Five days later, spawning was again observed in pond 38, where the water temperature had dropped to 13.3° C.

On 8 April, another pair of muskellunge appeared to be spawning in pond 44, but again egg and milt extrusion was not observed. The water temperature at this time was 11.1° C. Between 9 and 21 April, the muskellunge continued to cruise the banks, but no spawning was observed. During this period, the water temperature dropped to 7.2° C, a 8.3° C decrease since the first spawning was noted.

On 21 and 22 April, fresh water was pumped into the four ponds from the shallow end to create a current flowing toward the deep end. The next day, in pond 44, two muskellunge were noted swimming nearly side-by-side around the inflowing fresh water. By this time, the water temperature had risen to 20° C, and it was unlikely that actual spawning was occurring. By 24 April, it was assumed that all spawning activities had ceased, since the muskellunge were no longer cruising the banks.

During the first week of May, thirty-seven brood muskellunge were removed from the spawning sites to ponds containing forage fish. Two muskellunge died during the experiment when they jumped the kettle wall at the deep end of two ponds where fresh water was flowing into them, and another ripe female died on 29 April in pond 44 of unknown causes. One brood muskellunge escaped capture by electrofishing, but was later removed when the pond was drained. At the time of removal, none of the fish showed signs of ripeness, even though the dead female found in pond 44 had freely flowing eggs. Most of the fish appeared to be in good condition, although some had been without food for over a month.

Fry Occurrence and Transfer

Fry were noted in pond 38 on 25 April, 24 days after the first spawning activity was observed. Most of the fry were laying near the pond's edge on the rocks and hay, and were generally inactive. Two to three days later they began to actively feed on water fleas (Daphnia sp.). Fry were observed in pond 44 on 30 April, and they were noted in pond 37 on the next day. The fry in these two ponds were already drifting with the wind currents and feeding on zooplankton. Approximately a week later, two distinct sizes of muskellunge fry were found in pond 37. It was not until 9 May that fry, several weeks old, were discovered in pond 43. Spawning activity, fry observance, and daily water temperatures are presented in Table II.

Fry transfer from the spawning ponds to fingerling rearing ponds, containing goldfish or fathead minnows for forage, began on 1 May and continued until 21 May. A total of 45,000 muskellunge fry were transferred from the four ponds during this period. Fifteen one-acre ponds received 2,000 fry each, while 15,000 fry were placed into a seven and one-half acre rearing pond. Of the 45,000 fry transferred, 19,500 were removed from pond 38, 15,000 from pond 44, 6,050 from pond 43, and 4,450 fry from pond 37 (Table III).

Fingerling Production

From the total number of fry transferred to the 16 rearing ponds, 2,980 (15.2 to 25.4 cm) fingerlings were produced for stocking in the fall, representing a 6.6 per cent return. From the original spawning ponds, 2,270 (15.2 to 30.5 cm) fingerlings were raised. Spawning pond 43 yielded 1,044 fingerlings, pond 37 produced 638 fingerlings, pond 44 had 560 fingerlings, and pond 38 yielded only 12 fingerlings (Table III).

Thus, the total fingerling production resulting from pond spawning was 5,250 (15.2 to 30.5 cm) muskellunge. Most of these fish were stocked in the streams in the northeastern

Table II. Daily Pond Records.

Date	Pond Temperature (^oC)	Observations
3/26/73	13.3	
3/27/73	12.2	
3/28/73	13.3	Broodstock introduction began.
3/29/73	13.3	
3/30/73	14.4	
3/31/73	15.0	
4/1/73	15.7	Musky seen spawning in pond 38.
4/2/73	14.4	Musky cruising shoreline.
4/3/73	13.8	
4/4/73	11.6	
4/6/73	13.3	Musky seen spawning in pond 38.
4/8/73	11.1	Musky seen spawning in pond 44.
4/9/73	11.6	Musky still cruising shoreline.
4/10/73	7.7	
4/11/73	7.2	
4/13/73	8.8	
4/15/73	14.4	
4/16/73	13.3	
4/18/73	14.7	
4/19/73	17.7	
4/20/73	18.8	
4/21/73		Piped water to ponds 44 and 38.
4/22/73	20.0	Shut off ponds 44, 38 and started ponds 43, 37.

Table II. (Continued)

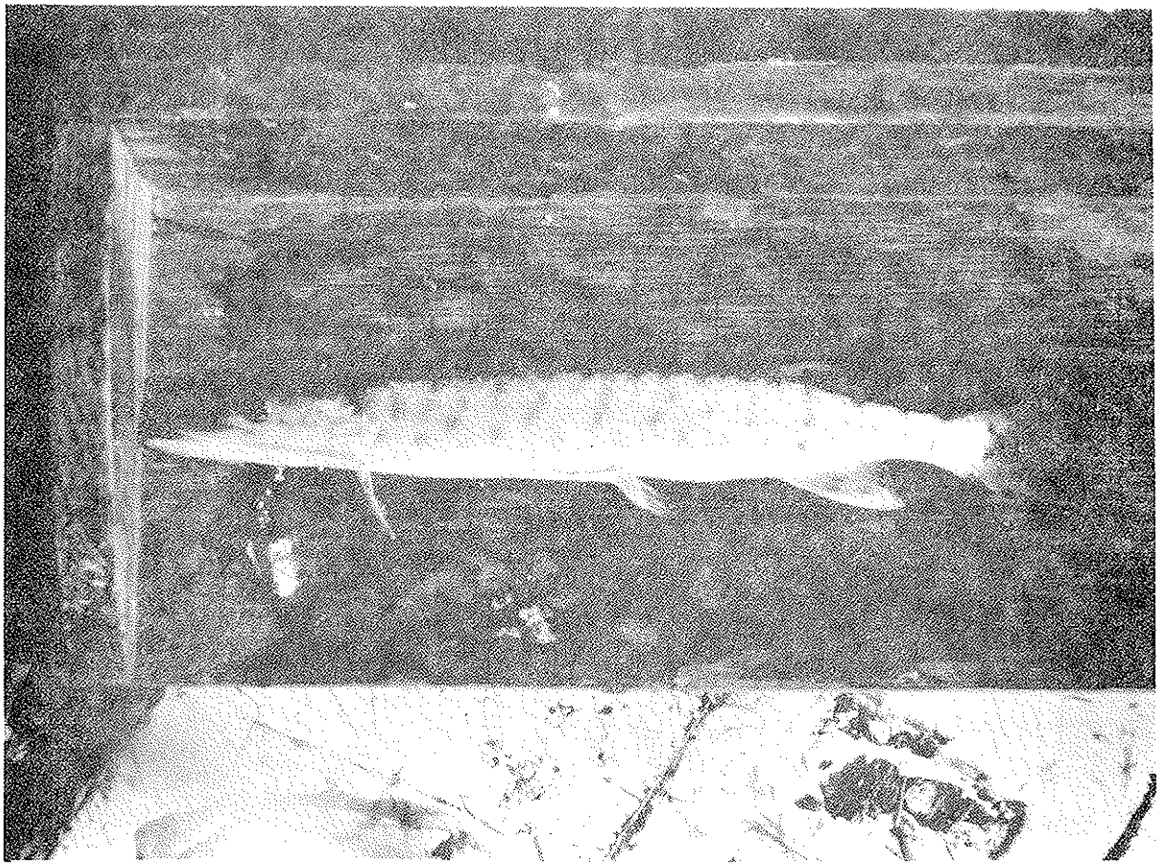
Date	Pond Temperature (^{o}C)	Observations
4/23/73	17.7	Stopped inflow in ponds 43, 37.
4/25/73	17.5	Fry observed in pond 38
4/26/73	16.6	
4/28/73	8.6	
4/29/73	15.7	
4/30/73	16.6	Fry observed in pond 44.
5/1/73		Starting moving brood fish.
5/2/73	18.3	Fry observed in pond 37.
5/3/73		Finished moving brood fish.
5/4/73	16.1	
5/5/73	17.7	
5/9/73		Fry observed in pond 43.

Table III. Fry Transfer and Fingerling Production Records from Spawning Ponds.

Pond No.	Year Brood Fish Collected	No. Fry Removed	Fingerling Produced
38	1972, 1973	19,500	12
44	1973	15,000	560
43	1970, 1971	6,000	1,044
37	1970	4,450	638

portion of the state, while 500 muskellunge fingerlings were retained at the hatchery for broodstock development (Fig. 4).

Fig. 4. A Nine and One-Half Month Old Fingerling.



DISCUSSION

Spawning

The muskellunge cruised the banks of the ponds in water so shallow that the dorsal and caudal fins were often extended above the pond surface. This apparently is a pre-spawning behavior, and appears to signal the beginning of ripeness. It occurred at no other time of the year other than during the spring, particularly in the month of April. During the remainder of the year, the muskellunge inhabited relatively deep water in the ponds.

Spawning activities were observed three times between 1 and 8 April. Pond temperatures of 11.1° C to 15.7° C were recorded during this period, and thus are coincidental with the 8.8° C to 15.7° C temperature range usually reported as being necessary before spawning can occur in this species. During each of my spawning observations, a pair of fish swam side-by-side approximately one to three feet from the edge of the pond in shallow water. One of the fish, undoubtedly the male, displayed a type of twisting or undulating motion for each two or three yards of the bottom covered. This action has been described by several observers. Williamson (1942) reported that the spawning act was accomplished when the male delivered a hard glancing blow to the body of the female. The results of this concussion are that the eggs are expelled from the female and the milt from the male. Svärdson (1949) described a similar motion while observing northern pike spawn in an aquarium. Spawning in our hatchery ponds continued until the fish were startled by my presence, after which the pair veered off to deeper water. However, spawning always resumed a short time later, principally near the banks of the pond. The spawning activities occurred without disturbing the water's surface; the splashing activities, often reported in the literature, were not noted. The spawning observations reported here were all witnessed in the late afternoon, usually continuing until dark.

The first of these activities was observed on 1 April in pond 38. That morning, a ripe male and female, captured by means of a fyke net set in a local stream, were placed in the pond. These muskellunge were possibly the same pair of fish observed spawning later that afternoon. A change from the 11.1° C stream temperature to the 15.7° C pond temperature could have triggered the reaction. On 6 April, spawning was again observed in pond 38, while on 8 April, two fish were noted spawning in pond 44. Later, on 22 April, two fish looked as if they might be spawning in pond 44 around the inflowing cooler water from the river, but actual spawning was unlikely since the pond temperature was 20° C at this time. Ponds 38 and 44 contained mostly muskellunge collected during March and April of 1973, so limited spawning activity was anticipated since a majority of these fish had ripened somewhat within the stream before capture. No muskellunge were seen spawning in ponds 37 and 43, even though the fish held in those ponds cruised the banks daily. Possibly the fish in these two ponds spawned at night; judging by the time of fry discovery, they apparently spawned from two to ten days later than the brood fish in ponds 38 and 44. It has been found that brood muskellunge held in ponds ripen as much as two weeks later than wild fish (Notes, 1967), and the muskellunge in ponds 37 and 43 had been held in captivity for two to three years.

Fry Production

Egg development varies with water temperature. The young may hatch from 8 to 14 days after fertilization in water temperatures of 12.2° C to 16.6° C (Oehmcke, et al, 1958), or they may take as long as two to three weeks to hatch after fertilization (Karvelis, 1964). Furthermore, any sudden decrease in water temperature toward 4.4° C after fertilization is detrimental to the eggs (MacKay, 1931). Muskellunge fry, hatched and reared in lower than normal developmental pond temperatures (8.8° C to 10.0° C), use up yolk sac food material without an increase in size and develop into smaller, weaker fry which may not feed (Johnson, 1958).

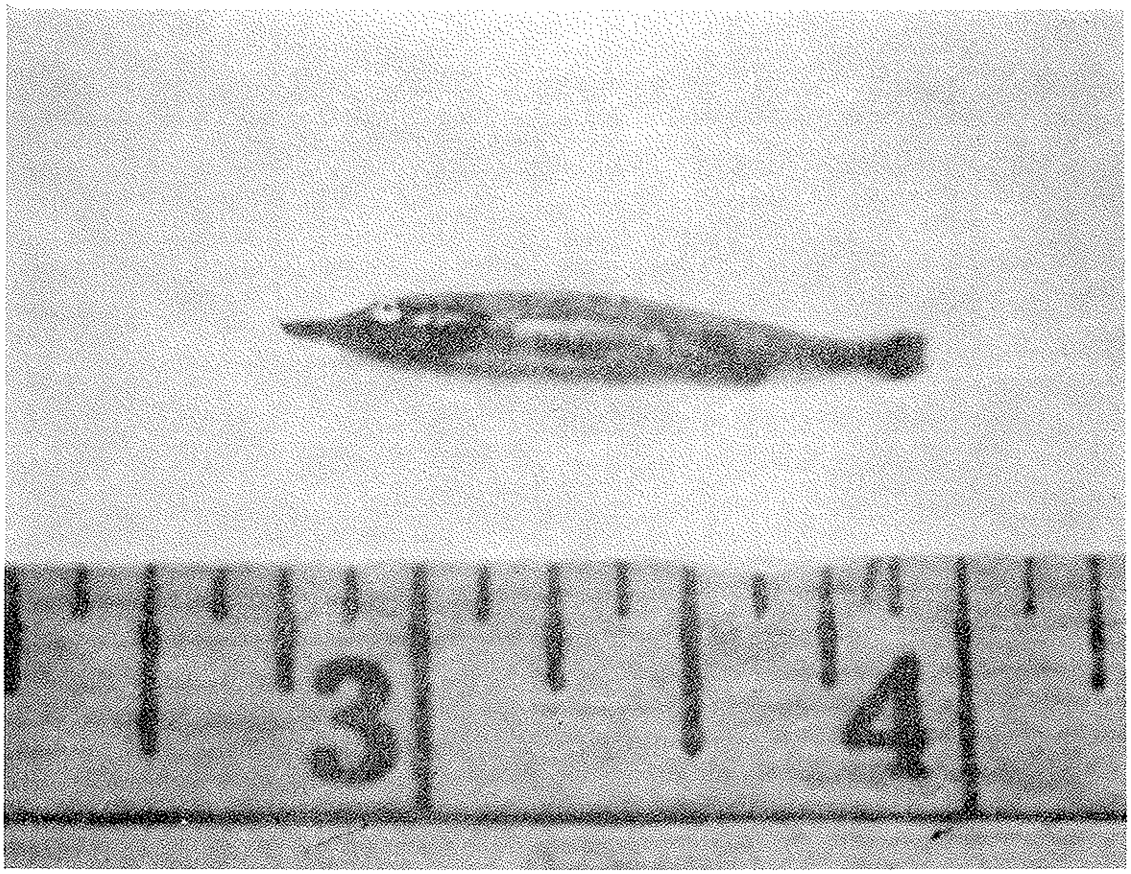
Between 8 April (last observed spawning) and 25 April (first observed fry), the water temperature in the spawning ponds fluctuated to a low of 7.2° C and a high of 20° C. This temperature fluctuation may have caused an excessive amount of muskellunge eggs to die. Mortality was noted when dead eggs were found on the surface of ponds 38 and 44 during broodstock removal, although these eggs may have been only those that were unfertilized or otherwise nonviable from the beginning.

Approximately three weeks after the spawnings were observed, fry were noted in ponds 44 and 38. The average pond temperature for the month of April was 15.3° C. Galat and Eipper (1969) have reported a 15-day period after fertilization until hatching at temperatures from 12.7° C to 15.7° C, and an additional 7-day period at the same temperatures is required by the larvae to reach the free swimming stage (Galat and Eipper, 1972). Based on the above data, the fry produced in pond 38 were probably the result of the spawning observed on 6 April and the fry produced in pond 44 were the result of the spawning activity which was witnessed on 8 April.

Upon initial discovery, the fry in pond 38 were inactive and lying so motionless in and around the rocks and hay along the bank, that it was often difficult to discern them from small particles of floating debris. Judging by their activity, they appeared to be in the last stages of yolk sac absorption. They were especially prevalent in areas containing large amounts of submerged hay, indicating that the majority of the eggs were scattered over these areas and that the hay apparently provided a suitable spawning site. Four days later, the fry in pond 38 began to actively feed on water fleas (Daphnia sp.). Fry, that were already active and feeding, were first observed in ponds 44 and 37 on 30 April and 1 May, respectively. Later, two sizes of muskellunge fry were noted in pond 37, indicating that unobserved spawning had taken place in that pond at least twice. Fry were not noted in pond 43 until 9 May. It was especially surprising to discover fry in ponds 37 and 43, since no spawning activity was ever noticed in these ponds during the experiment, and there was no previous record of fry production by the muskellunge held in those ponds during the past two to three years of captivity.

During the first 22 days of May, muskellunge fry (Fig. 5) were transferred from the four spawning ponds to rearing ponds containing goldfish (Carrasius auratus Linnaeus) or fathead minnows (Pimephales promelas Rafinesque). The goldfish and minnows had already spawned in a small number of the rearing ponds, and it was hoped that the rest of these fish would do so in order to furnish the muskellunge fry with food. The muskellunge fry were stocked at a rate of 2,000 per acre in 15 one-acre rearing ponds and one 7.5 acre rearing pond.

Fig. 5. Size of Fry at the Time of Transfer to Rearing Ponds.



Approximately 45,000 muskellunge fry were transferred to the rearing ponds, and an estimated 15,000 fry were retained in the four spawning ponds. During the experiment no fry mortality was actually noted, but some may have occurred from shocking as the broodstock were transferred. Although a relatively large number of fry (60,000) were produced from pond spawning, this number does not compare to the estimated 400,000 to 750,000 fry expected to be produced by artificial methods when the hatchery is under full production.

Fingerling Production

Only 2,980 fingerlings (15.2 to 25.4 cm) were regained from the 16 rearing ponds in the fall from the original 45,000 fry transplanted, while the four spawning ponds produced 2,250 fingerlings (15.2 to 30.5 cm) from those fry not removed. It is evident by looking at Table III that the spawning ponds that yielded the lowest number of fingerlings were those from which the greatest number of fry were transferred. Another reason for poor production in some of the spawning ponds was the unavailability of forage. Pond 43, which yielded the highest number of fingerling muskellunge, was drained early in the summer while there were still some forage fish present in the pond, while pond 38, which produced only 12 fingerlings, was the last spawning pond to be drained (late in the fall) because of an algae (Hydrodictyon) problem and the forage supply had long been exhausted.

Several factors contributed to the low fingerling production. One of the most important was the lack of forage during the critical stage of fry development. Although there was abundant zooplankton (Daphnia) in most of the rearing ponds, an adequate supply of goldfish and fathead minnow fry, used by the muskellunge fry for food, was not available due to an approximate two week delay in spawning because of unusual cold spring weather. As the muskellunge fry converted from plankton to piscivorous feeding, there was not a sufficient amount of food present for high survival. The lack of food also increased cannibalism among the species. Other factors contributing to the low fingerling production were oxygen depletions and algae problems in several ponds from over-fertilization, an inadequate water supply (unable to flush ponds), lack of equipment to test water quality and control algae, and lateness in stocking fingerlings.

Although the fingerling production was low in comparison to the total fry population, enough fingerlings were raised to stock most of the muskellunge streams in the northeastern portion of the state at a rate of 1 to 3 fish per acre. Licking River, which borders the hatchery and is the state's top muskellunge producer, was stocked at a rate of 4 fish per acre in an attempt to establish a muskellunge population large enough to produce broodstock for later years. It is hoped that in the future, this stream may give Kentucky a source of muskellunge eggs to supplement the domestic broodstocks' supply.

SUMMARY AND CONCLUSIONS

Muskellunge fry production at the Minor E. Clark Hatchery for 1973 was limited to the success from pond spawning because of an inadequate water supply to the hatching batteries. Forty-one muskellunge (71.1 to 114.3 cm long) collected during 1970, 1971, 1972 and 1973, were introduced into four one-acre ponds for the purpose of spawning. Suitable spawning conditions were created within the ponds by providing spawning sites consisting of hay and crushed limestone rocks, and by controlling certain factors, such as predation on eggs and fry and water level fluctuation, which are limiting to natural reproduction.

Spawning activity was actually observed three times in two ponds containing mainly muskellunge captured during March and April of 1973. Fry were produced in each of the four spawning ponds, even in those ponds containing muskellunge that had been held in captivity for two to three years with no previous record of pond spawning. An estimated total of 60,000 to 65,000 muskellunge fry were produced, but only 5,250 fingerlings (15.2 to 30.5 cm) were reared for stocking in the fall. Poor fingerling production resulted from insufficient forage for muskellunge fry at the critical period of development, oxygen depletions and algae problems, an inadequate water supply, lack of equipment to test water quality and tardiness in removing the fingerlings from the rearing ponds for stocking.

The amount of spawning which occurred in each of the ponds was unexpected, since all of the hatchery broodstock were captured from a native population that consisted strictly of stream spawners. Spawning success within the ponds may undoubtedly be attributed to several factors, such as the water quality of the Licking River (supports a native muskellunge population), the creation of suitable spawning conditions within the ponds, and a good quality of domestic brood fish. The number of fry (60,000) produced far exceeded expectations based on past records of pond spawning, even though this number is only a fraction of the expected fry production (400,000 - 750,000) when the hatchery is in full operation. Certainly muskellunge will never spawn in sufficient numbers within a pond to replace the artificial methods of propagation, but pond spawning can become very beneficial in cases where it is impossible to hatch eggs in jars or when large numbers of fry are not needed.

More experimentation is necessary to draw accurate conclusions and obtain a sufficient amount of data to develop pond spawning as a useful method for muskellunge fry production. This is the tentative plan at the Minor E. Clark

Hatchery for the next two or three years. Muskellunge production for 1974* will again depend heavily on pond spawning. Some changes in procedure, such as varying the number of brood fish per acre, continuously circulating water through several ponds and completely removing the fry from the spawning ponds, will be done to possibly enhance spawning and result in a larger number of fry being produced. Production next year can definitely be improved with a good water supply to flush or dilute the ponds in case of over-fertilization, an abundance of forage fish for the muskellunge fry and fingerlings, and better management practices gained through experience.

* This same method was used to propagate muskellunge in 1974. There were 37,800 fry (2.54 cm) produced and a total of 10,300 fingerlings (12.7 cm) reared for stocking.

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