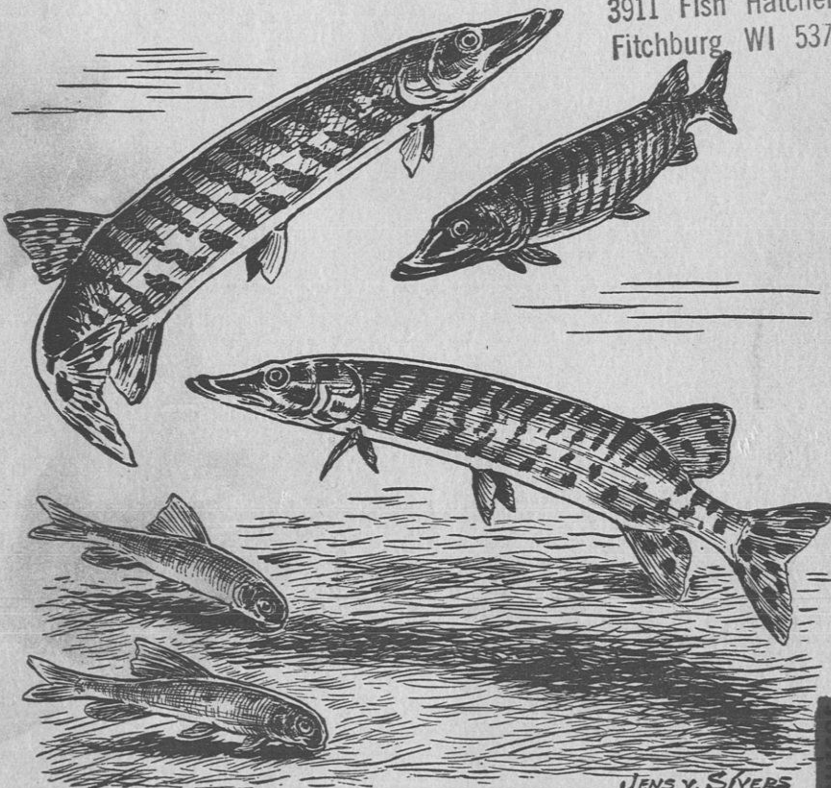
Pond culture of muskellunge in Wisconsin. Number 17 1958

OND CULTURE OF MUSKELLUNGE IN WISCONSIN



TECHNICAL BULLETIN NUMBER 17

WISCONSIN CONSERVATION DEPARTMENT
Madison 1, Wisconsin

1958

CONSERVATION COMMISSION

Leonard J. Seyberth, *Chairman*
Eau Claire

Arthur R. MacArthur, *Secretary*
Janesville

Guido R. Rahr
Manitowoc

A. W. Schorger
Madison

Charles F. Smith
Wausau

Russell D. Stouffer
Shell Lake

CONSERVATION DEPARTMENT

L. P. Voigt
Director

George Sprecher
Assistant Director

John A. Beale
Chief State Forester

C. A. Bontly
Finance

W. T. Calhoun
Information and Education

G. S. Hadland
Law Enforcement

Roman H. Koenings
Forests and Parks

Lulu M. Korn
Clerical

Neil LeMay
Forest Protection

Wm. A. Matson
Personnel

Laurence F. Motl
Engineering

Edward Schneberger
Fish Management

J. R. Smith
Game Management

S. W. Welsh
Forest Management

POND CULTURE OF MUSKELLUNGE IN WISCONSIN

by

LEON D. JOHNSON

(Dingell—Johnson Project F—10—R)

TECHNICAL BULLETIN NUMBER 17

WISCONSIN CONSERVATION DEPARTMENT
Madison 1, Wisconsin

1958

ACKNOWLEDGMENTS

Many personnel in the Wisconsin Conservation Department have contributed helpful assistance in the conduct of the muskellunge studies. The author is particularly indebted to Clarence A. Wistrom, Arthur A. Oehmcke, Harry H. Laughlin and William Billings for suggestions and cooperation. Dr. Edwin L. Cooper and Stanley Kmiotek provided helpful guidance, personal consultation and advice that was much appreciated.

Chemical analysis of water samples was conducted by the Wisconsin State Laboratory of Hygiene.

The contributions of the following people are gratefully acknowledged: Dr. Edward Schneberger and Lyle M. Christenson for critical review of the manuscript and Lois Donatell and Beverlee Bruce for the typing. The cover picture was reproduced from a drawing by Jens von Sivers. Photographs are by the author.

Note: This is a continuation of the Technical Wildlife Bulletin series. The series will now be called Technical Bulletins, and will include technical reports on game, fish, and forestry subjects. Titles of previous numbers are listed in the back of this report.

Edited by Ruth L. Hine

FOREWORD

Stocking of hatchery-reared fish is one of the oldest of fish management practices and the culture of muskellunge in Wisconsin started in 1899. Although erratic production and periodic mortalities have beset fish-culturists for years, only recently has specific information on the causes been obtained which will help provide a sound basis for correction.

Research on muskellunge in Wisconsin has been in progress for a considerable period of time, but has received more emphasis during the past few years. At the present time, investigations are directed at: (1) Improvement of efficiency in rearing operations, (2) Study of behavior and characteristics of natural populations, and (3) Evaluation of stocking practices.

This bulletin presents the findings of initial research on pond culture of muskellunge and details the best of older rearing practices, which together describe our established rearing operations.

As this bulletin went to press, results of preliminary experiments in trough rearing were reported which have suggested a need for reappraisal of our muskellunge rearing program. Since the major research work thus far has been on a problem common to all forms of fish culture, namely food requirements, any subsequent change in our program will in no way detract from the importance of the findings presented in this paper. Rather, any change would serve to further illustrate the need for continuing research on fishery problems as we constantly strive to achieve greater efficiency and effectiveness in our fish management practices and operations.

L. P. VOIGT
Conservation Director

CONTENTS

ABSTRACT

The muskellunge (*Esox masquinongy immaculatus*) is the most spectacular large game fish found in Wisconsin. Artificial propagation is one method used in an attempt to augment existing lake populations. Some of the findings from studies conducted during 1953 through 1957 coupled with the best of past practices have been applied at the Spooner and Woodruff hatcheries to formulate improved cultural procedures.

The basic food for the muskellunge is provided by zooplankton culture. *Daphnia pulex* is selected primarily because it will eat organic detritus. *Torula candida,* a wood yeast, is used as a direct food for the *Daphnia* thus circumventing many steps in the food chain. Fish forage is provided by the propagation of suckers *(Catostomus c. commersonnii)* and other fishes. Fathead minnows *(Pimephales p. promelas)* are trapped during winter months from freeze-out waters and stocked in outlying ponds to provide a natural brood stock of forage fishes. In summer months minnows are hauled to supply forage for hatchery ponds that have a low supply.

Ponds are filled late in the spring to retard the appearance of undesirable rooted aquatic vegetation, filamentous algae and predator insect larvae. Ponds are maintained at a high water level to maintain more stable warm water temperatures that favor development of zooplankton.

Pond management includes such chemical controls as the eradication of vegetation to prevent absorption of fertilizers. Sodium arsenite applied to the dry pond bottom eradicates the needle rush (*Eleocharis acicularis*), while Dowpon is effective for cattail control. Torula yeast used as a fertilizer acts to inhibit growth of filamentous algae. Filamentous algae is eradicated by spot application of the algicide Delrad. Fuel oil applied to the water surface is used to kill the predaceous dytiscid insect larvae.

Adult muskellunge spawners are captured in the spring from lakes that provide the earliest and largest muskellunge eggs. Spawning methods are similar to those used for other fish species. Care is taken that eggs are not disturbed during a critical 9- to 15-minute period after they are spawned. Optimum water temperatures range between 50° to 60° F. Between 85 to 95 per cent of the eggs hatch successfully.

Muskellunge are stocked in rearing ponds after the fry reach a "swim-up" stage. Swim-up fry are considered the same physical age even though they are hatched from eggs taken on different days. Extended periods of cold waters (50° F. or lower) delay muskellunge development and retard the fry so that they do not swim up.

Sucker fry, used as forage, are stocked in rearing ponds 4 to 8 days later than the muskellunge to minimize competition for the same forage. The later sucker stocking retards growth so that the muskellunge may continue to eat the smaller sized suckers. Pond temperatures over 85° F. cause sucker mortalities.

Muskellunge are harvested from hatchery ponds manually with a dip net 2 to 3 weeks after they have been stocked. Reduction of the population leaves more food for the remaining fish. Survival of the young muskellunge ranges from 30 to 70 per cent. Some of the muskellunge are stocked in lakes on established quotas and others are stocked in outlying rearing ponds.

The second and final harvest is made from all ponds beginning mid-September through October. Ponds are seined or drained to capture the 4- to 5½-month-old muskellunge that range 7 to 17 inches in length. The survival of muskellunge in outlying ponds has averaged 30 per cent.

INTRODUCTION

The northern muskellunge (*Esox masquinongy immaculatus,* Garrard) is found in certain waters of Wisconsin, Minnesota, Iowa and possibly Illinois (Greene, 1935). The importance of the muskellunge to Wisconsin is indicated by its designation as the official state fish. This species is one of the largest fresh-water game fishes in North America. Specimens that range from 6 to 30 pounds and larger are taken annually. The present official world-record muskellunge caught in 1957 on the St. Lawrence River weighed 69 pounds 15 ounces (*Field and Stream* Annual Fishing Contests). Johnson (1954a) described an unofficial record Wisconsin muskellunge at 70 pounds 4 ounces. Another Wisconsin specimen that weighed 102 pounds reported by the *Minocqua Times* in 1902 was undoubtedly very large, although Johnson (1952) indicated that this weight was not sufficiently authenticated.

The muskellunge is a heavily exploited sporting fish as demonstrated by angling records maintained by many Wisconsin resort operators. Stocking of artificially propagated muskellunge is one method that is employed in an attempt to augment existing populations in the face of mounting fishing pressure. It is an old program dating back to 1899 in Wisconsin (Nevin, 1901). Although the stocking of lakes has won wide public acceptance, the benefits are not thoroughly understood.

Two hatcheries are currently operated by the Wisconsin Conservation Department to supply muskellunge for stocking purposes. One hatchery is located at Spooner, Washburn County and the other at Woodruff, Oneida County, both in northern Wisconsin. Woodruff is the older station, with the first muskellunge reared in ponds in 1926. The Spooner station started the propagation of muskellunge in 1939; thereafter, there were years of high but often years of low production.

Few references are available that describe the problems involved in the propagation of muskellunge. Nevin (1901) and Bean (1908) were among the earliest to indicate difficulties encountered in the hatching of muskellunge eggs. Low muskellunge survival in rearing ponds during the early years of operation at Woodruff was described briefly by Webster (1929). Studies by MacKay and Werner (1934) and Elson (1941) indicated some of the problems of food supply and cannibalism. Oehmcke (1949) stated that pond fertilization at Woodruff worked too slowly at the low water temperatures in early spring to provide beneficial zooplankton production in time for the muskellunge and produced undesirable growths of filamentous algae. Similar algae growths that enmeshed thousands of fingerlings with resultant mortalities were observed at the Spooner station by O'Donnell (1945).

Information on muskellunge culture at Woodruff was described by Oehmcke (1949, 1951) and provided a basis for production that has been modified only recently. Fertilization of ponds was reported to be important to fish culture success in a review of the literature by Maciolek (1954). Many fertilization experiments, however, relate to different fish species in warm southern climate ponds and the results are not applicable to the culture of muskellunge in northern Wisconsin ponds influenced by a cooler climate and shorter growing season. Because of the uncertain benefits and often adverse effects, fertilization of muskellunge ponds has been reduced to a minimum during the recent years.

Erratic production of muskellunge in the hatcheries led to studies from 1953 through 1957 to learn more about the life history, habits, growth and survival of young muskellunge. Some of the findings from these studies coupled with the best of past practices have been applied at the Spooner and Woodruff hatcheries to formulate improved cultural procedure. These consist primarily of a manipulation of the rearing-pond ecology to attain increased production of desired zooplankton forms, with consequent increased survival and growth of the muskellunge. The purpose of this report is to describe the methods for muskellunge propagation that have been found most successful.

DESCRIPTION OF PONDS

Hatchery Ponds

Spooner. There are sixteen drainable ponds on the grounds that vary in size from 0.08 to 6.25 acres with a total of 16.8 acres. The ponds range from 1.5 to 6.0 feet in depth with an average depth of 3.0 feet. The ponds are aligned in three water systems that require passage of the water through several ponds before another can be filled. Under these conditions of multiple water use it is often difficult to maintain water levels in the lower pond of a series, due to seepage through the dikes and normal evaporation. The Spooner station is operated intensively for production of large numbers of 2- to 6-inch muskellunge that are stocked in lakes and outlying ponds.

Information on the fertility of the Yellow River Flowage, source water for the rearing ponds, was obtained from a chemical analysis of water samples performed by the Wisconsin State Laboratory of Hygiene

The Spooner muskellunge rearing station is made up of pond series arranged into three drainage systems that often require passage of the water through several ponds before another can be filled.

(Table 1). The chemical range of the non-fertilized waters indicated varying values; for example, the total phosphorus extended from .04 to 0.2 ppm., covering almost the complete range of 0.034 to 0.126 ppm. reported by Moyle (1956) for poor-to-good-producing Minnesota lakes.

Woodruff. The Woodruff station has twenty-one drainable ponds that range in size from 0.07 acres to 2.10 acres with a total of 7.5 acres. The water supply is obtained from Madeline Lake which has a native muskellunge population. Water levels in ponds are controlled by separate inlet and outlet bulkheads. Source waters are somewhat less fertile than the Spooner waters (Table 1), but contain higher numbers of natural zooplankton. Unlike the Spooner station, all shade trees have been removed from the pond banks within recent years. Removal of trees is said to reduce leakage of water through the dikes and the tendency toward clogged screens from falling leaves.

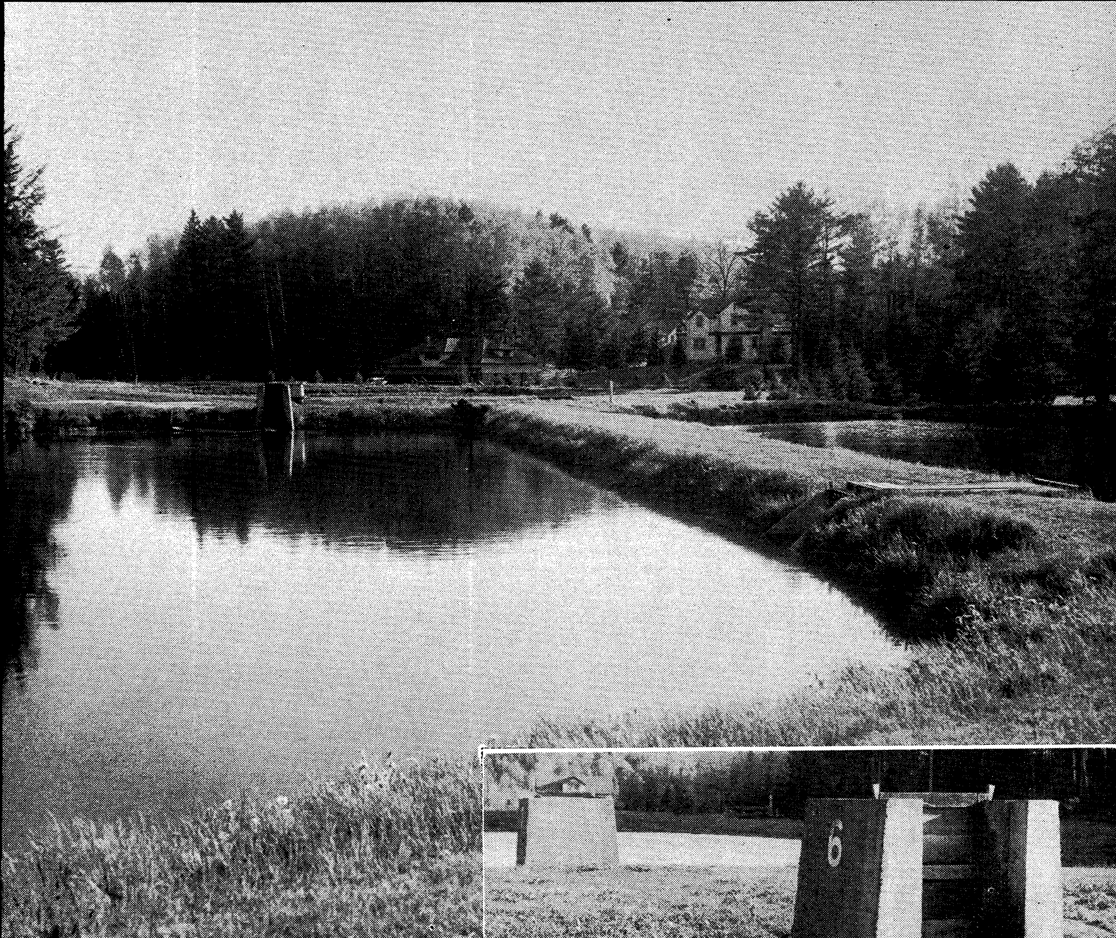
TABLE 1

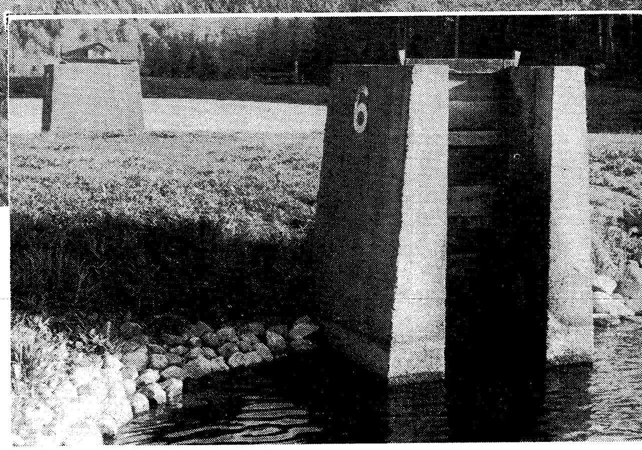
Chemical Analysis of Muskellunge Ponds

(Non-fertilized and Fertilized Spooner Waters, and Non-fertilized Woodruff Waters)*

	Yellow River Flowage (Non-Fertilized)						Spooner Waters (Fertilized)				Woodruff Waters
							Torula and 10–10–10	Torula Only	Torula Only	Torula and 10–10–10	(Non-fertilized)
	June 1952	June 1953	April 1956	June 1956	August 1956	Sept. 1956	June 1953	April 1956	August 1956	August 1956	June 1956
Total Organic Nitrogen	0.32	0.34	0.30	0.30	0.25	0.40	1.4	1.4	1.3	-----	0.29
Free Ammonium	0.012	0.24	0.10	0.05	0.07	0.06	0.86	0.5	0.20	0.72	0.05
Nitrites	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Nitrates	0.1	0.04	0.12	0.04	0.08	0.08	0.10	0.08	0.08	0.08	0.04
Total Solids	112.0	-----	108.0	114.0	94.0	78.0	-----	128.0	110.0	120.0	74.0
Fixed	-----	-----	64.0	66.0	64.0	34.0	-----	70.0	60.0	64.0	44.0
Volatile	-----	-----	44.0	48.0	30.0	44.0	-----	58.0	50.0	56.0	30.0
Soluble Solids	-----	-----	106.0	112.0	93.0	66.0	-----	114.0	98.0	106.0	72.0
Suspended Solids	-----	-----	2.0	2.0	1.0	2.0	-----	14.0	12.0	14.0	2.0
Fixed	-----	-----	1.0	1.0	0.0	1.0	-----	1.0	1.0	2.0	1.0
Volatile	-----	-----	1.0	1.0	1.0	1.0	-----	13.0	11.0	12.0	1.0
pH	7.4	-----	7.4	8.25	7.65	7.4	-----	7.3	7.4	7.5	8.05
MO Alkalinity	85.0	86.0	74.0	88.0	72.0	84.0	84.0	76.0	72.0	72.0	50.0
Total Phosphorus	0.09	0.2	0.16	0.08	0.05	0.04	0.68	0.6	0.30	0.74	0.06
Potassium	0.6	-----	0.6	-----	-----	-----	-----	-----	-----	-----	-----
Sulfates	2.5	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

*Results expressed in parts per million.





Woodruff ponds are arranged with individual inlet and outlet bulkheads so that ponds can be filled with water or lowered without affecting the water level in others.

The annual mean temperature of the Woodruff area is 1° to 2° F. colder than the temperatures at Spooner, according to Whitson and Baker (1928). The cooler climate results in a somewhat later and shorter muskellunge rearing season at Woodruff. The colder water, however, has one advantage because the slow-growing perch fingerlings can be used for muskellunge forage. Perch are unsuccessful as forage at Spooner because they grow too large in the warmer waters. Despite the climatic differences, both stations encounter similar cold weather so that the successful practices at one are generally applicable to the other.

Outlying Ponds

Both the Spooner and Woodruff stations utilize outlying ponds to rear muskellunge to a larger size than that generally attained in station ponds. The size of the fish produced has ranged from approximately 7 to 17 inches. Outlying ponds are usually located within 30 miles of the station. The Sand Lake pond of 43 acres, Maple Plains 22 acres, Shell Lake 4 acres, and Rib Lake 7 acres, are of a control type that can be drained similarly to rearing ponds on the hatchery grounds. Non-drainable farm-yard ponds of 3 to 4 acres are also used for muskellunge and minnow production. They are usually leased on a temporary basis.

PRODUCTION OF NATURAL FOOD

The production of muskellunge fingerlings in rearing ponds is almost completely dependent upon the quantity of live forage that is provided. Living zooplankton are a required beginning food for muskellunge fry and of importance to forage fishes as well. Muskellunge utilize zooplankton exclusively for the first four days of feeding and often longer. Live forage fishes then make up their diet. When zooplankton are unavailable to the muskellunge fry during the early feeding period, starvation occurs that has in the past reduced the numbers by 99 per cent. Complete mortalities have been demonstrated within 10 to 14 days in laboratory aquaria and in ponds where food has been withheld.

Zooplankton Production

Many involved factors combine to reduce the zooplankton population in rearing ponds in spring and summer, which in turn results in reduced muskellunge survival. (1) Cold waters and inadequate fertility limit the food and subsequent parthenogenic reproduction of the zooplankton; (2) The many introduced muskellunge and sucker fry exert an overgrazing effect that tends to decimate the zooplankton population; (3) High water temperatures of 85° F. or above cause sudden mortalities.

Less obvious is the fact that reduction of the zooplankton population results in further reductions the following spring season which again adversely affects muskellunge production. The explanation lies in the quantity and viability of the ephippial eggs that are produced. Ephippial eggs are an over-wintering stage very resistant to freezing, dessication, and other adverse conditions. If few ephippial eggs are produced because of a low population of mature *Daphnia,* for example, a delayed zooplankton pulse follows the next season. Ephippial eggs produced during an early spring season are less viable than the same type of eggs produced in the fall and also result in a delayed zooplankton pulse the following season. Conversely, ephippial eggs produced in the fall have greater viability because they are subjected to fewer adverse conditions during the shorter time interval of six months, compared to one year for eggs resting from spring to spring. The reduced viability of ephippial eggs that were exposed, wet or dry, for varying periods of time was reported by Banta (1939).

Daphnia pulex was selected as a zooplankton form for special culture because: (1) It is cosmopolitan in its distribution (Pennak, 1953) and is found naturally in Spooner ponds; (2) It will reproduce prolifically in colder waters (38° to 60° F.) than is optimum for reproduction of many other species of *Daphnia;* (3) It is a non-specific filtrator that thrives on detritus and suspended organic material, and is thereby readily cultured in the laboratory and outside ponds; and (4) Muskellunge fry and forage fishes will feed readily on all of the different-sized instar stages.

Other species of Cladocera appear in the rearing ponds without special attention, but for various reasons are of negligible value as initial starting foods for muskellunge fry. *Daphnia magna* appears later than desirable and is not a prolific reproducer. *Daphnia longispina* appears in ponds early, but does not compare to *Daphnia pulex* for reproductive rate. In addition individual *Daphnia longispina* are small in size so that the reproducing broodstock is often consumed by the muskellunge fry. *Sida crystallina* withstands very warm water near 85° F., but does not appear in ponds early enough for muskellunge forage.

Another cladoceran, *Polyphemus,* indicated by Elson (1941) and Oehmcke (1949) as a food item utilized to a large extent by muskellunge fry, is found only in some of the waters near Woodruff and in some outlying Spooner ponds. Furthermore, *Polyphemus* is less desirable than other forms because of selective predaceous characteristics that make it difficult to propagate in the laboratory and in ponds. The predaceous character adds one additional step to the food chain that reduces efficiency of food conversion.

The Copepoda are usually the first to appear in ponds but are seldom present when the muskellunge are introduced. The Ostracoda appear in large numbers in some years but are not utilized by the muskellunge perhaps because of the heavy shell that surrounds the animal.

The life history of *Daphnia pulex* provides a basis for working out the techniques that are applied to muskellunge culture. There are a series of individual life stages beginning with 10 to 36 or more parthenogenic eggs released into the brood chamber by the female. After approximately two days at 60° F. the parent molts its shell and releases the live young into the water. The newly hatched *Daphnia pulex* develop through three juvenile instars or separate moltings during which the old shell is cast off and the young *Daphnia* increase in size. The small-size instars can be and are readily consumed by the muskellunge fry. Table 2 presents the life history stages of *Daphnia pulex* correlated with the size of muskellunge that utilize them.

The adolescent instar of *Daphnia pulex* represents the fourth instar, or transition to adulthood during which the first eggs are in ovarian development. An individual in the adolescent instar stage is usually 5 to 8 days old at water temperatures of 68° F. and is still small enough to be taken by young muskellunge fry.

At the first adult instar, eggs are promptly laid in the brood chamber, and in about two days at 68° F. just before the molt that ends the first adult instar, the live young are released.

The adult passes through 18 to 25 adult instars, depending upon food, crowding, water temperatures and other conditions, during which the shell is molted and new broods of young are released into the water. These life history stages of various cladocerans are described by Banta (1939) and Pennak (1953). Survival of the muskellunge fry is dependent upon the young instar stages of the *Daphnia pulex* which can be freely eaten due to small size. Of further importance is the escape of adult stages which cannot be immediately eaten due to large size and thereby remain in the ponds to serve as brood stock to continue zooplankton production.

***Daphnia pulex* Culture.** The artificial culture of *Daphnia pulex* is a continuous year around procedure. A number of adults that contain parthenogenic eggs are brought into the laboratory from outside ponds in the early spring and held over summer in a yeast water-culture medium to make certain that *Daphnia pulex* is available again in the fall. Pure cultures are obtained by inserting an individual of any of the young instar stages into fresh medium contained in a glass flask. A pipette or medicine dropper may be used to transfer select individuals.

The culture medium for *Daphnia* production is made up of Torula wood yeast (*Torula candida*) manufactured by the Lakes States Yeast Corporation, added at the rate of 0.5 grams per cubic foot of pond water (Jackson, 1949) or chlorine-free tap water. When tap water is used, about 10 to 20 cc. of water from a natural pond or from an old culture are added to about 100 cc. of new media to provide a condition-

TABLE 2

The Size and Age of Muskellunge Fry Compared to the Size of *Daphnia pulex* Life History Stages That Are Consumed

Daphnia pulex life stages	Size of *D. pulex* Av. width x Lg. (mm.)	Size and Age Muskellunge Fry Lg. (in.)	Size and Age Muskellunge Fry Days from First Feeding
1. Sexual egg (ephippial) or	-------------	--------	--------
2. Parthenogenic eggs in adult	0.2426 diameter	--------	--------
3. Juvenile: 3 to 4 separate instars	0.1733 x 0.2773 to 0.3470 x 0.9360	.50	1
4. Adolescent: single instar stage	0.5896 x 1.3860	.51–.52	2 to 7
5. First adult instar stage	1.075 x 2.253	.53–.64	4 to 7
6. 18 to possibly 25 adult instars	1.906 x 3.446	1.9	14 to 30
7. Sterile senile adult to death	2.461 x 4.139	--------	--------

ing action apparently necessary for survival of the *Daphnia.* Conditioning action is not a clearly defined process but bacterial contamination of the media is probably one of the essentials. Exposure of sterilized yeast-distilled water media to the air for several days promotes conditions that support *Daphnia* growth, while unexposed sterile yeast media, even though adequately aerated, do not support growth. The yeast together with the bacteria present in the media are food particles that are directly assimilated by the *Daphnia.* While the term "conditioning action" was not defined by them, Banta (1939) and Bender (1955) described *Daphnia* culture methods, which suggest that bacterial contamination may have been a requirement for the culture medium.

Culture media made up of other food materials also support the growth of *Daphnia*: for example, bacteria, unicellular algae and to a lesser extent protozoa (Banta, 1939), various algal forms (Klugh, 1927), dry buttermilk, soybean meal and cotton seed meal, with the latter most successful for zooplankton culture (Embody and Sadler, 1934), dry commercial yeast (Bender, 1955), and many other organic materials (Needham and Brown, 1933). While some discrimination is displayed in the feeding by *Daphnia pulex* (Smith, 1936), it is apparent that a wide variety of food items are acceptable and that various foods can be fed directly to promote growth and reproduction.

Direct feeding to *Daphnia* in aquaria and in ponds is practiced as a valuable accessory cultural technique for muskellunge production.

Culture flasks that contain 50 to 100 cc. of Torula yeast medium and maintained at room temperature in subdued light have been effective for holding a continuous parthenogenic *Daphnia pulex* population through four consecutive years. For the purpose of effective pond procedure, however, it is necessary to hold *Daphnia* only over summer, since summer is the period when the numbers are most likely to be reduced. Special fall culture is practiced to provide the more effective ephippial-egg over-wintering stage.

Fall Zooplankton Production in Ponds. Preparations are begun in mid-August for production of *Daphnia pulex* ephippial eggs in the outside culture ponds. Laboratory cultures of *Daphnia pulex* are used for initial supply because other sources have usually disappeared. Accelerated reproduction of the *Daphnia* maintained in the flasks is attained by pouring the contents into a larger-sized container or aquarium filled with water and fertilized with Torula yeast. Usually within two weeks the reproduction has progressed so that the aquarium may be emptied into an outside culture pond filled with standing water and similarly fertilized. The size and construction of the outside pond is of minor importance. The Spooner hatchery uses available concrete raceways and circular ponds as well as earthen ponds for *Daphnia* culture. The dry Torula yeast powder is broadcast over the water surface to obtain as great a water suspension of organic material as possible. A man wading in the pond often assists in obtaining a more thorough mixing.

Daphnia reproduction has progressed sufficiently by mid-September to permit transfers with a plankton seine to other ponds. Many small muskellunge rearing ponds that have been drained and harvested are refilled to accommodate a fall plankton pulse. Fertilization is discontinued October 1, with the approach of colder waters (40° to 45° F.) and the coincident production of *Daphnia* ephippial eggs. Ponds are drained at the first light freeze-up and the very resistant ephippial eggs remain frozen in the thin ice and attached to the bottom and pond edges so that few are flushed away. Spooner ponds are kept dry over winter to prevent damage to soil banks, concrete structures and screens but drainage is not necessary to preserve ephippial eggs; in fact, they are reported to have a higher viability and greater hatch when they are not dried or frozen (Banta, 1939). An immeasurable loss of ephippial eggs occurs because of reduced viability due to adverse winter conditions but sufficient numbers remain to build up and continue the *Daphnia pulex* cycle the following spring.

Sucker Propagation

Muskellunge fry require an abundant and continuous live forage supply to survive and grow. Zooplankton provides the initial food and thereafter forage fishes are a required diet. Muskellunge fry reared in laboratory aquaria and ponds have been maintained on a zooplankton diet as long as 30 days, although they do not attain the size of muskellunge that also have access to live fish forage.

The common white sucker *(Catostomus c. commersonnii)* is a forage species that has received special attention. Suckers are cultured from spawn to the swimming-fry stage in the hatchery under circumstances similar to those for the muskellunge.

Unlike muskellunge eggs that are taken as early as possible to lengthen the growing season (to be described in detail later), sucker eggs are taken as late as possible so that fry remain small enough to be consumed by the muskellunge. The suckers begin the spawning run in the spring about the end of the muskellunge spawning run at water temperatures of 57° to 60° F. Fyke nets are set on rock and gravel shorelines of the colder lakes. Male suckers are usually found on the spawning grounds several days in advance of the females. Eggs are

Preparations are underway to provide forage for the muskellunge fry. Sucker eggs are measured into the hatchery jars using the wooden rack as a guide. The sucker fry are intended as forage required by the muskellunge.

Sucker eggs are incubated in row after row of hatchey jars. Dead eggs are siphoned off the thin layers that collect at the top of jars of good eggs. Much the same procedure is used to siphon off muskellunge eggs.

spawned with a technique similar to the method used for muskellunge. Eggs from more than one female may be spawned into a single pan, and milt from several males is used per pan of eggs to circumvent the possibility of impotent sperm. The milt is stirred into the eggs with the fingers; the eggs are rinsed with lake water immediately and transferred to a tub to water-harden. It is common practice to shade the eggs from direct sunlight but beneficial effects of this practice have not been demonstrated.

After sucker eggs have water-hardened for about thirty minutes, remaining solid masses are broken apart with the fingers and the eggs are given a red-clay water bath. The clay coats the eggs and is considered necessary for the free rolling of eggs in the hatching jars during incubation. Sucker eggs are transported to the hatchery in ten-gallon cans that contain 20 to 25 quarts of eggs. At the hatchery the eggs are floated in screen floating boxes in the fry tanks with fresh circulating waters until they can be put in the hatching jars. All eggs are preferably set up on the hatching jars on the same day that they are received.

A twenty-four hour vigil is maintained to see that eggs are kept rolling. A feather on a stick is used to free eggs if they stick to the sides of the jars. Dead eggs float to the top of the jars and are removed with a siphon hose to prevent the appearance of fungus that may spread to the healthy eggs. The retaining screens are removed when the eggs begin to hatch so that the egg shells will flow out of the jars. Sucker fry continue development and swim out of the jars into the fry tanks, where they are allowed to remain for one to three or more days before they are removed and stocked in the muskellunge rearing ponds.

Other Forage Species

During winter months freeze-out lakes and river sloughs are trapped to supply fathead minnows (*Pimphales p. promelas*) and other easily visible, prolific forage species. The forage fishes are transported to the outlying ponds to serve as reproducing stock for the production of the next season forage. Fish species that should be specifically excluded because of excessive predaceous characteristics include the northern creek chub *(Semotilus a. atromaculatus),* western golden shiner (*Notemigonus chrysoleucas*), and the bullheads (*Ameiurus spp.*). The western mud minnow (*Umbra limi*) is undesirable because it is not easily seen by the muskellunge.

The quantity of forage minnows that can be hauled to ponds from freeze-out waters during winter months is almost unlimited, and there can be a tendency to transfer too many fish. The carrying capacity of an average rearing pond in northern Wisconsin may be limited to 50 to 100 pounds of panfish or minnows per acre and under no circumstances should the maximum be approached by the introduced fish. A poundage figure that can be used as a rough index for stocking can often be obtained for each pond after one year of operation. The fish harvested at the end of any one season are weighed and the arbitrary figure of 10 per cent of the harvest is replaced with adult forage minnows to serve as brood stock. Further studies may indicate modifications that should be made in brood-fish stocking procedures. Only slight fish mortalities due to oxygen depletion from winter-kill occur in the drainable ponds because fresh waters are supplied from lakes and springs. No further attention is directed toward pond management during the remainder of the winter months.

POND PREPARATION AND MANAGEMENT

Eradication of Unharvested Fish

Muskellunge pond operations are conducted on a year around basis. The rearing ponds are drained beginning mid-September through October to facilitate the final harvest of all large 7- to 17-inch muskellunge. Fish that escape the harvest are eradicated with rotenone or chlorine applied to remaining pools or small streams. Rotenone may be impounded to confine the eradicant to a specified area. Chlorine may be neutralized with thiosulfate so that the drainage is not toxic to fishes below the desired downstream range. Hatchery ponds are usually kept dry over winter, while outlying ponds are refilled to full water capacity before the formation of ice cover so that brood minnows may be stocked. The dry bottom of the drained hatchery ponds allows for convenient eradication of aquatic vegetation.

Control of Rooted Vegetation

Overabundant growths of rooted vegetation are undesirable because they tend to physically choke the ponds and remove soluble nutrients from the waters. Rooted vegetation has been considered a deterrent to fish production and to ease of harvest in many ponds (Swingle, 1945; Edminster, 1947; Schlaeperclaus, 1933).

The needle rush *Eleocharis acicularis* var. *submersa* is offensive because it forms a lawn-like mat that spreads over the entire pond bottom. The effect of the mat is to seal the bottom and prevent the exchange of nutrients between the soil and water. The tangled mat also provides unfavorable habitat for tendipedid larvae with a corresponding reduction in food potential for bottom-feeding forage fishes. Weedy ponds even though heavily fertilized often remain clear, with low zooplankton production and less than one per cent muskellunge survival in observed situations. Eradication of vegetation coupled with pond fertilization is followed by increased water turbidity due to suspended organic materials and higher zooplankton and phytoplankton production. This results in muskellunge survival greater than 30 per cent for fishes up through 4 and 5 inches.

The application of sodium arsenite to the dry pond bottom as used by Hiland (1953) has proved to be more successful for eradication of rooted aquatic vegetation than other methods. Regrowth of *Eleocharis* occurs within 10 to 14 days after the ponds are drained in the fall. Ponds are then sprayed with sodium arsenite (Atlas A, 4 pounds arsenous oxide per gallon) at the rate of 40 gallons per acre of dry bottom at the first appearance of the green regrowth. One part sodium arsenite is usually mixed with about 50 parts water in a tank to make up sufficient bulk for greater ease of distribution. Application is made with a garden hose and nozzle with pressure supplied by a gasoline-powered water pump. Most effective use of the arsenite spray is accomplished when the application is completed before the final winter freeze-up or first snowfall. Application of the arsenite after the freeze-up has not been effective. Because of the poisonous nature of sodium arsenite, suitable precautions are taken against breathing the spray and contact with the skin.

Summer application of chemical vegetation controls to ponds filled with water is not the general practice because such usage presents an element of danger to small fishes and zooplankton, as well as greater costs of chemicals applied to the larger water areas. Summer application of Dowpon (2, 2 Dichloro propionic acid, sodium salt, Dow–Chemical Company) for cattail control is one exception. Dowpon is non-toxic to fish at application rates as high as 20 pounds per acre and provides 95 per cent control of cattails at rates as low as 5 pounds per acre, providing the foliage is thoroughly saturated. Most efficient results are obtained when the Dowpon spray application is completed before the flowering cattail spikes have matured. Table 3 presents some of the methods that may be used for vegetation control.

Some chemical and mechanical methods have proved ineffective for vegetation control. Fall application of CMU at 40 pounds per acre of dry pond bottom has failed to prevent regrowth of vegetation the following spring. Chlorox spray powder at 500 pounds per acre did not eradicate rooted aquatics. Various water solutions of 2,4–D and TCA have provided no control of vegetation when applied to dry ponds. Physical removal of the pond bottom soils has failed to remove root nodules and seeds, and regrowth of vegetation occurred the next spring.

Water Level Control

With approach of the spring season renewed activity is aimed at increased production of zooplankton in the muskellunge rearing ponds. Zooplankton culture ponds are first refilled with water as soon as the ice leaves the water source, usually about April 16. The standing water in the culture ponds is fertilized once a week with applications of Torula yeast. Although the waters are cold (40° F.) the *Daphnia pulex* which developed from the ephippial eggs produced the previous fall can be

TABLE 3

Summary of Methods Used for Control of Aquatic Vegetation in Northern Ponds

Vegetation	Control Measures
Filamentous algae *Spirogyra Spreeiana* *Spirogyra maxima* Other filamentous forms	1. Partial control with 50 pounds per acre foot Torula yeast application. 2. Local application of 100 cc. Delrad 50 (solution in water) per 0.2 to 1.0 acre of pond surface as needed. 3. Application of 0.2 to 0.3 ppm. Delrad to entire pond when muskellunge are larger than 4 inches. (Usually not necessary).
Submerged vegetation *Eleocharis acicularis* *Potamogeton* *Elodea*	1. Dry pond bottom: spray application Atlas "A" (4 lbs./gal. As_2O_3) at 40 gallons per acre before final freeze-up. 2. Dry pond bottom; spray application of Penite 6 (9.5 lbs./gal. A_2O_3) at 17 gallons per acre. 3. Filled pond: 4 ppm. sodium arsenite (As_2O_3) when muskellunge are larger than 4 inches. (Usually not necessary).
Emergent vegetation Water lilies Water shield	1. 0.25 per cent 2,4-D oil spray applied to leaves. 2. Repeat cutting of vegetation.
Marginal vegetation Cattails Willow Sedges	1. Dowpon spray application to foliage at rate of 5 to 20 pounds per acre. Cattail control most effective before the spikes mature. 2. Repeated cuttings of vegetation.
Floating vegetation Duck weeds	1. 0.25 per cent 2,4-D spray application to foliage. 2. Physical removal with seine or dip nets.

found within one week. Within two weeks the numbers of *Daphnia* are usually sufficient to permit successful transfers to the muskellunge rearing ponds.

The rearing ponds are refilled with water the same date that the first muskellunge eggs are taken. This provides an automatic time interval that insures that the ponds are not filled too early with the result that appearance of non-desirable filamentous algae, rooted aquatic vegetation and predator insect larvae is retarded without adverse effects on zooplankton production. Events that occur in ponds filled at an early date correlated with water temperature as registered by a recording thermometer are listed in Figure 1.

It is important that ponds be maintained at full water level in the early spring season to assure a constant warming water-temperature trend that favors increased zooplankton production. Data obtained from recording thermometers indicate that deep ponds of 4 feet or more average depth have less fluctuations in temperature than shallow ponds of two-foot depths. Zooplankton counts have indicated that constant temperatures result in greater zooplankton production than do rapid daily fluctuations. These findings agree with those of Schlaeperclaus (1933) who stated that shallow areas fluctuate readily in temperature with somewhat adverse results on production.

Fertilization

The hatchery rearing ponds are fertilized, without regard to natural fertilities, as soon as they are filled with water. Ponds up to one acre with water depths of 3 to 4 feet are fertilized with one-half gram Torula yeast (*Torula candida*) and one-fourth gram commercial 10–10–10 fertilizer per cubic foot of water. For practical purposes this is 50 pounds yeast and 25 pounds 10–10–10 per acre foot. The yeast provides an immediately available food that is directly assimilated by the zooplankton and promotes bacterial growth that also provides food for the zooplankton. The commercial fertilizer produces a mild blue-green algae bloom as the season advances that serves as additional food for the zooplankton. Commercial fertilizers of differing compositions can be used.

Ponds larger than one acre are usually fertilized at one-fourth the above rate to reduce costs. The fertilization of large ponds with a higher rate generally does not result in high muskellunge production because of the impossibility of adequately distributing the large amounts of fertilizer.

Several weeks to one month after muskellunge fry and forage fishes have been introduced into ponds, a special phenomenon may sometimes occur that is easily recognized by the caretaker in charge of cleaning the outlet screens. The screen may become clogged with mature *Daphnia pulex* that contain the large, black ephippial eggs. Formation of ephippial eggs at this early date is a result of adverse conditions in the ponds that signals the approaching demise of the zooplankton population unless pond conditions can again be made favorable. Shortage of available food is one of the more important factors among the many complex situations that may be responsible for formation of the ephippial eggs. An immediate resumption of the fertilization with Torula yeast at reduced rates usually retards ephippial egg formation and results in a renewed zooplankton pulse. Intermittent fertilization may successfully delay ephippia formation over several crises until other factors such as high (85° F.) water temperatures cause completely adverse conditions.

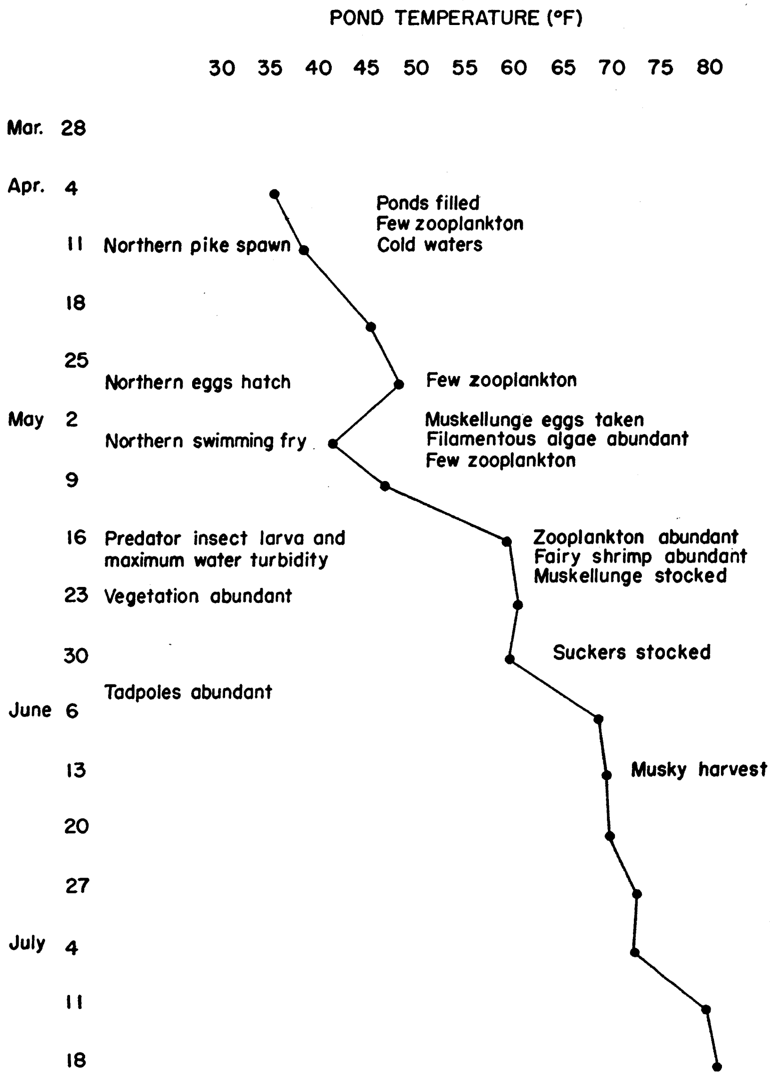


Figure 1. Sequence of events in Spooner muskellunge ponds, 1954.

In both large and small ponds the fertilizers are broadcast dry over the surface of the waters to create a suspension of the organic materials. The hatchery ponds are fertilized with three equal weekly applications of Torula yeast before the muskellunge fry are introduced. Fertilization is reduced to one-half the weekly rate after the fry are stocked to alleviate any possibility of oxygen depletion and subsequent fish mortality due to the high oxygen demand of the yeast. Use of commercial fertilizer is usually discontinued after the first three applications.

Control of Filamentous Algae

It is important to eliminate or reduce filamentous algae in ponds for several reasons. Filamentous algae remove soluble materials from the waters to the extent that the water becomes crystal clear and non-productive. Algal filaments tend to clog outlet screens, thereby creating a problem of cleaning them and maintaining constant pond water levels. Algal mats create alkaline values in excess of pH 11 that causes distress among the muskellunge and forage fingerling fishes that enter the vicinity of the filaments. Filamentous algae produce gas bubbles during daylight hours that lodge among the filaments, thereby causing the filamentous mats to rise and mechanically entrap small fishes at the pond surface where they die.

Fortunately the method of fertilizing ponds with Torula yeast provides a partial control for filamentous algae in addition to its unique direct food effect that favors zooplankton production. Jackson (1949) noted that filamentous algae did not appear in tanks fertilized with the wood yeast or with a combination of yeast and commercial fertilizers, but did appear in the tanks that were fertilized with only the commercial fertilizers or that remained unfertilized. Torula yeast used as a fertilizer in laboratory aquaria at Spooner, and in rearing ponds during each of four consecutive years, displayed an inhibiting effect on filamentous algae that was obvious from the gross appearance of the ponds and waters. Unfertilized ponds became choked with filamentous algae usually within two or three weeks after they were filled with water. Two filamentous algal forms that are inhibited by the yeast were identified as *Spirogyra Spreeiana* (Rabenhorst) and *Spirogyra maxima* (Hass).

The inhibition effect of the Torula wood yeast on filamentous algae is not complete, and some filamentous algae appears in yeast-fertilized ponds. Filamentous algae are usually noticed first near the water inlets where there is a constant dilution of the pond water. As the yeast applications are reduced or discontinued, filamentous algae may be seen in other areas of the ponds, possibly also a result of dilution by the incoming waters. Application of large amounts of commercial fertilizers also introduces factors that tend to overcome the inhibiting effects.

The manner in which *Torula candida* exerts an inhibiting action on filamentous algae cannot be explained on the basis of data obtained in these studies. Triple-washed yeast exerts the inhibiting effect as well as the more impure commercial grades. Live *Torula candida* applied to a walleye rearing pond at Woodruff exhibited similar action. Toranil, the ligno-sulfonic acids found as an impurity in the commercial-grade wood yeast, does not inhibit filamentous algae when used at over twenty times the concentrations that are ordinarily added to the ponds. Wood yeast, applied to settle immediately upon the bottom without mixing with the pond waters, does not exert an inhibiting effect.

The algicide Delrad (a technical grade of dehydroabietylamine acetate) can be used to eradicate filamentous algae. Delrad is manufactured by the Hercules Powder Company and is available in two forms. Delrad 70 is a paste-like material that contains 70 per cent active ingredient. Delrad 50 is a solution that contains 50 per cent active ingredient. Application of the Delrad 50 solution provides the most convenient method that can be used without danger to the zooplankton, muskellunge and forage fish.

About 100 cc. of Delrad 50 is added to 3 gallons of water in a bucket and the mixed solution is sprayed over the algal mats with a hand dipper or portable spray equipment. The recommended rate of 100 cc. Delrad 50 will safely spot-treat pond areas from 0.2 to 1.0 acres. Filamentous algae is killed within several hours after a single application. Additional treatments on two or three consecutive days per week can be made without hazard if it is found that certain areas have been missed. The quantity of Delrad used in muskellunge ponds is less than that recommended by Lawrence (1954) for *Pithophora* in southeastern state ponds because it was found that a 0.5 ppm. concentration is toxic to muskellunge fingerlings.

SPAWNING OPERATIONS

Exploratory nets are set in lakes to locate the earliest spawning muskellunge. Early procurement of eggs in the cold northern climate in effect tends to lengthen the growing season for the fish produced. Nets have been set as early as April 16 and as late as May 10 dependent upon the weather. Warming water temperatures along the shores and particularly in the mud bays tend to concentrate the spawners so that more of them are caught in the nets. The rising temperature determines the time that spawning takes place. The first muskellunge are taken in

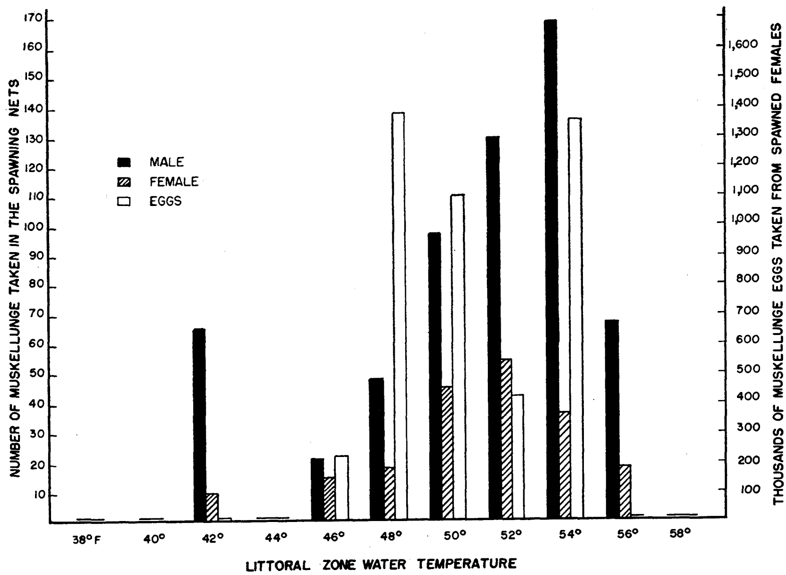


Figure 2. Most of the muskellunge and eggs are taken when the water temperatures of the littoral zones range from 48° F. to 56° F. Empirical data are based on fish collections from equal netting effort.

the nets when the waters reach 42° F. Almost all of the first fish caught are males. When the water reaches 46° F. very early eggs may be stripped from some females. The greatest numbers of muskellunge with easily taken ripe eggs which have the highest percentage hatch are taken when the waters range from 48° to 56° F. (Fig. 2). Similar correlation between spawning and temperature was reported for northern pike by Svärdson (1947). He said that spawning intensity is correlated with the temperature of the littoral water, but not with temperature in deeper portions of the lake. At the height of the season, adult muskellunge may be observed spawning naturally in the warm waters along the shores.

Muskellunge eggs may usually be taken for ten days, depending upon weather conditions. If the weather turns cold so that the water temperatures go below 50° F., the adult females move off the spawning beds into the deeper lake and usually can no longer be captured in the fyke nets. Occasionally the muskellunge return again to the spawning area under stimulus of warming waters but such returns are erratic and attempts to make further captures are uneconomical. If a run is missed it may be necessary to reset the fyke nets in another colder lake to catch the spawning run as the waters warm at the new location.

Fyke nets are placed in early muskellunge lakes to capture the adult muskellunge that furnish the eggs for rearing-pond operations. Nets are lifted each day, checked and reset. Perch, panfish and other species of fish are removed and returned to the waters.

Phenological events point to the spawning time of muskellunge in lakes. The various fish species spawn in turn as the waters warm. For example, northern pike spawn nearly the same time that the ice leaves the lake, at water temperatures that range from 40° to 46° F. Walleye spawn next at water temperatures of about 45° to 50° F. Perch spawn toward the end of the walleye run, and usually continue after the walleye are through. The muskellunge are next in spawning order in waters of 48° to 56° F. As the water temperature continues to rise other species important as forage begin spawning.

The large proportion of male muskellunge generally found in lakes is an advantageous situation because as many as six males may be needed to produce sufficient milt for the eggs from a single female. Lakes that contain predominantly large-sized female muskellunge enable the spawn-takers to obtain the required eggs from relatively few fish, since one large female will often produce up to four quarts of eggs. Exceptionally large female muskellunge over 50 inches in length, however, usually release eggs of inferior hatch potential. The large muskellunge are difficult to spawn because the spawn-takers must exert more strength and care in handling the large thrashing fish.

Muskellunge that produce large eggs are preferred to those that produce small eggs. Large eggs with a greater store of food materials in the yolk sac produce larger, stronger fry that have a better chance for survival. These findings are in accord with a generalization made by Svärdson (1949) that the larvae hatched from the largest eggs have the best chances for survival. Large fry have a head start into the growing season, and therefore a greater growth potential. Conversely, small fry from small eggs seldom catch up to their larger brothers and may fall prey more often to predator insect larvae as well as to the larger cannibalistic muskellunge. Size of water-hardened muskellunge eggs may range from 0.130 inch to 0.100 inch diameter which is 30,801 to 67,670 eggs per liquid quart respectively according to Von Bayer's tables (Lagler, 1952).

The relationship of muskellunge egg size to the parent is variable. There is a tendency for large muskellunge spawned from natural waters to produce large eggs, but many small muskellunge produce equal-sized and larger eggs than some of the larger fish. There is also a tendency for production of small eggs by all sizes of muskellunge in some individual lakes. Spider Lake, Sawyer County is an example of a lake in which all of the muskellunge produce small-sized eggs. The eggs range in number from 55,000 to 67,000 per quart. The average for Spider Lake is 58,000 eggs per quart. All muskellunge in Big Lac Court O'Reilles, Sawyer County produce large-sized eggs that range from 30,000 to 55,000 with an average of 47,000 eggs per quart. Hoar (1957) described a similar occurrence among Sockeye salmon (*Oncorhynchus nerka*) that produced small eggs in one lake and large eggs in another lake of the same river system. The factors such as genetics, cold water with inadequate forage supply, the age of the muskellunge, and other factors that might influence the size of the eggs are problems that merit further study.

Pond production efficiency is improved when all of the muskellunge eggs are taken during a short time interval of several days to one week. Such muskellunge will hatch out within the same or shorter time and allow all of the ponds to be planted within several days. Procurement of eggs quickly reduces the cost of the spawning operation and provides that all ponds receive muskellunge fry of near equal age and of similar size.

Differing sizes of muskellunge fry leads to eventual cannibalism. An early muskellunge plant also assures that the fry can be stocked in the rearing ponds ahead of the suckers and other forage fishes.

Female muskellunge are checked at the netting site to determine if eggs will flow freely from the vent. The fish is released if it is hard, which means the eggs would come with difficulty, or if it is soft and flabby, with the eggs already spawned out. Ripe females are retained in a large tank carried in the boat and occasionally are replaced in the nets until the next day if sufficient numbers of males are not available. Females with unripe eggs are not held over in the spawning nets from day to day because eggs apparently do not ripen when the muskellunge are confined to small quarters. Muskellunge held in fyke nets longer than 24 hours show evidence of the confinement by the scarred condition of the flesh that develops as a result of abrasions from contact with the webbing and other fishes. Use of hormone injections to speed the egg ripening process (Hasler, Meyer and Field, 1940) has proved impractical over the short intervals that muskellunge can be confined in the fyke nets.

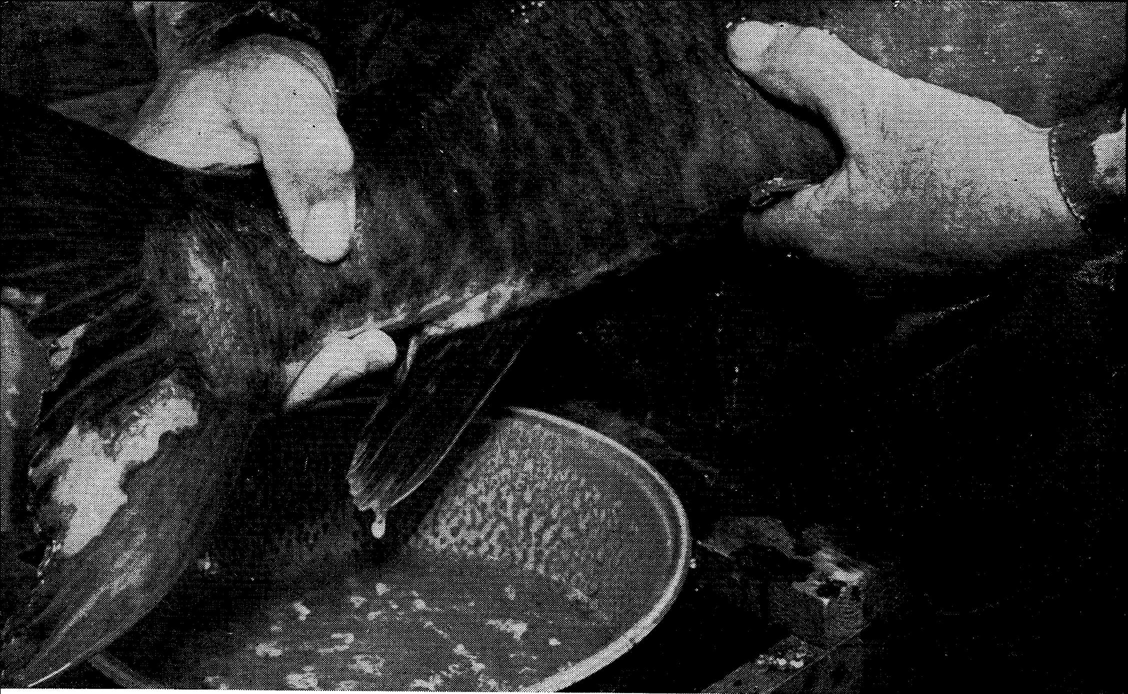
The artificial spawning of the muskellunge is accomplished by the spawn-taker with the assistance of a helper. The females and males are placed together in a large tank in the boat and taken to shore for the actual spawn-taking. A small porcelain pan is rinsed in the lake water and placed on a small stand that holds the pan in position without spilling eggs, even though the muskellunge may thrash. The spawner and helper lift the female from the tank and hold the muskellunge in position over the dry pan for the stripping process. Muskellunge spawn-taking is very similar to the process employed in trout hatcheries for taking trout eggs. Care is taken that broken eggs or bloody masses are not mixed with the eggs because these foreign materials appear to interfere with successful fertilization. If a muskellunge has more available eggs than the pan can hold, the female is placed back in the tank until there is time to take more eggs.

Male muskellunge produce only small quantities of milt, on the order of 0.2 to 0.3 cc., which is usually measured by the number of drops. Several males are used to minimize the failure to impregnate eggs due to the use of an impotent male. The ratio of sexes has been 61 per cent males to 39 per cent females, in Wisconsin lakes. The eggs and milt are stirred with the fingers to assure adequate mixing and are washed immediately with lake water. The lake water activates the sperm and fertilization occurs. An experienced spawning crew performs the stripping and fertilization of muskellunge eggs in about three

Female muskellunge are checked at the net site to determine when the eggs may be freely spawned. If the eggs cannot be easily taken, the muskellunge are released. Ripe muskellunge are retained in a large tank carried in the boat.

↑ The spawn-taker has a helper to assist him in handling the large muskellunge so that the eggs may be easily taken with no injury to the fish.

The kneading action used to release the eggs from the muskellunge is clearly illustrated. Eggs are stripped into a dry pan and several pans may be filled. One large female may release up to four quarts of eggs. →



Male muskellunge usually produce very small quantities of milt. Milt from several males is used to prevent the possibility of non-fertilization of eggs, through use of an impotent buck. The milt is stirred into the eggs with the fingers to assure adequate mixing. The eggs are then washed with lake water, the sperm is activated and fertilization takes place.

The stripping, fertilization of the eggs, and washing of milt from the muskellunge eggs requires about six minutes. Washed eggs are then immediately poured on floating screen trays in a tub of water and allowed to expand or water-harden without disturbance for at least 15 minutes.

minutes. Another three minutes are required to wash the milt from the eggs. Washed eggs are immediately poured on floating screen trays in a tub of lake water to expand and water-harden without disturbance for at least fifteen minutes. Twenty minutes to six hours later the egg screens are bundled together in an angle iron case, submerged in a tank of fresh lake water on a truck, and transported to the hatchery.

An essential of the spawning technique is the speed required to eliminate any disturbance to the muskellunge eggs during a critical 9- to 15-minute interval after the eggs are stripped. The need for careful handling was suggested by fragility tests conducted on muskellunge eggs in 1953. The results of a total of 3,900 egg-bursting trials show that musky eggs pass through a critical period of fragility when they may be easily injured (Table 5). After the critical fifteen minutes, the eggs become progressively more resistant to crushing and can support a 135-gram weight after 24 hours. Comparable figures for fragility of muskellunge eggs were reported by Roussow (1953).

The use of anesthesia to immobilize muskellunge has been investigated as possible aid to the spawn-takers and to the fish during the spawn-taking process. Urethane anesthesia for taking brook trout eggs described by Johnson (1954b) has been used on muskellunge with no injury to the eggs or to the adult muskellunge up through 30 pounds.

TABLE 5

Fragility Tests on Muskellunge Eggs (Based on 3,900 Egg-Bursting Trials)

Length of Time After Stripping	Condition of Eggs
0–3 minutes	Time required to take and fertilize eggs
3–6 minutes	Additional time required to wash eggs
6–9 minutes	Eggs broken when subjected to 8.3-gram weight
9–15 minutes	Critical period; fragile eggs easily broken with 5.8-gram weight.
15-25 minutes	Eggs expanded (hardened); support 13.7-gram weight
1 hour	Eggs very hard; support 135-gram weight (85 per cent of trials).
After 24 hours	Eggs support 135-gram weight (74 per cent of trials).

However, there are disadvantages, and its use has been discontinued. Ten to fifteen minutes of anesthesia are required to quiet a large muskellunge. The spawn-taker is lulled into relaxed vigilance and an unexpected spasmodic jerk by an incompletely narcotized fish can result in a dropped, possibly injured musky and spilled eggs. Up to one-half hour is required for a large muskellunge to recover from anesthesia.

Twenty minutes to six hours later the muskellunge screens are bundled together in an angle iron case, submerged in a tank of fresh lake water on the truck, and transported to the hatchery.

Use of urethane has been discontinued for all fish anesthesia following reports of possible carcinogenic properties (Wood, 1956). Alternative anesthetics used successfully in handling muskellunge up through 13 inches in length include M.S. 222 (Tricaine methane sulfonate, 1 gram per gallon of water) or methyl pentynol (3-methyl-1-pentyn-3-ol, 15 cc. per gallon of water).

INCUBATION OF MUSKELLUNGE EGGS

Upon arrival at the hatchery the muskellunge eggs are measured volumetrically and introduced into four-quart hatching jars for incubation. Each jar is usually reserved for the eggs of an individual muskellunge provided there are enough eggs to insure their rolling freely in the moving waters. When there are too few eggs to be rolled, the eggs from several females are combined in one jar for incubation. The usual quantity is from 1½ to 2 quarts of eggs per hatchery jar. The number per quart is determined by counts of eggs in a six-inch Von Bayer counting trough and reference to a modified Von Bayer table (Table 6). The number of eggs per quart and for each individual muskellunge is recorded on the individual hatchery jars together with the date and the spawn-taker's name.

Temperatures that normally range through 50° to 70° F. bring on an 85 to 95 per cent hatch of muskellunge sac fry from the eggs within 21 to 13 days. Constant temperature in the upper part of the range cause the eggs to hatch more quickly and only six days incubation may be required at 68° F. Incubation at the higher temperatures appears to result in normal fry. Muskellunge eggs hatch more slowly at low temperatures and are subject to higher mortalities. The incubation of muskellunge eggs at 39° F. in aerated constant temperature baths

TABLE 6

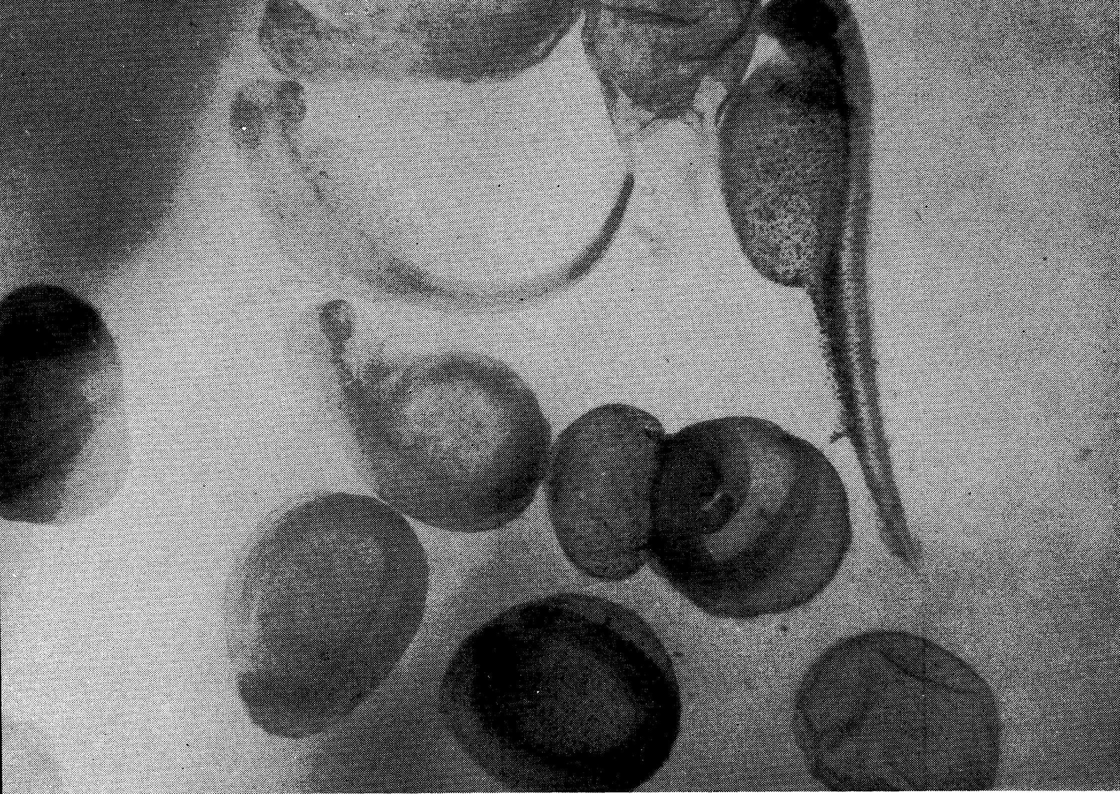
Chart for Measuring Muskellunge Eggs with a Six-Inch Metal Trough

Number of Eggs in Trough	Number of Eggs in Ounce	Number of Eggs in Quart	Number of Eggs in Trough	Number of Eggs in Ounce	Number of Eggs in Quart
45	899	28,764	54	1,546	49,480
46	963	30,801	55	1,633	52,254
47	1,008	32,268	56	1,726	55,239
48	1,083	34,647	57	1,827	58,456
49	1,165	37,265	58	1,935	61,925
50	1,224	39,161	59	2,052	65,680
51	1,287	41,186	60	2,115	67,670
52	1,390	44,494	61	2,247	71,899
53	1,466	46,899			

results in 100 per cent mortality by the end of 35 days. Muskellunge fry hatched and reared in below-normal water temperatures (48° to 50° F.) use up the yolk-sac food materials without an increase in size and develop into smaller, weakened fry that may not feed. In an early paper, Bean (1908) noted adverse effects of cold temperatures on muskellunge eggs.

Newly hatched muskellunge sac-fry are held in the jars for an additional 10 to 14 days until the yolk-sac is almost gone, and the fry have increased to the approximate 0.5-inch length of the "swim-up" stage. Retaining screens at the top of the hatching jars are removed and the muskellunge fry are allowed to swim up and out the jar overflow. The fry are caught and held in screen boxes in fresh circulating water as described by Oehmcke (1949).

Obvious advantages of holding sac fry in the hatchery until the swim-up stage are: (1) Swim-up fry are not subject to possible suffocation by oxygen depletion that can occur in the immediate waters surrounding sac fry at rest on bottom muds. Mortalities have been

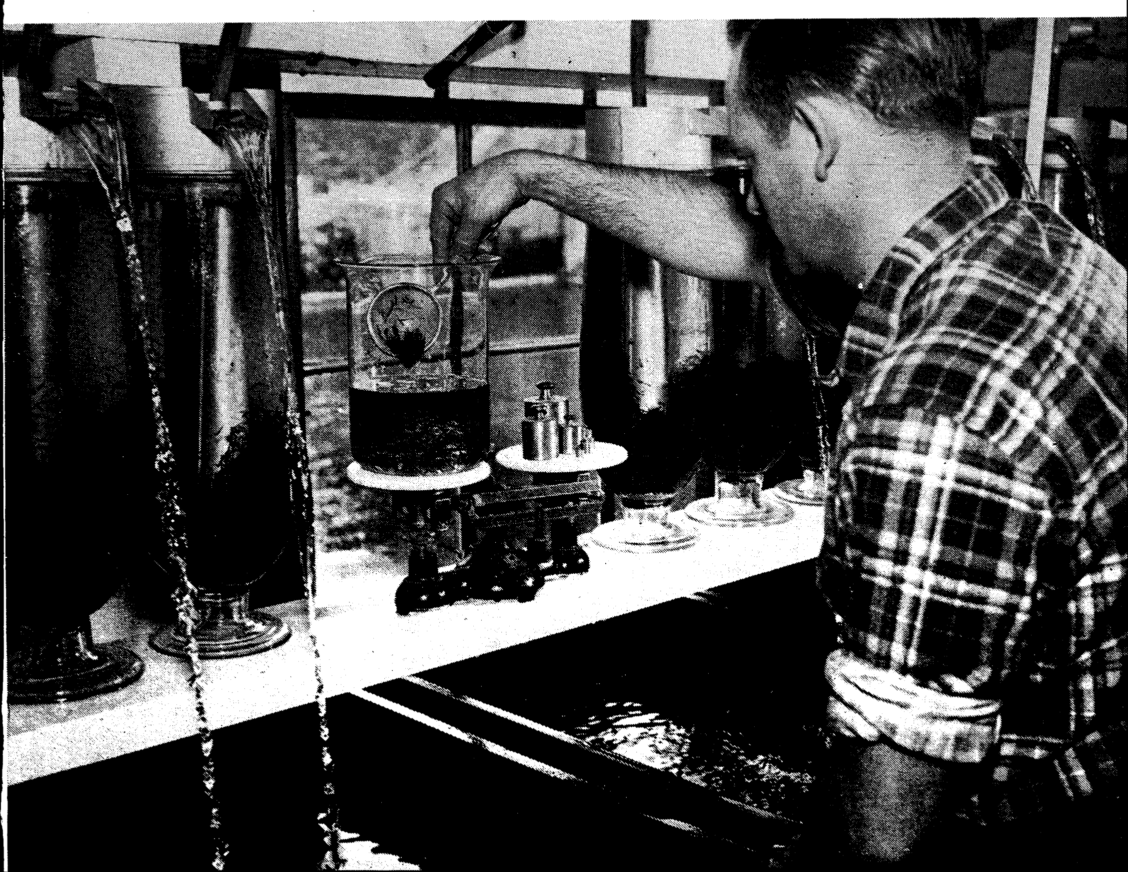


Thirteen to 21 days in the running waters of the hatchery jars at temperatures that range 50° F. through 70° F. are normally required to produce a hatch of the muskellunge sac fry. Warmer waters produce a more rapid hatch with a higher percentage of survival. Continued cold water temperatures below 55° F. tend to result in reduced survival.

observed among muskellunge sac fry on the bottom mud in algae-free standing water in experimental laboratory aquaria. Brundin (1951) described oxygen microstratification that occurs in waters in contact with bottom muds and ascribed low oxygen to the rich reducing substances in the muds. (2) Swim-up fry are less subject to predator insect larvae such as diving beetle, damsel fly and dragon fly larvae as well as to suffocation, and can be immediately seen in the ponds. Stocked sac-fry may not reappear until after six to ten days and usually never in abundant numbers. (3) Swim-up muskellunge begin to feed immediately on live forage zooplankton and may be considered the same physical-age fish even though they have originated from eggs spawned from muskellunge on different days. The same-age concept is convenient when rearing ponds are stocked because ponds may be selected and stocked with an entire quota of muskellunge on one day, consequently it is not necessary to wait over several days for a single lot of eggs to hatch for a pond. The same-age concept can be applied only when the original eggs are of similar size, so that the hatching fry will be of equal size.

On the other hand, there are inherent dangers in holding muskellunge sac fry to the swim-up stage. (1) Water circulation in the jars and screen boxes may be so great that the sac fry expend the energy stored in yolk-sac materials under stimulus of strong water currents. Over-worked fry developed from the sac stage may be 2 to 4 mm. shorter than normal fry and usually die within six to eight days after they are hatched at water temperatures of 68° F. Conversely muskellunge fry reared to swim-up stage in comparatively still water develop into larger fry than those subjected to forceful water agitation. (2) Below-normal water temperatures, lower than 55° F., constitute a threat to survival of the fry since the yolk-sac materials are used up without contributing to the growth. Fry undergoing extended periods of incubation (beyond 20 days) due to cold waters must be observed closely to determine the extent of absorption of the yolk-sac in order to anticipate mortalities among fry that may never swim up as long as the waters continue cold. (3) Improper circulation of water within

Muskellunge fry are kept in the hatchery jars until the yolk is almost used up and a swim-up fry stage is attained. The swim-up fry are allowed to pass out of the jar overflow into the screen boxes below. Swim-up fry are removed from the screen boxes when sufficient numbers have collected, and weighed on a gram balance. Swim-up fry are considered the same physical age although they may have originated from eggs taken on different days.



the holding screen boxes may cause the muskellunge fry to pile up in corners and subsequent mortality due to suffocation may occur. Screens must be maintained free of silt and debris that is brought in by spring season storms and a twenty-four hour watch is recommended during critical incubation periods.

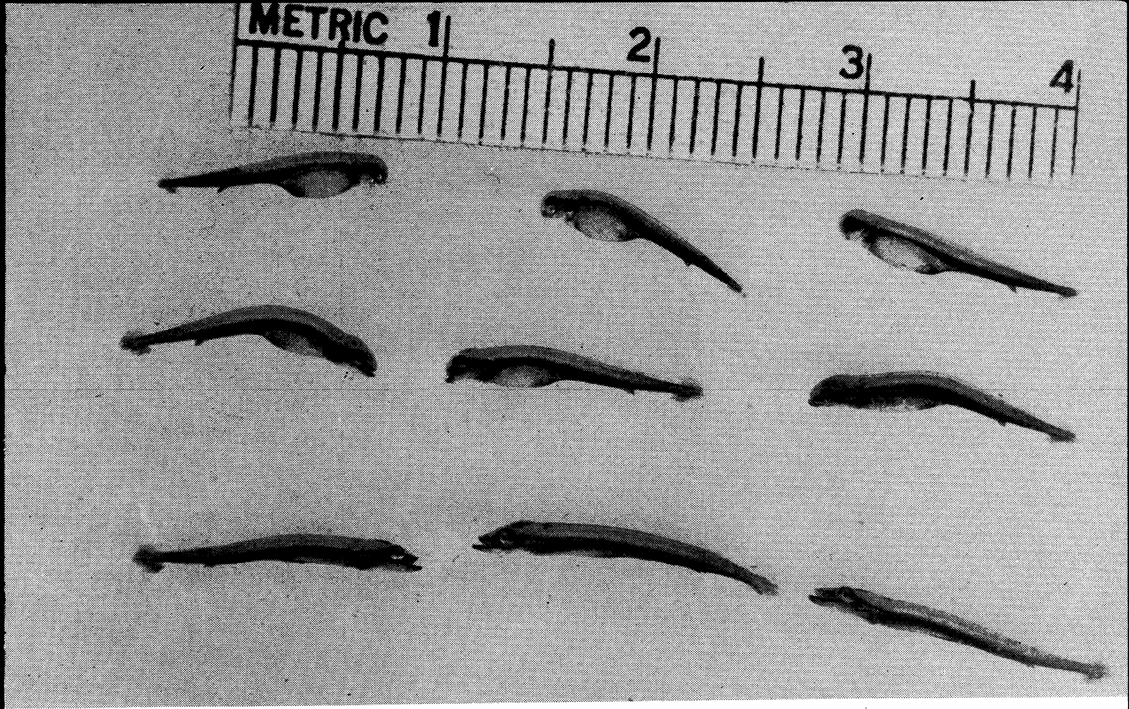
STOCKING SWIM-UP MUSKELLUNGE FRY

Muskellunge rearing ponds are stocked at the rate of 100,000 swim-up fry per acre (Oehmcke, 1949). Stocking rates of 150,000 to 200,000 muskellunge per acre have yielded as much as 30 per cent greater returns in harvest but the fish are about 1/3 smaller. Stocking rates of less than 100,000 require further studies. Rearing ponds are stocked with swim-up fry skimmed from the surface of the screen boxes with a fine bobbin netting or wire strainer and weighed on a gram balance to provide the established quota for each pond. Fry range in number from 40 to 50 fry per gram weight. Counts of weighed samples can be made as necessary to establish pond quotas. Swim-up fry are allowed to remain in the screen boxes for not longer than one or two days when adverse conditions arise that could cause a mortality. Swim-up fry are transported to the rearing ponds in any convenient container and are distributed around the edges.

Size of the yolk sac is used as a criterion to determine when fry should be stocked into ponds, particularly when it appears that the fry will not swim up because of an extended period of low water temperature. At temperatures of 68° F. fry can survive eight days from the swim-up stage without feeding and recover providing food is then supplied. Swim-up fry that live through eleven days of starvation at 68° F. are no longer capable of recovery.

Pond waters are maintained at constant levels, particularly during the first week following introduction of the muskellunge fry. The muskellunge hang within inches of the pond edge and can easily be stranded on the banks by sudden fluctuations.

The highest survival of muskellunge fry in ponds has been obtained from the introduction of the swim-up stage into the ponds. An experimental introduction of sac fry was tried on a large shallow submerged screen tray (3 in. deep, 3 ft. wide and 30 ft. long) to keep the yolk-sac stage from contact with bottom muds and possible suffocation. The transfer of the sac fry to the screens was not successful because the fry exerted nervous spurts of swimming energy that carried them out of the trays to rest on the pond bottom where many died. Sac fry seldom remained on the screen trays longer than six hours.

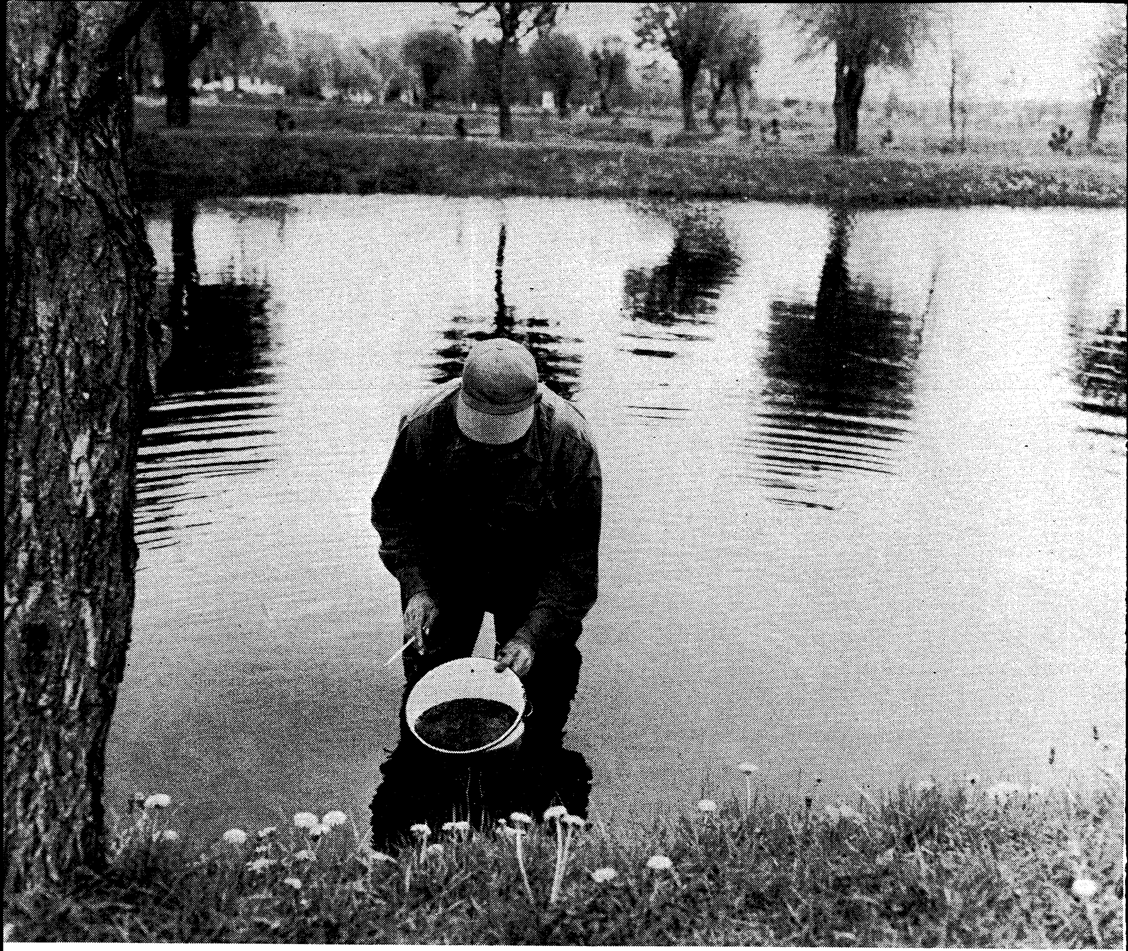


The size of the yolk sac is used as a criterion to determine when fry should be stocked in ponds, particularly when it appears that the fry will not swim up because of excessive cold waters (below 55° F. for extended periods). The top row of muskellunge development indicates the yolk-sac-fry stage prior to the swim-up stage. The second row indicates swim-up fry development when the muskellunge may be properly stocked in ponds. The third row shows excessive yolk-sac absorption that will probably result in mortality of the fry placed in the ponds.

Properly timed stocking of muskellunge swim-up fry in rearing ponds is important to their survival. Introduction of fry into ponds where the zooplankton have passed the peak population density results in reduced forage and muskellunge starvation. A declining zooplankton population is evident when ephippial eggs begin to appear. The over-grazing effect of the many introduced fry on a rising zooplankton pulse may sometimes decimate the zooplankton population before it attains the peak with resultant starvation and fry mortality. Water temperatures of over 85° F. can also cause a sudden zooplankton mortality in ponds that will reduce the forage and have a detrimental effect on pond productivity.

STOCKING OF FORAGE FISHES

Ideal pond conditions for the rearing of muskellunge describes a condition where there is abundant live forage of edible size available to the muskellunge on a continuous basis. Zooplankton, namely *Daphnia pulex* populations, are produced in the ponds to provide the initial food. As the muskellunge grow in size, they prefer larger food



Muskellunge swim-up fry are transported to the hatchery ponds in any convenient container. The swimming fry are distributed around the pond edges where they begin to feed almost immediately.

items in their diet. Sucker fry are introduced to meet this larger-sized food preference and to bridge the food gap between the zooplankton and the naturally spawned forage fishes that are produced later. Properly timed introductions allow some of the suckers to continue growth and provide muskellunge forage throughout the growing season.

Sucker Fry

The sucker eggs hatch over a period of several weeks, some of them at the same time or slightly before the muskellunge. The early sucker fry are stocked in outlying rearing ponds at the rate of 100,000 to 1,000,000 per acre. These are intended as forage for the larger muskellunge that will be transferred later from the hatchery ponds. Muskellunge fingerling about 2 inches in length are transferred to the outlying ponds about three weeks after the suckers are introduced.

Sucker fry hatched later than those stocked in the outlying ponds are stocked in the hatchery muskellunge rearing ponds. The stocking rate in hatchery rearing ponds is 50 or more sucker fry per muskellunge, which is 500,000 to 1,000,000 suckers per acre. The ratio of eggs incubated in the hatchery is about 2,000 to 3,000 quarts of sucker eggs to 35 to 40 quarts of muskellunge eggs.

Sucker fry are stocked in ponds over as many days or weeks as the hatch can be delayed in the hatchery. The first fry are not intended as starting forage for the muskellunge but rather as a food supply for later consumption. The later plants are intended as immediate forage for muskellunge that have outgrown their "taste" for the now too small zooplankton and require a more substantial diet.

The stocking of sucker fry occurs four to eight days later than that of the muskellunge swim-up fry to minimize competition for the same food source. When the suckers are introduced first or on the same day as the muskellunge the more numerous suckers rapidly deplete the zooplankton population. Table 7 shows the yield of muskellunge obtained from rearing ponds stocked with: (1) Suckers first (2) Muskellunge first, and (3) Muskellunge and suckers stocked on the same day. A later stocking of sucker fry is also desirable because suckers have a greater initial growth rate than the muskellunge, which is most readily apparent in the large head, and are not easily swallowed by the muskellunge. Some early suckers in hatchery ponds grow so fast that they are never available forage. An early theory that sucker fry might be stocked in rearing ponds on the same day if greater quantities of zooplankton were present was invalidated by the fact that the great initial growth of the sucker made it unavailable as a source of food for the muskellunge.

Mortalities may occur among sucker fry from several causes. Fry held in the hatchery until the yolk sac is absorbed may die of starvation, since no food is provided in the holding tanks. Starvation may occur in ponds stocked with high numbers of fry that strip the pond of zooplankton. Predaceous insect larvae may kill both suckers and muskellunge. Muskellunge remove suckers by predation and by inefficient strikes that cripple. Crippled and dead forage fishes are not eaten by the muskellunge. High water temperatures above 85° F. may cause a sucker mortality. Forage mortalities tend to result in less food and lowered muskellunge production.

Torula yeast may be applied to provide a direct food supplement in circumstances where ponds are overstocked with fish. Sucker fry are particle feeders that will eat yeast particles and thereby relieve some

TABLE 7

The Production of Muskellunge Ponds in Relation to the Time That Sucker Forage Fry Are Introduced

Planting Procedure	Number of Ponds Used	Total Acres	Muskellunge Production	
			Per Acre	Per Cent of Total
Muskellunge planted first	5	3.45	14,674	67
Muskellunge and suckers planted on same day	7	11.46	2,147	33
Suckers planted first	3	1.21	182	--

of the predation upon the zooplankton. Predation on zooplankton is also alleviated as the suckers grow larger and feed less on zooplankton and more on bottom materials. Torula yeast, red dog flour, soybean meal, cotton seed meal, and tendipedid larvae are foods that may be utilized by the larger suckers.

Fuel oil may be sprayed over the ponds to create a film surface of oil (Oehmcke, 1949) that will eradicate the *Dytiscus* larvae that are probably the most damaging predators to suckers as well as muskellunge. Minimum quantities of oil are needed when application is made during calm weather. Four gallons of Number 2 fuel oil generally serve to cover one acre of pond surface. Action of the oil is toxic to surface breathing insect larvae, but has no effect on fish or zooplankton.

As previously stated temperatures above 85° F. are a cause of sucker mortality. Shade trees and fresh water inflow help to cool the ponds. Muskellunge fry and fingerling are more resistant to the effects of high water temperature than suckers and have been observed feeding at 85° F. and above while suckers were dying. Muskellunge have safely tolerated 90° F. for 24 hours in constant-temperature laboratory aquaria, although their feeding activity was reduced. High water temperatures affect muskellunge survival and growth indirectly by reducing the food supply.

Other Forage Species

The hatchery ponds are in effect initially overstocked to insure sufficient production of muskellunge fingerlings for transfer to outlying ponds and to obtain full utilization of the hatchery ponds as well. As a result, the zooplankton and forage fish supply is overgrazed and reduced to less than sustenance values, usually within two months.

Continuing harvests or cropping of small muskellunge throughout the season serve to reduce the feeding pressure and lengthen the time adequate food is available. Many factors, however, operate to deplete the forage in ponds to an extent that recovery may not take place within the same season. The zooplankton disappears and remaining sucker fingerlings are often too large to be utilized by the muskellunge. An attempt is made to alleviate the food deficiency by direct feeding with live forage hauled to the rearing ponds from outside sources.

Ponds leased from farmers, and lakes and streams in the vicinity of the hatchery, provide the supplementary forage. Minnows are trapped or seined and hauled to the hatchery rearing ponds. The main objective is to provide forage small enough in girth to be eaten by the muskellunge. The forage fish consumed may be almost as long as the muskellunge, and in fact, muskellunge may eat muskellunge.

The fathead minnow is a desirable forage species, but other forage may be introduced because the requirements for a summer stocking are not as strict as those specified for brood minnows stocked during winter months in the outlying ponds. The Woodruff hatchery utilizes perch (*Perca flavescens*) fingerlings for muskellunge forage because they are of small enough size. Perch fingerlings are not used at Spooner because perch grow too large during the earlier and longer growing season. Other fish that have proven satisfactory as forage are brook stickleback (*Eucalia inconstans*), bluegill fingerlings (*Lepomis m. macrochirus),* lake emerald shiners *(Notropis atherinoides acutus).* Minnows that are able to reproduce in the ponds are also desirable.

Undesirable forage forms are black crappie fingerlings (*Pomoxis nigromaculatus*) and northern pike fingerlings (*Esox lucius*) because they grow too large to be swallowed by the muskellunge and because they are predaceous.

A low forage supply in rearing ponds is indicated when the species provided cannot easily be detected by visual inspection and when muskellunge crowd into the inlet water bulkheads. Muskellunge that appear in the inlets are hungry and cannibalistic. They must then be trapped and removed from the ponds or be dispersed by introduction of forage. Three to four hundred pounds of minnows per day may be required for distribution to certain ponds.

The great expense of securing and hauling supplementary forage is the chief disadvantage in this phase of muskellunge culture. In addition it is often impossible to obtain forage fast enough to prevent cannibalism and often unavoidable wastes of forage occur as a result of mortality through handling.

The natural forage supplies of a hatchery rearing pond are usually depleted within about two months. Additional forage is supplied from farm ponds, lakes and streams to supply the increasing demands. Minnow traps are often used to secure this additional forage. Almost any forage will do during the summer season, such as fathead minnows, bluegill fingerlings, brook stickleback and others. The main requirements are that the forage must be alive and of small enough diameter so the muskellunge can swallow it.

Natural chronological provision of food of the correct size for muskellunge from fry to fingerling stages is another approach which should be considered for all types of muskellunge culture. The food sequence based on experiments conducted for five years would probably be as follows: (1) Zooplankton, (2) Sucker fry, (3) Naturally spawned bluegill fry, and (4) Naturally spawned fathead minnow fry. The sequence differs from methods under discussion by the introduction of adult spawning bluegills to the rearing ponds. The bluegill fry would help to fill one of the gaps in the sequence that sometimes results in muskellunge starvation and low survival. Mixed fish forage populations, however, are difficult to control and require further studies to assure successful continuous forage.

HARVEST OF PONDS

Initial Harvest and Transfer

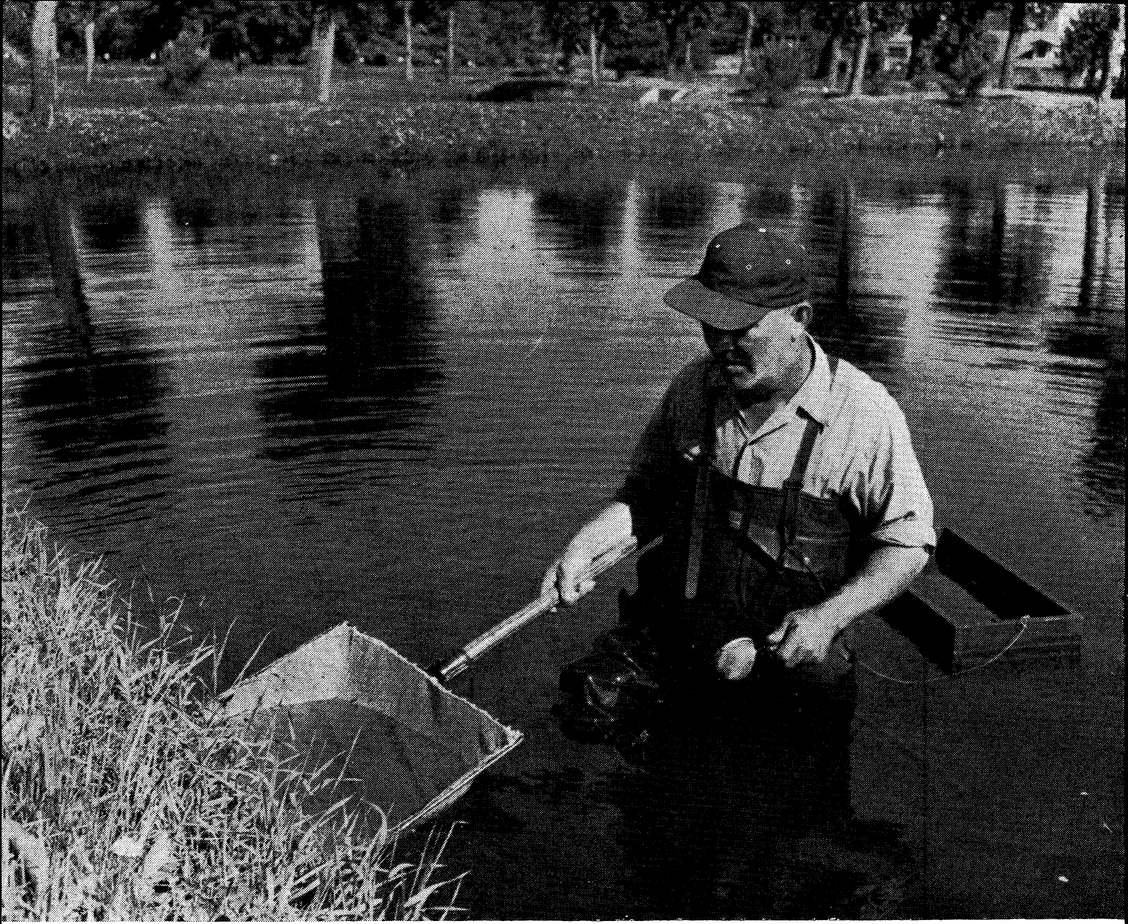
The harvest of muskellunge is begun when the fingerlinges reach a length of $1\frac{1}{2}$ to 2 inches, usually within two to three weeks after the swimming fry are stocked in the rearing ponds. The first harvest is continued over about six weeks to reduce the number of muskellunge in the ponds, and thereby extend the food supply for those remaining. Many of the fish harvested initially are stocked in lakes in accordance with established planting quotas. Remaining muskellunge fingerlings are transferred to outlying rearing ponds that have by then attained an optimum forage fish population. Transfer of relatively small numbers of muskellunge to the forage supply is a new concept that differs from the common practice of hauling large quantities of forage to the muskellunge and probably represents more economical procedure. Outlying ponds with abundant forage have the further advantage of providing enough space to isolate the individual muskellunge which gives him less chance to become cannibalistic.

Early muskellunge are harvested from rearing ponds by means of fine-meshed dip nets. Muskellunge fingerlings at this stage tend to lie close to the water surface often within two or three inches from the pond banks, beneath cover afforded by the long overhanging grasses. Personnel wading in the ponds with the long handled dip nets make short blind sweeps along the shore edges to capture a dozen or more muskellunge at a time which are counted into floating screen boxes.

Larger muskellunge are harvested by means of wire-mesh traps placed in or near inlet bulkheads. As the muskellunge grow, from $2\frac{1}{2}$ to 5 inches, the forage becomes more difficult to find and the fish range more extensively about the pond seeking food. Movement is toward the water currents, a positive rheotropism that results in an eventual concentration of the muskellunge in the faster moving waters of the inlet bulkheads. When forage is abundant the roaming tendency is not apparent.

A sample of weights and measurements is taken of all muskellunge harvested and recorded for each individual pond. The muskellunge are transferred to the outlying ponds and lakes with pick-up trucks carrying small water tanks and oxygenation equipment.

Survival through the first six weeks of growth has been as high as 70 per cent, but usually averages between 30 and 40 per cent. However, survival of less than one per cent, due specifically to low zooplankton production, has been recorded.



The young muskellunge fingerling tend to lie close to the water surface, within two or three inches from the pond banks. The first harvests are made with a long-handled dip net with short blind sweeps into the water beneath the overhanging grasses. Later harvests of muskellunge are made with wire traps placed in or near inlet bulkheads.

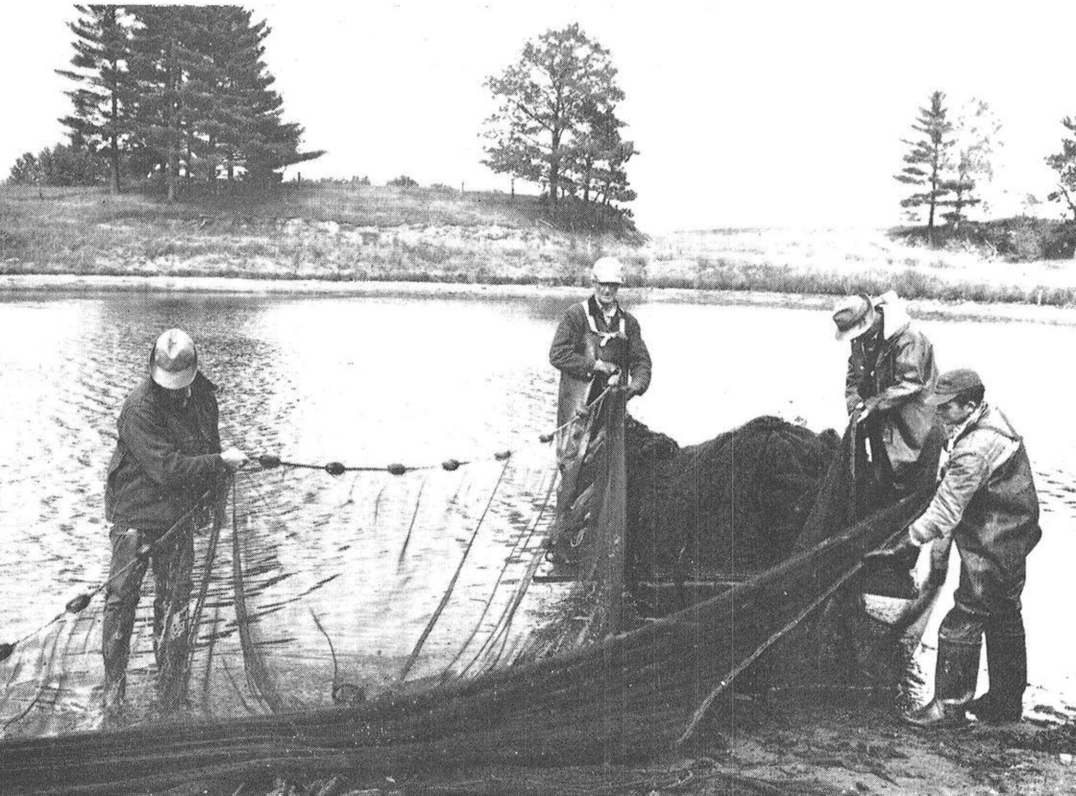
Final Harvest

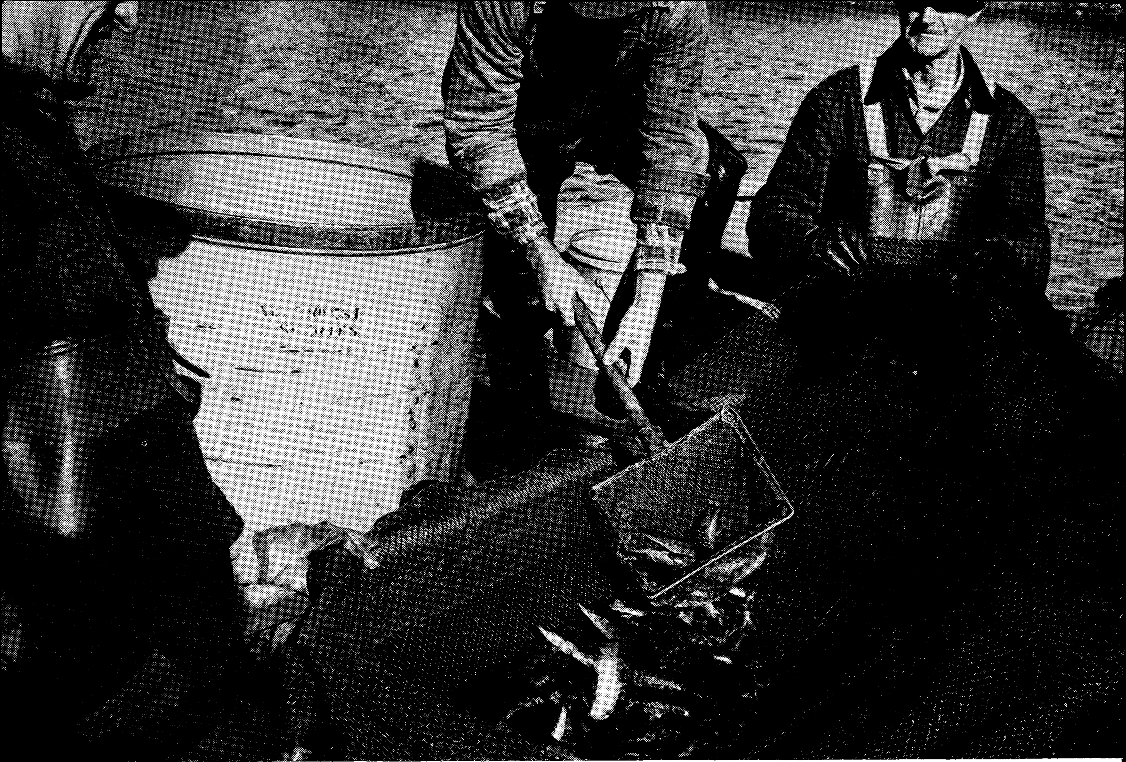
The hatchery rearing ponds and outlying ponds with controllable outlets are drained beginning mid-September and extending through October to facilitate the final harvest of muskellunge. At this time pond waters at approximately 60° F. are sufficiently cool to permit handling of the muskellunge without significant mortality and the weather is still pleasant enough to provide good working conditions for the harvest crew. Small ponds of less than one acre are drained in a single day and the muskellunge removed with dip nets. Large ponds 6 to 42 acres in size are drained over a period of one to three weeks to allow the muskellunge to follow the receding waters and escape entrapment in shallow pocket areas. When the waters have receded into the drainage basin, the muskellunge are harvested by means of seines of variable length, depending upon the area to be covered.

The natural farm ponds used for muskellunge production cannot be drained for final harvest. Such ponds were originally selected because they are free of weeds, filamentous algae, heavy bottom muds, stumps, and other debris and hence can be easily seined. Seines from 600 to 1200 feet in length are swept across an entire pond for very efficient capture of muskellunge. Experimental second and third seine hauls have usually yielded fewer than a dozen muskellunge. The use of a small gasoline-powered winch facilitates harvest from ponds over 3 acres in size.

Turbidity due to stirring of the bottom soils by the seine is a distinct hazard to the fish concentrated in the seining pocket and it is imperative that the muskellunge fingerlings be transferred quickly to fresh clean water. Muskellunge are loaded on tank trucks equipped with aeration equipment for transport to water designated for stocking quotas. The muskellunge are stocked the same day, when the distance to the lake or river is short. When the haul is long, one hundred miles for example, muskellunge are returned to the hatchery and held in screen-covered holding tanks until the following day.

Final harvests of muskellunge are accomplished by draining the ponds and seining the drainage basins. Seine lengths may range from 25 feet to 1,200 feet. Sometimes the last muskellunge may be removed with a dip net.





Dirty waters from bottom muds roiled into suspension by the seining operations constitute a distinct hazard to the harvested muskellunge confined to the seine purse. To prevent undue mortality it is imperative that the muskellunge be removed quickly and placed in the fresh clean waters of the oxygen truck.

Muskellunge are loaded on tank trucks equipped with aeration equipment for final transport to a lake designated for planting quotas.

SUMMARY

The propagation of muskellunge is a continuous year around procedure. The important steps are listed chronologically beginning with the fall season:

1. *Daphnia pulex* from laboratory cultures are transferred about September 1 to outside zooplankton culture ponds which are fertilized with Torula yeast twice per week. *Daphnia pulex* developed in the first culture raceway are transferred to other culture ponds and small hatchery ponds after two weeks. Fertilization is discontinued with the approach of cold weather to allow formation of winter resting eggs (ephippia) that are intended for zooplankton seed stock the following spring season. Culture ponds can be drained after formation of ephippia since these adhere to the sides and bottom and are not flushed away with the water.

2. Following the drainage of the rearing ponds and the final harvest of muskellunge, ponds that require eradication of aquatic vegetation such as *Eleocharis acicularis* are sprayed with a sodium arsenite water solution within 1 to 2 weeks after they are drained. The spraying should be completed before the final freeze-up or first snow fall. It is not necessary to spray ponds each year.

3. During the winter, outlying muskellunge rearing ponds are stocked with fathead minnows and other desirable forage species obtained from freeze-out waters. These fish provide a reproductive brood stock for the following year.

4. The following spring, zooplankton culture ponds are filled with water as soon as possible, usually not later than the first date that fyke nets are set to capture muskellunge spawners. The *Daphnia pulex* develop from the winter egg resting stages (ephippia) produced the previous fall. Standing water in the zooplankton culture ponds is fertilized twice per week with one-half gram Torula yeast per cubic foot of water, until zooplankton production is no longer necessary.

5. Fyke nets are set in lakes that produce the largest and earliest muskellunge eggs. Eggs are spawned into a dry pan, fertilized, washed quickly and transferred to egg-holding screens within six to nine minutes. Eggs are transported back to the hatchery any time after a lapse of 30 minutes for incubation.

6. The muskellunge rearing ponds are flooded in the spring beginning with the first date that muskellunge eggs are taken. Ponds should be filled not earlier than two to three weeks before the muskellunge

swim-up fry are introduced. When this schedule is followed the appearance of non-desirable rooted aquatic vegetation, filamentous algae and predator insect larvae is retarded.

7. On the final date that the muskellunge eggs are taken to the hatchery (about May 1) transfers of zooplankton (*Daphnia pulex*) are made from the culture ponds to each of the rearing ponds each day until the culture ponds are depleted. A small-mesh plankton seine is used to collect the *Daphnia.* Zooplankton transfers help to speed up the production of muskellunge in ponds.

8. Before the zooplankton cultures are depleted, *Daphnia pulex* containing parthenogenic eggs are transferred to the biology laboratory and cultured over summer to make certain that they will be available again in the fall.

9. Ponds are fertilized with one-half gram Torula yeast and one-fourth gram commercial 10–10–10 per cubic foot of water for three applications at one-week intervals before the muskellunge are introduced. For each application, this rate approximates 50 pounds of yeast and 25 pounds of 10–10–10 commercial fertilizer per acre foot. The fertilizers are broadcast dry over the pond surface to create as great a suspension of the yeast as possible. Fertilization is reduced to one-half the rate after the muskellunge are introduced, or is discontinued, but may be increased when *Daphnia pulex* winter eggs (ephippia) are noted. Development of ephippia signals that food materials in the waters are being depleted and should be renewed.

10. Rearing ponds are maintained at as high a water level as possible. High levels insure a more constant water temperature and a warming trend that contributes toward increased zooplankton production. Constant water level is essential to prevent mortality due to stranding during the first four days after muskellunge fry are introduced into the ponds.

11. The muskellunge eggs are hatched and the fry held in the hatchery jars until the yolk sac is sufficiently absorbed so that the fry are able to pass out through jar overflow and into the retaining screen boxes below. When sufficient numbers have collected in the screen boxes the fry are gathered with a fine bobbin netting and transferred to the rearing ponds. Prolonged incubation in water below 55° F. necessitates careful observation of the stage of absorption of the yolk sac to insure that the fry do not die in the jars. Pond quotas are weighed into ponds with a gram scale at a count that ranges from 40 to 50 muskellunge fry per gram. Swim-up fry are considered to be of the

same physical age even though they may have developed from lots of eggs taken on different days.

12. Late sucker eggs are obtained from cold lakes to make certain that sucker fry are available for stocking four to eight days later than the muskellunge swim-up fry. The late sucker stocking procedure minimizes the competition that exists between the sucker fry and the muskellunge for the same zooplankton. The delayed sucker stocking also automatically ensures that the suckers do not outgrow the muskellunge and become unavailable as food.

13. Muskellunge are harvested manually with a dip net beginning two to three weeks after they have been stocked in the ponds. At this time the muskellunge are about 2 inches in length. Some of these are stocked in lakes on established quotas and others are introduced into outlying ponds. Outlying ponds are stocked with an entire quota of identical-sized muskellunge on the same day or a part plant on consecutive days. The harvest is continued over several weeks until the muskellunge are no longer easily captured.

14. The algicide Delrad "50" is used in muskellunge rearing ponds, applied locally to filamentous algae mats that are not controlled by the inhibiting action of the Torula yeast. Spot application by spray or by hand, broadcast with a dipper, should not exceed 100 cc. of Delrad "50" per 0.2 acre of pond on any one day to eliminate danger of mortality to muskellunge, zooplankton and minnow forage.

15. The delayed filling of muskellunge rearing ponds in the spring results in smaller and fewer *Dytiscus* larvae and other predator insect larvae, which in turn reduces the need for control by fuel oil application. Fuel oil, however, can be applied to provide a surface film for eradication of surface-breathing insect larvae at any time that predators are noted.

16. Within two months the minnow forage in hatchery ponds is usually depleted. Daily observations of the rearing ponds indicate the one in greatest need of forage. The forage deficiency is corrected by trapping and seining outside sources for a supplementary minnow supply that can be hauled to the hatchery.

17. Hatchery rearing ponds are drained for final harvest beginning mid-September. Natural ponds and outlying drainable ponds are harvested through mid-October. The total weight and the size range of the harvested muskellunge are recorded for each pond. The muskellunge are then transported by tank trucks with aeration equipment to lakes that have been assigned stocking quotas.

LITERATURE CITED

BANTA, A. M.
1939. Studies on the physiology, genetics, and evolution of some Cladocera. Publ. Carnegie Inst., Wash., 513:1–285.

BEAN, T. H.
1908. Muskellunge of the Ohio River Basin. Trans. Am. Fish. Soc., 37: 145–151.

[BENDER, H. A.]
1955. The culture of *Daphnia.* Prog. Fish Cult., 17(4):191.

BRUNDIN, LARS
1951. The relation of O_2-microstratification at the mud surface to the ecology of the profundal bottom. Inst. Freshwater Research, Report 32:32–42.

EDMINSTER, FRANK C.
1947. Fish Ponds for the Farm. Charles Scribner's Sons, New York, 114 pp.

ELSON, PAUL F.
1941. Rearing masquinonge in a protected area. Trans. Am. Fish. Soc., 70:421–429.

EMBODY, G. C. AND W. O. SADLER
1934. Propagating *Daphnia* and other forage organisms intensively in small ponds. Trans. Am. Fish. Soc., 64:205–211.

GREENE, WILLARD C.
1935. The distribution of Wisconsin fishes. Wis. Conservation Comm., Madison, 235 pp.

HASLER, A. D., R. K. MEYER AND H. M. FIELD
1940. The use of hormones for the conservation of muskellunge, *Esox masquinongy immaculatus* Garrard. Copeia, 1:43–46.

[HILAND, R. M.]
1953. Sodium arsenite on dry pond bottoms. Prog. Fish Cult., 15(3):113.

HOAR, WILLIAM S.
1957. Gonads and reproduction, *in* The Physiology of Fishes, Vol. I. Academic Press Inc., New York, 447 pp.

JACKSON, C. F.
1949. Experiments on the value of wood yeast *Torula utilis* as an aquatic fertilizer. Trans. Am. Fish. Soc., 79:105–111.

JOHNSON, CAL
1952. Facts about big muskies. Sports Afield, 128(2):28–29,49.

JOHNSON, LEON D.
1954a. And It Didn't Get Away, Wis. Conservation Bull., 19(8):16–17.
1954b. Use of urethane anesthesia in spawning eastern brook trout. Prog. Fish Cult., 16(4):182–183.

KLUGH, A. B.
1927. The ecology, food-relations and culture of fresh-water Entomostraca. Trans. Roy. Canad. Inst., 16:15–98.

LAGLER, KARL F.
1952. Freshwater Fishery Biology. William C. Brown Co., Dubuque, Iowa, 360 pp.

LAWRENCE, J. M.
1954. Control of a branched alga, *Pithophora,* in farm fish ponds. Prog. Fish Cult., 16(2):83–86.

MACIOLEK, JOHN A.
1954. Artificial fertilization of lakes and ponds. U. S. Fish and Wildlife Service, Spec. Sci. Rep. Fish No. 113, 41 pp.

MACKAY, H. H. AND W. H. R. WERNER
1934. Some observations on the culture of masquinonge. Trans. Am. Fish Soc., 64:313–317.

MOYLE, JOHN B.
1956. Relationships between the chemistry of Minnesota surface waters and wildlife management. Jour. Wildl. Mgt., 20(3):303–320.

NEEDHAM, P. R. AND L. A. BROWN
1933. Notes on the use of water fleas as fish food. Trans. Am. Fish. Soc., 63:131–138.

NEVIN, JAMES
1901. The propagation of the muskellunge in Wisconsin. Trans. Am. Fish. Soc., 30:90–93.

O'DONNELL, D. J.
1945. Control of *Hydrodictyon reticulatum* in small ponds. Trans. Am. Fish. Soc., 73:59–62.

OEHMCKE, A. A.
1949. Muskellunge fingerling culture. Prog. Fish Cult., 11(1):3–18.
1951. Muskellunge yearling culture and its application to lake management. Prog. Fish Cult., 13(2):63–70.

PENNAK, R. W.
1953. Fresh water invertebrates of the United States. The Roland Press Co., New York, 769 pp.

ROUSSOW, GEORGE
1953. Rearing and pathology of maskinonge, yellow pike, perch, and carp and other works. Ninth Report of the Biological Bureau, Quebec, Canada, 1951–52, pp. 377–383.

SCHAEPERCLAUS, W.
1933. Textbook of pond culture. U. S. Fish and Wildlife Serv., Fishery Leaf. 311, 261 pp.

SMITH, M. W.
1936. Notes on the food of *Daphnia pulex* (DeGeer) in fertilized water. Trans. Am. Fish. Soc., 66:287–290.

SVÄRDSON, GUNNAR
1947. Gäddlekstudier, Södra Sveriges Fiskeriförening. Skrifter: 34–59.
1949. Natural selection and egg number in fish. Inst. Freshwater Research Drottningholm, Report 29:115–122.

SWINGLE, H. S.
1945. The improvement of fishing in old ponds. Trans. N. Amer. Wildl. Conf., 10:299–308.

WEBSTER, B. O.
1929. Propagation of muskellunge. Trans. Am. Fish. Soc., 59:202–203.

WHITSON, A. R. AND O. E. BAKER
1928. The climate of Wisconsin and its relation to Agriculture. Ag. Exp. Stat. Bull. 223, Univ. of Wisconsin, Madison, 65 pp.

WOOD, E. M.
1956. Urethane as a carcinogen. Prog. Fish Cult., 18(3):135–136.

TECHNICAL BULLETINS

Published by
The Wisconsin Conservation Department

*No. 1 A Device for Dating Natural Events in Game Animals.
Cyril Kabat, Donald R. Thompson and Frank M. Kozlik (1950)

*No. 2 Pheasant Weights and Wing Molt in Relation to Reproduction with Survival Implications.
Cyril Kabat, Donald R. Thompson and Frank M. Kozlik (1950)

*No. 3 Improved Rations and Feeding Procedures for Pheasants.
Harry E. Stanz, Jr. (1952)

*No. 4 Food Habit Studies of Ruffed Grouse, Pheasant, Quail and Mink in Wisconsin.
Bruce P. Stollberg and Ruth L. Hine (1952)

*No. 5 Experimental Level Ditching for Muskrat Management.
Harold A. Mathiak (1953)

*No. 6 Wisconsin Fox Populations.
Stephen H. Richards and Ruth L. Hine (1953)

No. 7 Some Winter Habits of White-tailed Deer and the Development of Census Methods in the Flag Yard of Northern Wisconsin.
Cyril Kabat, Nicholas E. Collias and Ralph C. Guettinger (1953)

*No. 8 Muskrat Growth and Litter Production.
Robert S. Dorney and Alan J. Rusch (1953)

No. 9 Sex and Age Criteria for Wisconsin Ruffed Grouse.
James B. Hale, Robert F. Wendt and George C. Halazon (1954)

No. 10 Role of Refuges in Muskrat Management.
Harold A. Mathiak and Arlyn F. Linde (1954)

No. 11 Evaluation of Stocking of Breeder Hen and Immature Cock Pheasants on Wisconsin Public Hunting Grounds.
Cyril Kabat, Frank Kozlik, Donald R. Thompson and Frederic H. Wagner (1955)

No. 12 Studies on Level Ditching for Marsh Management.
Harold A. Mathiak and Arlyn F. Linde (1956)

No. 13 Seasonal Variation in Stress Resistance and Survival in the Hen Pheasant.
Cyril Kabat, R. K. Meyer, Kenneth G. Flakas and Ruth L. Hine (1956)

*No. 14 The White-tailed Deer in Wisconsin.
Burton L. Dahlberg and Ralph C. Guettinger (1956)

No. 15 A Guide to Prairie Chicken Management.
F. N. Hamerstrom, Jr., Oswald E. Mattson and Frances Hamerstrom (1957)

No. 16 An Evaluation of Artificial Mallard Propagation in Wisconsin.
Richard A. Hunt, Laurence R. Jahn, Ralph C. Hopkins and George H. Amelong (1958)

---

* Out of print.