A DESCRIPTION AND KEY OF THE EGGS AND LARVAE OF FIVE SPECIES OF FISH IN THE SUBFAMILY COREGONINAE

by

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ABSTRACT

The objective of this study was to develop a key to the eggs and larvae of five species of fish representing the three genera in the subfamily Coregoninae. Data were collected from hatchery rearing of fertilized eggs of the lake herring (Coregonus artedii), lake whitefish (C. clupeaformis), bloater (C. hoyi), round whitefish (Prosopium cylindraceum), and the inconnu (Stenodus leucichthys).

Seven embryonic stages were described for each species with the exception of the inconnu, for which only the first and seventh stages were described. Lake herring and bloater eggs were inseparable using diameter, color and oil droplet number, as were eggs of the lake whitefish and inconnu. However, diameter was useful in separating the eggs of the lake herring ($\bar{x}=2.0\pm.03$ mm) and bloater ($\bar{x}=1.9\pm.08$ mm) from eggs of the lake whitefish ($\bar{x}=2.8\pm.20$ mm), round whitefish ($\bar{x}=3.2\pm.17$ mm) and inconnu ($\bar{x}=3.1\pm.10$ mm). Eggs of the round whitefish were separated from those of the lake whitefish and inconnu by the orange rather than colorless chorion and higher oil droplet number.

Six post-hatching stages were described for each of the five species. At hatching, lake herring and bloater larvae could not be positively identified one from the other, however, the largest dorsal melanophores were generally greater than the width of a myomere in the bloater and less than the width of a myomere in the lake herring. Lake whitefish and inconnu larvae were similar to each other as well as to the lake herring and bloater, however, they were larger and remained larger for comparable stages. Round whitefish larvae had 6-12 oil droplets after hatching, whereas larvae of the other species had one. Lake whitefish larvae had a post-anal myomere count of 16-18, and a subterminal lower jaw which separated it from the inconnu which had 19-22 post-anal myomeres and a terminal lower jaw.

Melanophores were often paired across the dorsal finfold in the lake whitefish, irregular anterior to the notch in the dorsal finfold and paired posterior to it in the inconnu, and irregular to alternate in the lake herring, bloater, and round whitefish. The largest of the dorsal stellate melanophores was greater than or equal to the width of a myomere in the round and lake whitefish and less than the width of a myomere in the inconnu. The round whitefish was the only species to exhibit parr markings.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

The genera Coregonus, Prosopium, and Stenodus comprise the subfamily Coregoninae, family Salmonidae. Eggs from five species in this subfamily were reared in the Wetlands Laboratory, University of Wisconsin, Stevens Point, to permit description of development and construction of keys to differentiate eggs, protolarvae, mesolarvae, metalarvae, and juveniles. The five species, C. artedii (LeSueur), C. clupeaformis (Mitchill), C. hoyi (Gill), P. cylindraceum (Pallas), and S. leucichthys (Güldenstadt) were chosen on the basis of generic and sub-generic representation and availability of fertilized eggs.

Habitat influenced morphological variations are known to occur in the genus Coregonus (Svärdson 1970; Parsons and Todd 1974; McPhail and Lindsey 1970). In order to investigate any affects these variations would have on the proposed keys, comparisons were made for: C. artedii from Pallette Lake and Sunset Lake, Wisconsin, (this study; Hinrichs and Booke 1975), Lake Huron (Faber 1970), Lake Erie (Fish 1932), and Lake Ontario and Lake Michigan (Pritchard 1930); C. clupeaformis from Lake Michigan (this study), Lake Erie (Fish 1932; Price 1934-1935); Lake Huron (Faber 1970), and Lake Ontario (Hart 1930); C. hoyi from Lake Superior (this study) and Lake Huron (Faber 1970); P. cylindraceum from Lake Superior (this study) and Newfound Lake, New Hampshire (Faber 1970) (Normandeau 1969); S. leucichthys from Alaska (this study) and the USSR (Smol'yanov 1957). The embryonic and larval development of the lake herring was described by Hinrichs and Booke (1975) from eggs taken from Pallette Lake, Vilas County, Wisconsin. In 1976 eggs were obtained from Sunset Lake, Portage County, Wisconsin as well as Pallette Lake. I wanted to see if variations in growth rate and morphometry observed in the adult herring (L. Cleveland, Wisconsin Cooperative Fishery Research Unit, pers. comm.), were evident in the larvae.

Several of the coregonine species as described by Koelz (1929) are considered endangered in at least one of the Great Lakes by Parsons, Todd and Emery (1975). The U. S. Fish and Wildlife Service "Red Book", however, lists only the long jaw cisco (C. alpenae) as endangered in the Great Lakes. The threat of extinction in conjunction with declining populations, has brought about renewed interest in rearing members of this subfamily for stocking. These descriptions, keys and hatchery techniques will provide tools for managing and perhaps preserving the stocks of this possibly vanishing resource.

MATERIALS AND METHODS

Egg Taking and Incubation

Trout and salmon culture methods described by Leitritz (1969) and Greenberg (1892) were used to raise the fish in the laboratory. In several cases it was necessary to modify these methods to insure survival of the larvae. Modifications were the initial feeding of brine shrimp; the reduction in particle size of trout starter feeds; the taking of eggs from female inconnu which had been injected with pituitary extract; and rearing in aquaria rather than raceways. Aquaria provided a non-flowing environment with a depth (0.4 m) that increased the time feed was suspended in the water column and therefore increased feed availability to the larvae.

Eggs were stripped from ripe females and fertilized with sperm from several males by the "dry method" (Leitritz 1969). A description of the location from which the adult fish were taken, as well as the method of capture, is in Table 1. Eyed inconnu eggs were flown from Alaska. All other eggs were held in 3.8 l jars and transported by car from the capture site to the University of Wisconsin-Stevens Point Wetlands Laboratory. There the egg containing jars were floated in an incubation temperature water bath until the water in the jars was within 1^{o}C of the incubation water. Eggs were then poured into 5.7 l hatchery jars containing .95 l of pea gravel. Egg handling from fertilization to hatchery jar is summarized in Appendix A.

Table 1. Source of spawning coregonine species, indicating method of capture, depth, location, date, and surface water temperature at the capture site.

Species	Method of Capture	Depth in Meters	Bottom Type	Location	Date	Surface Water Temperature
C. artedii	23 m seine	1-3	gravel and rubble	Pallette Lake Vilas Co., Wisc.	18 Nov. 1975	4°C
C. artedii	23 m seine	1-3	sand	Sunset Lake Portage Co., Wisc.	19 Nov. 1976	4.5°C
C. clupeaformis	trap net	15.2	rock and rubble	Lake Mich. Door Co., Wisc.	11 Nov. 1975	4°C
C. hoyi	Gill net	127.7		Lake Superior Marquette, Mich.	1 Dec. 1976	0°C
P. cylindraceum	Gill net	6.8	rock and rubble	Lake Superior Bayfield, Wisc.	4 Dec. 1975	3.5°C
S. leucichthys	seine, hook and line	2.0	gravel	Upper Yukon R., Alaska	6 Oct. 1976	Approx. 0°C

A combination of fluorescent and incandescent lights was used to produce a photo-period of eight hours light, and sixteen hours darkness for eggs and larvae. However, intensity was diminished to one-half of full daylight during egg incubation to approximate natural, under-ice, water conditions.

Well water was aerated and chilled with the intent of maintaining a constant temperature of 4.0°C. Inconsistency in the function of the chillers, which had produced 4°C water for 30 days prior to the shipment of eggs, made it impossible for all eggs to be subjected to identical temperature regimes. However, except for two 24-hour periods, the daily water temperature (Appendix B) remained within the range of 3.2° to 8.1°C, which Brooke (1975) found to be optimum for incubation of lake whitefish eggs. Temperature also remained within 3°C of the optimum incubation temperature of 5.6°C found for eggs of the lake herring (Colby and Brooke 1970). Since water temperature is the most important factor affecting rate of development in fish eggs (Colby and Brooke 1973), temperature units (TUs) were calculated for each stage of embryological development. Temperature units equal the number of degrees above 0°C per 24-hour period of incubation.

Chilled well water was raised one meter, where it flowed over an aeration screen and was collected. Gravity flow carried the water from the reservoir through the jars (Figure 1). A flow of 500 ml/min. was maintained, except during fungal treatments. This flow did not roll the eggs. Water chemistry data is found in Appendix C.

Samples of 10-25 eggs were removed every six hours for the first 72 hours, then at 48 hour intervals, from fertilization until hatching. Eggs were preserved in a 10% formalin solution to which 5.0 g of NaCl/100 ml had been added. Preservation by this method retained the separation of yolk and chorion.

Black and white, and color slides were taken of live eggs and larvae using transmitted light. Photography of eggs, protolarvae, and mesolarvae was done with a 35 mm

A. Water Inlet
B. Chilling Units
C. Submersible Pump
D. Aeration Screen
E. Water Reservoir
F. Hatching Jar
G. Collection Basin
H. Trough
I. Water Outlet

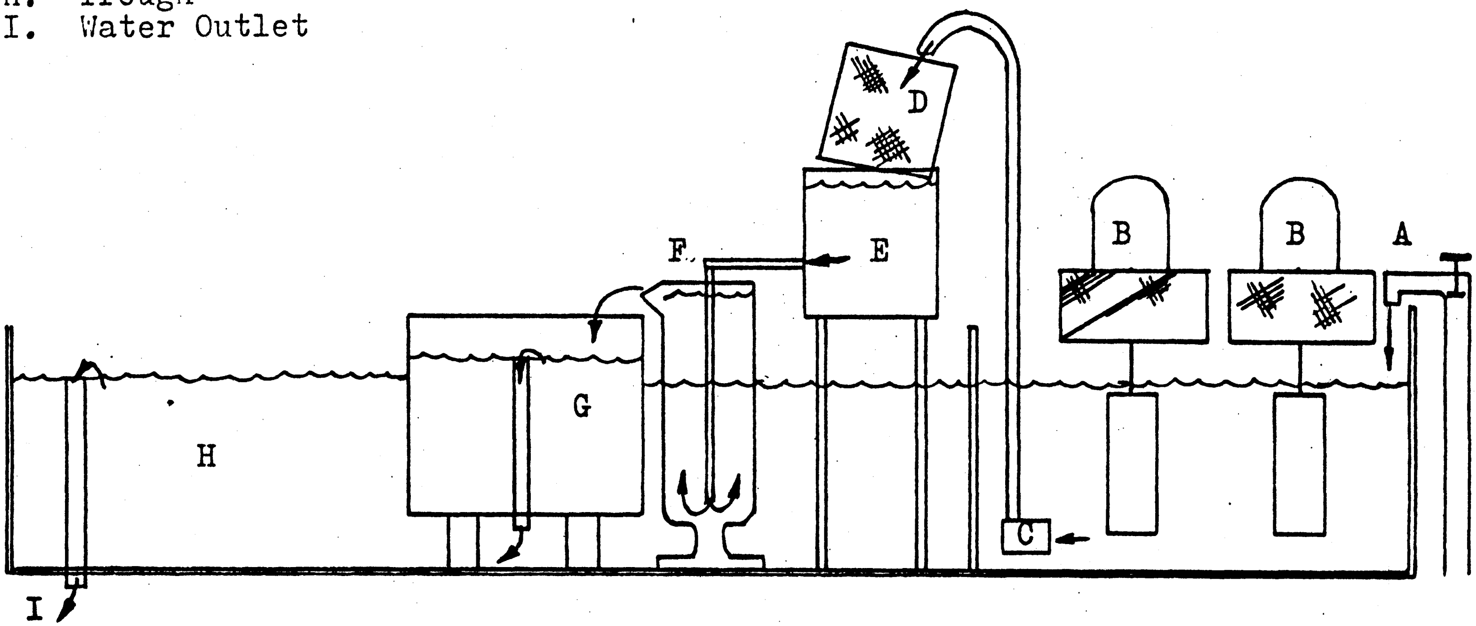


FIGURE 1. **Schematic drawing of the hatchery apparatus used for the incubation of coregonine eggs, with arrows indicating water flow.**

camera mounted on a variable power (6x, 10.3x, 30x) binocular microscope. Close-up attachments and extension tubes were used for photography of metalarvae and juveniles. Drawings were traced from slides projected on the screen of a Singer Graflex Caramate, model 8806. Measurements were made with a ruler, accurate to 0.1 mm. Data were taken from preserved specimens, unless otherwise specified, since in practice most identification is done from preserved samples. Data in Appendix F were taken from individual eggs and larvae.

One to three malachite green treatments were given to the eggs of each species, by the "California flush" method, as described in the U. S. Fish and Wildlife Service Region III Fish Disease Manual (1971). Treatments were used only when fungus had become widespread. There is evidence (Fish Disease Manual) that malachite green can cause coagulated yolks in salmonid eggs, however, this has not been reported to occur in coregonine eggs and was not observed in this study.

Seven embryonic stages, five larval stages, and one juvenile stage were described for each species, with the exception of the inconnu where stages two through six were not obtained. The terminology used for the embryonic development stages was taken from Price (1934-1935).

Hatching and Larval Development

The terminology used for the larvae was proposed by Snyder and Snyder (1975). They described three major development phases as follows:

1) Embryonic---- fertilization to hatching
2) Larval------- hatching to full fin ray development
3) Juvenile----- full fin ray development and lack of fin fold to sexual maturity.

They divided the larval phase into protolarval, mesolarval, and metalarval. Protolarva was defined as the stage in which distinct median fin elements were not yet apparent. Mesolarva was defined as the stage from first medial fin ray development to when the full complement of medial rays were present and pelvic fins were not present. Metalarva was defined as the stage in which the full complement of distinct principal rays in all medial fins were present and pelvic fins were present. These terms were suggested in an effort to standardize terminology, and will be used here with the exception that the protolarval and metalarval stages have each been divided into two stages (Table 2).

Table 2. Definitions of the thirteen developmental stages used in the comparison of the eggs, protolarva, mesolarva, metalarva and juveniles of the lake herring, lake whitefish, bloater, round whitefish and inconnu.

Stage	Definition
Embryonic Stages	
1	Egg after water uptake
2	Cell division
3	Morula to blastula
4	Eoiboly 1/2 to 2/3 over yolk
5	Embryo 1/2 to 2/3 around yolk
6	Embryo 2/3 to 3/4 around yolk
7	Embryo 3/4 to once around yolk
Larval Stages	
8	Protolarva, at time of hatching, with no medial fin rays (dorsal, caudal, anal)
9	Protolarva yolk sac approximately 1/2 of what it was at hatching. First medial fin rays become apparent in the caudal fin at the end of this stage.[a]
10	Mesolarva with several medial (caudal) fin rays, but not all (pelvic fins appear during this stage).
11	Metalarva with all medial fin rays and pelvic fins present[b]
12	Metalarva with all medial fin rays and pelvic fin rays present
Juvenile	
13	No finfold remains and all rays present in all fins

a Stage 9 depicts the transition period between protolarva and mesolarva as defined by Snyder and Snyder (1975)

b Inconsistancy between this definition and that proposed by Snyder and Snyder (1975) was due to the fact that the pelvic fins were present in all species prior to the development of the full compliment of medial fin rays.

Upon hatching, protolarvae were carried by the water current from the hatching jars into a 56.8 l aquarium. Each day, hatched, free-swimming protolarvae were transferred from this aquarium, by siphon, into 56.8 l rearing aquaria with a water flow of 500 ml/min. The mean water temperature in the rearing aquaria, was 10.5°C range 9.9-13.0°C. No mortality was attributed to either the transfer technique or the approximately 5°C change in temperature between incubation jar and rearing tank water. Total egg number and mortality were determined by counting hatched larvae, larvae that died at hatching, dead eyed-eggs, and eggs which had died prior to becoming eyed (Appendix D).

To obtain comparable stages, daily samples were taken of larvae, from hatching until yolk sac absorption. Samples were taken approximately weekly thereafter. Larvae were preserved in 10% formalin and measurements were made under the dissection microscope. Larvae from the day of maximum hatch were reared separately and collections made only from these in order that the age of the sampled fish would be known. Ranges for myomere numbers were established for each larval stage, by counting myomeres several times on each of three individuals.

Newly hatched brine shrimp were washed on a soils screen to remove excess salt and were hand fed to larvae twice daily to larvae satiation. Oregon moist pellets (Halver 1922) and SD-7-28 (Orme 1977) diets were fed in combination with brine shrimp for a period of one week following the transfer to the rearing aquaria for the lake whitefish, round whitefish, and inconnu, and for a period of two weeks for the lake herring and bloater. Brine shrimp were then eliminated from the diet. Automatic feeders were used that fed 0.5 g of a mixture of 50% Oregon moist pellets and 50% SD-7-28 diets, eight times per day. This mixture was used because Oregon moist pellets alone clogged the feeders. A mortar and pestle was used to reduce the particle size of the feed to a powder. Yolk sac larvae were observed to be selective against feed with too large a particle size. The particle size was increased after about 30 days to #1 trout starter due to the growth of the larvae and secondary bacterial infections caused by powdered feed becoming entrapped in gill lamellae.

At approximately 20.0 mm TL metalarvae were transferred from aquaria to rearing troughs with a water flow of 100 ml/min. In the troughs, they were fed by hand several times daily, as well as by the automatic feeders. Metalarvae were able to orient into a current and feed from the water surface, whereas more immature larvae could not. Unlike the other species, the round whitefish larvae were seldom observed feeding from the surface.

RESULTS AND DISCUSSION

Part I

Description and development of the lake herring *Coregonus artedii*

The range of the lake herring is restricted to North America where it is found in the north-central and eastern United States, and all but the most western province of Canada. Spawning generally occurs in mid to late November in Wisconsin at water temperatures of 4.0-5.0°C (Cahn 1927), although gravid females have been found in December in Lake Mendota, Wisconsin (John and Hasler 1956), and some northern Wisconsin lakes.

EGG AFTER WATER UPTAKE (Stage 1, Figure 3)

By the 18th hour after fertilization, 6 TUs, the eggs had taken on some water, which increased the perivitelline space. Oil droplets were concentrated in the area under the animal pole. There were 100, but less than 200 oil droplets; the largest was contained 10x in the yolk diameter, and was 0.2 mm in diameter. The oil droplets were spherical and the yolk was somewhat spherical in all species. The adhesive, colorless, chorion occasionally caused the eggs to adhere to one another in the hatching jars. The yolk was yellow to pale yellow in color. Pallette and Sunset Lake eggs were 2.0 mm in diameter. Yolk diameter was 1.7 mm for Pallette Lake eggs and 1.8 mm for Sunset Lake eggs. Individual egg measurements for all species are presente in Appendix E with a summary by species, in Table 3. Hinrichs and Booke (1975) found the mean diameter for live lake herring eggs to be 2.1 mm, and Fish (1932) gave 1.8 mm for the yolk diameter of a typical eggs, and 2.0-2.5 mm as the range for egg diameter.

EARLY CELL DIVISION (Stage 2, Figure 4)

A swelling at the animal pole occurred between 18 and 24 hours after fertilization, 6-8 TUs, and preceded the first cleavage. The oil droplets were concentrated below the area of cell division. The largest of the more than 100 oil droplets was contained 8x in the yolk diameter, and was 0.2 mm in diameter.

Table 3. Summary of chorion and yolk diameters for preserved eggs of five species of coregonine fishes.

Item	*C. artedii* (Pallette Lake)	*C. artedii* (Sunset Lake)	*C. clupeaformis*	*C. hoyi*	*P. cylindraceum*	*S. leucichthys*
Age (hours)	24 and 72	48	48	24	24 and 36	eyed eggs
Chorion						
Color	colorless	colorless	colorless	colorless	orange	colorless
Mean diameter	2.0	2.0	2.8	1.9	3.2	3.1
SD	.03	.05	.20	.08	.17	.10
Range	1.9-1.0	1.95-2.0	2.3-3.0	1.8-2.1	2.9-3.5	2.9-3.3
n	29	39	41	42	25	19
Yolk						
Color	yellow to amber	yellow to amber	amber	yellow to amber	amber	yellow to amber
Mean diameter	1.7	1.8	2.0	1.6	2.8	2.8
SD	.08	.10	.07	.07	.17	.08
Range	1.5-1.8	1.55-1.9	1.8-2.1	1.4-1.6	2.4-3.0	2.6-2.9
n	24	39	41	42	25	11

BLASTULA (Stage 3, Figure 5)

The blastula was evident at three days, 22.5 TUs. The largest oil droplet was contained 8x in the yolk diameter, and oil droplet number had decreased to approximately 80. Although oil droplet number varied from one egg to another, this number is useful as a general indicator of developmental stage. In all species oil droplets decreased in number, but increased in size from fertilization to hatching (Appendix F).

EPIBOLY 1/2 to 2/3 OVER YOLK (Stage 4, Figure 6)

This stage was reached on the fifth day, 34.5 TUs. The largest oil droplet was contained 6.5x in yolk diameter and oil droplet number had decreased to 50. A ridge of tissue was present in a plane perpendicular to the plane of epiboly, however, no tissue differentiation was visible using the dissection microscope.

EMBRYO 1/2 to 2/3 AROUND YOLK (Stage 5, Figure 7)

At eight days, 81 TUs, the embryo was easily distinguished in the blastoderm. Closure of the yolk plug was nearing completion and was complete in some eggs. The embryo extended half-way around the yolk. Tissue differentiation was evident in the optic primordia, notochord, brain, and myomeres; although the boundaries of these tissues were often vague. Twenty-three myomeres were evident. The oil droplets had consolidated to 40, the largest being 0.4 mm in diameter, or contained 3.5x in the yolk diameter. Kupffer's vessicle was seen in the caudal region, below and posterior to the most caudal myomere.

EMBRYO 2/3 to 3/4 AROUND YOLK (Stage 6, Figure 8)

The 18 day embryo, 127.5 TUs, had 43 myomeres. The telencephalon, mesencephalon, metencephalon and myelencephalon, otolith, and the pupil of the eye were visible. The eyes were not pigmented. There remained 7-10 oil droplets, the largest was 0.5 mm and was contained 3x in the remaining yolk diameter. The tail was free from the yolk to the area where the anus would develop. The heart was beating, but no blood vessels or blood cells were seen. No pelvic fins or movement were observed until the embryo was 23 days old.

EMBRYO 3/4 TO ONCE AROUND YOLK (Stage 7, Figure 9)

The 35 day embryo, 222.6x TUs, surrounded the yolk. Oil droplets had combined to three, the largest of which was contained 3x in the diameter of the yolk sac. The heart had developed two chambers, gill slits were present, and the eye had become pigmented. The myomere count remained at 43, of which 28 were pre-anal and 15 were post-anal. The anus was not open through the ventral finfold. Pectoral fins were present, but not rayed. Stellate melanophores had appeared along the posterior margin of the yolk sac near its juncture with the embryo and along the gut. The lower jaw was distinct from the upper jaw, and the embryo rolled and twisted in the egg. The embryo was 6.0 mm long when withdrawn from the chorion.

PROTOLARVA, NEWLY HATCHED (Stage 8, Figure 33)

Hatching occurred between the 77th and 104th day with maximum hatching on the 99th day. The 24 hour protolarva had been exposed to 454.5 TUs. Figure 33 was drawn from a specimen which was 9.0 mm TL, although total length of 10 specimens ranged from 8.5 mm to 9.5 mm. Newly hatched lake herring larvae were free swimming immediately after hatching and were seldom seen resting on the bottom. A total of 53-56 myomeres was observed; 35-38 pre-anal and 18 post-anal. Pigmentation consisted of a line of melanophores along the gut, several large melanophores on the top of the head, and posterior area of the yolk sac, and an irregular line of stellate melanophores along either side of the dorsal finfold. The largest dorsal melanophore was half the width of a myomere. The lower jaw projected forward to the anterior margin of the eye. No pigment was observed on the gill arches. Nares were present.

PROTOLARVA, YOLK SAC HALF ABSORBED (Stage 9, Figure 34)

The four day larva was drawn from a specimen 10.0 mm TL. The dorsal finfold was more deeply notched than in the previous stage, in the area between the dorsal and adipose fins. Melanophores, relative to Stage 8, were larger, more distinct, and more numerous, especially on the head. The first signs of fin ray development were evident on the ventral surface of the caudal fin.

The total myomere count ranged from 54 to 56, with 36-38 pre-anal and 18-19 post-anal. Faber (1970) reported 38 pre-anal and 12 post-anal myomeres for a 10.8 mm larva, and Fish (1932) reported 38 pre-anal and 19 post-anal myomeres for a 10.25 mm larvae. Most larvae had begun to feed on brine shrimp.

MESOLARVA (Stage 10, Figure 35)

All fish were feeding by the 11th day after hatching. On the 16th day (Figure 35) no yolk sac or oil droplet remained. There were eight caudal rays and the urostyle had begun to turn upward. No dorsal or anal rays were present. Pelvic fin formation became evident during medial finray formation not after, as in the definition proposed by Snyder and Snyder (1975). Pigmentation was limited to melanophores along the dorsal and ventral finfolds, along the gut tract, and an oval patch on top of the head. Total length was 13.0 mm.

My description of a stage 10 larva is the same as described by Fish (1932) for a 12.5 mm larva, with the exception that I found the body depth (1.8 mm) to be greater than the head depth (1.5 mm). The larva in her drawing appeared not to be feeding.

METALARVA (Stage 11, Figure 36)

By the 33rd day after hatching, 10 dorsal rays were present as well as 11 anal rays. The pelvic fins were more apparent, due to increased tissue density in the area of finray formation, than in Stage 10, however, the pelvic fins were not rayed. The caudal fin was slightly forked with 18 rays below the urostyle. The urostyle was upturned at 45° to the horizontal axis. The total length of the larva drawn was 18.8 mm. Pigmentation had changed little from the previous stages, except for the dorsal melanophores which had increased from half the size to almost equal to the width of a myomere. Fish (1932) pictured a 17.5 mm larva in which melanophores had begun to appear in the area of the lateral line. I did not observe this until the larvae were over 20.0 mm TL. The metalarva had begun to show a metallic silvery shine from the peritoneum.

METALARVA (Stage 12, Figure 37)

By the 43rd day after hatching all fin rays had developed. There were 11 dorsal rays, 24 caudal rays, 13 anal rays, 10 pelvic rays and 10 pectoral rays. Ranges of adult finray counts for all five species are in Table 4. The swim bladder was filled in all species by the end of Stage 12. The larva drawn was 23.8 mm TL. Melanophores had become more numerous, especially along the posterior half of the lateral line and along the dorsal surface above the lateral line. The largest of these melanophores were half the width of a myomere and most were of the contracted type (Figure 2). The lower jaw was terminal with respect to the snout. The tail was forked and the margins of the gill arches were pigmented.

Figure 2. Terms of keys

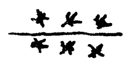
Melanophore shapes and configurations

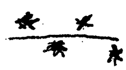
Contracted melanophores....................... 

Ovate stellate melanophores................... 

Reticulate stellate melanophores.............. 

Squared stellate melanophores................. 

Paired across dorsal finfold.................. 

Alternate across dorsal finfold............... 

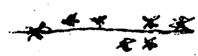
Irregular across dorsal finfold............... 

Table 4. The ranges of dorsal, anal, pelvic, and pectoral fin ray counts for adult lake herring, lake whitefish, bloater, round whitefish, and inconnu, from data combined from this study, Scott and Crossman (1973) and Hubbs and Lagler (1964).

SPECIES	DORSAL RAYS	ANAL RAYS	PELVIC RAYS	PECTORAL RAYS
Coregonus artedii	10-15	11-15	11-12	14-18
Coregonus clupeaformis	11-13	11-13	11-12*	14-17
Coregonus hoyi	9-11	11-12	11	15-16
Prosopium cylindeaceum	11-15	10-13	9-11	14-17
Stenodus leucichthys	12-19	15-18	11	16-17

*I found 12 pelvic rays present on one of the larvae I observed.

JUVENILE (Stage 13, Figure 38)

The 123 day old fish was 39.5 mm TL. A heart-shaped area of dark pigment was seen on the head. There were large stellate melanophores along and slightly below the lateral line. Little pigment was obvious below the lateral line. There was no pigment on the rays of the pectoral, pelvic, or anal fins, however, the caudal and dorsal fins were pigmented. A row of vomerine teeth was evident. Hogman (1970) found the first scales to appear on C. artedii at a total length of 37.0 mm and full scalation at a total length of 55.0 mm. Stage 13 fish appeared to be fully scaled with the exception of the ventral surface anterior to the anus.

Part II

Description and Development of the Lake Whitefish, *Coregonus clupeaformis*.

The lake whitefish is found in the northeastern United States and all provinces of Canada, and Alaska. Spawning usually occurs in November and December in the Great Lakes region, at a water temperature below 7.8°C, over rocky offshore reefs. Eggs hatch in the spring. Faber (1970) and Reckahn (1970) found larval whitefish in Lake Huron to be transient in water less than 10 mm during April and May. Hart (1930) found them near shore in Lake Ontario during June and early July.

Faber (1970) reported to have found lake whitefish larvae 10.0 to 18.0 mm TL. I observed lake whitefish hatching at a minimum of 11.0 mm at an incubation temperature above what would be expected in nature. Since it has been shown (Price 1940; Brooke 1975) that total length in lake whitefish increases with decreased incubation temperature, and abnormal development was 86.9% in larvae hatching with a mean TL less than 12.4 mm. It seems probable that the larvae Faber found which were less than 11.0 mm were not lake whitefish. They could possibly have been lake herring larvae which are similar and have been reported to be sympatric with lake whitefish larvae, at hatching time, by Faber (1970) Pritchard (1930) and Hart (1930).

EGG AFTER WATER UPTAKE (Stage 1, Figure 10)

I have drawn a dorsal view of a 12 hour egg (4.5 TUs), with the animal pole and oil droplets in the foreground. This orientation was typical of the eggs of all species until embryo movement made orientation variable. Oil droplet migration and consolidation under the animal pole was progressing with 100, but less than 100 oil droplets present. The largest oil droplet was 0.2 mm in diameter and was contained 10.3x in the diameter of the yolk. The chorion was slightly adhesive, but unlike the lake herring eggs, no clumping in the jars was observed.

I found egg diameter at 12 hours to be 2.8 mm. Fish (1932) found preserved eggs to be 3.0 mm (2.8-3.0) at 6 hours and Holman (1931) found the diameters of 8 hour eggs to range from 3.0-3.2 mm. Yolk diameter was 2.0 mm in this study, but was found to be 2.6 mm by Fish (1932) and 2.3 mm by Hart (1930).

EARLY CELL DIVISION (Stage 2, Figure 11)

The lake whitefish eggs at one day, 8.5 TUs, had two and four cell stages present as well as a few eggs which had not undergone the first cleavage. Oil droplet number was over 100, although the size of the oil droplets had increased due to consolidation. The largest oil droplet was 0.3 mm in diameter and was contained 6.5x in yolk diameter.

BLASTULA (Stage 3, Figure 12)

The blastula was present at two days, 16.5 TUS. Oil droplet migration had left few oil droplets unconsolidated, and the size of the largest droplet had not changed from the previous stage. However, oil droplet number had decreased from more than 100 to approximately 100.

EPIBOLY 1/2 to 3/4 OVER YOLK (Stage 4, Figure 13)

On the eighth day, 64.5 TUs, epiboly had reached 3/4. Embryonic development had begun as a thickening line of tissue perpendicular to the plane of epiboly. Oil droplets in most cases were 90-100 and the size of the largest oil droplet had increased to 0.4 mm and was contained 5x in the yolk diameter.

EMBRYO 1/2 to 2/3 AROUND YOLK (Stage 5, Figure 14a)

At 14 days, 104.3 TUs, the embryo extended half around the yolk. Epiboly had reached completion and the eye could be distinguished. The fore and hind brain was visible as well as the otolith. Oil droplet number had decreased to approximately 70, with the largest 0.4 mm in diameter and contained 5x in the yolk diameter. Myomere development had begun, but no count was obtained. No heartbeat or blood were observed. Kupffer's vesicle was present. The lake whitefish embryo lay in a depression in the yolk (Figure 14b). This was also true of the other four species.

EMBRYO 2/3 to 3/4 AROUND YOLK (Stage 6, Figure 3)

The 19 day embryo, 137.5 TUs, had begun to exhibit caudal movement as the tip of the tail was free from the yolk. Oil droplet consolidation continued such that five or six large droplets remained, each 0.5 mm in diameter and contained 4-5x in yolk diameter. These larger droplets were centrally located in a mass of approximately 30 smaller droplets. The eye lens and 40 myomeres could be seen but there were no melanophores, heartbeat or blood.

EMBRYO 3/4 TO ONCE AROUND YOLK (Stage 7, Figure 16)

The 57 day embryo was used in Stage 7 rather than one of 40 days, which would have been more comparable with the seventh stages of the other species, because clear photographs were not obtained of the younger embryo. At 57 days, 392.7 TUs, the embryo reached more than once around the yolk, and the eyes were darkly pigmented. Square, stellate melanophores were present on the head and paired along both sides of the dorsal fin fold. The melanophores originated anterior to the origin of the dorsal fin fold, and extended to the caudal peduncle. On the ventral surface, melanophores were present on the rear of the yolk sac, close to where it joined the embryo, and ran back in an irregular line along the ventral fin fold to the tip of the spinal column. The largest dorsal melanophores were less than or equal to the width of a myomere.

Pectoral fins and 50 myomeres were present. Nares were not observed. The head was free from the yolk. There was one oil droplet present that was 0.7 mm in diameter and contained 2.5x in the yolk diameter. In some eggs, however, small oil droplets remained scattered through the yolk. The embryo vibrated, beat its pectoral fins, rolled and twisted within the chorion. This made photography within the egg difficult at this and the previous stage. Blood was visible, even in preserved specimens, in the area of the heart, and in yolk sac blood vessels.

PROTOLARVA, NEWLY HATCHED (Stage 8, Figure 39)

Hatching began on the 56th day after fertilization, and ended on the 79th day, with the greatest number hatching on the 65th day. The 24 hour protolarva (442.7 TUs) was free swimming immediately after hatching. The specimen drawn was 11.5 mm TL. The preserved larva was approximately 2.0 mm smaller than live larva.

Faber (1970) and Fish (1932) observed a yellow pigment that was confined to the posterior of the yolk sac in the lake herring and extended onto the body and head of the larva in lake whitefish. I did not observe this pigment in live or preserved specimens.

Melanophores were present on the head, in a row on either side of the dorsal finfold, around the urostyle, and posterior to the anus along the ventral finfold. Stellate melanophores were present in an interlaced network along the gut, and were absent anterior to the anus and along the ventral finfold. The most anterior point of the lower jaw did not extend beyond the snout, and the length of the snout was less than one-half the width of the eye. The protolarva of the lake whitefish was similar in body conformation to the protolarva of the lake herring and bloater, however, it was larger by about 2.0 mm TL and in general, there was more pigment present.

PROTOLARVA, YOLK SAC HALF ABSORBED (Stage 9)

Stages 9-13 will be briefly described to aid the reader in the use of the fish key presented in the concluding section. Excellent descriptions, drawings, and photographs can be found in Fish (1932), Faber (1970), and Hart (1930).

The 10 day protolarva had the yolk sac approximately half absorbed. Total length was 13.7 mm for the specimen observed. Pigmentation was similar to the previous stage. Ten rays were present in the caudal fin, but dorsal and anal fins were not rayed. Pelvic buds were not visible. Fish (1932) reported dorsal rays, but no caudal rays, in a 13.5 mm larva. Hart (1930) found 13 caudal rays and 11 dorsal rays in a 14.9 mm larva. The larva was feeding.

MESOLARVA (Stage 10)

The 19 day larva was 18.0 mm TL. Eleven dorsal rays, the bases of nine anal rays and 17 caudal rays were present. An increase in pigmentation had occurred in areas previously pigmented, and melanophores had appeared on the snout, opercle, and the posterior half of the lateral line. The urostyle was upturned 45° and the lower jaw was terminal with respect to the snout. No teeth were present on the vomer, and adipose and dorsal fins had separated. Pelvic fins were present and little or no yolk sac remained.

METALARVA (Stage 11)

The lake whitefish metalarva, 36 days after hatching, was 23.0 mm TL. Pelvic fins were unrayed and the tail was forked slightly, but almost square. The snout had become pointed and the lower jaw did not extend beyond the snout. Pigment had increased, especially as contracted and small expanded melanophores along the dorsal margin of the intestine, and above the lateral line. Melanophores were present on the rays of the caudal fin, but none were evident on rays of the dorsal or anal fins.

METALARVA (Stage 12)

At 46 days the larva was 24.0 mm TL. The ventral finfold was present, but only from the insertion of the pelvic fins to the anus. The lower jaw did not extend beyond the snout and the rear margin of the maxilla was in line with the anterior edge of the pupil.

Pigment on the fins was the same as the previous stage, however, rows of melanophores had appeared on the gill arches.

JUVENILE (Stage 13)

The 92 day juvenile was 41.0 mm TL. Pigmentation on the head had developed a heart shaped pattern. There were a few large stellate melanophores, but most were contracted.

The lake whitefish juveniles were silvery-gray in color, unlike the brown of the round whitefish, and did not possess dark scale margins on the dorsal scales. I found that scalation was similar to that observed by Hart (1930). He found no scales on 34.2 mm metalarvae, but full scalation on 54.4 mm juveniles. I found scales present on all but the ventral surface anterior to the anus on a juvenile 45.0 mm TL.

Part III

Description and Development of the Bloater, *Coregonus hoyi*

The bloater was considered endemic to all the Great Lakes, except Lake Erie, however, only Lakes Huron, Superior, and Michigan continue to have populations of these fish (Parsons et al. 1975). Bloater generally spawns during February and March in water 36-91 m deep, over all bottom types, however, ripe or spent adults have been reported in almost every month (Scott and Crossman 1973). Wells (1966) found bloater larvae in Lake Michigan at depths from 18.5-148 m. Approximately 83% of the larvae he caught were found between 74-111 m from April 9 through August 22. None were found as late as October 15. Wells suggests that the larvae may have gone to deeper water. He found peak hatching in mid-June with 96% of the larvae taken from water strata 4.7°C or colder.

EGG AFTER WATER UPTAKE (Stage 1, Figure 17)

The 24 hour egg, 6 TUs, was not fully water hardened. Mean egg diameter was 1.4 mm (1.2-1.5 mm; n=18). Separation of yolk and chorion was evident and oil droplet migration was in progress. Oil droplet consolidation in these eggs was not consistent with observations made on eggs of the lake herring, lake whitefish, and inconnu. Variations from 100 droplets, approximately 0.1 mm in diameter, to fewer than 25 droplets, with the largest 0.3 mm in diameter were observed in bloater eggs. Although the eggs with fewer and larger oil droplets were more common, I believe the smaller, more numerous droplets showed a general trend consistent with observations on eggs of the other species. The bloater eggs used in this study were subjected to rough treatment during and immediately after collection. This, I believe, caused a premature coalescence of oil droplets.

The colorless chorion was similar in adhesiveness to what was observed for eggs of *C. artedii*. The yolk ranged from pale yellow to light amber, giving an overall yellow cast to the eggs. Booke (1970) found C. hoyi eggs to be 1.97 mm ±.02 mm in diameter. At 36 hours, 18 TUs, the egg in this study was 1.9 mm in diameter and yolk diameter was 1.6 mm.

EARLY CELL DIVISION (Stage 2, Figure 18)

The third day after fertilization, 18 TUs two- and four-cell stages were present. Oil droplet number was similar to that of the first stage. The largest oil droplet was 0.3 mm in diameter and contained 5x in the diameter of the yolk. This is larger for this period of development, than found in C. artedii and C. clupeaformis, but probably reflective of the rough handling.

BLASTULA (Stage 3, Figure 19)

By the fifth day, 30 TUs, a blastula was present in which individual cells were no longer distinguishable under the dissecting microscope. The oil droplets were consolidated in a circular area directly beneath the animal pole. There were 30 oil droplets, the largest of which was 0.4 mm in diameter and was contained 4x in yolk diameter.

EPIBOLY 1/2 to 3/4 OVER YOLK (Stage 4, Figure 20)

On the eighth day, 48 TUs, epiboly was approximately half complete and the first evidence of tissue development was apparent in a ridge perpendicular to the plane of epiboly. No differentiation within this tissue was observed. Oil droplet number was 20, with the largest 0.4 mm in diameter and was contained 3.3x in the diameter of the yolk.

EMBRYO 1/2 to 2/3 AROUND YOLK (Stage 5, Figure 21)

On the 10th day, 60 TUs, the embryo was easily recognizable on the yolk, and epiboly was almost complete. Thickened areas of tissue had appeared at the anterior and posterior ends of the embryo, and a cleft separating the fore and hind brain was visible. The embryo extended 2/3 around the yolk. Oil droplets, which appeared less densely consolidated than in the previous stage, had coalesced to as few as 12-16 in some eggs, and were contained 4-5x in yolk diameter. Eggs were also observed in which oil droplet consolidation was slower (Figure 21). In these there were 40-50 oil droplets present, the largest 0.2 mm in diameter and was contained 7.0x in the diameter of the yolk.

EMBRYO 2/3 to 3/4 AROUND YOLK (Stage 6, Figure 22)

In the 15-day egg, 96 TUs, the embryo had begun to show visible tissue differentiation of muscle and optical tissues (including the pupil of the eye), and the otolith. No blood was observed.

EMBRYO 3/4 TO ONCE AROUND YOLK (Early Stage 7, Figure 23a)

The 34 day embryo, 193.5 TUs, was 6.0 mm TL, and extended once around the yolk. The embryo had 30 myomeres and the eyes were grey. The yolk was attached to the embryo at the lower jaw, but not in the caudal region. There was one large oil droplet present with one to several smaller ones distributed in the yolk. The heart was beating and blood could be seen in the heart and larger vessels. The embryo flexed within the chorion. The pectoral fins were present and motile, and finfold formation was evident. Several melanophores with diameters less than the width of a myomere, were found on the dorsal surface of the head and back. No pigmentation was observed on the yolk, and no separation of the opercle and preopercle was evident.

EMBRYO 3/4 TO ONCE AROUND YOLK (Late Stage 3, Figure 23b)

The 64 day embryo, 342.5 TUs, was 9.0 mm TL after being withdrawn from the egg.

Although ranges of 32-34 pre-anal myomeres and 16-18 post-anal myomeres were observed, the total number of myomeres on any one larva varied only from 50 to 52. The yolk sac was 2.0 mm long. The head, as measured from the tip of the snout to the posterior edge of the opercle, was 1.5 mm. The dorsal finfold was high at 4.0 mm from the snout, notched at 4.5 mm, and highest at 5.3 mm (the area of the adipose fin). The heart was two-chambered and the embryo vibrated within the chorion. Nares were not present.

Pigmentation had increased greatly over the previous stage and consisted of several to a dozen stellate melanophores on the dorsal surface of the head. Broken lines of melanophores, the largest of which were equal to the width of a myomere, were seen as pairs of stellate melanophores on either side of the dorsal finfold, or as stellate melanophores which were bisected by the finfold. Ventral pigmentation began with a line of three or four melanophores at the junction of the yolk sac and embryo below the pectoral fin, and continued caudally as a band of interlaced melanophores, extending from the rear of the yolk sac along the intestine, to just anterior to the anus. This line resumed for a short distance between the anus and caudal peduncle.

PROTOLARVA, NEWLY HATCHED (Stage 8, Figure 40)

Hatching began the 84th day at 445 TUs, and ended the 86th day due to a laboratory power failure. The two day old larva was 10.1 mm TL. The lower jaw was subterminal with respect to the snout.

Nares had developed, and pigmentation had increased. A few contracted and expanded stellate melanophores were present on the yolk sac and head. Stellate melanophores continued to form an irregular pattern across the dorsal finfold. Pigmentation had also increased in the area around the urostyle and along the ventral finfold posterior to the anus. Stellate melanophores were interlaced along the gut and on the posterior half of the yolk. There was also an oval patch of melanophores on the dorsal surface of the head. The yolk sac had been reduced to 1.5 mm in length. The first evidence of caudal fin ray formation could be seen as an opaque area under the tip of the urostyle which was upturned at 45°. The larva was free swimming immediately after breaking from the chorion and did not rest on the aquarium bottom for more than a few seconds.

PROTOLARVA, YOLK SAC HALF ABSORBED (Stage 9, Figure 41)

The four day protolarvae were 10.0-10-2 mm TL, n=12. Appearance, other than increased overall length and reduced yolk material, was similar to the previous stage. Exogenous feeding behavior had begun. Protolarvae were seen coiling and striking at brine shrimp, but were not ingesting them. Thirteen day old larvae had been feeding on brine shrimp for two days.

The larva drawn in Figure 41 was 11.3 mm TL. The lower jaw extended forward to the anterior edge of the eye. Faber (1970) described an 11.3 mm bloater larva that was less pigmented than what I observed. I observed that the largest of the dorsal melanophores were consistantly greater than the width of a myomere.

MESOLARVA (Stage 10, Figure 42)

The 28 day larvae ranged from 15.5-16.5 mm TL, prior to preservation. After preservation they had shrunk approximately 1.0 mm. Thirteen caudal rays were present on the lower side of the upturned urostyle. The dorsal and adipose finfolds were only slightly connected. The lower jaw extended forward to the tip of the snout. Pigmentation had increased, especially along the gut. Expanded stellate dorsal melanophores were equal to or greater than the width of a myomere. Contracted melanophores were also present along the dorsal finfold.

METALARVA (Stage 11, Figure 43)

The 45 day larva was 20.0 mm TL and the air bladder was filled. Nine dorsal rays, 18 caudal rays, and 13 anal rays were present. Pigmentation consisted of large stellate melanophores along the lateral line and along the intestine. Contracted melanophores were present on the caudal fin. On the dorsal surface of the head there were approximately 20 stellate melanophores, with as many contracted ones. The ventral finfold originated below the origin of the dorsal fin. There were also melanophores on the gill arches, and on the tip of the lower jaw.

METALARVA (Stage 12, Figure 44)

The 59 day old metalarva was 25.0 mm TL. There were 35-38 pre-anal myomeres and 15-16 post-anal myomeres. No ventral finfold remained and twelve dorsal, 21 caudal, 10 pectoral, and 13 anal fin rays were present. All medial fin rays were within the ranges found for adults (Table 4). The lower jaw was equal in length to the snout and unlike the lake whitefish, the distance from the tip of the snout to the origin of the dorsal fin was greater than half the standard length. Pigmentation consisted of a heartshaped mass of melanophores on the dorsal surface of the head, and a general gradation from stellate to contracted melanophores on the sides from the dorsal to below the lateral line.

JUVENILE (Stage 13, Figure 45)

The 145 day larva was 45.0 mm TL and was deeper bodied than in earlier stages. Twenty-one caudal rays, 13 anal, 11 dorsal, 14 pectoral, and 11 pelvic rays were present. Pigmentation was uniformly distributed with most melanophores being stellate. There were two bands of heavier pigment, one running from the caudal peduncle to the base of the skull on the dorsal surface, the other running along the lateral line from the caudal peduncle to the opercle. There was an absence of pigment along the ventral surface from the anus to the point of pectoral insertion.

Part IV

Description and Development of the Round Whitefish, *Prosopium cylindraceum*

The round whitefish, also known as "Menominee" or "Menominee whitefish", is found in the eastern United States as well as in the eastern, central, and northwestern provinces of Canada. It has been reported in all of the Great Lakes except Lake Erie, where spawning takes place in October and November, in about seven meters of water.

Larvae of the round whitefish have not been captured in great numbers, if at all, by conventional collecting gear. Faber (1970) collected no round whitefish larvae, although he assumed they spawned in his collecting area. Reckahn (1970) collected several over a sand substrate, in mid-July in four meters of water at 17°C. Normandeau (1969) observed that larvae "stay near the bottom and seek shelter when disturbed". Hagen (1970) found round whitefish, 61 mm TL, in Phelps Lake, Wyoming, but was unable to locate smaller fish. I believe their lack of mobility during the first couple of weeks after hatching, coupled with their ability to hide in their rubble habitat, have made them inaccessible to nets and trawls.

EGG AFTER WATER UPTAKE (Stage 1, Figure 24)

The 24 hour round whitefish egg, 6 TUs, had taken up water, causing increased separation of yolk and chorion. The yolk was flattened in the region of future cell development, rather than being spherical as in eggs of the lake herring, bloater, lake whitefish, and inconnu. Mean live egg diameter was 3.4 mm, range 3.0-3.6 mm, n=10. The mean diameter of preserved eggs was 3.2 mm, range 2.9-3.5 mm, n=25. The yolk diameter in preserved specimens was 2.8 mm (2.4-3.0 mm). The yolk was amber and the chorion was orange. There were more than 200 oil droplets, the largest of which were less than 0.7 mm in diameter. The size of the oil droplets was more uniform than observed for species in the other two genera. Normandeau (1969) gave the diameters as 2.7 mm (2.40-2.95 mm) for eggs prior to water hardening. Booke (1970) found preserved eggs to average 3.15 mm±.03 mm. Egg color was orange in both studies.

EARLY CELL DIVISION (Stage 2, Figure 25)

The 36 hour egg, 9 TUs, had reached the four cell stage of development. Migration of oil droplets to the area under the animal pole was complete and oil droplet size remained at 0.7 mm, or contained 12x in the yolk diameter. Oil droplet number was greater than 200.

BLASTULA (Stage 3, Figure 26)

On the third day, 18 TUs, the late morula and early blastorderm stages were present. Under a dissection microscope individual cells were discernible within the cell mass. Size and number of oil droplets had not changed from Stage 2.

EPIBOLY 1/2 to 3/4 OVER YOLK (Stage 4, Figure 27)

The eight day egg, 48 TUs, has epiboly occurring 1/3 over the yolk. No tissue thickening was seen until the tenth day. Unlike the other species, oil droplet size and number were similar to the previous stages.

EMBRYO 1/2 to 2/3 AROUND YOLK (Stage 5, Figure 28)

By the 14th day, 88.8 TUs, eggs had almost completed epiboly and each embryo was well defined and lay in a groove on a plane perpendicular to the plane of epiboly. Optic tissue was the only visibly differentiated tissue on the embryo.

EMBRYO 2/3 to 3/4 AROUND YOLK (Stage 6, Figure 29)

Not until the 37th day, 243.4 TUs, did the embryo reach over 2/3 around the yolk. This was due in part to the large yolk and in part to the comparative stoutness of the embryo of this species. The heart was beating and blood was visible in major vessels. Head and tail were free from the yolk, that had reduced in size by 10%. The 6.5 mm TL embryo had 34 pre-anal and 13 post-anal myomeres. The embryo flexed on the yolk.

Pigmentation along the dorsal finfold was irregular and broken from one side of the dorsal finfold to the other. A network of melanophores was present along the gut, but no pigment was seen on the head. Oil droplets had decreased in number to approximately 100, the largest of which was 0.3 mm in diameter and was contained 10-11x in the yolk diameter. Lenses and pigment were present in the eyes.

EMBRYO 3/4 TO ONCE AROUND YOLK (Stage 7, Figure 30)

The 41 day embryo, 269.4 TUs, was 7.0 mm TL after being withdrawn from the egg. The lower jaw was mobile and the digestive tract was complete through the ventral finfold. Thirty-five pre-anal and 16 post-anal myomeres were observed on each of the two specimens examined. The notch in the dorsal finfold was less pronounced in the round whitefish than in the lake herring, lake whitefish, bloater or inconnu.

Pigmentation had increased so that there were two distinct rows of melanophores along the gut tract from the rear of the yolk to the anus. Melanophores also appeared along the lateral line, and were not seen at this stage in the other species. Oil droplets had consolidated to 25-100, the largest was 0.3 mm in diameter and was contained 8-9x in the diameter of the yolk. The embryo was light orange in color. Embryos of the other four species were pale yellow to off-white.

PROTOLARVA, NEWLY HATCHED (Stage 8, Figure 46)

Figure 46, 376.4 TUs, was drawn from a larva sampled the first day after initiation of hatching because photographs of larvae from the day of maximum hatching were poor. Hatching occurred from the 70th to the 96th day with the maximum on the 87th day. Mean length of live protolarvae was 12.3 mm range (12.0-13.0 mm), n=4. The preserved larva drawn was 11.0 mm TL. Round whitefish protolarvae spent most of their first and second weeks resting upright on the bottom of the collection basin. Oil droplets numbered 6-12 for specimens one day after hatching and the lower jaw was subterminal with respect to the snout. Pigmentation had increased on the top of the head onto an oval patch of melanophores, but elsewhere remained the same as in the previous stage. There were 34-35 pre-anal and 15-16 post-anal myomeres.

PROTOLARVA, YOLK SAC HALF ABSORBED (Stage 9, Figure 47)

The 14 day old protolarva had not increased in total length. I believe growth was slowed because these fish were kept at 5.0°C for two weeks until they were free swimming, whereas the larvae of the other species were free swimming and transferred to warmer water within 24 hours of hatching. The larvae were feeding. No fin rays were present and the urostyle had begun to turn upward. Oil droplets remained at 6-12, but the yolk sac had to be opened to see them. Pigment along the dorsal finfold was irregular. Melanophores were equal to the width of a myomere at 13.0 mm TL, but less than the width of a myomere at 18.7 mm TL. Nares were present. Yolk sac length had been reduced from 4.3 mm to 1.8 mm from the previous stage.

MESOLARVA (Stage 10, Figure 48)

The 43 day larva was approaching the metalarva stage of development. The mesolarva drawn was 18.7 mm TL.

Stellate and contracted melanophores were found along the dorsal surface and along the lateral line. The largest dorsal melanophores were less reticulate and approximately half the width of a myomere. This was smaller than in the other species.

Melanophores were also present on the opercle, snout, and both the caudal and dorsal fins. Gill arches were not pigmented. A distinct characteristic was the circular cluster of melanophores, on the peritoneum, just behind the base of the pectoral fin. They were evident from this stage through the metalarval stage.

METALARVA (Stage 11, Figure 49)

The 81 day metalarva had developed most fin rays with only the pectoral rays not in full count. The two metalarvae sampled were 28.2 and 29.0 mm TL. Pigmentation had spread to the entire dorsal surface and sides. The ventral surface from the jaw to the anus, and the pectoral, pelvic, and anal fins were the only areas not pigmented. Each larva had stellate melanophores that were not expanded greatly. Pigmentation on the head was seen as a heart shaped cap. No scales were observed.

METALARVA (Stage 12, Figure 50)

The 115 day metalarva had its full complement of rays in all fins except the pelvic: 12 dorsal, 14 pectoral, 10 anal, 8 pelvic, and 24 caudal rays below the urostyle. In the 35.0 mm TL specimen drawn, no finfold remained. Pigmentation was similar to the previous stage, with addition of oval parr markings along the dorsal and lateral surfaces. There were usually seven parr marks on each side of the mid-dorsal line, spaced irregularly from side to side. In addition there were four or five on each side along the lateral line. In some cases only the dorsal parr marks were present. The spot of pigment at the base of the pectoral fin, present in stages 10 and

11, was seen in only a few specimens, always the less mature. Scales were seen along the lateral line, and below it in the area of the anal fin. No scales were observed above the lateral line or on the ventral surface anterior to the anus. No dark margin of pigment had appeared on the scales.

JUVENILE (Stage 13, Figure 51)

The 137 day old fish had assumed adult characteristics. It was fully scaled at the total length of 44.5 mm. Hagan (1970) found that full scalation occurred at 40.0 mm. Pigmentation had increased (Figure 51), and an increase in the density and number of parr markings had occurred. Eight parr marks were present along the lateral surface beginning just posterior to the opercle and ending at the caudal peduncle. Dark margins had developed on the first four rows of dorsal scales between the dorsal fin and the lateral line.

Part V

Description and development of the inconnu, *Stenodus leucichthys*

Stenodus is a monotypic genus consisting of three subspecies; *S. leucichthys leucichthys*, found in the area of the Caspian Sea; *S. leucichthys nelma* found in North America in the MacKenzie, Kubuk and Yukon River systems in Canada and Alaska; and *S. leucichthys mackenzie* found in the basin of Great Slave Lake (Alt 1969). In Alaska, these fish are found in fresh to saline waters and in some instances are thought to be semi-anadromous (Alt 1977).

Inconnu spawn in September and October at water temperatures of 1.4°-4.6°C. Eggs are spawned in swift current over different sized gravel. Eggs apparently lodge in the gravel where they incubate through the winter. Larvae have not been studied in North America, but they hatch during April at 12.0-13.0 mm TL in Russia (Smol'yanov 1957). Kenneth Alt (pers. comm.) assumed that the eggs hatched in the spring, in Alaska and that the larvae were carried from upper portions of rivers to the estuaries (lakes, in lake run species) by the spring floods where they would remain for several years before re-entering the river systems.

EGG AFTER WATER UPTAKE (Stage 1, Figure 31)

The inconnu egg so closely resembles the lake whitefish egg that I was unable to separate them. Since both species spawn in the fall and inhabit the same bodies of water, I know of no way to identify spawned eggs. Mean egg diameter was 3.1 mm, range 3.0-3.2 mm, n=19. Yolks were 2.8 mm (2.6-2.9 mm) in diameter, n=11. Smol'yanov (1957) found egg diameter to range from 3.1-3.2 mm, and yolk diameter to range from 2.6-2.8 mm. The chorion was colorless and the yolk was yellow to light amber. There were over 100 oil droplets, the largest was 0.4 mm in diameter and was contained 7x in the yolk diameter. Oil droplets in the eggs of the lake whitefish were 0.2 mm in diameter and contained 10.2x in the yolk diameter, therefore, a potential difference may exist between inconnu eggs and lake whitefish eggs. However, since the inconnu eggs were subjected to extreme temperatures, the difference may be apparent but not real. Inconnu eggs arrived at a temperature of 15.9°C and all ceased development by the third day. Eggs were not shipped again until the eyed stage (Stage 7) had been reached, therefore, stages 2-6 were not observed.

EMBRYO 3/4 TO ONCE AROUND YOLK (Stage 7, Figure 33)

The 90 day embryo reached once around the yolk. The yolk contained only one oil droplet, which was almost half the diameter of the yolk sac. Nares were present. Total length was 11.0 mm live and 10.0 mm preserved, for the one specimen that was withdrawn from the egg. The inconnu's overall body conformation was found to be similar to that of the lake whitefish, lake herring, and bloater. However, the lake herring and bloater, when withdrawn from the egg, were two to three millimeters smaller and therefore would not likely be confused with those of the inconnu or lake whitefish.

The inconnu differs from the lake whitefish in several basic characters. The dorsal finfold on the inconnu originated anterior to the rear margin of the yolk sac, whereas the dorsal finfold on the lake whitefish originated posterior to the rear of the yolk sac. The post-anal myomere count for the inconnu ranged from 20-22, but was most commonly 21 or 22. The post-anal myomere count for the lake whitefish in this study ranged from 16-18, however, Faber (1970) found lake whitefish with 38 pre-anal and 15 post-anal myomeres. The pigmentation differed also between the two species. The melanophores on the inconnu were smaller, fewer, and less dense than those of the lake whitefish. The lake whitefish and round whitefish had melanophores on the anterior half of the yolk sac, which were usually absent on the inconnu.

PROTOLARVA, NEWLY HATCHED (Stage 8, Figure 52)

The hatched inconnu was 12.0 mm TL live, and 11.0 mm TL preserved. This specimen was taken 24 hours after hatching, which occurred 110 days after fertilization. Hatching began on the 104th day, was maximum on the 129th day, and ended on the 144th day. Little difference was noted from the previous stage in either measurements or pigmentation with the exception of an increase in pigmentation of the yolk sac. Smol'yanov (1957) reported 43-44 pre-anal and 23-25 post-anal myomeres for a protolarva 12-13 mm total length. My counts were the same as those for stage seven.

PROTOLARVA, YOLK SAC HALF ABSORBED (Stage 9, Figure 53)

At five days the larvae had consumed approximately half the original yolk and total length had increased to 13.9 mm. Most were feeding and the lower jaw was terminal with respect to the snout. Four to six caudal rays were present, however, the other fins were not rayed.

MESOLARVA (Stage 10, Figure 54)

Pelvic buds were present in most of the 21 day old larvae, as was the separation of dorsal and anal fins. The urostyle was upturned approximately 30° and 18 caudal rays were present in a specimen 15.9 mm TL. Pigmentation had increased especially on the head and yolk sac. Melanophores were present on the snout, and in a large oval patch on the head. Melanophores were also present over the rear of the yolk sac. Dorsal melanophores were less than the width of a myomere, and were paired posterior to the dorsal notch, however, anterior to the dorsal notch they were irregular and often alternate. The maxillae extended to the rear of the pupil.

METALARVA (Stage 11, Figure 55)

The 39 day metalarva was 17.9 mm TL. All fins were present and separate. Only the ventral finfold anterior to the anus remained. The lower jaw had become prominent and extend beyond the snout in this and the two following stages. Pigmentation was similar to the previous stage and there was an absence of pigment on the fins. The urostyle was upturned at 45°.

METALARVA (Stage 12, Figure 56)

Smol'yanov (1957) found 13 caudal and 13 dorsal rays present in a metalarva 18.2 mm TL. I observed 21 caudal and 10 dorsal rays in larvae of that length. The 95 day larvae were late Stage 12 larvae. The jaws did not flair out wider than the head, but the head became laterally compressed and pointed by the end of this stage. The metalarva was 30 mm TL. All fins except the pectoral had their full adult complement of rays; 12 dorsal, 16 anal, 10 pelvic, 24 caudal, and 13 of 15 pectoral rays. The snout had become equal in length to the diameter of the eye and the maxillary bone extended to the rear of the pupil. Dense pigmentation had appeared of the snout and bases of the adipose, anal and dorsal fins. Diffuse stellate melanophores along with the pigmentation on the gill arches were present much later in the inconnu than in lake whitefish. The air bladder filled between Stage 11 and 12.

JUVENILE (Stage 13, Figure 57)

The 184 day juvenile measured 47.0 mm TL. The jaws had begun to flair out. Pigmentation had increased so the fish, overall, looked dark, but melanophores were smaller than in earlier developmental stages. Scales were present except for the ventral surface anterior to the anus and unlike the other species, the inconnu showed no pigmentation between the rays in the caudal or dorsal fins.

Part VI

Keys and Figures

The keys will be more useful if the following are kept in mind:

1. The use of the wrong key will cause misidentification. Therefore, the definitions of egg, protolarva, mesolarva, metalarva, and juvenile, (Table 2 and Page 8) must be understood.

2. Pelvic fins appear before development has progressed to the metalarva stage. Medial fin ray development, therefore, should be the primary determinant of the metalarval stage.

3. Figure 2 portrays melanophore shapes and configurations and should be consulted when needed.

4. Melanophore size in relation to the width of a myomere is the more reliable character when a contradiction arises among size, position and configuration.

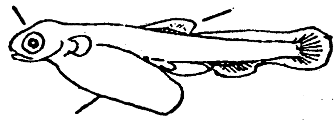
5. Lengths given are minimal lengths for that stage of development because of the lower water temperatures in the natural environment.

KEY TO THE SUBFAMILY COREGONINAE
(Taken directly from Lippson 1976)

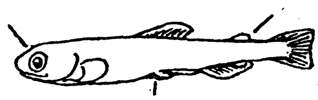
Salmonidae - Trouts

Salmons and trouts

Yolk-sac larvae - large, robust; yolk large, initially pendulous; fin development well advanced before yolk absorbed; vent ca. 2/3 back on body; dorsal finfold with marked identation behind developing dorsal fin.

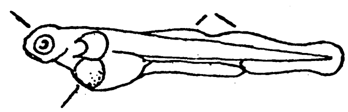


Larvae (alevin) - robust, head rounded; adipose fin; pelvic fin origin below dorsal fin; anal fin origin well posterior to dorsal fin base.



Coregoninae - whitefish

Yolk-sac larvae - large, less robust than salmons and trouts; head large; yolk absorbed before fin development; vent ca. 2/3 back on body; dorsal finfold with two indentations.



Larvae - as with salmons and trouts

KEY TO EGGS

1 a. Eggs 1.8 to 2.5 mm in diameter; chorion colorless; yolk pale yellow to light amber; oil droplets greater than or equal to 100 but less than 200 from fertilization to morula, and consolidate to one at hatching. (See Appendix F)............. *C. hoyi* (Figures 17-23b) or *C. artedii* (Figures 3-9).

b. Eggs 2.5 to 3.5 mm diameter, possibly to 4.6 mm; yolk yellow or amber; chorion colorless or orange; oil droplets greater than or equal to 100 but less than 200 from fertilization to morula, and may or may not consolidate to one at hatching..........2

2 a. Chorion orange; yolk amber to orange; oil droplets amber, possibly orange. Diameter 2.9 to 3.5 mm, possibly as large as 4.6 mm; oil droplets greater than or equal to 200 from fertilization to epiboly, and consolidate from 6-12 at hatching.......... *P. cylindraceum* (Figures 24-30).

b. Chorion colorless; yolk yellow to amber; diameter 2.5 to 3.2 mm; oil droplets greater than or equal to 100 but less than 200 from fertilization to morula, and consolidate to one at hatching........ *C. clupeaformis* (Figures 10-16) or *S. leucichthys* (Figures 31-32).

C. artedii Scale: 10 mm = 1 mm

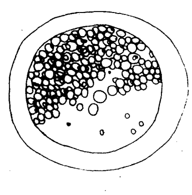


Figure 3.

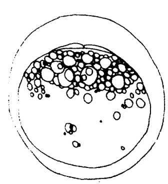


Figure 4.

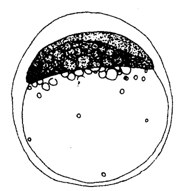
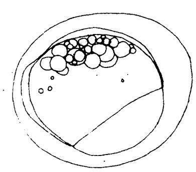


Figure 5.



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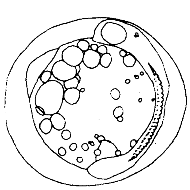

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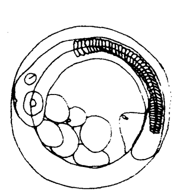


Figure 8.

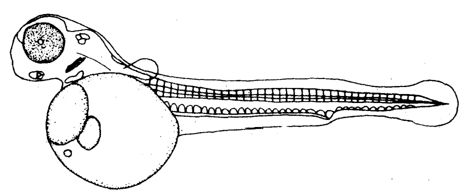


Figure 9.

C. clupeaformis   Scale: 10 mm = 1 mm

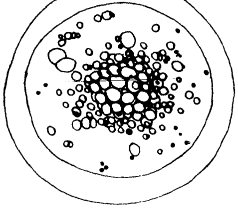
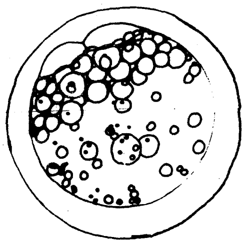


Figure 10.



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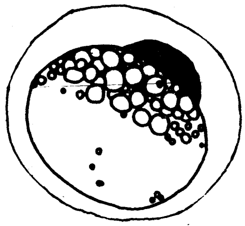

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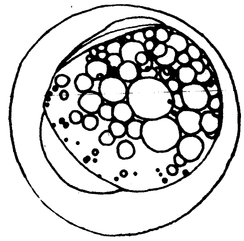

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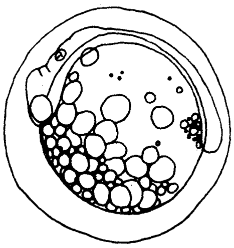


Figure 14a.

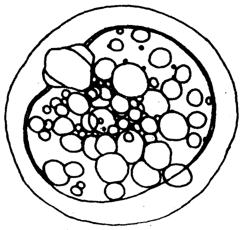
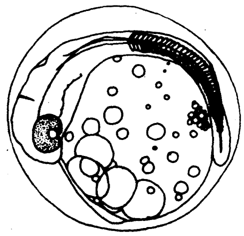


Figure 14b.



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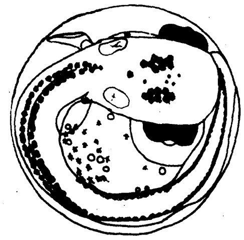
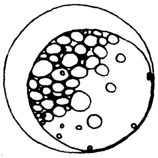


Figure 16.

C. hoyi



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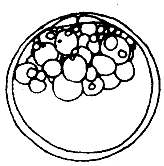

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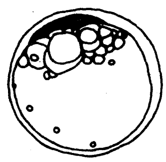

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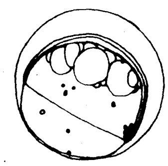

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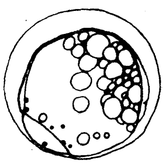

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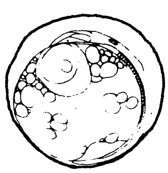


Figure 22.

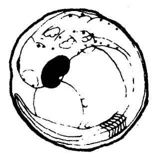


Figure 23a.

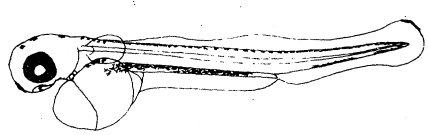
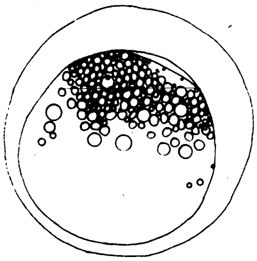


Figure 23b.

P. cylindraceum Scale: 10 mm = 1 mm



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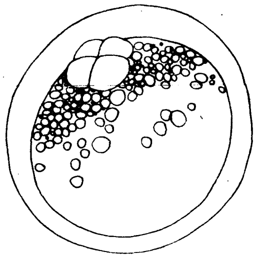

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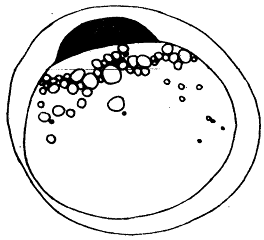

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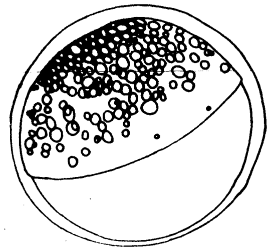
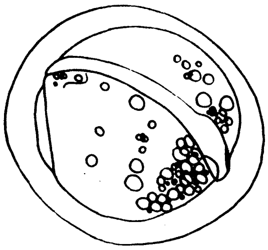


Figure 27.



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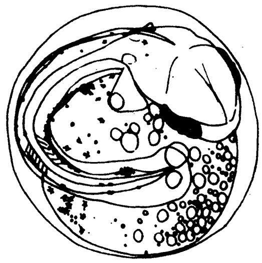

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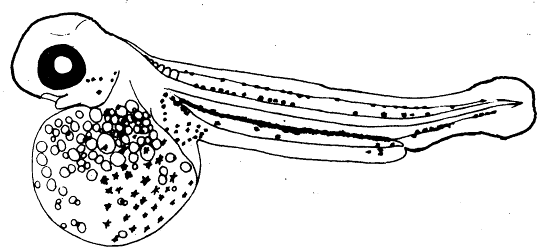
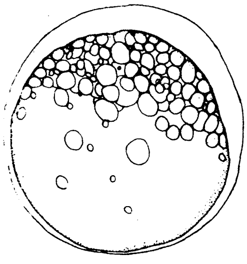


Figure 30.

S. leucichthys



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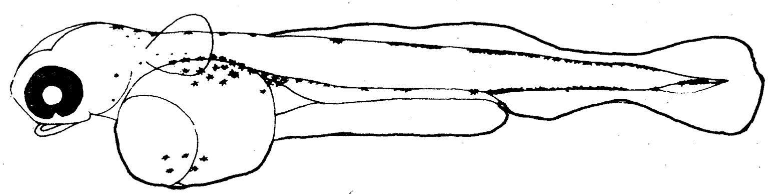


Figure 32.

KEY TO PROTOLARVAE

(Covering the period of development from hatching through the first sign of medial fin ray development. Medial Rays first appear in the caudal fin. Pelvic fins are not present).

1 a. Protolarva at least 9.0 to 13.0 mm TL, single oil droplet contained 4x or less in yolksac length. 2

b. Protolarva 11.0 mm TL or larger; multiple oil droplets 6x or greater in yolksac length, droplets appear as clear areas in opaque yolk when yolksac is removed from body cavity. Post-anal myomeres 19 or less. Lower jaw, when viewed ventrally, does not extend beyond a line across the anterior of the eyes. The largest of the ovate stellate dorsal melanophores greater than or equal to the width of a myomere and myomeres alternate or at least irregular across dorsal finfold.......... P. cylindraceum (Figures 46-47).

2 a. Post-anal myomeres 16-19; lower jaw not protruding beyond snout..........3

b. Post-anal myomeres greater than 19; total length at least 11.0 to 13.0 mm, lower jaw extends beyond snout; ovate stellate melanophores less than or equal to width of a myomere paired across dorsal finfold posterior to dorsal notch and irregular anterior to dorsal notch.......... S. leucichthys (Figures 33 and 34).

3 a. Protolarva less than 11.4 mm TL. Pre-anal myomeres 35 to 38; stellate melanophores ovate to square irregular across dorsal finfold..........4

b. Protolarva 11.5 to 18.0 mm TL, possibly a millimeter longer; pre-anal myomeres 38 to 40, squared stellate dorsal melanophores paired across dorsal finfold and the largest greater than the width of a myomere..... C. clupeaformis (Figure 39).

4 a. Dorsal melanophores greater than width of myomere... C. hoyi (Figures 40 and 41).

b. Dorsal melanophores less than or equal to width of myomere..........C. artedii (Figures 33 and 34)

C. artedii Scale: 10 mm = 1 mm

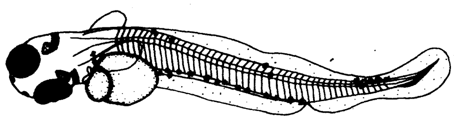


Figure 33.

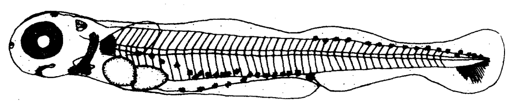


Figure 34.

C. clupeaformis

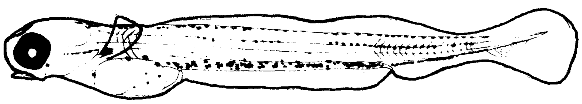
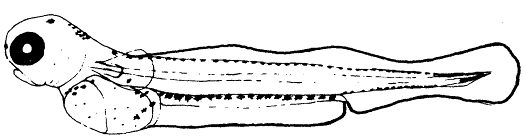


Figure 39.

C. hoyi



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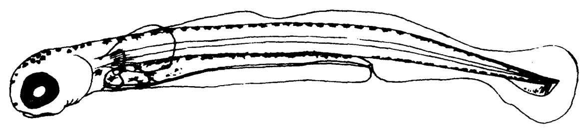

Figure 41.

P. cylindraceum

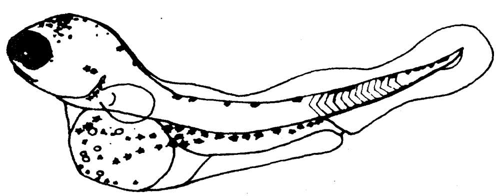

Figure 46.

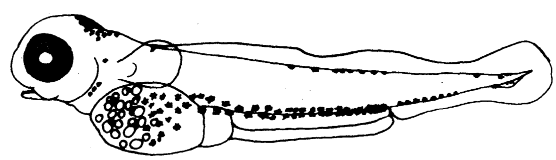

Figure 47.

S. leucichthys

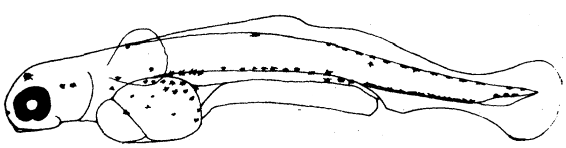

Figure 52.

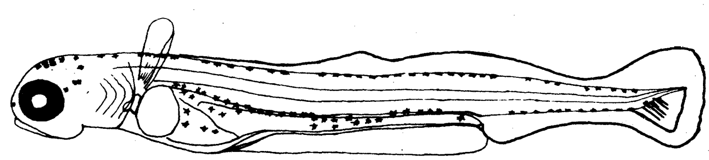

Figure 53.

KEY TO THE MESOLARVAE

(Covering the period of development from the first sign of medial fin ray development to when all medial fins are at least basally rayed. Pelvic fins appear toward the end of this stage).

1 a. Tip of lower jaw does not extend beyond the snout; Pre-anal myomeres 36-40, post-anal myomeres 19 or less..........2

b. Pre-anal myomeres 39-40, post-anal myomeres greater than 19; the largest stellate melanophores along dorsal finfold less than or equal to the width of a myomere, melanophores irregular often alternate anterior to the notch in the dorsal finfold and paired across the finfold posterior to the notch; total length at least 14.0mm; lower jaw extends beyond snout..........*S. leucichthys* (Figure 54).

2 a. Total length at least 18.0 mm..........3

b. Total length at least 11.0 mm but not 18.0 mm. 4

3 a. Melanophores usually square and paired across dorsal finfold, the largest greater than the width of a myomere; mesolarva white, if yellow, on or near yolksac only; length from snout to highest point on dorsal fin greater than or equal to one-half standard length; lower jaw inferior or equal to snout..........*C. clupeaformis*

b. Stellate and contracted melanophores, irregular across dorsal finfold and less than the width of a myomere; mesolarva stout and yellow over entire body; length from snout to highest point of dorsal fin less than one-half standard length; lower jaw inferior to snout and cluster of several melanophores on peritoneum, posterior to base of pelvic fins..........*P. cylindraceum* (Figure 48)

4 a. Largest ovate melanophores less than or equal to the width of a myomere........*C. artedii* (Figure 35)

b. Largest ovate melanophore greater than the width of a myomere..........*C. hoyi* (Figure 42)

C. artedii   Scale: 5 mm = 1 mm

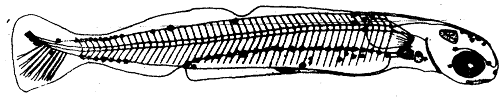

Figure 35.

C. hoyi

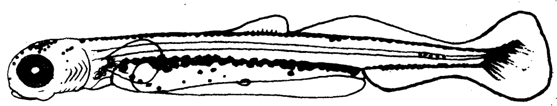

Figure 42.

P. cylindraceum

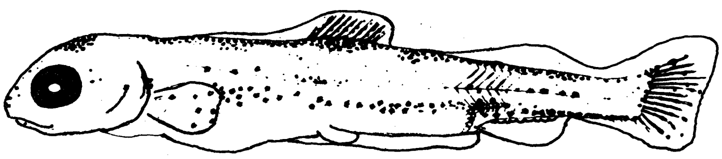

Figure 48.

S. leucichthys

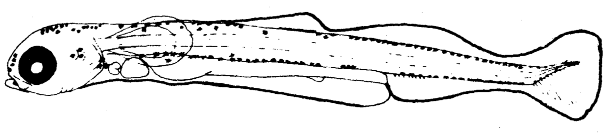

Figure 54.

KEY TO METALARVAE

(Covering the period of development in which the full complement of medial fin rays appear and pelvic fin buds or fins are present.)

1 a. Total myomeres 57 or less; lower jay equal to or inferior to snout; anal rays 15 or less........2

b. Total myomeres 59-62 or more, 39-40 pre-anal and more than 19 post-anal; total length at least 19 mm; caudal fin with 21-24 major rays below urostyle; anal rays 12-18; lower jaw superior with respect to the snout and snout to origin of dorsal fin greater than one-half the standard length. ....S. leucichthys (Figures 55 and 56).

2 a. No parr markings present and/or no cluster of melanophores at base of pectoral fin; lower jaw does not extend beyond the snout........3

b. Parr markings and/or cluster of melanophores at base of pectoral fin; total length at least 28.2 mm; lower jaw does not extend beyond snout; snout to origin of dorsal less than one-half the standard length........P. cylindraceum (Figures 49 and 50).

3 a. Tip of lower jaw does not extend beyond snout; snout to origin of dorsal greater than or equal to one-half the standard length; 39-40 pre-anal myomeres; total length at least 23.0 mm....... C. clupeaformis.

b. Tip of lower jaw extends equal to the snout; snout to origin of dorsal less than or equal to one-half the standard length; 38 or less pre-anal myomeres; total length at least 18.0 mm. ....C. artedii (Figures 36 and 37) or C. hoyi (Figures 43 and 44).

C. artedii Scale: 5 mm = 1 mm

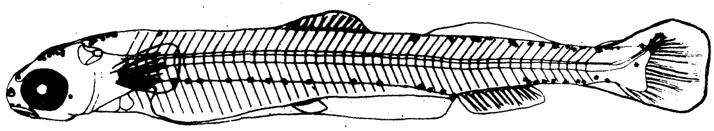

Figure 36.

C. hoyi

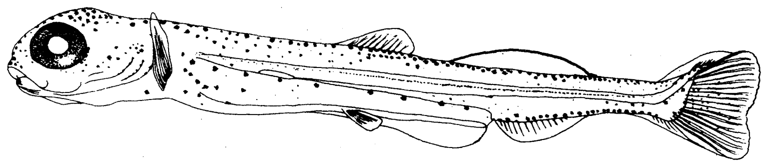

Figure 43.

P. cylindraceum

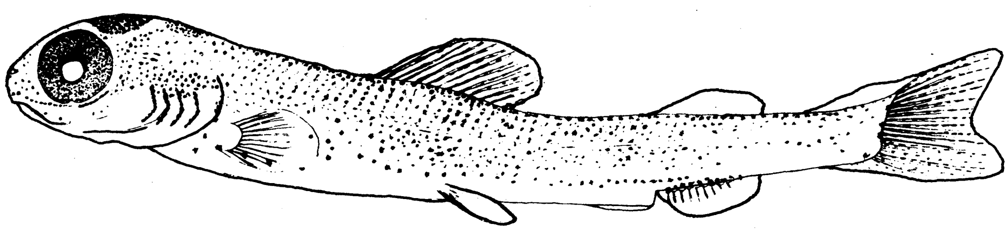

Figure 49.

S. leucichthys

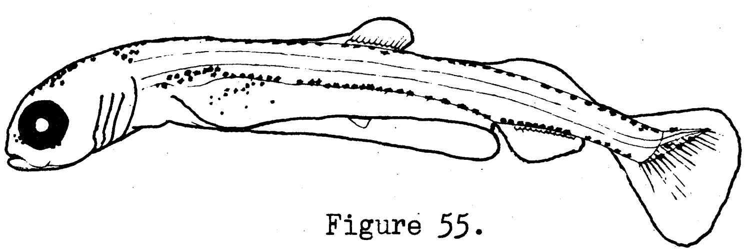

Figure 55.

Scale: 3.5 mm = 1 mm

C. artedii

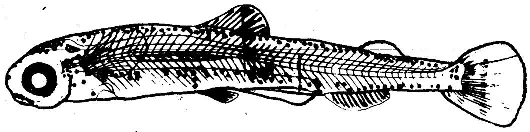

Figure 37.

C. hoyi

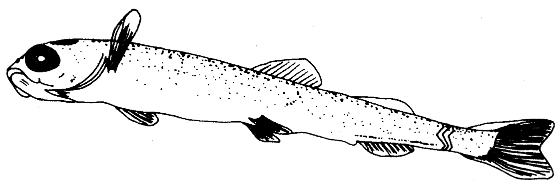

Figure 44.

P. cylindraceum

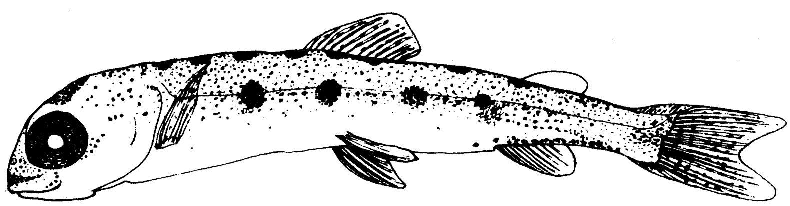

Figure 50.

S. leucichthys

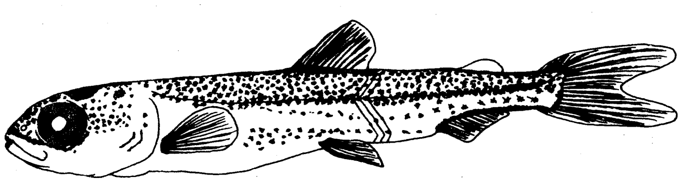

Figure 56.

KEY TO JUVENILES

(Covering the period of development when all fin rays in all fins are apparent, but fish has not reached sexual maturity).

1 a. No parr marking present; double internarial flap; body laterally compressed; non-pigmented dorsal scale margins, color silver, gray or green........2

b. Parr markings present along sides and on dorsal surface; lower jaw inferior to snout; single internarial flap; body round in cross section; total length 45 mm;color brown........
P. cylindraceum (Figure 51).

2 a. Jaws equal to or less than head width, lower jaw equal to or extends slightly beyond snout; anal rays 15 or less........3

b. Jaws wider than head width, lower jaw distinctly superior to snout; anal rays 15-18........
S. leucichthys (Figure 57).

3. a. Snout to origin of dorsal greater than (seldom equal to) one-half the standard length; lower jaw equal to or extends beyond snout........
C. artedii (Figure 38) or *C. hoyi* (Figure 44).

C. artedii

Scale: 3.5 mm = 1 mm

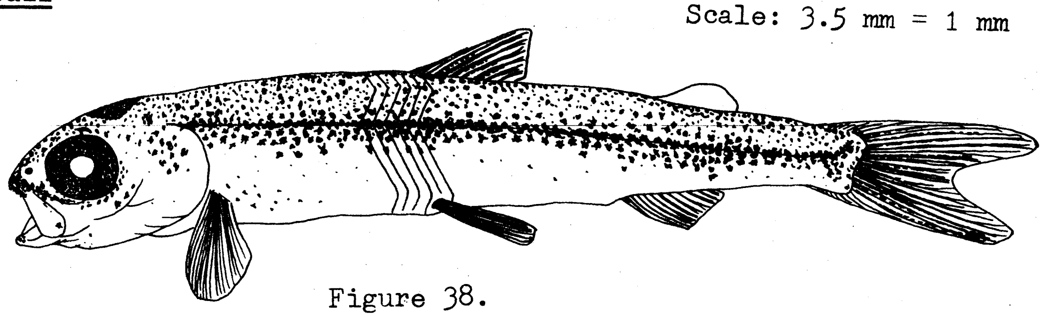

Figure 38.

C. hoyi

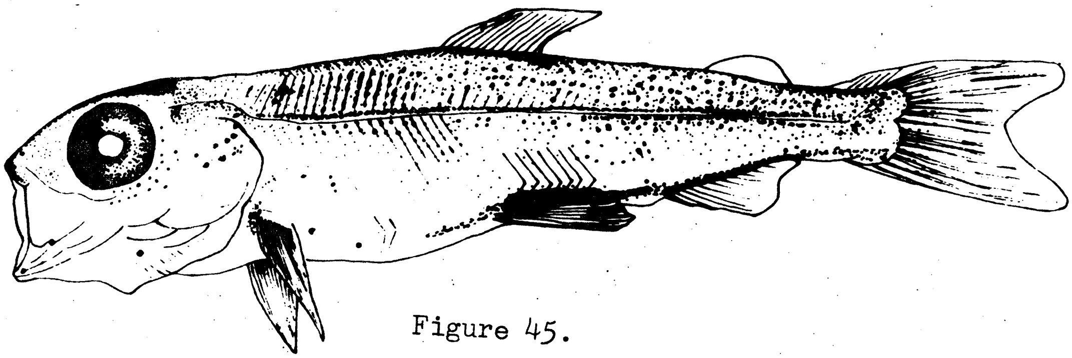

Figure 45.

P. cylindraceum

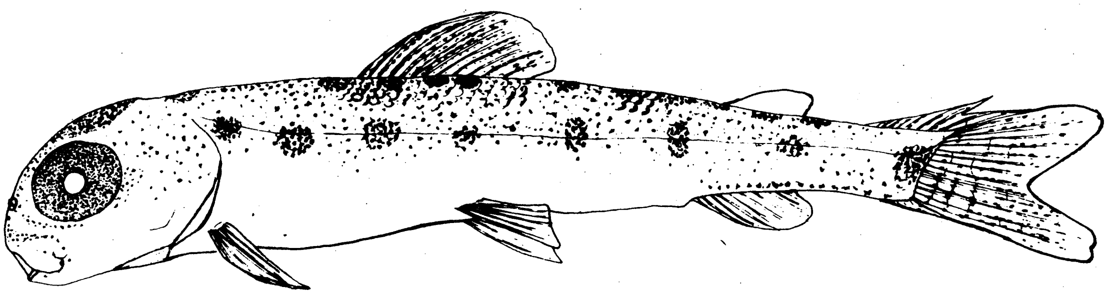

Figure 51.

S. leucichthys

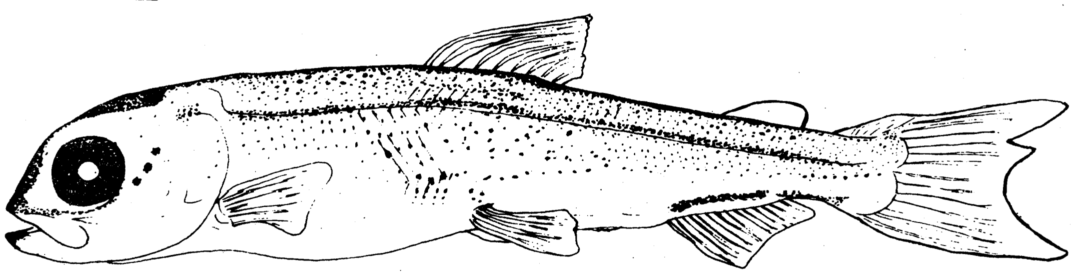

Figure 58.

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APPENDIX A. Summary of temperature changes eggs of the lake herring, lake whitefish, bloater, round whitefish and inconnu were subjected to from the time of capture to placement into incubation units.

Species	Water Temperature at Egg Taking	Water Temperature After Transport	Transport Duration	Initial Incubation Temperature	Time of Acclimation
C. artedii	4.0°C	3.0°C	3 hrs.	8.0°C	2 hrs.
C. clupeaformis	4.0°C	5.0°C	24 hrs.	8.5°C	2 hrs.
C. hoyi	0°C	4.0°C	8 hrs.	6.0°C	1 hrs.
P. cylindraceum	3.5°C	4.0°C	6 hrs.	6.0°C	1 hrs.
S. leucichthys	Approx. 0°C	5.0°C	36 hrs.	5.0°C	0 hrs.

APPENDIX B. **Daily incubation temperatures for the eggs of the lake herring, lake whitefish, bloater, round whitefish and inconnu.**

Date	Temperature in °C	Date	Temperature in °C
Nov. 11, 1975	8.5a	22	6.0
12	8.0	23	6.0
13	8.0	24	6.0
14	8.0	25	8.0
15	8.0	26	8.5
16	8.0	27	7.5
17	8.0	28	8.0
18	8.0b	29	7.5
19	7.5	30	6.5
20	7.0	Jan. 1, 1976	6.5
21	6.5	2	6.5
22	6.25	3	7.0
23	6.25	4	6.5
24	6.25	5	6.8aa
25	6.0	6	6.8
26	6.5	7	6.5
27	6.5	8	6.5
28	7.75	9	6.5
29	6.5	10	6.5
30	6.5	11	6.5
Dec. 1, 1975	5.8	12	6.5
2	6.5	13	6.5
3	6.0	14	6.0
4	6.0c	15	5.0
5	6.0	16	4.5
6	6.0	17	4.0
7	6.0	18	3.5
8	6.0	.	.
9	6.0	.	.
10	6.0	.	.
11	6.0	31	.
12	6.0	Feb. 1, 1976	.
13	6.0	2	.bb
14	9.75	.	.
15	7.0	.	.
16	6.0	11	.cc
17	6.0	.	.
18	6.0	21	3.5
19	6.0	22	8.0
20	6.0	23	8.0
21	6.0		

a Eggs of C. clupeaformis fertilized, aa eggs hatched.
b Eggs of C. artedii fertilized, bb eggs hatched.
c Eggs of P. cylindraceum fertilized, cc eggs hatched.

APPENDIX B. Continued

Date	Temperature in °C
Feb. 24, 1976	8.0
.	.
.	.
29	8.0
Mar. 1, 1976	8.0
.	.
.	.
.	.
.	.
14	8.0

No eggs incubated from March 14 to December 1, 1976. Eggs of S. leucichthys were incubated in Alaska, and no incubation temperatures were available.

Date	Temperature in °C
Oct. 6, 1976	.d
.	.
.	.
31	.
Nov. 1, 1976	.
.	.
.	.
.	.
30	.
Dec. 1, 1976	6.0e
2	6.0
.	.
.	.
.	.
19	6.0
20	5.5
21	5.0
22	5.0
23	4.5
24	4.5
25	4.5
26	5.0
27	5.0
28	5.0

Date	Temperature in °C
Dec. 29, 1976	5.0
30	5.0
31	5.0
Jan. 1, 1977	5.0
.	.
.	.
.	.
.	.
16	.dd
.	.
.	.
27	5.0
28	4.0
29	5.0
30	5.0
31	5.0
Feb. 1, 1977	5.0
2	5.0
3	5.0
4	5.0
5	5.0
6	4.5
7	4.5
8	4.5
9	4.5
10	5.0
.	.
.	.
.	.
.	.
20	5.0
21	4.5
22	4.5
23	5.0
24	5.0ee
25	5.0
26	5.0
27	4.5
28	4.5

d Eggs of S. leucichthys received, dd eggs hatched.
e Eggs of C. hoyi fertilized, ee eggs hatched.

APPENDIX C. Analysis of hatchery water (Wetlands Laboratory, University of Wisconsin, Stevens Point).

Temperature from well	9.9°C
Dissolved Oxygen	10.0 ppm
pH	7.9
Conductivity	353 um ho/cm
NA+	2.3 mg/1
Total hardness	158 mg/1 CaCO^3
Alkalinity	142 mg/1 CaCO^3

APPENDIX D. Mortality encountered during incubation for eggs of the lake herring, lake whitefish, bloater, round whitefish and inconnu.

Species	Dead Larvae	Dead Eyed Eggs	Dead Uneyed Eggs	Successful Hatch	Total Eggs	% Success
C. artedii	83	39	410	4883	5415	90
C. clupeaformis	1723	952	1163	4718	8556	55
C. hoyi	3412	120	1394	300	5226	5.7
P. cylindraceum	970	83	2003	1827	4883	37.
S. leucichthys	1067	215	303	2603	4188	62

APPENDIX E. Chorion and yolk diameters, in mm, for eggs of the lake herring, lake whitefish, bloater, round whitefish and inconnu.

C. artedii Sunset Lake		*C. artedii* Pallette Lake		*C. clupeaformis*		*C. hoyi*	
Chorion	yolk	Chorion	yolk	Chorion	yolk	Chorion	yolk
2.0	1.6	1.95	1.7	2.8	2.0	2.0	1.4
2.1	1.8	1.95	1.75	2.9	2.0	1.8	1.5
1.95	1.55	2.0	1.8	2.7	1.9	1.9	1.5
2.1	1.7	2.0	1.7	3.0	2.0	2.0	1.6
2.0	1.8	1.95	1.7	2.9	2.05	1.9	1.5
2.0	1.8	2.0	1.8	3.0	2.0	1.9	1.6
2.0	1.8	2.0	1.8	3.0	2.0	1.9	1.6
1.95	1.6	2.0	1.8	3.0	2.1	1.8	1.5
2.0	1.75	1.95	1.8	2.8	1.8	1.8	1.5
2.0	1.75	1.95	1.7	3.0	2.0	1.8	1.5
2.1	1.9	1.95	1.7	3.0	2.1	1.9	1.6
2.0	1.8	1.95	1.8	3.0	2.0	1.8	1.6
1.95	1.6	2.0	1.7	3.0	2.1	1.8	1.5
1.95	1.6	1.95	1.75	3.0	2.0	1.9	1.6
2.0	1.7	2.0	1.8	3.0	2.0	1.9	1.6
2.1	1.8	2.0	1.8	3.0	2.0	2.0	1.6
2.0	1.7	2.0	1.8	3.0	2.0	1.8	1.5
2.0	1.8	1.9	1.5	3.0	2.0	2.0	1.7
2.0	1.8	2.0	1.8	3.0	2.0	1.8	1.4
2.0	1.7	1.95	1.7	3.0	2.0	1.9	1.6
2.0	1.8	1.95	1.7	2.9	1.9	1.8	1.5
2.0	1.8	2.0	1.6	2.8	1.8	2.0	1.5
2.0	1.7	2.0	1.7	2.7	2.0	1.9	1.6
2.1	1.9	1.95	1.6	2.7	2.0	2.0	1.7
2.0	1.8	2.0	.	2.8	2.0	1.95	1.6
2.1	1.9	1.95	.	2.5	1.9	2.0	1.6
2.1	1.9	2.0	.	2.5	2.0	1.95	1.6
2.0	1.8	2.0	.	2.5	2.0	1.9	1.5
2.0	1.8	2.0	. (Yolk Broken)	2.8	2.0	2.05	1.6
2.0	1.7			2.6	2.0	1.8	1.5
2.0	1.8			2.6	1.9	1.9	1.6
2.0	1.85			2.6	2.0	1.9	1.6
2.0	1.9			2.7	2.0	1.9	1.6
2.1	1.8			2.6	2.0	1.8	1.5
2.0	1.9			2.6	2.0	1.9	1.6
2.1	1.8			2.8	2.0	1.8	1.5
2.0	1.8			2.6	2.0	1.9	1.5
2.0	1.9			2.7	2.0	2.0	1.6
2.0	1.8			2.7	2.0	2.0	1.6
				2.7	2.0	1.9	1.6
						2.0	1.6
						1.95	1.6

APPENDIX E. Continued

P. cylindraceum Chorion	yolk	*S. leucichthys* Chorion	yolk
3.3	2.8	2.9	. (Yolk Broken)
3.3	2.8	3.2	2.8
3.0	2.5	3.2	2.8
3.0	2.4	3.3	2.8
3.3	3.0	3.0	2.6
3.3	2.9	3.1	.
3.2	2.7	3.0	.
3.3	2.9	3.0	.
3.2	2.9	3.0	.
3.4	2.9	3.1	.
3.0	2.7	3.1	.
3.0	2.5	3.0	.
3.2	2.8	3.1	2.8
3.0	2.7	3.0	2.7
2.9	2.4	3.1	2.8
3.0	2.8	3.0	2.7
3.5	3.0	3.0	2.7
3.1	2.8	3.1	2.8
3.1	2.9	3.2	2.9
3.0	2.7		
3.4	2.9		
3.0	2.7		
3.2	2.8		
3.4	3.0		
3.4	2.8		

APPENDIX F. Summary of measurements taken on the eggs, protolarvae, mesolarvae, metalarvae and juveniles of the lake herring, lake whitefish, round whitefish, and inconnu, for each of thirteen developmental stages.

Stage	*C. artedii*	*C. clupeaformis*	*C. hoyi*	*P. cylindraceum*	*S. leucichthys*
1 Egg after water uptake					
Date	19 Nov. 75	10 Nov. 75	2 Dec. 76	4 Dec. 75	8 Oct. 76
Days	18 hours	12 hours	1 day	1 day	2 days
TUs	6.0	4.5	6.0	6.0	—
Figure	3	10	17	24	31
Chorion diameter X̄	—	3.0	1.4	—	3.1
Yolk diameter X̄	—	—	—	—	2.8
Oil droplet number	Equal to or greater than 100	Equal to or greater than 100	25–100	Equal to or greater than 200	Equal to or greater than 100
Oil droplet size	10x in yolk	10.3x in yolk	10x in yolk	12x in yolk	7x in yolk
Color yolk/chorion	Yellow/colorless	Amber/colorless	Yellow to amber/colorless	Orange/amber	Yellow to amber/colorless
2 Early cell division					
Date	20 Nov. 75	11 Nov. 75	5 Dec. 76	5 Dec. 75	—
Days	1	1	3 days	36 hours	—
TUs	8.0	8.5	18.0	9.0	—
Figure	4	11	18	25	—
Chorion diameter X̄	2.0	2.8	1.9	3.2	—
Yolk diameter X̄	1.7	2.0	1.6	2.8	—
Oil droplet number	Equal to or greater than 100	Equal to or greater than 100	25–100	Equal to or greater than 200	—
Oil droplet size	8x in yolk	6.5x in yolk	5x in yolk	12x in yolk	—
3 Morula-Blastula					
Date	22 Nov. 75	12 Nov. 75	7 Dec. 76	7 Dec. 75	—
Days	3	2	5	3	—
TUs	22.5	16.5	30.0	18.0	—
Figure	5	12	19	26	—
Oil droplet number	80	100	30	Equal to or greater than 200	—
Oil droplet size	8x in yolk	6.5x in yolk	4x in yolk	12x in yolk	—
4 Epiboly 1/2–3/4					
Date	26 Nov. 75	18 Nov. 75	10 Dec. 76	12 Dec. 75	—
Days	5	8	8	8	—
TUs	34.5	64.5	48.0	48.0	—
Figure	6	13	20	27	—
Oil droplet number	50	90	20	Equal to or greater than 200	—
Oil droplet size	6.5x in yolk	5x in yolk	3.3x in yolk	12x in yolk	—
5 Embryo 1/2–2/3 around yolk					
Date	29 Nov. 75	24 Nov. 75	12 Dec. 76	18 Dec. 75	—
Day	8	14	10	14	—
TUs	81.0	104.3	60.0	88.0	—
Figure	7	14A 14B	21	28	—
Oil droplet number	40	70	12–16	Less than or equal to 100	—
Oil droplet size	3.5x in yolk	5x in yolk	7.0x in yolk	12.0x in yolk	—
Myomeres	23	Present	None	None	—
6 Embryo 2/3 to 3/4 around yolk					
Date	5 Dec. 75	29 Nov. 75	17 Dec. 76	9 Jan. 76	—
Days	18	19	15	37	—
TUs	127.5	137.5	96.0	243.4	—
Figure	8	15	22	29	—
Oil droplet number	7–10	30 small 5–6 large	6–20	Approximately 100	—
Oil droplet size	3x in yolk	4x in yolk	3x in yolk	10–11x in yolk	—
Myomeres pre/post-anal	43 total	40 total	25 total	34/13	—
Pigment	None	None	None	Dorsal finfold gut, rear yolk sac	—
7 Embryo 3/4 to once around yolk					
Date	22 Dec. 75	7 Jan. 76	4 Jan. 77	13 Jan. 76	5 Jan. 77
Days	35	57	34	41	90
TUs	222.6	392.7	193.5	269.4	—
Figure	9	16	23a	30	32
Oil droplet number	1 large several small	1 large several small	1 large possible small	25–100	1
Oil droplet size	3x in yolk	~2.5x in yolk	~2.5x in yolk	8–10x in yolk	2.5x in yolk
Myomeres pre/post-anal	43 28/15	50 total	30 total	51 35/16	60 38/22
Dorsal melanophores	None	Squared stellate regular	Few stellate irregular	Small stellate irregular	Ovate stellate irregular anterior 1/2 regular posterior 1/2
Total length	6.0	9.8	6.0	7.0	10.0

APPENDIX F. Continued

Stage	C. artedii	C. clupeaformis	C. hoyi	P. cylindraceum	S. leucichthys
8 Protolarval newly hatched					
Date	25 Feb. 76	15 Jan. 76	26 Feb. 77	11 Feb. 76	16 Jan. 77
Days	1	1	1	1 (70 days)	1 (110 Days)
TUs	454.5	442.7	445.5	376.4	—
Figure	33	39	40	46	52
Oil droplet number	1	1	1	6-12	1
Oil droplet size	2.5x in yolk	2.5x in yolk	2.5x in yolk	6x in yolk	2.5x in yolk
Myomeres pre and post-anal	35-38/18	39-40/16-18	35-37/17-19	34-35/15-16	38/22
Dorsal melanophores	Stellate irregular ovate	Stellate, paired squared	Stellate regular ovate	Alternate ovate	Paired stellate ovate
Total length	9.0	11.5	10.1	11.0	11.0
Standard length	8.5	10.4	9.9	10.5	10.2
Anus	6.0	8.0	6.0	7.0	7.1
Head	1.2	2.0	1.4	1.9	1.9
Origin of dorsal	2-8	3.0	2.9	3.0	2.6
Dorsal highest	4.1	5.9	5.2	4.6	5.6
Notch	4.0	6.4	5.5	5.5	6.0
Adipose highest	5.4	7.4	6.8	6.9	7.0
Hatch beginning	77	56	83*	70	104
Maximum	99	65	84	87	129
End	104	79	86	96	144
Choroid fissure	Present	Present	Present	Present	Present
Lower jaw	Inferior	Inferior	Inferior	Inferior	Equal
Snout to dorsal origin greater or less than 1/2 standard length	Less than	Less than	Less than	Less than	Less than
9 Protolarvae yolk sac 1/2 absorbed					
Date	29 Feb. 76	24 Jan. 76	9 Mar. 77	25 Feb. 76	10 Feb. 77
Days after hatch	4	10	13	14	5
Figure	34	—	41	47	53
Oil droplet number	—	—	—	—	—
Oil droplet size	—	—	—	—	—
Myomeres pre/post	36-38/18-19	38-40/17-18	36-38/15-16	37-38/17-18	38-40/21-22
Dorsal melanophores	irregular small stellate less than width of myomere	Paired large squared stellate equal to or greater than width of myomere	Large stellate squared irregular greater than width of myomeres	Irregular equal to or greater than width of myomeres reticulate alternate	Alternate stellate pre adipos[illegible] paired stellate after adipos[illegible] less than width of myomeres
Total length	10.0	13.7	11.3	11.0	13.9
Standard length	9.3	12.1	10.0	10.6	12.0
Length to anus	6.4	9.9	7.1	7.5	9.4
Head length	1.4	2.9	1.7	2.0	2.5
Origin of Dorsal	3.0	5.9	4.2	3.0	5.0
Dorsal highest	4.8	6.5	5.6	5.6	6.9
Dorsal notch	5.2	8.0	6.0	6.0	7.4
Adipose highest	6.5	9.8	7.2	7.5	9.0
Rays dorsal	—	—	—	—	—
caudal	Basal	10	Basal	3 basal	4-6
pectoral	Basal	Basal	Basal	—	Basal
pelvic	—	Buds	—	—	—
anal	—	—	—	—	—
Pelvic insertion	—	7.0	—	—	—
Lower jaw	Inferior	Inferior	Inferior	Inferior	Equal
Snout to origin of dorsal greater than, less than or equal to 1/2 standard length	Less than	Less than	Less than	Less than	Less than

APPENDIX F. Continued

Stage	C. artedii	C. clupeaformis	C. hoyi	P. cylindraceum	S. leucichthys
10 Mesolarvae					
Date	12 Mar. 76	8 Feb. 76	24 Mar. 77	26 Mar. 76	19 Feb. 77
Days after hatch	16	19	28	43	21
Figure	35	—	42	48	54
Oil droplet number	—	—	—	—	—
Oil droplet size	—	—	—	—	—
Myomeres pre/post	53-55 36-38/17-19	55-57 38-40/17-18	52-53 36-38/15-16	54-56 36-38/16-18	60-61 39-41/20-21
Dorsal melanophores	10 less than width of myomeres	Paired but contracted added equal to or greater than myomeres	Greater than width of myomeres irregular squared stellate	Greater than or equal to width of myomeres stellate and contracted	Greater than width of myomeı stellate ovate irregular
Total length	13.0	18.0	14.5	18.7	15.9
Standard length	11.1	16.2	13.1	16.4	14.0
Length to anus	8.0	13.0	9.5	12.3	10.2
Head length	2.0	3.5	2.4	3.5	2.9
Origin of dorsal	4.0	8.2	5.3	4.5	5.0
Dorsal highest	6.1	10.0	7.6	7.6	7.2
Dorsal notch	6.6	10.9	8.0	10.0	8.4
Adipose highest	8.2	11.4-14.4	8.0-12.0	13.3	10.5
Rays dorsal	None	11	7	9	10 Basal
caudal	8	17	13	23	18
pectoral	Buds	Buds	Buds	Buds	—
pelvic	Buds	—	Buds	—	—
anal	—	9	9	7	8
Pelvic insertion	5.6 only in some	9.5	7.0	9.0	7.7
Lower jaw	Inferior	Equal	Inferior almost equal	Inferior	Equal to superior
Snout to origin of dorsal greater, less than or equal to 1/2 standard length	Less than	Greater than or equal to	Less than	Less than	Less than
11 Metalarvae					
Date	29 Mar. 76	25 Feb. 76	14 Apr. 77	3 May 76	9 Mar. 77
Days after hatch	33	36	45	81	39
Figure	36	—	43	49	55
Myomeres pre/post	36-38/17-19	38-40/17-18	52-54 35-38/15-16	54-56 36-38/16-18	60-61 39-41/20-22
Dorsal melanophores	—	—	—	—	—
Total length	18.8	23.0	20.0	28.2	17.9
Standard length	26.6	19.7	16.8	23.0	15.4
Length to anus	11.6	15.0	12.1	18.5	12.0
Head length	3.3	4.6	3.8	6.0	3.5
Origin of dorsal	7.0	10.0	8.4	11.0	8.1
Dorsal highest	—	—	—	—	—
End dorsal	10.0	12.8	18.4	13.8	10.0
Origin of adipose	11.0	14.9	11.2	18.0	10.3
Adipose highest	—	—	—	—	—
End adipose	15.1	17.4	15.0	21.0	14.0
Rays dorsal	10	11	9	11	10
rectoral	No rays	7	18	24	21
caudel	18	17	None	11	No rays
pelvic	Present no rays	Present no rays	None	9	—
anal	11	11	13	10	12
Pelvic insertion	8.6	11.0	9.0	12.0	13.8
Lower jaw	Inferior	Inferior	Terminal inferior	Inferior	Terminal superior
Dorsal greater, less than or equal to 1/2 standard length	Less than	Greater than	Less than or equal to	Less than	Greater than

APPENDIX F. Continued

Stage	*C. artedii*	*C. clupeaformis*	*C. hoyi*	*P. cylindraceum*	*S. leucichthys*
12 Metalarvae					
Date	15 Apr. 76	7 Mar. 76	28 Apr. 77	6 June 76	11 May 77
Days after hatch	43	46	59	115	95
Figure	37	—	44	50	56
Myomeres pre/post	52-55 34-37/16-19	54-56 38-40/16-17	52-54 35-38/15-16	37-38	60-61 40-41/19-20
Total length	23.8	24.0	25.0	35.0	30.0
Standard length	20.0	20.8		28.5	24.4
Length to anus	15.3	16.0		21.0	18.2
Head length	4.4	4.5	Specimens dried up	7.0	7.0
Origin of dorsal	9.5	10.4		13.0	12.5
End of dorsal	12.7	13.4		17.0	15.4
Origin of adipose	14.6	15.0		22.0	19.2
End of adipose	18.0	19.0		24.6	21.5
Rays dorsal	11	11	12	12	12
caudal	24	21	21	24	24
pectoral	10	10	10	14	13
pelvic	10	7	10	10	10
anal	13	10	13	10	16
Pelvic insertion	10.6	11.2	—	13.8	13.6
Lower jaw	Equal	Inferior	Equal	Inferior	Equal to superior
Dorsal greater, less than or equal to 1/2	Less than or equal to	Greater than or equal to	Less than or equal to	Less than	Greater than
13 Juvenile					
Date	28 June 76	15 Apr. 76	27 July 77	29 June 76	27 July 77
Days after hatch	123	92	145	137	172
Figure	38	—	44	51	57
Myomeres pre and post anal	—	—	—	—	—
Total length	39.5	41.0	46.0	44.5	47.0
Standard length	32.5	34.0	38.0	37.5	38.3
Length to anus	23.1	26.5	28.5	27.5	30.0
Head length	7.2	9.0	11.0	9.0	11.0
Origin of dorsal	15.0	17.0	19.0	17.0	20.0
End of dorsal	18.4	22.0	23.0	22.0	23.8
Origin of adipose	23.3	27.0	29.0	28.0	30.0
End of adipose	28.0	30.0	34.0	31.0	34.5
Rays dorsal	10	12	41	13	12
caudal	24	22	21	24	24
rectoral	15	15	14	14	15
pelvic	11	11	10	9	10
anal	13	12	12	10	16
Pelvic insertion	16.0	19.2	20.0	18.5	21.9
Lower jaw	Equal	Inferior	Equal to superior	Inferior	Superior
Dorsal greater, less than or equal to 1/2 standard length	Less than	Greater than or equal to	Less than	Less than	Greater than