GREAT LAKES FISHERY COMMISSION

Project Progress Report[1]

Studies Towards a more Efficient Method of Predicting Metamorphosis in Larval Sea Lampreys, *Petromyzon marinus*

by

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December 1995

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Year 1 Progress Report - 1995

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December 1, 1995

Introduction

The sea lamprey management program has achieved partial control of lamprey abundance in the Great Lakes primarily through the application of a selective toxicant, 3-trifluoromethyl-4-nitrophenol (TFM), that kills larvae in their natal streams. In response to socio-economic and environmental concerns, the Great Lakes Fishery Commission (GLFC) is committed to reducing reliance on chemical control and using alternative control technologies to suppress sea lamprey abundance in the Great Lakes. Some alternative technologies such as barrier dams and the sterile-male-release technique (SMRT) have been implemented or are at the experimental stage of their development.

Metamorphosis is an essential event for the acquisition of the parasitic behavior in sea lamprey and has been identified as a potential point from which alternative control methods might be devised (Lamsa et al. 1980). Until recently not enough was known about developmental or environmental cues of metamorphosis to even contemplate manipulating the event, nor was it possible to precisely identify presumptive metamorphosing animals prior to the occurrence of this event. Recent findings in our laboratory relevant to the studies described in this report include:

1. Differences in water temperature (Purvis 1980; Youson et al. 1993) but not photoperiod (Cole and Youson 1981; Youson et al. 1993) in the month prior to the normal commencement of metamorphosis affects the number of animals metamorphosing. The incidence of metamorphosis is significantly greater in warm water (e.g., 21 °C) compared with colder water (e.g., 13 °C).
2. Lamprey larvae in the presumed arrested growth-phase require a winter chill period to prepare physiologically for metamorphosis followed by rising temperature in the spring to initiate the event (Holmes et al. 1994; Holmes and Youson 1994). The absence of either component of the seasonal temperature cycle significantly reduces the number of

animals that will metamorphose under laboratory conditions.

3. The size (length and weight) and condition factor of ammocoetes in the spring or fall provides an accurate means of identifying larvae likely to enter metamorphosis the following summer under controlled conditions in the laboratory (Youson et al. 1993; Holmes and Youson 1994; Holmes et al. 1994).

This project on sea lamprey metamorphosis has two major components. The first part consists of studies designed to validate the utility of our predictors of metamorphosis under field conditions and to fine-tune these predictors using weight-length relationships. The other part of our project consists of studies designed to provide more definitive information on the age of metamorphosing animals and the nature of the relationship between temperature and the incidence of metamorphosis. A combination of field and laboratory studies are described below to address the following objectives:

1. Assess the utility of the size and condition factor criteria for predicting metamorphosis in larval sea lamprey populations from field data collected in the fall and spring;
2. Determine weight-length relationships of larval sea lamprey populations and assess variation in slope as related to season and locale;
3. Determine the age and variability in age of metamorphosing larvae in Great Lakes populations; and
4. Determine the relationship between the incidence of metamorphosis and temperature.

The first year of our studies and this report focus on our activities to address objectives 1, 2, and 3. In the second year we will continue work to finish these objectives and will address objective 4 as well. A new graduate student, Anna Hollett, is addressing objectives 1 and 3 for her M.Sc. degree under the supervision of both contractors.

1. An assessment of the practical field value of size and condition factor criteria for predicting metamorphosis of sea lamprey.

Short-term studies in 1991 and 1992 (early June to mid-August) established that larvae at least 120 mm and 3.0 g in size and with a CF $\geq$ 1.50 (CF=weight/length^3 x 10^6) in the spring enter metamorphosis in July of that year. Those larvae of the appropriate size (length and weight) but with a CF < 1.50 do not enter metamorphosis and require at least one more year to increase lipid levels to about 14% of their body weight (Youson et al. 1993). These minimum criteria were also used in the fall to identify animals likely to metamorphose the following summer (Holmes and Youson 1994; Holmes et al. 1994). The length criterion identifies larvae in the arrested growth phase of the larval period (i.e., a period when length changes little but weight increases greatly) while the weight and CF criteria identify those larvae of the appropriate size with sufficient lipid reserves to enter and survive metamorphosis. The size and CF criteria together seem to be a more accurate tool for predicting the proportion of larvae in a population likely to enter metamorphosis the following summer than a 120 mm criterion alone, which greatly overestimated the incidence of metamorphosis in the four populations for which we have made comparisons (Youson et al. 1993; Holmes and Youson 1994; Holmes et al. 1994).

We began a field study to test the practical utility of the size and condition factor criteria for predicting metamorphosis in the fall of 1995. In consultation with the the Sea Lamprey Control agent in Sault Ste. Marie, we identified streams suitable for this study based on temperature and electrofishing efficiency and effectiveness. We have chosen three streams in the Lake Ontario watershed representing fast growth conditions (warm water streams), and three in the Lake Huron watershed representing slow growth conditions (cold water streams) (see Table 1). Because we require ammocoetes that are larger than 120 mm and 3.0 g in size, we are using streams that will be recommended for lampricide treatments in 1996, with the exception of Cannon Creek (West West

Root River, which was treated in 1995 along part of its length). We have asked the Canadian control agents in Sault Ste. Marie to delay their treatments until after August 15, 1996 but as of December 1 treatment decisions have not been made. However, the practical effect of our request, if granted, is that treatment of the streams in the Lake Ontario watershed would have to be delayed until the fall of 1996 whereas those in the Lake Huron watershed are local to Sault Ste. Marie and probably can be treated mid-August or later.

Between the end of September and November 21 we captured, tagged, and released sea lamprey larvae ≥ 120 mm and 3.0 g in size in Gordon, Oshawa, and Wilmot Creeks (Table 1). The animals are tagged with sequential coded wire tags in the dorsal muscle mass (Bergstedt et al. 1993) so that they will be individually identifiable upon recapture in the summer of 1996. Because of bad weather and false starts in two streams we were only able to tag animals in three of our six study streams. Although there are no significant differences ($P > 0.05$) in the average lengths, weights, and CFs of larvae tagged and released in the fall of 1995, larvae from Gordon Creek tended to be longer and heavier but have lower CFs than larvae from the two southern populations (Fig. 1). Based on their size and CFs, we predict that 23% of the animals tagged in Gordon Creek and 46 and 64% of the tagged animals in Oshawa and Wilmot Creeks respectively, will enter metamorphosis in the summer of 1996.

We attempted to use two other streams but rejected them because we could not get enough large sea lamprey (i.e., ≥ 120 mm and 3.0 g in size). Grassy Creek, a tributary of the Serpent River, Lake Huron, yielded only six large larvae despite electrofishing from its mouth to the upstream limit of sea lamprey distribution (i.e., the 20 m high falls above Highway 17). Cobourg Brook (a tributary of Lake Ontario) produced only 16 large sea lamprey despite extensive electrofishing in the main stem and a western tributary (Factory Creek) which historically use to be the most heavily infested section in this watershed.

Table 1. Streams chosen for field trial of size and condition factor criteria and the results of electrofishing activity in the fall of 1995. Streams with blank columns will be electrofished in the spring of 1996.

	Lake Huron streams			Lake Ontario Streams		
	Gordon Ck.	Richardson Ck.	Cannon Ck.	Oshawa Ck.	Wilmot Ck.	Shelter Valley Ck.
Number tagged	344			259	113	
Metamorphosing[A]	78 (22.7%)			120 (46.3%)	72 (63.7%)	
Non- metamorphosing[B]	266			139	41	
Statolith validation[C]	50			55	15	
Number for aging (< 120 mm)	≈180			≈172	≈398	
Total number of animals captured	≈574			≈486	≈526	

A Number of animals predicted to metamorphose in the summer of 1996 based on a size ≥120 mm and 3.0 g and a CF ≥ 1.50) and the percentage of total number tagged in brackets below.

B These animals are ≥ 120 mm and 3.0 g in size but CF < 1.50.

C Animals returned to our laboratory at Scarborough College for validation of statolith aging through metamorphosis. All animals are ≥ 120 mm and 3.0 g in size and were not tagged.

Field work to tag and release large larvae in Richardson, Cannon, and Shelter Valley Creeks will begin as soon as weather and runoff permit in the spring of 1996. We will be combining our efforts with those of F.W.H. Beamish and B. Morrison at the University of Guelph who are conducting a BOTE study of density effects on growth in streams near those we have chosen to use. All six study streams will be resampled between the end of July and the end of August 1996 after metamorphosis has begun but before the event is completed. The size, CF, and metamorphic status of recaptured animals will be compared with their original data from the previous spring or fall to assess the accuracy of our predictions. Water temperatures of each of the study streams will be recorded using thermographs beginning in the spring of 1996. All of the data should be compiled and analyzed by December 1996 and a manuscript describing the study should be available by the spring of 1997.

Both the condition factor and the influence of water temperature on the incidence of metamorphosis have significant implications for the control of sea lamprey abundance. The ability to identify presumptive metamorphic larvae more precisely in the fall, in conjunction with the use of temperature data will allow for a more accurate determination of the proportion of ammocoetes metamorphosing in a stream. As well, this type of information will allow the control agents to identify the relative importance of different streams as producers of parasitic phase animals in the Great Lakes. Holmes and Youson (1994) suggested that some larvae of the appropriate size (≥120 mm and 3.0 g) but with a CF of 1.45-1.49 in the fall may fatten up over the winter, attaining a CF of 1.50 or greater, and enter metamorphosis the following July. Our field study will also provide an indirect test of of whether fattening can occur during the winter since recaptured animals can be identified individually.

2. Weight-length Relationships of Larval Sea Lamprey Populations

The exponent of length in the CF criterion is the slope (b) of the weight-length relationship (i.e., $W = aL^b$). Using an exponent of 3 assumes that growth of sea lamprey larvae is isometric, i.e., body form and specific gravity do not change as individuals grow larger. This assumption has not been formally tested partly because there are few published weight-length data sets for sea lamprey larvae. There is evidence that growth in some lamprey larvae populations may be allometric, with exponents of the weight-length relationship less than 3 (O'Boyle and Beamish 1977; Beamish and Austin 1985) implying that weight increases proportionately slower than length. Within a group (e.g., animals > 120 mm in length or an age-class) the functional exponent b could differ from 3 at the same time as the same exponent for the overall weight-length relationship does not differ from 3 (Ricker 1975). Weight-length relationships and CFs of teleosts are known to vary with age, season, sex, locality and other factors (Ricker 1975). We are testing the hypothesis that growth is isometric in landlocked populations of sea lamprey larvae in the arrested growth phase of the life cycle by estimating weight-length relationships for all populations treated with lampricide in the spring and fall of one field season since our laboratory data apply to these periods.

Sea lamprey larvae were collected in an ad hoc fashion during some lampricide treatments on Lakes Ontario and Huron in 1993 (J.A. Holmes, unpublished data) and a more systematic effort was undertaken in 1995 with the help of the Canadian control agent in Sault Ste. Marie (Table 2). In both years a representative sample of all sizes of sea lamprey larvae killed during a lampricide treatment was collected and frozen (1993) or preserved in formalin or 95% alcohol (1995). Lengths and weights of frozen or preserved animals were back-calculated to live lengths and weights using relationships published by Morkert and Bergstedt (1990) for formalin or relationships developed in our laboratory for this purpose (frozen and 95% EtOH). Live lengths

Table 2. Collections of sea lamprey larvae killed during lampricide treatments for determination of weight-length relationships.

Stream	Lake	Collection Date	Preservation
	1993		
Wilmot Creek	Ontario	April	fresh
Oshawa Creek	Ontario	April	fresh
Skinner Creek	Ontario, NY	May	frozen
Lindsey Creek	Ontario, NY	May	frozen
South Sandy Creek	Ontario, NY	May	frozen
Duffins Creek	Ontario	June	frozen
Trout River	Huron, MI	June	fresh
Hartwick Creek	Huron, MI	June	fresh
Pigeon River	Huron, MI	June	fresh
	1995		
Snake Creek	Ontario, NY	May	95% EtOH
Sodus Creek	Ontario, NY	May	95% EtOH
Little Sandy Creek	Ontario, NY	May	95% EtOH
Deer Creek	Ontario, NY	May	95% EtOH
Salmon River, Main	Ontario, NY	May	95% EtOH
Salmon River Pekin Brook	Ontario, NY	May	95% EtOH
Salmon River Trout, John, & O'Hara	Ontario, NY	May	95% EtOH
Bronte Creek[A]	Ontario	June	fresh
Proctor Creek	Ontario	June	95% EtOH
Lakeport Creek	Ontario	June	95% EtOH
Boyne River	Huron	June	95% EtOH
Sturgeon River[A]	Huron	June	fresh
Gargantua River	Superior	June	95% EtOH
Farewell Creek[A]	Ontario	Sept	formalin
Lynde Creek[A]	Ontario	Sept	formalin

[A] Heads were removed and frozen for later statolith aging from 50 animals $\geq$ 120 mm and 3.0 g in size.

and weights of animals that were frozen and then thawed for measurement were calculated using the following regressions developed using larvae collected from Duffins Creek in 1993:

$$LL = 1.114*ThL + 1.081, R^2 = 0.99, N = 30; \text{and}$$

$$LW = 1.185*ThW + 0.122, R^2 = 0.995, N = 30,$$

where LL is live length (mm), LW is live weight (g), and ThL and ThW are thawed lengths (mm) and weights (g) respectively. Heads were also frozen for statolith aging from 50 animals at least 120 mm and 3.0 g in size from four populations (Lynde, Farewell and Bronte Creeks and the Sturgeon River), from which we made the collections in 1995.

Length and weight data were collected from 9 populations of sea lamprey larvae in 1993 and 15 populations in 1995 (Table 2). At present, weight-length relationships have been estimated for all populations in 1993 and 7 populations in 1995 (Table 3). The slopes of the relationships estimated for live length and weight data in 1993 (8 datasets) and 1995 (2 datasets) ranged from 2.24 to 2.76 compared with slopes of 2.75 to 3.34 estimated from preserved lengths and weights in 1995 (5 datasets). Since the data are incomplete, we have not analyzed them to determine if the slopes vary significantly from 3 nor has an ANCOVA analysis been completed to examine differences in slopes related to locality. However, from the limited data shown in Table 3, slopes from larval populations at the southern end of the range in the Great Lakes (New York) seem to be higher than slope values reported for other populations. This difference is not related to season since all collections shown in Table 2 were made between late April and early June; we do not know yet if some or all of the difference is related to comparing relationships from preserved and live lengths and weights. One interpretation of these data is that the rate of weight increase in larvae from New York is greater compared with other populations in the Great Lakes. Thus, larvae in New York may attain the appropriate size for metamorphosis (≥120 mm and 3.0 g) at a

Table 3. Estimated sea lamprey weight-length relationships. Regressions are in the following form: Log_{10} (weight, g) = $\text{Log}_{10}\, a + b * \text{Log}_{10}$(length, mm).

Stream	Lake	N	r^2	$\text{Log}_{10}a$	b
		1993			
Wilmot Creek	Ontario	499	0.98	-4.25	2.26
Oshawa Creek	Ontario	275	0.94	-4.75	2.52
Skinner Creek	Ontario, NY	106	0.93	-4.59	2.42
Lindsey Creek	Ontario, NY	259	0.97	-4.22	2.24
South Sandy Creek	Ontario, NY	274	0.96	-5.14	2.69
Trout River	Huron, MI	226	0.99	-5.16	2.69
Hartwick Creek	Huron, MI	32	0.97	-5.30	2.76
Pigeon River	Huron, MI	212	0.97	-5.02	2.62
		1995			
Snake Creek, ± Stn 12[A]	Ontario, NY	148	0.96	-5.72	2.98
Snake Creek, Stn 9[A]	Ontario, NY	120	0.98	-6.46	3.34
Sodus Creek[A]	Ontario, NY	422	0.94	-6.12	3.16
Bronte Creek[B]	Ontario	122	0.98	-5.18	2.72
Lakeport Creek[A]	Ontario	317	0.98	-5.21	2.75
Boyne River[A]	Huron	355	0.96	-6.01	3.05
Sturgeon River[B]	Huron	435	0.98	-4.93	2.59

[A] Based on preserved lengths and weights that have not been back-calculated to live lengths and weights.

[B] Based on live lengths and weights.

younger age than larvae in more northerly populations. Data from the remaining populations will be compiled and analyzed over the winter of 1995-96 and a manuscript will be prepared for publication by the spring of 1996.

3. Age and variability in age of metamorphosing larvae in Great Lakes populations.

A general consensus exists among researchers that larval sea lamprey enter an arrested growth phase prior to metamorphosis (e.g., Hardisty and Potter 1971; Potter 1980; Youson 1988). During this period, which marks the end of the larval stage of development, there is no increase in length but weight increases. This weight increase is in the form of lipid which will be used to see the animal through the non-trophic metamorphosis. Thus, metamorphosing animals should be at least a year older than non-metamorphosing larvae of the same size. The age of metamorphosing animals is also related to the growth rate of the larvae (Potter 1980). Growth is faster in warm productive streams compared with colder less productive habitats (Potter 1980; Holmes 1990; Young et al. 1990) so larvae should enter metamorphosis at a younger age in streams that normally have warmer summer temperatures.

We have been collecting animals for statolith aging to test two hypotheses:

i) because sea lamprey enter an arrested growth phase prior to metamorphosis, metamorphosing animals are at least one year older than non-metamorphosing ammocoetes of the same size (length and weight); and

ii) that sea lamprey ammocoetes metamorphose at a younger age in warm streams with favorable growth conditions compared with sea lamprey living in streams with colder water temperatures.

A validation study of statolith aging during metamorphosis is necessary since we do not know if an annulus is formed on the statolith during metamorphosis, or if there is resorption of the statolith during metamorphosis that would influence the number of annuli counted for aging. Note that an annulus consists of that portion of the statolith laid down during one year (i.e., a light portion laid down during fast growth in the summer and a dark band laid down during the winter [Medland and Beamish 1991]) but for practical purposes we refer to the dark bands as annuli. Approximately 50 sea lamprey ammocoetes greater than 120 mm and 3.0 g in size and varying numbers of ammocoetes < 120 mm long were collected from each of the three study streams sampled in the fall (Table 1). These lamprey were transported to Scarborough and have been maintained in the laboratory. The large animals will be injected or immersed in oxytetracycline (OTC, 35 mg/kg) to put a mark on the statolith in the fall (Beamish and Medland 1988), and kept until the following summer when metamorphosis begins. After metamorphosis has taken place, the lamprey will be sacrificed and aged using their statoliths. Ten large ammocoetes marked with oxytetracycline will be killed in the spring to ensure that a marker is present on the statolith and to measure the distance from the marker to the edge of the statolith for determining if resorption or growth of statoliths occurs during metamorphosis. The smaller (<120 mm) ammocoetes will be used to test different marks and delivery methods, and to provide evidence that we can discriminate the number of annuli with animals of different ages. Approximately 50 large larvae collected in the spring of 1996 from Richardson, Cannon, and Shelter Valley Creeks will be marked with OTC and will be kept until metamorphosis begins to assess statolith changes during metamorphosis.

Statoliths will be available from at least 12 populations to test our hypotheses (Table 4). Some are from animals used in past experiments (Chippewa River, MI, Great Chazy River, NY, Brown Creek, Ontario), some are from animals killed during lampricide treatments in 1995 (Bronte and Sturgeon Rivers, Farewell and Lynde Creeks), and some will be collected from animals killed in the lampricide treatments of the six populations used in our field test of size and CF. Most of these collections consist of statoliths from approximately 50 animals ≥ 120 mm and 3.0 g in size.

Table 4. Sea lamprey larvae used in statolith validation and aging studies.

Validation	Aging
Richardson Creek[A]	Richardson Creek[A]
Cannon Creek[A]	Cannon Creek[A]
Shelter Valley Creek[A]	Shelter Valley Creek[A]
Gordon Creek	Gordon Creek
Wilmot Creek	Wilmot Creek
Oshawa Creek	Oshawa Creek
	Great Chazy River, NY[B]
	Chippewa River, MI[C]
	Sturgeon River
	Bronte Creek
	Farewell Creek
	Lynde Creek

[A] To be collected in the spring of 1996.
[B] Collected in 1991, 1993, and 1996.
[C] Collected in 1991.

During the winter of 1995-96 the statoliths will be removed and prepared by immersing them in glycerine at room temperature for two weeks prior to mounting on slides in acetone soluble Crystalbond adhesive. Annuli on each statolith will be counted three times and an index of error will be calculated for each population (see Beamish and Medland 1988; Medland and Beamish 1991).

4. Determine the relationship between the incidence of metamorphosis and temperature.

A short-term experiment was conducted between May and August 1995 to compare the effects of two densities and a constant and rising temperature regime on the incidence of metamorphosis in landlocked sea lamprey. Treatments consisted of densities of 10 animals/tank (55 larvae/m^2) and 30 animals/tank (164 larvae/m^2) and temperatures of a constant 21 °C and a regime rising from about 15 °C (ambient when the animals were collected) to 21 °C by mid-June. Larval sea lamprey were collected May 9-12, 1995 from Beaverdam Brook, New York, a tributary of the Salmon River, which drains into Lake Ontario. The experiment was started on May 17, which is about 2 weeks in advance of the starting date of previous short-term experiments (e.g., Youson et al. 1993), and was terminated August 10, 1995. Tanks (60 cm long, 30.5 cm wide, 30 cm high) were supplied with about 7 cm of sand for burrowing, a continuous flow of aerated, dechlorinated tap water at rates of 0.5-0.6 L/min, a water depth of 12-15 cm, and a photoperiod of 15 h light:9 h dark from lights (4 fluorescent tubes) suspended 40 cm above the water surface. Animals were fed baker's yeast once weekly at a rate of 1 g/animal/week. The volume of yeast solution was adjusted depending on the density in each tank to ensure similar food quantities per animal (225 mL of solution for 10 animals, 675 mL for 30 animals), eliminating competition for food as a confounding factor. Thus, if density has an effect in this experiment, that effect should be related to space rather than food.

The incidence of metamorphosis does not appear to be significantly affected by either temperature or density independently (Fig. 2). The incidence of metamorphosis ranged from 50 to 90% of the animals in a tank, with means for each treatment ranging from 58 to 67% (Fig. 2). In contrast, short-term exposure to the temperature and density treatments we used may have influenced the size of metamorphosing animals . Animals metamorphosing in the constant temperature (21 °C) and high density conditions appear to be smaller than animals metamorphosing in other combinations of temperature and density (Fig. 3); there were no significant differences in the size of larvae among treatment combinations when the experiment began in May ($P > 0.05$). However, variation among replicate tanks is high, and is perhaps sufficient to overshadow effects related to density. Proportionately more animals were metamorphosing in the low density-constant temperature conditions (72.5%) compared with the other treatment combinations where 57.5-59% of the animals were metamorphosing (Fig. 4). More complete results will be available after the statistical analyses are completed in the next two months.

Purvis (1980) found that the incidence of metamorphosis increased with the mean temperature at which sea lampreys were kept beginning in mid-May in each of 4 years. However, many other factors were uncontrolled between temperature "treatments" as larvae were kept in aquariums in the laboratory and in cages in the Big Garlic River and Lake Superior. We plan to conduct a short-term laboratory study of the relationship between the incidence of metamorphosis and fixed water temperatures in the summer of 1996. We expect that the relationship will be a unimodal curve skewed towards warm temperatures, with the peak incidence of metamorphosis occurring near the preferred temperature of larval sea lampreys, which Holmes and Lin (1994) reported was about 21 °C during the summer. Between the lower limit and the optimal temperature, the relationship is probably direct and positive as implied by Purvis (1980).

An experiment to determine the relationship between the incidence of metamorphosis and water temperature will be conducted **from early June to mid-August 1996** at Scarborough College. The animals for this study will be collected from either South Sandy Creek (Lake Ontario) or the Great Chazy River (Lake Champlain) in New York. Constant temperatures of 9, 13, 17, 21, and 25 °C will be used, with 4 replicate tanks per temperature. Larvae (N = 600) will be at least 120 mm and 3.0 g in size and will be randomly sorted into aquaria at a density of 30 per tank (164 larvae/m^2), held at a photoperiod of 15 h light:9 h dark, and fed 1.0 g yeast/larva/week. Lengths and weights will be measured at the beginning of the study in June and again at the end of July when the stage of metamorphosis will also be determined. The study will be terminated by mid-August when a final determination of the staging will be made.

Our experience suggests that the results of short-term studies from June to August are directly comparable to long-term overwinter studies with respect to temperature in that they simulate average stream temperatures experienced by larvae in the critical period prior to the commencement of metamorphosis. These data will provide information on the nature of the relationship between the incidence of metamorphosis and temperature. Combining these data with the results of our field validation of the size and CF criteria may provide a simple tool for predicting the incidence of metamorphosis among larvae of suitable size and physiological condition (i.e, condition factor), based on water temperature.

Deliverables for 1996

All of our studies that are presently underway should be completed in 1996. Specific deliverables include:

1. a report on the utility of size and CF for predicting metamorphosis in the field using data obtained in the fall or spring preceding the event (probably ready in early 1997),

2. a report on weight-length relationships and potential modifications to the CF criterion for predicting metamorphosis,
3. a report on validating statolith aging in metamorphosing animals and comparisons of the age of metamorphosing and nonmetamorphosing animals of the same size (i.e., supporting or refuting evidence for the concept of an arrested growth phase at the end of the larval period) (probably ready in early 1997),
4. a report on the relationship between temperature and the incidence of metamorphosis across a broad spectrum of temperatures, so that temperature limits for metamorphosis can be established, and
5. a report discussing the effects of temperature and density on the incidence of metamorphosis under laboratory conditions.

These reports will be in the form of manuscripts suitable for publication in journals.

The size and CF criteria may provide a better way of discriminating premetamorphic larvae from those not likely to enter metamorphosis. Knowledge of larvae meeting the minimum size criteria and CF values combined with data on temperature may provide a means of more precisely determining the number of larvae metamorphosing in a stream and hence the relative importance of different streams to the abundance of parasitic phase sea lamprey in the Great Lakes. Such information may allow more precise scheduling of lampricide treatments, perhaps resulting in less frequent treatments in some streams and a one-time reduction in lampricide use.

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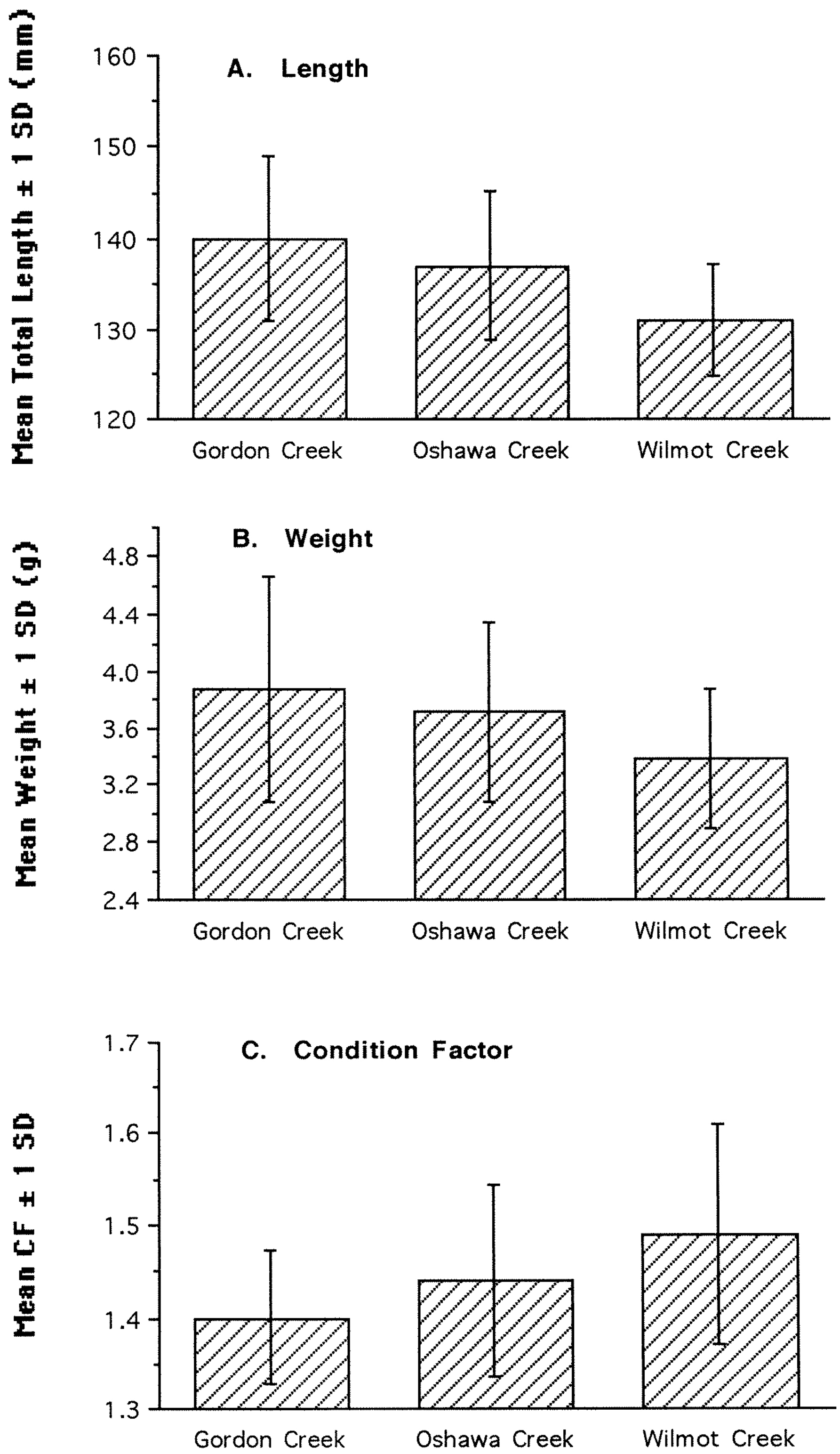

Figure 1. Mean size and condition factor (± 1 SD) of sea lamprey larvae from Gordon, Oshawa, and Wilmot Creeks tagged in the fall of 1995.

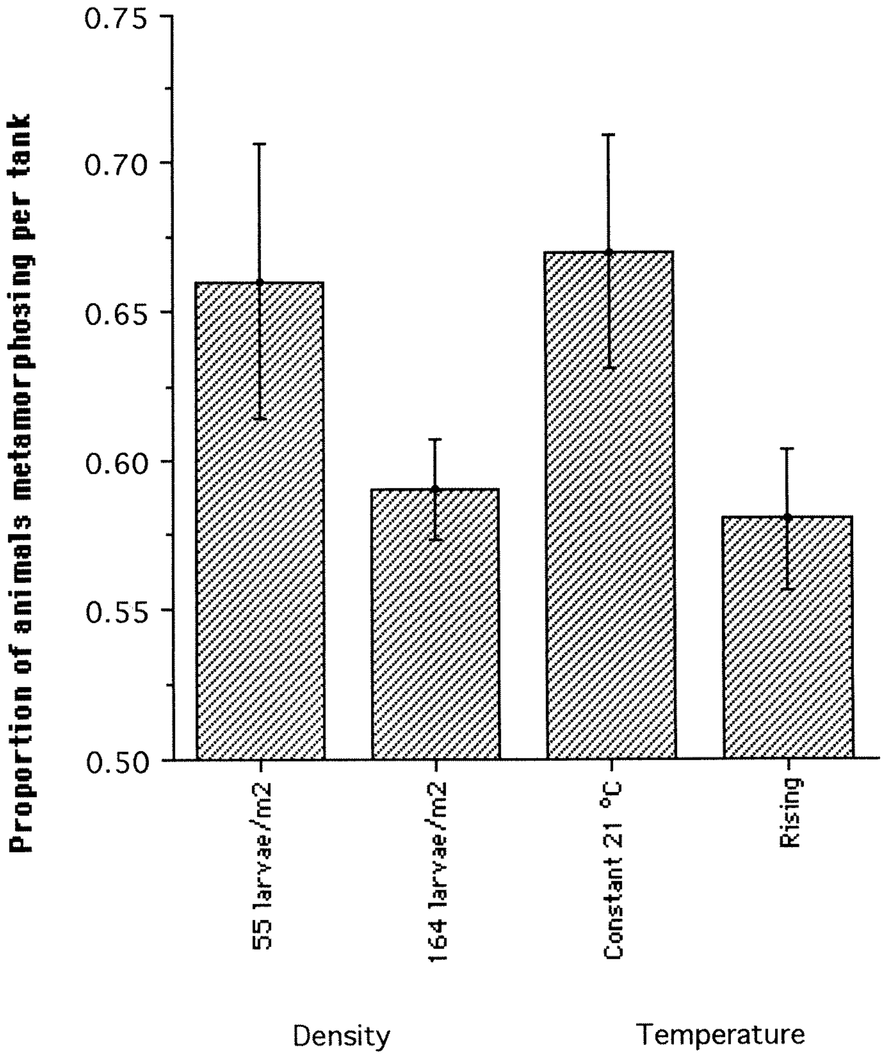

Figure 2. Incidence of metamorphosis in a short-term temperature-density experiment, May-August 1995.

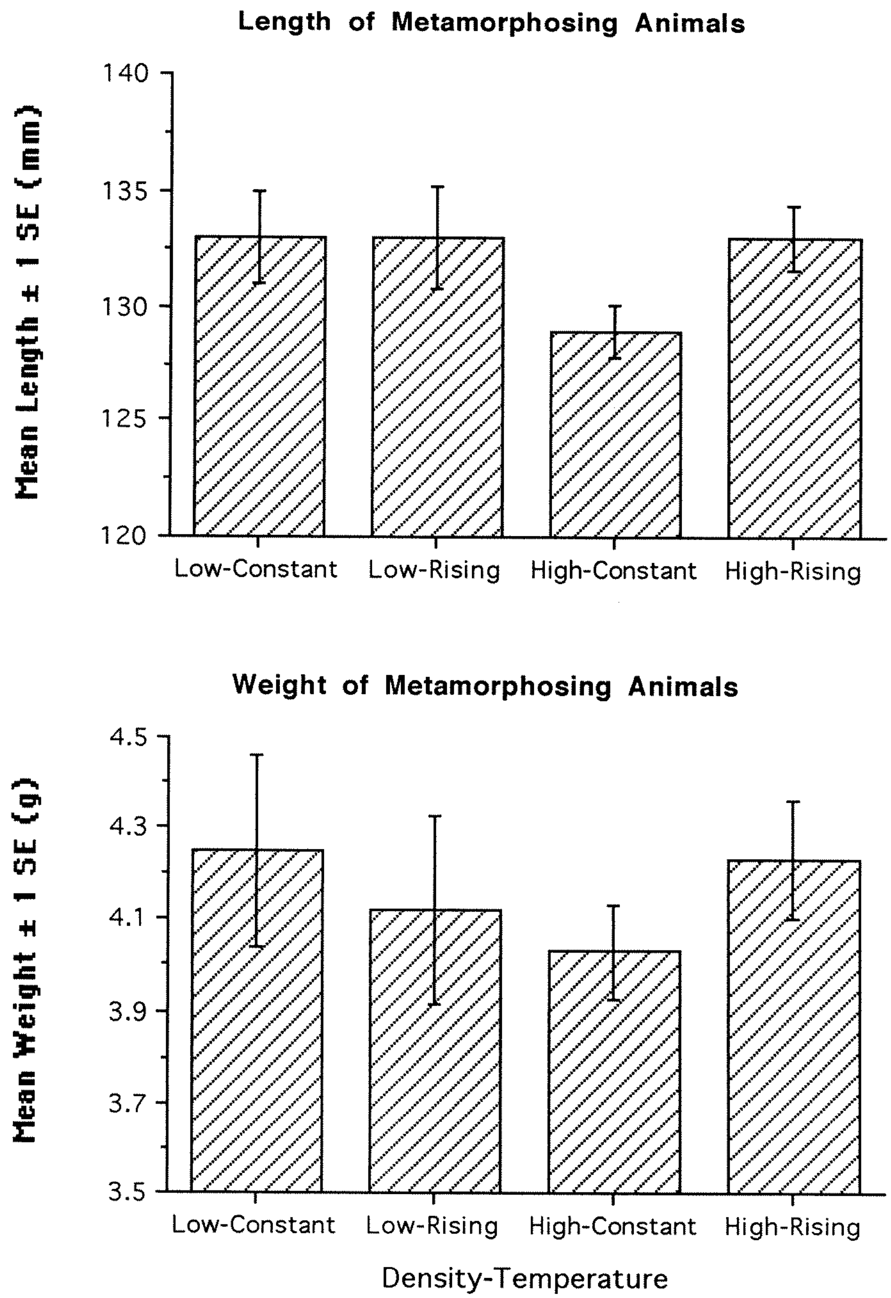

Figure 3. Size of metamorphosing sea lamprey in August 1995.

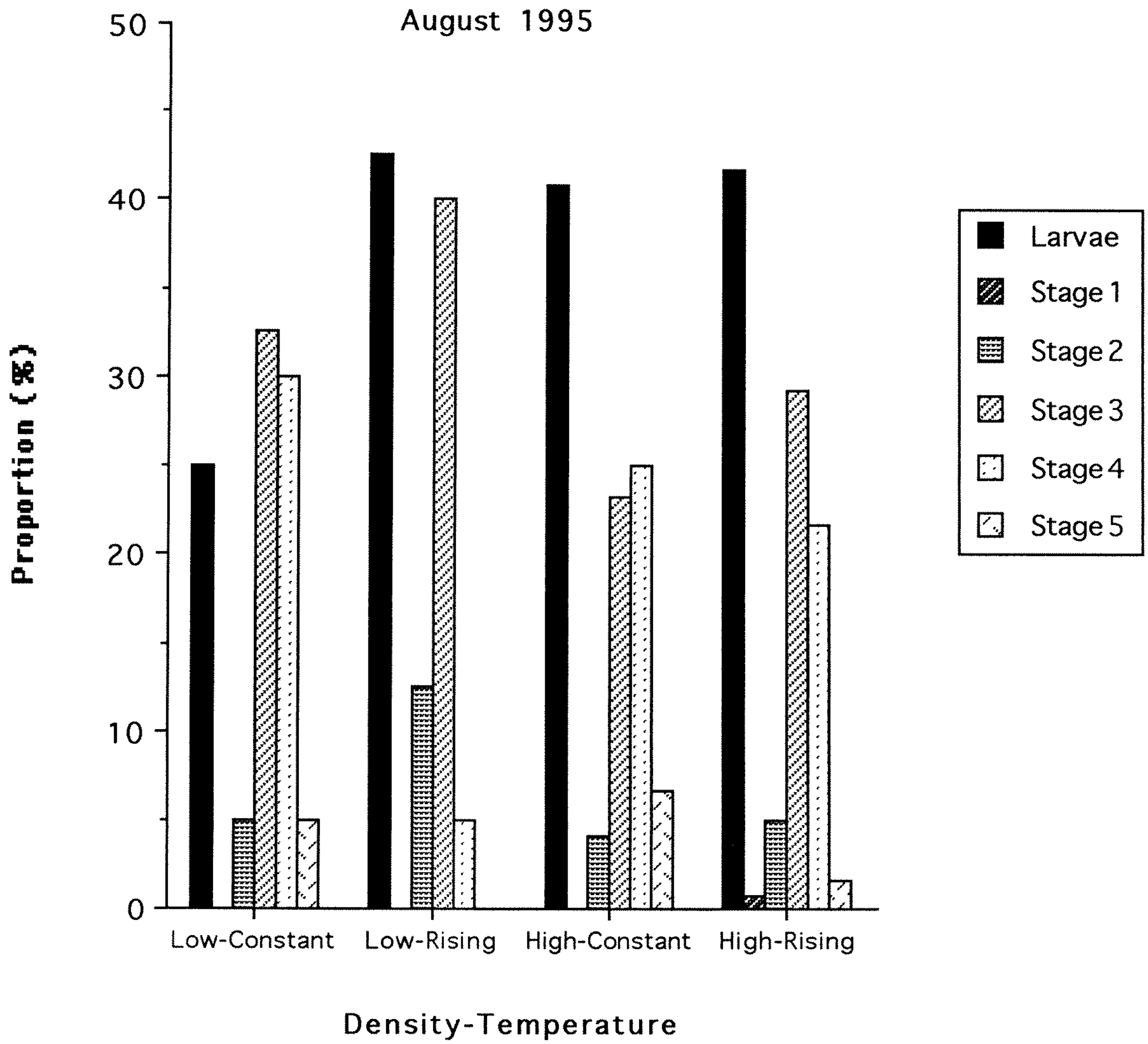

Figure 4. Metamorphic stages attained by sea lamprey in mid-August 1995.