SWIMMING PERFORMANCE OF ARCTIC GRAYLING IN HIGHWAY CULVERTS

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INTRODUCTION

The principle purpose of this study is to establish design criteria for culverts that will insure the maintenance of fish populations in streams traversed by the proposed Alaska Pipeline and its supporting highway.

The original objectives of the study were:

a) to determine the sustained swimming speed of mature Arctic grayling (*Thymallus arcticus*) during their spawning run in an inclined culvert in which flows and velocities were regulated,

b) to determine the cruising speed of various size-classes of grayling in a circular channel at prevailing stream temperatures, and,

c) to investigate the influence of water temperature on the swimming performance of arctic grayling in controlled bioassay laboratories at the University of Idaho.

In this report we use the terminology of Bell (1973) for defining swimming speeds. Cruising speed is one that can be maintained for long periods of time (one or more hours), but in our circular channel research, we used one-hour intervals. Sustained speed is one that can only be maintained for a number of minutes and for purposes of our research is used with reference to culvert ascents and 10-minute circular channel tests. Darting or burst speed represents a single, non-sustainable effort and was not determined in this research.

The study required a stream small enough for us to install cheaply a dam to block fish migration and provide a head of water for a culvert facility, yet large enough to provide adequate numbers of grayling for test purposes. We selected Poplar Grove Creek for this purpose.

As the study progressed, grayling and longnose suckers (*Catastomus catastomus*) of all size classes ascended the stream in sufficient numbers to obtain a direct correlation between fish size and swimming performance in an experimental culvert. It was not necessary to develop a scaling factor from circular flume data to predict culvert swimming performance of immature grayling.

In this research we use the term "swimming performance" to mean the capability plus the motivation of a fish to swim at a maximum rate of speed. Swimming capability refers to the physical ability of a fish to swim. The speed is mainly dependent on size and body temperature. In contrast, the voluntary response or motivation of a fish to swim at a maximum rate of speed is governed by the psychological and physiological state of the fish, which can be influenced by many factors, including temperature.

Water temperatures at the culvert site, where the circular flume was assembled, varied from 0 to 17 C in 1973. This range was considered sufficient to determine the effect of temperature on swimming speed for the usual temperature range of Alaska grayling habitat and thus data from controlled bioassay laboratory tests were not needed to scale probable swimming velocities. In 1974, additional tests were made at low temperatures to supplement the 1973 data.

Swimming speed studies in the circular channel were expanded well beyond what was initially planned. The performance of grayling moving upstream in Poplar Grove Creek was compared to the performance of fish moving downstream at corresponding temperatures. Also, marked differences in swimming speed were observed between grayling obtained in Poplar Grove Creek and grayling obtained from Town Lake. We were fortuitous in that sufficient fish were available for this expanded study.

Initially, we designed our research to measure the swimming capability of grayling. However, our preliminary tests suggested that the physiological and psychological state of the fish had to be considered in our analyses of data. Thus, it was necessary to make a comprehensive study to determine factors affecting motivation. Portions of the migration study that relate to swimming performance of grayling in culverts are covered in this report. Aspects of the life history of the longnose sucker in Poplar Grove Creek were studied, but are not reported here.

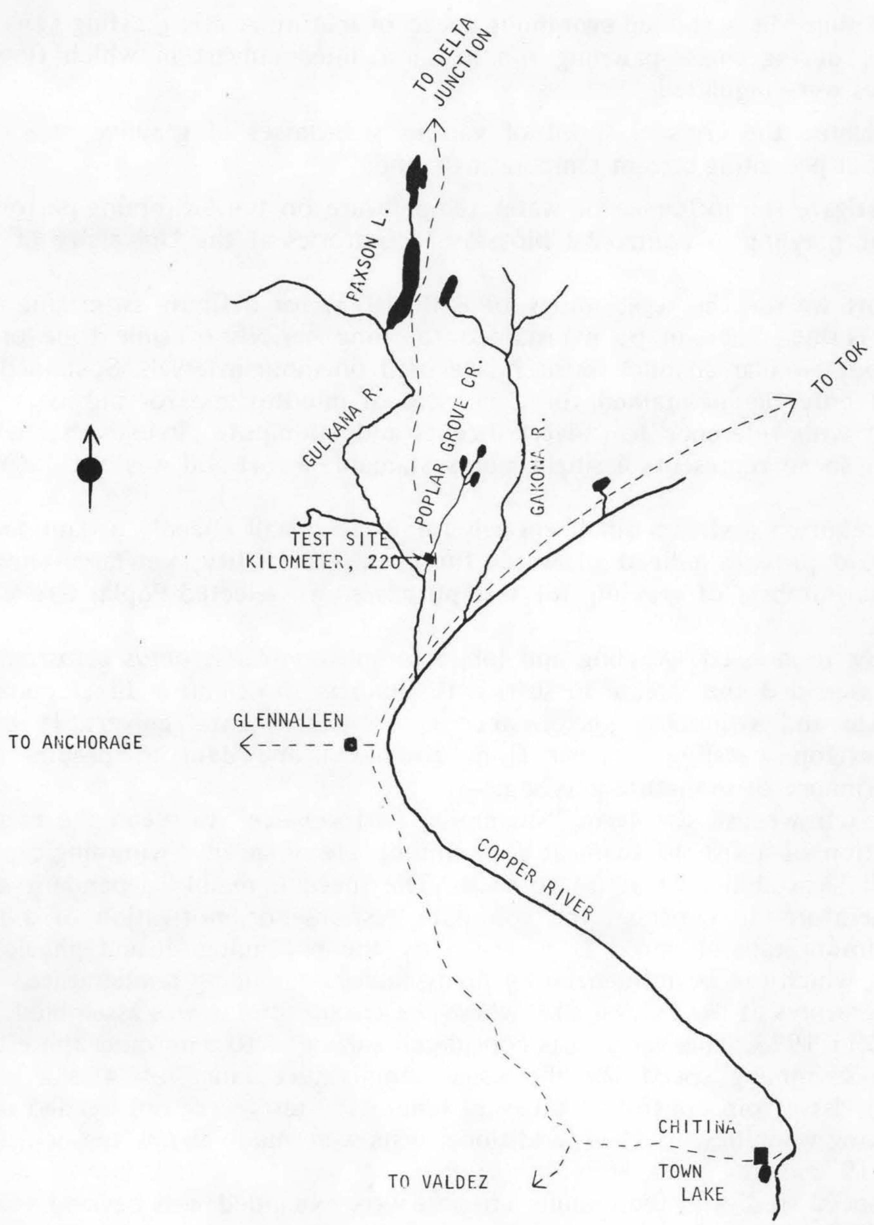

Figure 1. Schematic map of the study region showing the location of the test site and collection areas

POPLAR GROVE CREEK

Topography

Poplar Grove Creek flows into the Gulkana River, a tributary of the Copper River in south-central Alaska. A schematic map indicates the relative position of the study site and fish collection areas (Figure 1). The 8 km long creek originates in a bog drainage containing numerous shallow ponds, several of which drain directly into the creek. Between the Richardson Highway and the mouth of the creek, a distance of about 3 km the stream has a steeper gradient with alternating pool and riffle areas.

Discharge

Typical of small streams in the upper Copper River drainage, Poplar Grove Creek contains no flowing water and therefore no fish during the winter months. The creek began to trickle on 21 April, peaked at 3.3 m^3/s on 28 June due to rainfall and stopped flowing by 21 October, 1973 (Figure 2). Because of an unusually low snow pack and an early, but gradual, spring melt, the stream discharged at a maximum estimated rate of 1.8 m^3/s during May of 1973. In 1974, we recorded flows between 2 May and 20 June. During this period, discharges peaked at 4.2 m^3/s on 10 May (Figure 3). We estimated that the discharge at times could range to 7.1 m^3/s at the study site.

Water Temperature

In 1973, we monitored water temperatures from the time that Poplar Grove Creek thawed until it froze. The water temperature of Poplar Grove Creek was 0 C between 21 April and 10 May, and then increased rapidly to a maximum 6 C on 16 May (Figure 2). Between 17 May and 12 June, stream temperatures remained below 10 C. With the exception of 12 to 16 August, stream temperature was above 10 C from 13 June to 29 August. For two brief periods in July the water reached a maximum of 17 C. Water temperature dropped below 10 C on 30 August and gradually cooled to 4 C by 30 September. October water temperatures were mainly near freezing. Water in the impoundment above the dam froze on 9 October. Minimum air temperature was minus 27 C on 22 October, 1973.

In 1974, the stream was warmer during the culvert tests. Water temperatures averaged 3 C on 13 May when the first of the grayling run arrived, and climbed fairly regularly to peak at 15 C on 31 May when the run of large mature fish was essentially over (Figure 3). Water temperatures varied between 9 and 14 C from 1 to 20 June.

Poplar Grove Creek was characterized by small diel variation in water temperature. Maximum temperatures occurred by late afternoon and minimum temperatures occured during the early morning. Diel temperatures varied mostly between 1 and 2 C during spring and summer. The greatest variation occurred 29 September, 1973, with maximum and minimum water temperatures of 6 and 1 C respectively. A few other daily variations of 3 C occurred also in the fall of 1973.

During the spawning run the Gulkana River flowed considerably colder than Poplar Grove Creek (Table 1). On 20 May, 1973, during the height of the spawning run, the creek was 4 C warmer than the river. On 15 May, 1974, three days after the start of the run, the creek was 3 C warmer than the river at 1900 hr. After the spawning run, the temperature of the river tended to catch up with the creek so that the river was usually only a few degrees colder than the creek.

Table 1. Water temperatures in Poplar Grove Creek and the Gulkana River during the grayling spawning runs in 1973 and 1974

Date	Hr.	Temperature Poplar Grove Creek	Degrees Centigrade Gulkana River
2 May, 1973	1200	0	0
12 May, 1973	1200	2	1
20 May, 1973	1200	6	2
21 June, 1973	0915	12	11
24 June, 1973	1400	10	11
15 May, 1974	1900	6	3
21 May, 1974	1500	10	4
23 May, 1974	1135	11	4
6 June, 1974	1115	11	8
7 June, 1974	1100	11	9

Water Chemistry

Water samples were obtained from Poplar Grove Creek during August, 1973, a low flow period. The water had a very light yellow color, a pH of 7.4, and the following chemical constituents:

Chemistry	mg/l
Total hardness as calcium carbonate	70
Total alkalinity as calcium carbonate	70-120
Total dissolved solids	97-147
Sodium	12
Potassium	1
Calcium	13
Magnesium	9
Sulfate	2
Chloride	18
Carbonate	0
Bicarbonate	85-146

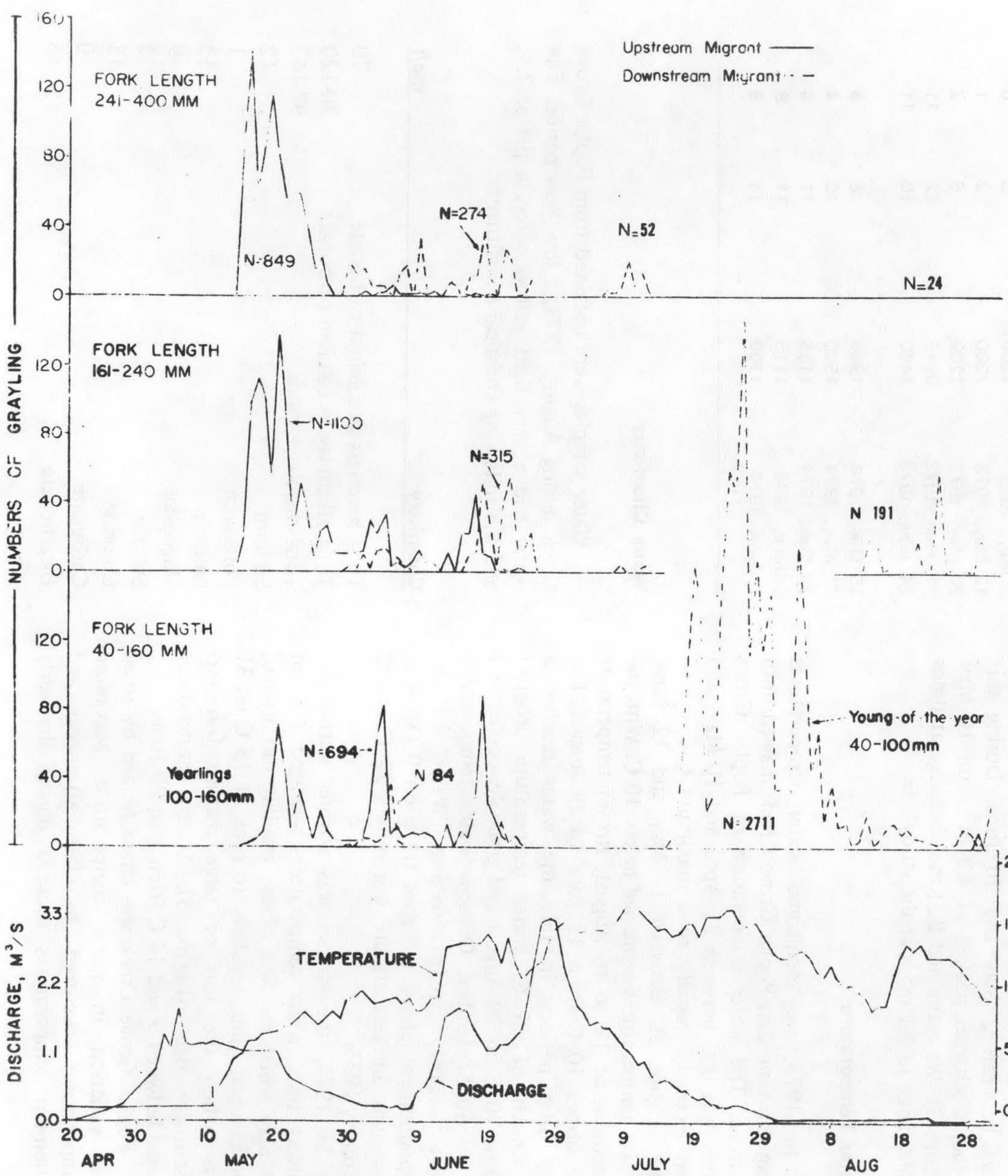

Figure 2. Seasonal variation of discharge, mean water temperature, and counts of upstream and downstream migrating grayling in Poplar Grove Creek in 1973

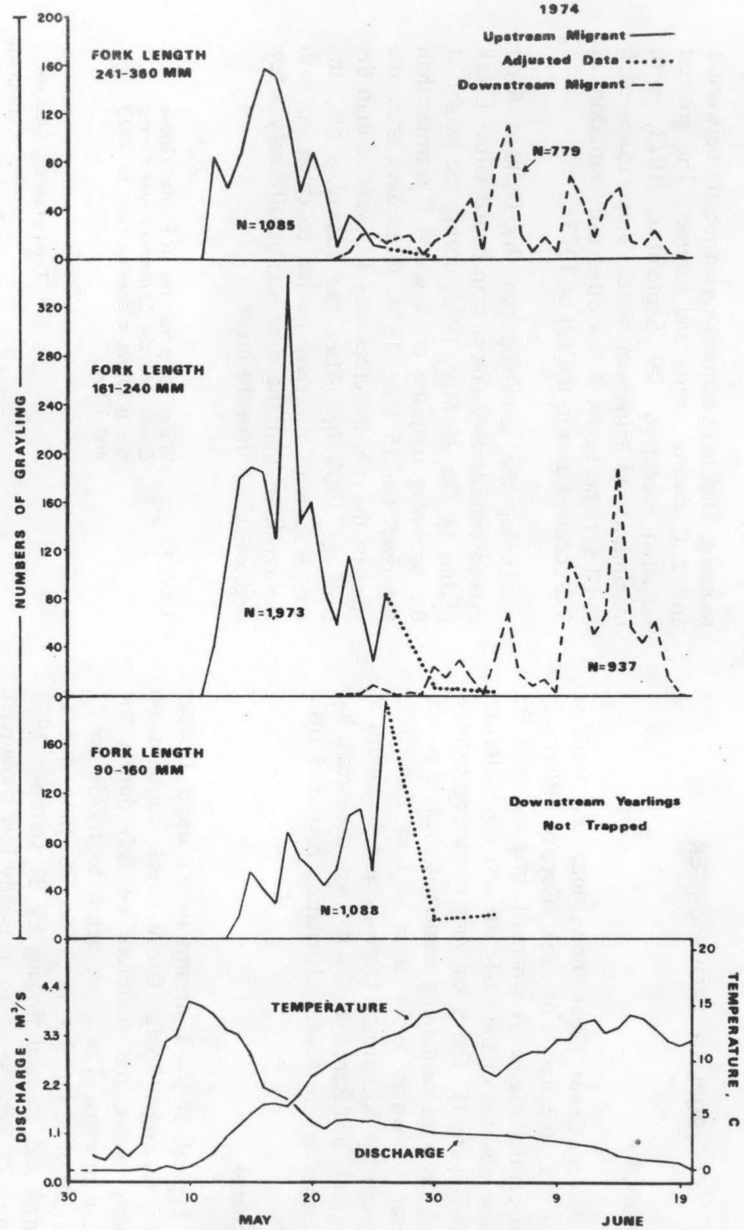

Figure 3. Seasonal variation of discharge, mean water temperature, and counts of upstream and downstream migrating grayling in Poplar Grove Creek in 1974

AGE, GROWTH AND MIGRATION

Introduction

The general objective of this portion of the study was to determine the characteristics of the stocks of grayling with which we were experimenting. The specific objectives were to determine:

1) age – length – weight relationships of Town Lake and Poplar Grove Creek grayling,
2) length and age structure (numbers) of Poplar Grove grayling population,
3) seasonal pattern of upstream and downstream migrants in Poplar Grove Creek,
4) juvenile production of Poplar Grove grayling,
5) sex ratios and state of maturity of Poplar Grove grayling, and,
6) diel movements of Poplar Grove grayling.

The speed at which a healthy fish swims or attempts to swim depends partly on its response to visual cues, water velocity, and temperature. Superimposed on this are innate responses cued by photoperiodism and hormonal cycles. The interaction of such a complex of factors motivates fish to stem a current. Knowledge of migratory behavior becomes important in the interpretation of responses and its effect on voluntary swimming performance of fish in test facilities.

Methods

A 1.5 m high dam with a 4.9 m crest length blocked all fish moving upstream (Figure 4). Fish were collected below the dam by trapping and by driving them downstream into a small mesh net. The drives were made systematically through a 50 m riffle and pool area directly below the dam. During the 1973 culvert tests, netting was extended to pools further downstream on days when the runs of large fish were small. However, this extra effort was limited to only a few collections. As catches were meager the practice did not greatly increase the daily catch, nor alter the general pattern of migration. A wire mesh weir was used to trap upstream migrants during low flows in early June, 1973, but with high water its use was discontinued. Fish in both culvert and swimming channel experiments were released above the dam immediately after use.

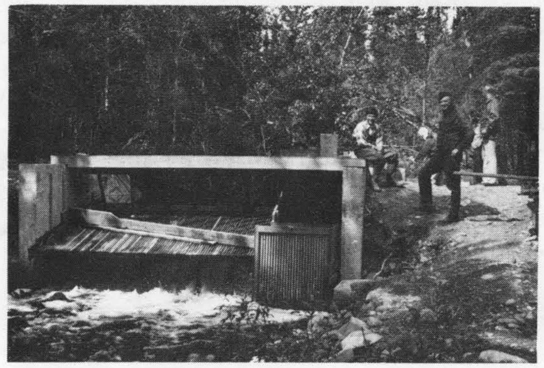

Figure 4. View of dam with inclined plane trap installed for the collection of downstream migrants (1974)

On 20 May, 1973, when the spawning run was essentially ended the spill of the dam was screened with 13 mm square mesh wire and part of the culvert facility was converted to a downstream trap. The spill screens were removed during high water from 27 June to 4 July and downstream moving fish could not be trapped during this period. Later, when the water was low, 6 mm square mesh wire was used to trap young-of-the-year fish. The planks of the dam were removed on 19 October and operation of the downstream trap ceased.

In 1973, we deduced that grayling less than 260 mm were generally immature because of their small size and lack of visible sex products when handled. We confirmed this in 1974 by sexing all grayling over 200 mm in fork length, and by applying gentle pressure to the abdomen to determine the state of "ripeness." If any eggs or milt flowed from the genital pore we deemed the fish as "ripe."

An estimate of the diel activity of upstream migrants was obtained by systematically counting grayling that jumped and surfaced below the dam in 1974. Six 14- to 25-minute observations were made between 1400 and 2300 hr on 15 May, 1974.

Between 22 May and 20 June, 1974, we used an inclined plane trap to collect downstream migrants (Figure 4). The trap had an inclined rack (3.6 m wide x 2.4 m long) that contained 19 mm wide slots capable of capturing fish at least 181 mm in fork length or longer. A chute stretched diagonally across the rack to a 1.2 m x 1.2 m x 1.2 m holding pen. Most fish less than 181 mm slipped through the slots of the rack and we made no count of them.

Scale samples were taken below the insertion of the dorsal fin just above the lateral line, and fork lengths and live weights were recorded for growth analysis of grayling. For age determination, scales were magnified 81 times and projected onto an opaque glass viewing screen. Measurements from the center of the focus to each annulus and the margin of the scale were made obliquely to the dorsal corner of the anterior portion of the scale. A direct proportion method was used for backcalculating at each annulus the fork length of grayling. Poplar Grove grayling captured from 15 May to 5 June in 1973 (139 fish) and 19 May to 1 June, 1974 (21 fish), and Town Lake grayling captured 7 June, 23 June and 24 July, 1973 (55 fish), were used for age determination.

Growth Analysis

As Poplar Grove Creek grayling spawn in late May and early June, fish captured in May were aged almost exactly to the year. In many cases, no distinct annulus was observed at the margin of the scale for fish captured in May, but margin annuli became more defined in June. When margin annuli were absent the margin of the scale was used in calculating fork length of the last year of life.

The fork lengths of each age class of 1973 and 1974 Poplar Grove grayling computed to the last annulus were 111, 194, 255, 289, 313, 331 and 336 mm for ages I to VII (Table 2), and the fork lengths of Town Lake grayling were 141, 183, and 262 mm for age classes II, III and IV, respectively (Table 3). We did not initially collect Town Lake grayling for growth analysis and consequently, did not try to keep any small fish although we had observed grayling under 100 mm in length in May.

That slower growing fish generally live longer could account for the progressively shorter lengths of the early age classes of older Poplar Grove fish. The data indicate that Town Lake grayling were much smaller than those from Poplar Grove Creek for corresponding age classes. The sample size of age classes III and IV of Town Lake fish were small and could bias the lengths of age classes I and II of older fish.

The mean weights and corresponding mean fork lengths of each age class of 1973 Poplar Grove and Town Lake grayling are given in Tables 4 and 5. The fork lengths are the actual lengths at the time of collection and represent ages one plus, two plus, etc.

Based on a random sample of 50 fish, the mean fork length of Poplar Grove grayling measured on 18 October, 1973 was 102 mm (range, 64-151 mm). Selective over-winter mortality favoring the survival of larger fish and/or the eight months difference in age, could account for the difference between the October 102 mm and the June 111 mm mean length estimates.

In 1973, length-class frequencies of May upstream migrants indicate a bimodal distribution. The 221-240 mm length class contained relatively few fish and represented an intermode (Figure 5).

Table 2. Age and computed mean fork length in millimeters of Poplar Grove grayling in 1973 and 1974

		Annulus						
No.	Age	I	II	III	IV	V	VI	VII
20	I	111						
53	II	115	194					
22	III	97	184	255				
33	IV	95	179	249	289			
19	V	78	171	241	281	313		
10	VI	83	172	230	276	307	331	
3	VII	73	159	236	270	301	319	336

Table 3. Age and computed mean fork length in millimeters of Town Lake grayling in 1973

		Annulus			
Number	Age	I	II	III	IV
0	I	0			
46	II	73	141		
6	III	72	134	183	
3	IV	90	166	222	262

Table 4. Mean weight and fork length of age classes of Poplar Grove grayling in 1973

Age	II+	III+	IV+
Mean fork length, millimeters	156	194	271
Mean weight, grams	28	74	210
Number of fish	46	6	3

Table 5. Mean weight and fork length of age classes of Town Lake grayling in 1973

Age	I+	II+	III+	IV+	V+	VI+
Mean fork length, millimeters	116	199	266	295	321	345
Mean weight, grams	17	78	200	281	342	436
Number of fish	20	53	23	35	7	4

In 1973, the mode of the length-class frequencies of early June upstream migrants was 121-140 mm and late June migrants, 101-120 mm. Length frequencies of age I and II grayling as interpreted from scale readings resulted in an intermode between 141 and 160 mm which contained few fish. On the basis of the intermodes in the length-frequency distributions, we separated the upstream migrants into three groups; namely, 100-160 mm (age I+), 161-240 mm (age II+), and 241-400 mm (age III+ to VII+) (Figure 2). In May, however, the length ranges of age I and II grayling were essentially 101-140 and 161-220 mm and as shown in Figure 2, they could grow about 20 mm before they would become misclassified, by which time the upstream run was mostly completed. In 1974, the pattern of the length frequency histogram changed and the 221-240 mm length class became the most abundant one (Figure 6). For comparison, however, the 1974 data (Figure 3) were grouped in the same length classes as those in 1973 (Figure 2).

Upstream Migrants

The first dense schools of the spawning run of grayling arrived at the dam site by 0800 hr on 15 May, 1973 (water temperature 3 C at 1000 hr, 6 C at 2020 hr) and on 13 May, 1974 (water temperature: 2 C at 0900 hr, 3 C at 1715 hr). A few grayling jumped at the dam in the late afternoon of 14 May, 1973 (water temperature: 3 C at 1000 hr, 4 C at 1430 hr), but none appeared by 1230 hr on 12 May, 1974 (water temperature, 2 C). We assume that some grayling arrived during the late afternoon of 12 May when observers were absent. Based on the first appearance of large schools of fish, the 1974 run arrived two days earlier than the 1973 run.

The minimum length of early arrivals at the dam decreased as the run progressed. In 1973, the smallest length classes were 161-180 mm on 15 May, 141-160 mm on 16-18 May, and 101-120 mm by 19 May. In 1974, the smallest length classes were 201-220 mm on 13 May, 161-180 mm on 14 May, 121-140 mm on 15 May, and 101-120 mm on 16 May.

In 1973, grayling (161-400 mm) arrived at the dam site in two major groups, with peak numbers three days apart (Figure 2). The 241-400 mm grayling peaked on 16 and 19 May – the 2nd and 5th days after schools of grayling first appeared; the 161-240 mm fish, on 17 and 20 May – the 3rd and 6th days, and the 100-160 mm yearling, on 20 May – the 6th day. Two other major peaks occurred during the yearling run on 4 and 28 June. Secondary peaks for 161-240 mm grayling occurred 4 and 17 June.

In 1974, the 241-360 mm grayling peaked on 17 May; the 161-240 mm, on 19 May; and the 90-160 mm, on 27 May (Figure 3). These dates represent the 5th, 7th and 14th days after schools first appeared. Except for yearlings which forage for food but do not spawn, the timing of the spawning run was very similar for both years.

By 6 June of each year a total of 2,254 grayling in 1973 and 4,146 grayling in 1974 ascended Poplar Creek. After 6 June, upstream migration of fish longer than 160 mm had essentially ceased. The percentage number of fish in each major length class (90-160, 161-240 and 241-400 mm) for each year compared rather well and so we averaged the percentages. For both years 90-160 mm grayling formed 23% of the run; 161-240 mm fish, 45%; and 241-400 mm fish, 32%.

Although more grayling showed in 1974, no grayling exceeded 360 mm in fork length; in contrast, in 1973, 5 grayling exceeded 360 mm, 408 mm being the longest.

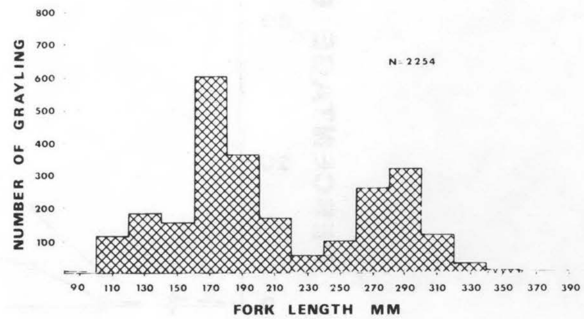

Figure 5. Length-frequency histogram of the spring run of Poplar Grove grayling (15 May to 5 June, 1973)

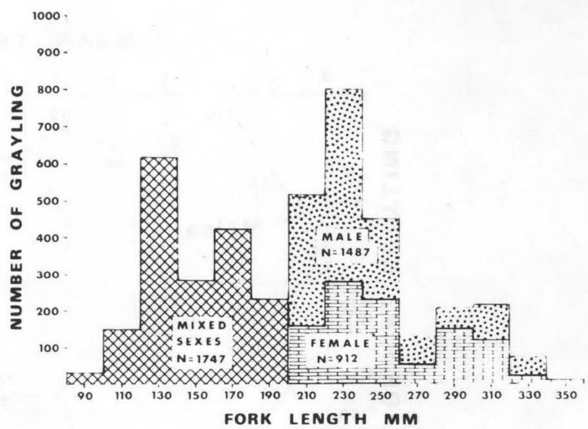

Figure 6. Length-frequency histogram of the spring run of Poplar Grove grayling (13 May to 4 June, 1974)

In 1974, we analyzed the sex ratio and proportion of ripe fish in the spawning run. We did this to determine whether the state of maturity of the fish could influence the results of culvert tests. The spawning run contained more males than females in the 201-260 mm length class, but more females than males in the 261-360 mm class (Figure

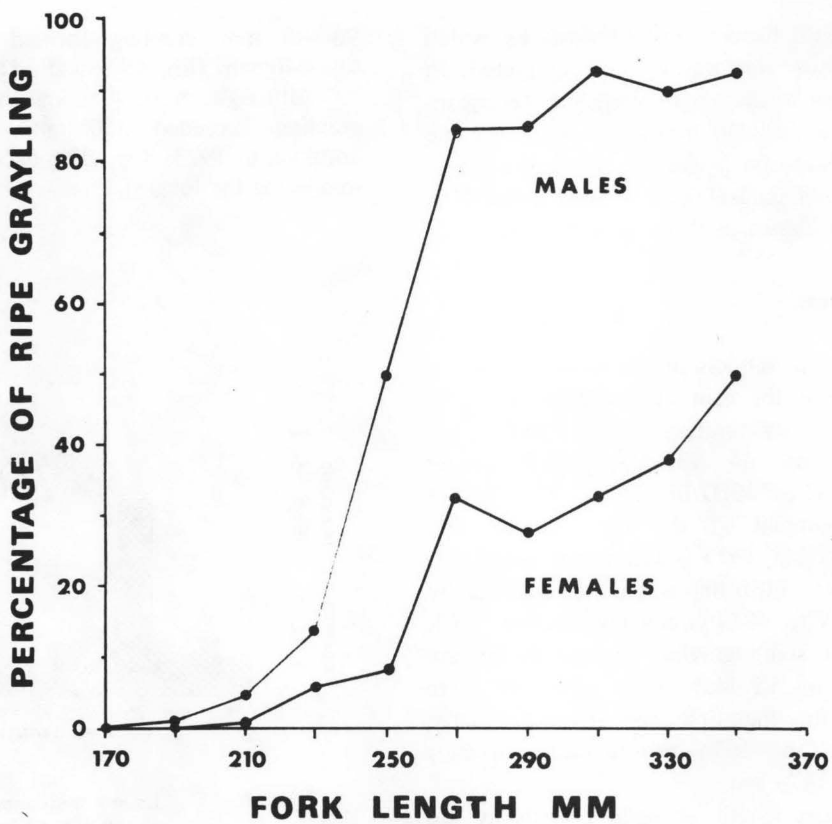

Figure 7. Proportion of ripe grayling by length class in the spawning run of Poplar Grove Creek, 13 to 27 May, 1974

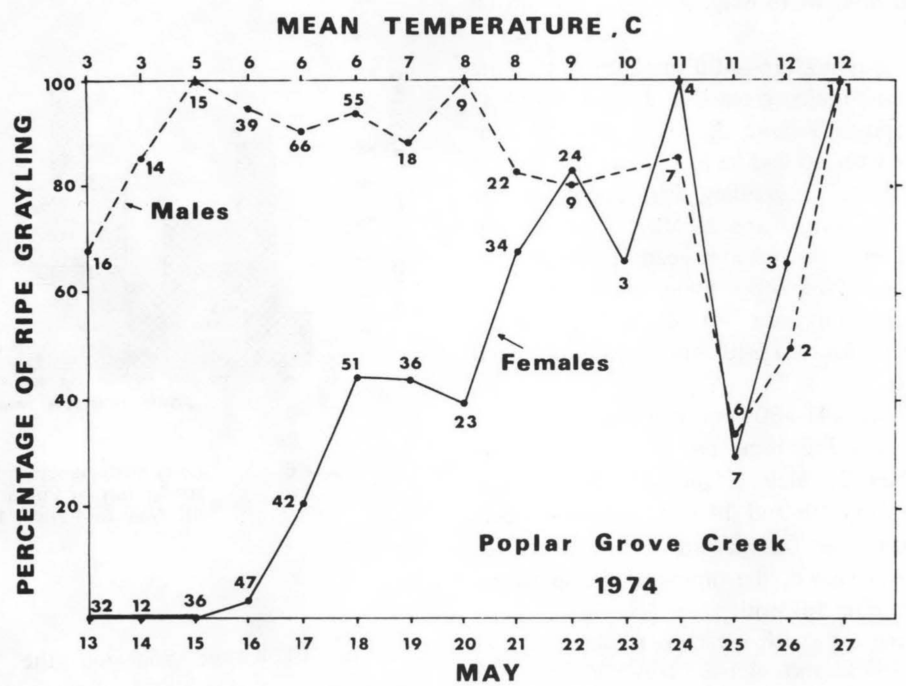

Figure 8. Proportion of ripe grayling (261-360 mm) that occurred each day during the first 15 days of the 1974 spawning run in Poplar Grove Creek. Numerals by each point indicate total daily counts of fish

6). The two smallest ripe grayling that we noted measured 176 mm, a female, and 177 mm, a male.

Length classes less than 261 mm had only a small proportion of ripe fish (Figure 7). Ripe males were about twice as numerous as ripe females. Most males were ripe at the beginning of the spawning run, whereas, early female arrivals even though mature, were not deemed "ripe" unless they readily yielded eggs (Figure 8). Likely, many females spawned later, although they were not classified as "ripe" when we examined them in the early part of the run. Except for 6% of the males and 5% of the females, the spawning run of 261-360 mm grayling finished 22 May and lasted essentially 10 days. Irregularities in Figure 8 on 25 and 26 May could be due to small sample size or possibly to the presence of spent fish.

In 1973, between 7 June and 30 August, we counted 225 small grayling (100-160 mm), 159 medium-sized grayling (161-240 mm), and only 10 large grayling (> 240 mm) that moved upstream. After 30 August, no more upstream migrants occurred that year. In 1974, we took no counts after 5 June when we started the last culvert test, but we assume that the relative number of upstream migrants would be comparable to that noted in 1973.

Downstream Migrants

A total of 66,870 grayling were trapped as they moved downstream between 30 May and 18 October in 1973. Of these, 641 were yearlings and 693 were grayling older than two years. The length class distribution indicated that most upstream migrants had returned downstream by late June (Table 6). Of the grayling that had migrated upstream from May through August, only 53% of the yearlings and two-year-old fish, and 41% of the fish longer than 241 mm were captured as downstream migrants. Probably the fish that cannot be accounted for emigrated prior to 30 May, before the downstream trap was installed and/or between 27 June and 4 July, during peak discharge when the trap was not workable.

During the 30 days in 1974 that we operated the inclined plane trap, 72% of the 241-360 mm upstream migrants (1,085 grayling) and 60% of the 181-240 mm upstream migrants (1,549 grayling) came back downstream (Figure 3).

Yearlings measured 100-160 mm in fork length as they migrated upstream in May and June, 1973. A few grayling were shorter and slipped through the seine. Those that remained in the stream during the summer grew rapidly and essentially grew longer than 160 mm by 1 August (Table 6).

Small grayling were observed moving downstream on 12 July, 1973. Presumably, they had hatched in early June. Many of these "nomad" fry must have drifted downstream before we began trapping them on 17 July. Survival of these nomads is deemed poor as they could be easily preyed upon by salmonid predators and would have to compete for food with larger juvenile salmonids which abound in the Gulkana River.

Between 17 July and 18 October, 1973, we trapped 65,536 young of the year grayling. Of these 62,680 or 96% were caught after 11 September.

Young-of-the-year grayling had a mean fork length of 55 mm (16 fish) on July and 102 mm (50 fish) on 18 October, 1973. They ranged considerably in fork length: 43-69 mm on 18 July and 64 – 151 mm on 18 October. Few grayling measured less than 60 mm in length by 1 September, 1973, and the shortest four of a 20 fish sample of the same year class (< 101 mm) captured 27 May, 1974, were 87, 87, 88 and 91 mm.

Apparently, Poplar Grove Creek functions as a nursery area for young-of-the-year grayling. Food organisms are presumably abundant as fry grow about 25 mm per month after hatching. Moreover, the opportunities for cannibalism by older fish are reduced as many of the upstream migrants have left the creek by the time that fry hatch.

Table 6. Number of Arctic grayling trapped in Poplar Grove Creek as they migrated downstream to the Gulkana River. The trap operated between 30 May and 18 October, 1973 except for 27 June to 4 July high water period and a 9-10 September debris period

Date	Fork length classes, millimeters				
	40-100	60-160	101-160	161-240	241-400
30 May-26 June	–	–	84*	315	274
5-16 July	–	–	8*	13	52
17-31 July	1983*	–	4*	0	0
1-31 August	721*	–	7*	178*	24
1-8 September	–	142*	–	151*	6
11-30 September	–	23,805**	–	196*	9
1-18 October	–	38,875**	–	13*	0

*yearling fish
**young-of-the-year fish

Diel Movements

Schools of grayling formed below the dam on the first mornings of the 1973 and 1974 spawning runs. Except for these first appearances, most grayling appeared in the late afternoon (1600-1800 hr) for the remainder of the runs.

In the mornings before our netting operation, few grayling were active, whereas, in the late afternoon many fish surfaced and jumped. Maximum activity of grayling correlated with time of day and changes in water temperature (Figure 9). The peak of fish activity occurred about 1800 hr when water temperature was near maximum.

We captured only two fish on 22 May, 1974 when we first trapped downstream migrants and eight fish the day afterwards. The number of downstream migrants increased markedly thereafter. Some grayling may have moved downstream before we installed the inclined plane trap. However, the number must have been small because the major part of the spawning run had just passed.

Most grayling from both the 161-240 mm and 241-360 mm classes returned downstream in the late afternoon and early evening (Figure 10).

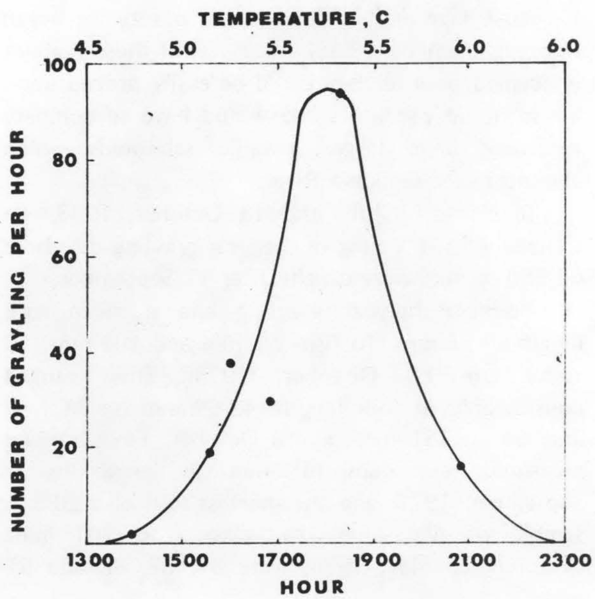

Figure 9. Diel variation in the number of upstream migrating grayling that jumped or surfaced below the research dam on Poplar Grove Creek on 15 May, 1974

Few moved downstream during the morning and mid-day periods. A greater percentage of the 241-360 mm fish went downstream between 22 May and 20 June, 1974.

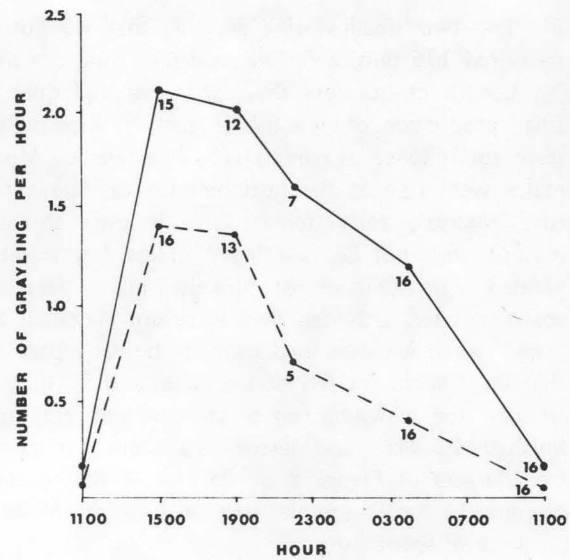

Figure 10. Number of downstream migrating grayling captured per hour in inclined plane trap from 24 May to 8 June, 1974. Numerals beside points indicate the number of days that observations were made. Broken lines represent 234 grayling 161-240 mm in fork length; solid lines, 444 grayling 241-360 mm in fork length

Discussion

This study details information on movements of the fluvial grayling in a small creek. Such movements could have managerial inference as to the timing of upstream movements relative to seasonal changes in discharge through the culverts. The extent that culverts will interfere with upstream movement of grayling will depend on the size and manner in which a culvert is installed, on the temperature regime and flow characteristics of a stream, on the timing and duration of spawning runs of mature fish and on forage movements of immature fish.

Management of grayling stocks requires a comprehensive knowledge of their life history. Like other salmonids the grayling have both fluvial races that are residents of streams, and adfluvial races which obtain their growth in lakes, but utilize tributary streams for spawning and nursery areas. The migration patterns, growth, and habits of these two races could differ. That small creeks are needed as nursery areas for grayling is an important discovery. It points out the necessity of maintaining and/or providing good access to the upstream reaches for spawning runs.

This study also provides basic life history and growth data and supplements material on Arctic grayling reported by Reed (1964) and Tack (1972).

SWIMMING PERFORMANCE IN ASCENDING CULVERTS

Introduction

The general objective of the culvert tests was to determine the maximum water velocities that different size grayling could stem so that their upstream movements would not be limited by highway culverts.

The specific objective of the culvert tests was to determine the water velocities that would permit 25, 50 and 75% of a selected length class of grayling to pass upstream through 18.3 m (60 ft) and 30.5 m (100 ft) culverts. The presence of a spawning run of longnose suckers enabled us to compare their ability to swim up culverts with that of grayling even though this was not an original objective of our research.

Culverts for the new highway, which will parallel the proposed pipeline, vary from 12 to 73 m in length, with most of the culverts being between 18 and 30 m in length. Thus, the lengths chosen for this study delimit the swimming capability of grayling for most anticipated culverts. Interpolation of critical water velocities for intermediate lengths should be practical within the 18 to 30 m range. The voluntary 1-hour cruising speed of grayling obtained in a circular swimming channel, which is detailed later in this report, should be used to determine critical velocities for culverts longer than 30 m.

In 1974, in addition to the specific objective, we aimed to explore the impact of two minor factors that might influence migration; namely, 1) the effect of a longer than one-day test on the success of grayling to ascend a culvert, and 2) the effect of maturation on the swimming response of grayling.

When considering the upstream passage of grayling through culverts, four major variables are involved: the size of fish, the velocity of water within the culvert, the length of the culvert, and the temperature of the water. Of these, we could select the size of the fish, the water velocity, and the length of the culvert, but we could not control the water temperature in the culvert. We anticipated that the run of highly motivated mature fish would be of short duration and that any variation in stream temperature would be minimal. Because of this, we did not expect to obtain any significant relationship between swimming performance in the culvert and temperature and we did not, in 1973, when the daily mean temperature range was, with two exceptions, 4 – 9 C. In 1974, however, the daily mean temperature was 4 – 8 C for 6 tests, and 9 – 12 C for 8 tests. Fortuitously, this temperature change permitted us to sort out temperature effects in the 30.5 m culvert tests. Also, we determined temperature effects in the circular swimming channel and used this data to infer how temperature could affect swimming capability in a culvert.

Culvert Facility

A diversion dam (4.8 m crest length, about 1.2 to 1.5 m variable depth), a headgate, approach conduit, a headbox (2.4 m long x 1.8 m wide x 0.9 m deep), an 18.3 m long (in 1973) and 30.5 m long (in 1974) tiltable, 0.6 m ID (inside diameter) culvert (culvert could be set prior to each run to a slope ranging from 0% to 4%), and tailbox (4.8 m long x 1.8 m wide x 1.2 m deep in 1973 and 4.8 m x 1.8 m x 2.0 m deep in 1974) were constructed on Poplar Grove Creek. Figures 11 and 12 are photographs of the 18.3 m and 30.5 m culvert facilities and dam. The width and height of the dam crest were varied by removing or adding wooden planks.

In 1974, after the second test, a vertical slot fence divided the tailbox into an upstream and downstream half (Figure 13). The lower compartment provided storage so that fish could be netted the day before the test and recover overnight from handling. After each test the water in the tailbox was drained to a depth of about 20 cm to facilitate the recovery and measurement of failures in the upstream compartment. Sufficient water flowed through the culvert to provide plenty of oxygen. On removal of failures, the fish in the downstream compartment were herded into the upstream compartment. Apart from the advantage of an overnight conditioning period, this new procedure provided more time for us to: 1) measure the greater number of 1974 test fish, and 2) change the slope of the 30.5 m culvert, which had more jacking points than the 18.3 culvert.

Water velocity was measured inside the lower end of the culvert with an Ott current meter. In addition, the time necessary for a wooden block (38 x 88 x 88 mm) to pass through the culvert was clocked several times with a stop watch and the results averaged. Velocity in the culvert barrel was varied from 0.6 to 1.9 m/s.

All runs were conducted with optimum tailwater depth, i.e., tailwater depth was held at approximately the normal depth of flow in the culvert. Thus, the fish could swim directly into the culvert without jumping.

In 1973, because of the nature of the system used for varying the slope of the culvert, the depth of the pool below the invert of the culvert outfall varied from 80 m for the 0% slope to about 30 cm for the 3.2% slope. The minimum depth of water in the tailbox was about 50 cm at 3% slope. The maximum depth was about 115 cm at 0% slope.

Figure 11. Upstream view of the 18.3 m culvert facility showing the position of the headbox, tailbox and dam (1973)

Figure 12. Downstream view of the 30.5 m culvert facility showing the position of the headbox, tailbox, and dam (1974)

In 1974, the depth of the pool below the invert of the culvert outfall varied from 160 cm for the 0% slope to about 80 cm for the 2.5% slope. The minimum depth of water in the tailbox was about 100 cm at 2.5% slope and the maximum depth was about 180 cm at 0% slope.

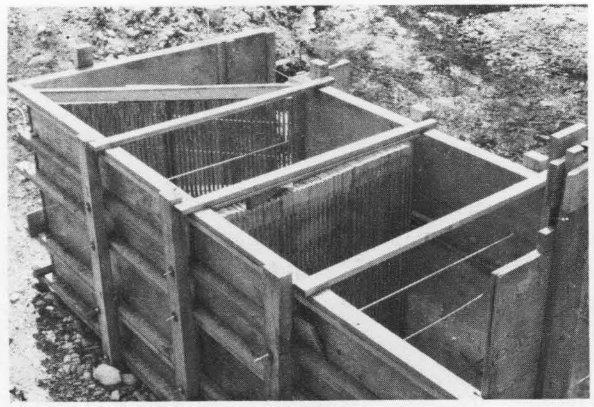

Figure 13. Tailbox of the 30.5 m culvert facility showing the upstream experimental compartment (right) from which test fish could ascend the culvert, and the downstream conditioning compartment (left) in which fish could recover overnight from any effects of netting

Experimental Procedure

The general daily procedure used for the culvert study was to block the upstream migration of fish with the dam, trap or seine fish in the riffle and pool close to the dam, place the fish in the tailbox below the culvert, and measure and count the fish that successfully ascended or failed to ascend the culvert for a particular water velocity.

The larger 1974 runs necessitated our handling of more fish. The periodic activity of netting larger numbers of fish increased the time that investigators disturbed the water in the headbox. Because of this and of certain anomalies in our 1973 data, we modified our 1974 operations to minimize the time necessary to check the headbox. To net fish more easily we divided the headbox in half with a temporary partition, and to reset the headbox more quickly we stored the netted fish temporarily in plastic containers and sexed and sized them later.

Most fish were released alive in the pond above the dam immediately after measurement. However, some grayling were detained an extra day and tested in a circular channel designed to measure sustained and cruising speeds.

We made two exceptions to the general procedure to increase the sizes of our next day sample. In tests of 19-20 and 21-22, May, 1973, we observed that no fish less than 241 mm in length was able to stem the 1.8 m/s water velocities of the culvert. These failures were unsorted as to swimming performance; and because of this, we deemed that their use would not unduly bias tests to be made at slower flows (0.6-0.8 m/s) on a subsequent day. To avoid extra handling, the retained fish were not measured until after they were mixed with new fish collected for the 20-21 and 22-23 May tests; the length distribution of the retained fish, however, would be essentially similar to that of the combined distribution of retained and new fish.

We measured the fork length of fish to the nearest millimeter. Length measurements were grouped in discrete 20 mm intervals or length classes. The data were analyzed as in a bioassay test in which flow velocity is analogous to dose, and fish ascent through the culvert (success) is analogous to survival.

By inspection of each day's data, length classes were determined where 25, 50, and 75% of the fish in a size class ascended the culvert (successes). The criteria which were used for making this determination were as follows:

1) If two length classes of fish achieved the critical level of performance (25, 50, and 75% success), the shorter length class was selected as the data point. A tolerance of ± 5% was allowed making this selection; i.e., for the 50% level of performance, a range of 45% failures to 55% successes or vice versa was considered acceptable.
2) An average length (to the nearest 10 mm) was interpolated where the percentage of two consecutive sets of successes and failures were above and below the critical level of performance. Example: The 25 and 75% sucess points for the test on 27-28 May, 1974 are 150 and 200 mm, respectively, (Table 7).
3) An average length (to the nearest 10 mm) was calculated to attain a ± 5% tolerance limit where the percentages of consecutive sets of successes and failures oscillated. Example: The 50% success point for 27-28 May, 1974, was 170 mm. The success values, 13, 11 and 5 gave a total of 29; the failure values 17, 4, and 11 gave a total of 32. The quotient of 29/61 equals 47% which is within the 50 ± 5% range (Table 7).

Small samples that were closely matched as to water velocity, temperature, and timing of the run were combined (Table 8). As the critical levels of performance in the combined samples were within the range of those in the separate samples, this procedure did not bias the determinations of critical lengths.

Results

The sizes and numbers of grayling available for culvert tests varied daily with the size of the run (Tables 9 and 10). The proportion of fish that successfully ascended the culvert varied with the length of the fish and the speed of the water. Using the criteria set forth in the Experimental Procedure section, we identified the fish length that permitted 25, 50 and 75% success in each test. For 16-17 May, 1973, for example, grayling with fork lengths of 160 mm, 200 mm and 220 mm provided success ratios of 25, 50 and 75%, respectively, in a 1.3 m/s current. The critical lengths of grayling thus determined in Tables 8, 9 and 10 are summarized in Table 11 and plotted in Figure 14. Likewise, the results of sucker tests are presented in Tables 12 and 13, summarized in Table 14, and plotted in Figure 15.

Table 7. An example of how culvert data on 27-28 May, 1974, was analyzed to determine the 25, 50 and 75% success points

Fork length, millimeters	No. of Grayling Successes	No. of Grayling Failures		% of success	Critical success point	Critical length, mm
81-100	0	20		0		
101-120	1	56		2		
121-140	11	81		14	25%	140
141-160	13	17		43		
161-180	11	4	47%	73	50%	170
181-200	5	11		31	75%	200
201-220	21	4		84		
221-240	24	5		83		
241-260	5	3		62		
261-280	0	0		—		
281-300	2	0		100		

Table 8. Fork length class distributions of *combined* samples of Poplar Grove grayling (1973 upstream migrants) that were successful in ascending an 18.3 m culvert at indicated water velocities. The data are derived from tests on the dates indicated in Table 9. S = success, F = failure; upper bar = 25%, double dots = 50%, and lower bar = 75% successful length class for each water velocity

Velocity, meters per second	1.2		0.9		1.1	
Temperature, C	7-8		8-9		13-14	
Date	May 25-26 and 27-28		June 6-7 and 11-12		June 18-19 and 19-20	
	S	F	S	F	S	F
Fork length, millimeters						
81-100					0	5
101-220	0	5	2	21	5	35
121-140	0	7	9	14	7	49
141-160	0	2	3	1	5	7
161-180	6	8	6	3	2	3
181-200	8	5	10	5	4	3
201-220	5	3	3	6		
221-240	1	0	0	2		
241-260	6	1	0	1		
261-280	6	2	2	1		
281-300	4	2	4	0		

Table 9. Fork length class distribution of Poplar Grove grayling (1973 upstream migrants) that were successful in ascending an 18.3 m culvert in one-day tests at indicated water velocities. S = success, F = failure; upper bar = 25%, double dots = 50% and lower bar = 75% successful length class for each water velocity

Velocity, meters per second	1.4	1.3	1.5	1.6	1.9	0.8	1.8	0.6	1.8	1.7	1.2	1.4	1.3	0.9	1.0	1.1	1.1
Slope, percentage	2.2	1.7	2.7	3.2	3.2	0.7	3.0	0.0	3.0	3.0	1.5	2.0	2.5	0.5	1.0	1.0	1.0
Headwater depth / Culvert diameter	0.5	0.5	0.5	0.5	0.8	0.5	0.7	0.5	0.7	0.6	0.5	0.5	0.3	0.5	0.6	0.7	0.5
Temperature, C	3-5	4-6	5-6	5-7	6-7	6-7	6-7	6-7	7-8	7-8	7-8	6-8	7-8	8-9	8-9	13-14	13-14
Date, 1973	May 15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	24-25	25-26	26-27	27-28	June 6-7	11-12	18-19	19-20
	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F
Fork length millimeters																	
81-100								<-						<-		0 4	0 1
101-120					0 ↑	0 3	0 ↑	<·· 5 2	0 8	0 5		0 4	0 5	2 ·· 2	0 19	0 32	5 3
121-140					0	1 41	0	14 - 8	0 11	0 8	0 3	0 13	0 4	4 4	5 10	1 39	6 10
141-160		0 3	0 4	0 9	0	16 - 41	0	24 3	0 15	0 6	0 1	0 5	0 1	0 0	3 1	5 7	0 0
161-180		9 14	1 31	0 37	0 83[a]	30 77	0 161[b]	35 13	0 23	0 5	1 3	1 7	5 ·· 5	1 2	5 - 1	2 3	0 0
181-200		19 26	5 50	6 36	0	24 ·· 24	0	40 6	0 18	0 18	0 3	2 - 6	8 - 2	1 - 0	9 5	2 3	2 - 0
201-220		16 7	9 ·· 11	8 ·· 9	0	17 12	0	13 3	0 10	0 10	0 - 0	2 4	5 3	0 1	3 5	>··	
221-240	0 1	6 1	6 0	4 1	0 ↓	4 4	0 ↓	5 1	0 3	3 3	1 0	1 0	0 0	0 1	0 1	>-	
241-260	3 3	10 2	7 1	5 2	1 13	5 4	0 6	7 3	0 6	0 3	4 1	1 2	2 0	0 0	0 1		
261-280	8 13	27 5	12 2	26 2	5 31	20 10	4 - 14	22 2	2 17	8 ·· 8	2 1	0 4	4 1	0 1	2 0		
281-300	32 19	41 0	18 5	29 1	8 34	15 - 6	14 ·· 11	15 1	5 - 20	7 6	4 2	4 6			4 0		
301-320	13 - 4	16 0	8 0	14 0	7 12	12 4	1 4	6 1	4 2	1 4		1 1					
321-340	2 1	4 0	8 0	3 0	2 ·· 2	2 1	1 1	2 0	0 1	2 - 0		0 1					
341-360	0 1	1 0	0 1	3 0	1 - 0	3 0	>-		0 0			1 1					
361-380		1 0	1 0						0 0			>-					
381-400		1 0							0 2								
									>-								

[a]The May 20-21 test included these fish
[b]The May 22-23 test included these fish

Table 10. Fork length class distribution of Poplar Grove grayling (1974 upstream migrants) that were successful in ascending a 30.5 m culvert in one-day tests at indicated water velocities. S = success, F = failure; upper bar = 25%, double dots = 50% and lower bar = 75% successful length class for each water velocity

Velocity, meters per second	0.9	0.6	1.2	1.5	0.9	1.2	0.6	1.1	1.5	1.1	0.8	0.8	1.0	1.0	0.8	0.6	0.9
Slope, percentage	0.9	0.0	1.5	2.5	0.6	1.5	0.0	1.0	2.5	1.0	0.5	0.5	1.0	1.0	0.4	0.0	1.0
Headwater depth / Culvert diameter	0.73	0.68	0.53	0.63	0.62	0.53	0.68	0.61	0.56	0.61	0.53	0.53	0.5	0.5	0.62	0.68	0.5
Temperature, C	2-4	3-4	4-6	4-7	4-7	5-7	6-8	7-9	9-10	9-11	9-11	10-12	11-12	11-13	11-13	13-16	10-11
Date, 1974	May 13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	24-25	25-26	26-27	27-28	May June 31-1	5-6
	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F
Fork length millimeters																	
81-100											0 2	0 2	0 5	0 6	0 20	1 0	
101-120				0 5			3 2	0 6			1 7	1 7	0 18	0 18	1 56	3 6	0 18
121-140			0 3	0 19	0 24	0 20	12-32	0 41	0 36	0 34	6 27	4 63	0 62	2 26	11 81	18 25	0 63
141-160			0 15	0 32	0 17	0 10	9 31	0 19	0 21	0 10	4-11	5-20	4 18	0 4	13 17	1 7	0 17
161-180		0 9	0 47	0 46	0 30	0 23	25 50	0 36	0 52	0 22	5 8	6 14	6 12	4 3	11··4	2 3	1 5
181-200		0 9	0 19	0 30	1 25	0 10	22··21	0 15	0 17	2-5	4 2	7··6	3 5	3 4	5 11	3 2	1-3
201-220	0 13	2 29	4 46	0 43	14-40	1 36	55 32	9-33	0 42	5 9	9 0	19 12	7··9	1 3	21 4	9 4	3··2
221-240	0 28	11 49	6 57	0 70	53 22	11 49	102-40	19 30	0 51	29 15	27 3	43 10	20-5	8-2	24 5	5 2	1 1
241-260	1 35	12 21	12 23	0 41	45 5	17 29	52 5	15 5	0 33	22 4	6 1	22 5	11 4	6 1	5 3	2 0	-
261-280	1 12	4··5	7 3	0 17	21 3	4 6	11 1	5 1	0 17	6 3	0 0	1 1	3 0	1 0	0 0		
281-300	3-7	2 6	5 19	0 31	18 5	11 26	26 0	8 2	0 16	4 2	1 0	3 1	4 1	1 0	2 0		
301-320	3 15	3 3	3 5	2 27	33 5	24 12	12 0	13 1	1 15	14 2	2 0	2 0	3 0	1 1			
321-340	4··3	1 2	2 1	1 8	18 1	13-5	5 0	2 0	1 6	3 0		0 2	0 0	0 1			
341-360	-	-	-	0 2	4 0	4 1						1 0	1 1				

Table 11. Summary of critical points for fork lengths of grayling which successfully ascended 18.3 m and 30.5 m culverts in one-day tests at indicated water velocities. The critical points were obtained from Tables 8, 9 and 10 and are plotted in Figure 14

18.3-meter culvert					30.5-meter culvert				
Velocity	Mean temp-	Percentage of Success			Velocity	Mean temp-	Percentage of Success		
m/s	erature, C	25	50	75	m/s	erature, C	25	50	75
1.4	4.0	240	280	310	0.9	3.0	290	330	-
1.3	5.0	160	200	220	0.6	3.5	240	270	-
1.5	5.5	200	210	220	1.2	5.0	240	260	-
1.6	6.0	200	210	240	1.5	5.5	-	-	-
1.9	6.5	300	330	350	0.9	5.5	210	220	240
0.8	6.5	150	190	290	1.2	6.0	240	300	330
1.8	6.5	270	290	-	0.6	7.0	130	190	230
0.6	6.5	-	-	130	1.1	8.0	210	240	260
1.8	7.5	290	300	-	1.5	9.5	-	-	-
1.7	7.5	220	270	330	1.1	10.0	190	220	240
1.4	7.0	190	240	-	0.8	10.0	150	180	200
1.2[a]	7.5	160	180	220	0.8	11.0	150	190	220
0.9[a]	8.5	120	140	150	1.0	11.5	160	210	230
1.1[a]	13.5	140	180	-	1.0	12.0	160	200	230
					0.8	12.0	140	170	200
					0.6	14.5	-	180	220
					0.9	10.5	190	210	-

[a]Data from two tests are combined to increase sample size.

Table 12. Fork length class distribution of longnose sucker (1973 upstream migrants) that were successful in ascending an 18.3 m culvert in one-day tests at indicated water velocities. S = success, F = failure; upper bar = 25%, double dots = 50% and lower bar = 75% successful length class for each water velocity

Velocity, meters per second	1.9	0.8	1.8	0.6	1.8	1.7	1.2	1.4	1.3	0.9	1.1
Temperature, C	6-7	6-7	6-7	6-7	7-8	7-8	7-8	6-8	7-8	8-9	13-14
Date, 1973	May 19-20	20-21	21-22	22-23	23-24	24-25	25-26	26-27	27-28	June 6-7 and 11-12[a]	18-19
	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F
Fork length, millimeters											
101-120											0 4
121-140											0 9
141-160										0 2	1 36
161-180								0 1		1 1	7 25
181-200		<..					0 1	0 1		4 6	9 17
201-220	0 ↑	1 0	0 ↑	0-1	0 1		0 0	0 3	1 0	2 2	12-4
221-240	0	5 1	0	2-0	0 0	0 1	1 2	0 6	1 6	2..4	11 1
241-260	0	8.4	0	7 1	0 1	0 3	5..6	0 15	4 6	3-0	3 1
261-280	0	10 5	0	6 2	0 0	0 5	7 11	0 23	13 8	5 1	3 0
281-300	0	7 6	0	5 0	0 3	0 5	9 7	0 6	6 6	2 1	0 1
301-320	0 53[b]	13 4	0 51[b]	6 4	0 3	0 5	12-4	0 7	6 1	2 0	0 0
321-340	0	21 5	0	11 3	0 16	0 8	15 8	7 13	11 3	1 0	0 0
341-360	0	14 3	0	5 3	0 19	0 9	16 10	5 16	16 5	3 0	1 0
361-380	0	15 2	0	16 1	0 16	0 8	19 8	5 19	10 3	91	1 0
381-400	0	5 0	0	11 4	0 8	0 2	4 2	3 5	3 0	3 0	1 0
401-420	0 ↓	1 0	0 ↓	4 0	0 1	>–	1 1	0 2	1 1	1 0	1 0
	– >..		>– >..		>– >..	>..		>..			

[a]Data combined to increase sample size
[b]Fish not measured

Table 13. Fork length class distribution of longnose sucker (1974 upstream migrants) that were successful in ascending a 30.5 m culvert in one-day tests at indicated water velocities. S = success, F = failure; upper bar = 25%, double dots = 50% and lower bar = 75% successful length class for each water velocity

Velocity, meters per second	1.2	1.5	0.9	1.2	0.6	1.1	1.5	1.1	0.8	0.8	1.0	1.0	0.8
Temperature, C	4-6	4-7	4-7	5-7	6-8	7-9	9-10	9-11	9-11	10-12	11-12	11-13	11-13
May, 1974	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	24-25	25-26	26-27	27-28
	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F
Fork length, millimeters													
141-160											0 1	0 2	0 1
161-180	0 1										0 1	0 1	0 5
181-200	0 0									<-	0-0	0 0	- 2··2
200-220	0 1						0 1		<··	2 1	2··2	0-2	2 0
221-240	0 0		<-	0 1	0-2	2 3	0 3	1-3	2-0	·· 0 1	4-1	·· 3 2	- 8 3
241-260	0 0		3··3	1 1	·· 4 1	2-6	0 7	1 5	4 0	4-1	8 2	9 6	12 1
261-280	0 3	0 1	7 3	3-7	7-5	4 18	0 19	·· 9 6	5 0	6 2	11 1	6-2	19 2
281-300	0 4	0 5	10 5	2 9	9 1	5 16	0 11	9 1	9 3	9 1	15 0	9 4	20 1
301-320	0 6	0 3	- 8 4	5 7	10 1	3 12	0 8	- 8 6	9 1	8 2	12 0	13 3	12 1
321-340	0 8	0 8	15 5	5 14	14 1	10 13	0 15	13 2	23 0	16 2	12 1	15 1	15 0
341-360	0 16	0 5	23 7	7 27	14 2	13 27	0 15	26 6	23 3	30 4	40 2	24 1	24 1
361-380	0 24	0 5	27 2	17 22	13 7	9 31	0 22	28 5	24 2	24 1	26 2	33 1	23 1
381-400	0 8	0 3	17 1	6 17 ··	16 5	2 31	0 5	18 6	25 5	21 3	19 0	18 1	18 1
401-420	0 4	0 2	4 3	2 0	3 0	2 5	0 13	4 1	11 2	7 2	4 2	10 2	10 2
421-440	0 2	0 1		1 1	1 0	1··1 -	>- >··			1 0	2 1	1 0	2 0
441-460	>- >··	0 0		1-0		9 0				1 0			2 0
461-480		0 0				2 0				1 0			1 0
481-500		0 1 >- >···											

Table 14. Summary of critical points for fork lengths of suckers that successfully ascended 18.3 m and 30.5 m culverts in one-day tests at indicated water velocities. The critical points were obtained from Tables 12 and 13 and are plotted in Figure 15

18.3-meter culvert					30.5-meter culvert				
Velocity m/s	Mean temperature, C	Percentage of success 25	50	75	Velocity m/s	Mean temperature, C	Percentage of success 25	50	75
1.9	6.5	-	-	-	1.2	5.0	-	-	-
0.8	6.5	-	-	240	1.5	5.5	-	-	-
1.8	6.5	-	-	-	0.9	5.5	-	250	300
0.6	6.5	210	220	230	1.2	6.0	270	400	450
1.8	7.5	-	-	-	0.6	7.0	230	240	270
1.7	7.5	-	-	-	1.1	8.0	250	430	440
1.2	7.5	220	250	310	1.5	9.5	-	-	-
1.4	7.0	320	-	-	1.1	10.0	230	260	300
1.3	7.5	240	260	300	0.8	10.0	-	-	230
0.9[a]	8.5	160	230	250	0.8	11.0	-	220	250
1.1	13.5	180	200	210	1.0	11.5	190	210	230
					1.0	12.0	210	220	270
					0.8	12.0	180	190	220

[a]Data from two tests are combined to increase sample size.

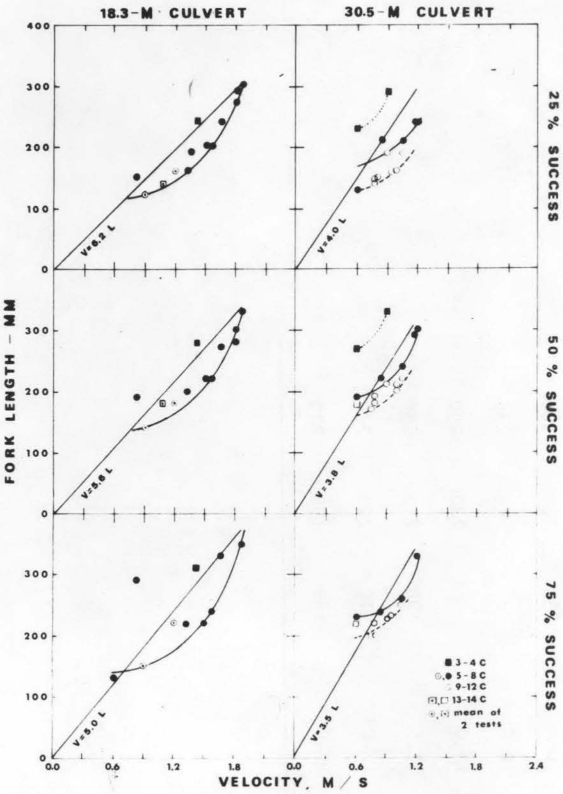

Figure 14. Relationship between fork length and water velocities which permitted 25, 50 and 75% of Arctic grayling to ascend 18.3 and 30.5 m culverts in one-day tests. Curved lines approximate "barrier" parameters (dotted, 3-4 C; solid, 5-8 C; dashed, 9-12 C). Straight lines represent maximum "safe" velocities

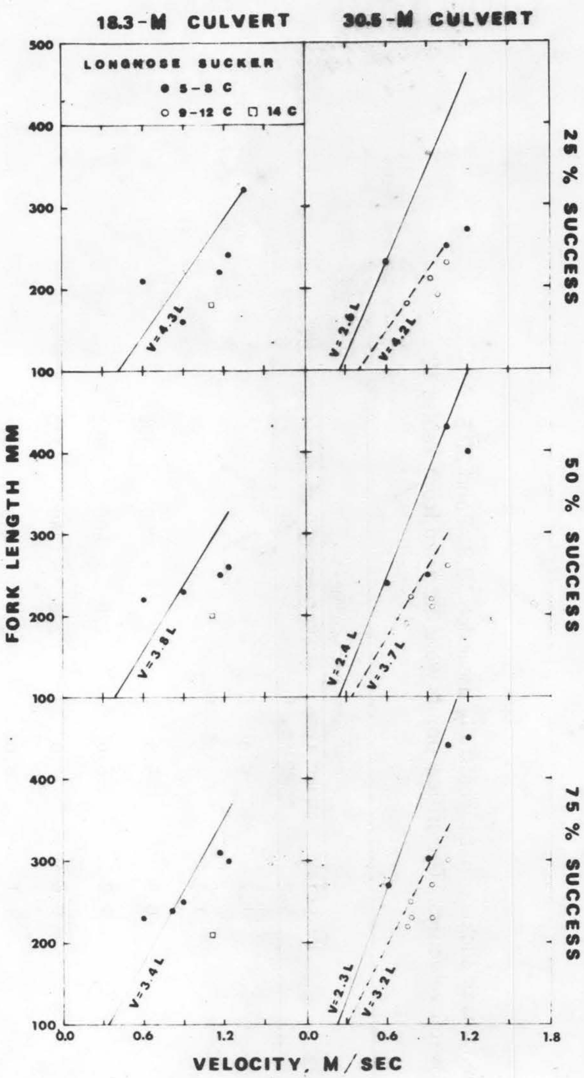

Figure 15. Relationship between fork length and water velocities which permitted 25, 50 and 75% of the longnose sucker to ascend 18.3 and 30.5 m culverts in one-day tests. Solid lines (5-8 C) and dashed lines (9-12 C) represent maximum "safe" velocities

The > and < symbols used in Tables 8-10 and 12-13 require interpretation. In some instances because of excessive water velocity or lack of fish in suitable size classes, 75% (or 50% or 25%) of the fish did not ascend the culvert. For the grayling test on 21-22 May, 1973, in Table 9 for example, the > symbol indicates that a grayling longer than 340 mm would be required to achieve 75% success at 1.8 m/s; for the 22-23 May test the < symbols indicate that the fish in the sample were not short enough to determine 25 or 50% of success at 0.6 m/s.

The range in mean temperature of Poplar Grove Creek during the major portion of the spawning run was greater in 1974 (3-12 C) than in 1973 (4-7.5 C). Because of this we were able to separate the data for the 30.5 m culvert into two major temperature regimes; namely, 5 – 8 C and 9 – 12 C. For these two regimes the effect of temperature on swimming capability was discretely significant, the grayling and the sucker swimming faster at higher temperatures.

Each mean water temperature in Tables 11 and 14 represents an average of a maximum afternoon temperature and a minimum morning temperature taken daily between 0900 and 0900 hr. The mean water temperatures between 1100 and 2300 hr, when most successes stemmed the culvert, averaged about 0.5 C more than the daily mean temperatures. Thus, a 0.5 C correction was added to adjust for the warmer afternoon and evening temperatures. The adjusted mean of the 5 – 8 C series is about 7 C, and that of the 9 – 12 C series about 11.5 C.

In the 18.3 m culvert, the fastest flow tested (1.9 m/s) blocked 77% of the 261-360 mm grayling at 6 – 7 C (Table 9). In the 30.5 m culvert, the fastest water velocity (1.5 m/s) tested stopped all grayling under 300 mm in length (Table 10). For longer fish (301-340 mm) 1.5 m/s blocked the upstream migration of all but 3 successes out of 40 fish (4-7 C), and 2 successes out of 21 fish (9-10 C).

In the 18.3 m culvert, a flow of 1.7 m/s blocked all suckers (410 mm, max) and 1.4 m/s blocked 75% of the 320-410 mm fish at 6 – 8 C. In the 30.5 m culvert, a flow of 1.2 m/s blocked all suckers (430 mm, max) when the first wave of the sucker spawning run arrived on 15-16 May (4-6 C), but 1.2 m/s did not stop fish three days later (5-7 C). The state of maturation of the sucker presumably influenced its migratory drive. A water velocity of 1.5 m/s blocked all suckers (410 mm, max), regardless of the state of maturation of the fish in the 18.3 m culvert at 9 – 10 C.

Grayling passage through 18.3 and 30.5 m culverts is limited at the water velocity, described by the curved lines, for prescribed levels of success (Figure 14). Curved "barrier" lines for maximum limits of swimming capability of the sucker could be described in the same manner, but for simplicity are omitted from Figure 15. A straight line (solid) constructed to pass through the origin of the coordinates bounds the lower velocity range of most points above 5 C. For suckers tested in the 30.5 m culvert a second straight line (dashed) separates the limits of performance at two temperature regimes (5-8 C and 9-12 C). The straight lines represent conservative relationships between length and water velocity in that it includes all well-motivated fish.

As the length of culvert and the speed of flow increases, the ability of fish to stem the current decreases. In grayling, to permit 25% to 75% success flows were changed from 6.2 to 5.0 times the fork length of the fish for 18.3 m culverts, and from 4.0 to 3.5 times the length for 30.5 m culverts. In the sucker, to permit 25 to 75% success, flows were changed from 4.3 to 3.4 times the fork length of fish for 18.3 m culverts (5-8 C), from 2.6 to 2.3 times the length for 30.5 m culverts (5-8 C), and from 4.2 to 3.2 times the length for 30.5 m culverts (9-12 C). The data indicates that the length of the sucker must be about 1.5 times the length of the grayling to stem the same water velocities.

Depending on motivation rather than swimming capability, datum points could occur any place in the area above "barrier" lines within the length range of the test fish. These "barrier" curves tend to become horizontal at slower water velocities, perhaps because smaller fish are less mature than larger ones, and thus respond less actively to the migratory drive. However, the points group reasonably well considering the small sample sizes and the unknown degree that unassessed factors could have influenced behavior.

Near the end of the run in 1974, exploratory 3- and 5-day trials were conducted to determine the cumulative effect of time on the response essentially immature grayling to stem culverts. These were the last three tests of the run and stream temperatures were 9 – 15 C. The critical lengths of immature grayling attained at the 25, 50 and 75% levels of success in 2-day tests were about 24% shorter than those attained in 1-day tests; and those attained in 3-day tests were about 8% shorter than those attained in 2-day tests (Table 15).

Data from 2-day and 3-day response periods appear to markedly alter the shape of the "barrier" curve at lower velocities by directing datum points more towards the base of the graph (Figure 16). The straight line which bounds the lower velocity range of the fish at 5 – 8 C in Figure 14 is included for reference. Presumably, the initial lack of motivation of the smaller size groups is largely overcome with a longer test period.

At the end of 3 days the level of swimming success was more stable at lower flows (0.6 m/s) than at higher flows (0.9 m/s), with the degree of stability measured by the amount of change in critical lengths between successive days (Figure 17). Even at the end of 5 days, a greater percentage of small fish succeeded in stemming a velocity of 0.9 m/s and their critical length decreased. The cumulative effect of 2- or 3-day tests at higher velocities on larger fish has yet to be tested, but it is likely that such cumulative tests would result in a marked improvement in swimming performance.

In 1974, we analyzed the effect of state of maturation on the motivation of grayling to ascend the 30.5 m culvert in one-day tests. We classified fish as "ripe" if they lost eggs or milt when handled or if any eggs or milt flowed when gentle pressure was applied anterior to the genital opening.

The percentage of ripe fish in any given length class varied with the size of the length class (Figure 7). Only the larger fish (261-360 mm) were used for analyses as this group contained the highest and most consistent percentages of ripe fish (males, 89%; females 37%).

A large percentage of males were ripe at the beginning and during most of the run whereas the percentage of ripe females increased with time (Figure 8). Thus, we divided the females chronologically into three groups. These represented three levels of maturation (Table 16). The three groups each had fairly discrete temperature regimes and were coincidently separated by the 1.5 m/s tests. There were just a few successes during these high velocity tests and, therefore, data for these tests were omitted from this analysis. The data for males were partitioned to correspond with those for females.

Table 15. Cumulative effect of time on success of grayling of various length classes to ascend a 30.5 m culvert, 1974. S = success, F = failure; upper bar = 25%, double dots = 50% and lower bar = 75% successful length class for each water velocity

Velocity, meters per second	0.6			0.8			0.9				
Temperature, C	10-16			11-15			9-13				
Date, 1974	May 31-1	31-2	31-3	May 27-28	27-29	27-30	June 5-6	6-7	7-8	8-9	9-10
Duration, hours	24	47	70	22	46	71	22	46	69	93	117
	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F	S F
Fork length, millimeters		<-	<-								
	<-	<··	<··								
81-100	1 0	1 0	1 0	0 20	1 19	3 17					
						-					<-
101-120	3 6	6 3	6 3	1 56	12-45	30··27	0 18	0 18	0 18	0 18	6 12
											··
121-140	18 25	24 19	25 18	11 81	45··47	63 29	0 69	2 67	17-52	19-50	39 30
				-						··	
141-160	1 7	2 6	4 4	13 17	21 9	23-7	0 17	3 14	9··8	10 7	10 7
					-			-			
161-180	2 3	4-1	4-1	11··4	12 3	14 1	1 5	2 4	2 4	2 4	3 3
	··							··			
181-200	3 2	5 0	5 0	5 11	11 5	11 5	1-3	3-1	3-1	3-1	3-1
				-							
201-220	9 4	13 0	13 0	21 4	25 0	25 0	3··2	4 1	4 1	4 1	4 1
	-										
221-240	5 2	6 1	6 1	24 5	28 1	28 1	1 1	2 0	2 0	2 0	2 0
241-260	2 0	2 0	2 0	5 3	8 0	8 0	>-				
262-280				0 0	0 0	0 0					
281-300				2 0	2 0	2 0					

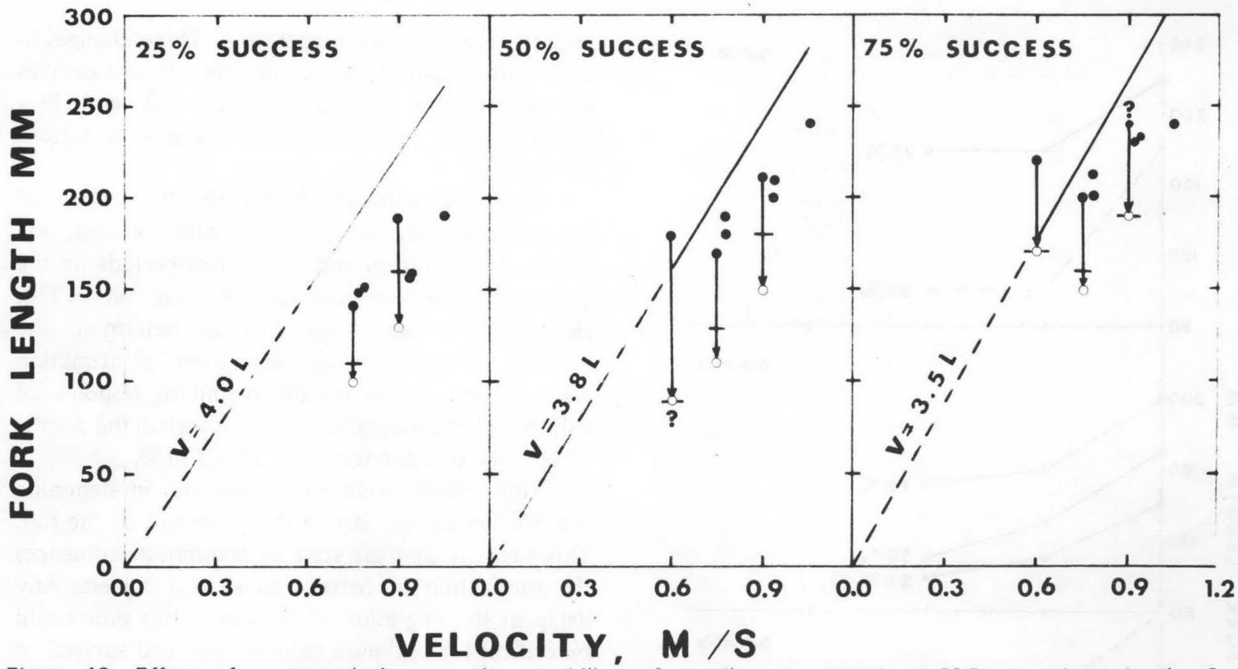

Figure 16. Effect of water velocity on the capability of grayling to ascend a 30.5 m culvert in 1-, 2- and 3-day trials (temperature, 9-16 C). Arrows indicate the direction of change of critical lengths for 3-day tests. Solid circle = 1-day test; cross bar = 2-day test; open circle = 3-day test and a ? = extrapolated value to the next length class

For the total run 88% of the successes and 70% of the failures were males with milt. The proportion of successes versus failures of males with milt was fairly consistent throughout the spawning run.

There were no ripe females in the early run (13-15, May 1974). During the mid-run (17-20 May) when a large percentage of the females were not ripe (Figure 8) there were less ripe females among the successes (31%) than among the failures (51%). For the latter part of the run (22-27 May) when a large percentage of the females were ripe, there were more ripe females in the successes (76%) than in the failures (67%). Thus, the situation reversed itself.

Discussion

The first tests began with the first wave of grayling that arrived at the dam on the mornings of 15 May, 1973 (3 C) and 13 May, 1974 (2 C). Most of these fish were of spawning size and remained in the tailbox several hours prior to attempting to ascend the culvert. During subsequent tests, the fish attempted ascent of the culvert at progressively earlier hours. We assume that water temperature and state of maturation regulated the timing of their upstream swimming response. During the first days the water did not get warm enough for significant numbers of fish to ascend the culvert until late afternoon. On subsequent days as fish ripened and the weather and water warmed, grayling stemmed the culvert earlier in the afternoon.

Significant numbers of suckers arrived at the dam site on 19 May, 1973 (6-7 C) and 15 May, 1974 (4-6 C). After their arrival, suckers and grayling were mixed together in the tailbox, as this would be the normal situation in the pool below a culvert installation. Because the capacity of the tailbox was limited, we tested only a portion of the suckers that we captured most days. Moreover, we set water velocities in the culvert to maximize the behavior data for grayling and not for sucker. Thus, several tests had flows too fast for the sucker to stem and we obtained fewer datum points for analysis.

By 27 May, 1973 and 1974, the spawning run of grayling 240 mm and longer had essentially ended. After these dates, the run was small and made up primarily of small fish. These fish do not have the same motivation as spawning fish, but because of warmer water their swimming performance is somewhat comparable to that of motivated spawners swimming at lower temperatures.

In 1974 the culvert tests on the average were stopped about 1½ hours later in the morning than those in 1973. This difference in termination time had minimal effect on the results. Overnight checks on diel movement in 1973 indicated that very few grayling ascended the culvert during the early morning when water temperature was lowest. Cessation of the culvert operation for retreiving failures and altering the slope of the culvert was geared to low morning temperatures when fish were least active.

In 1974, we refined our techniques by: 1) reducing stress on fish during the netting operation by capturing fewer fish at a time, 2) allowing an overnight recovery and conditioning period, and 3)

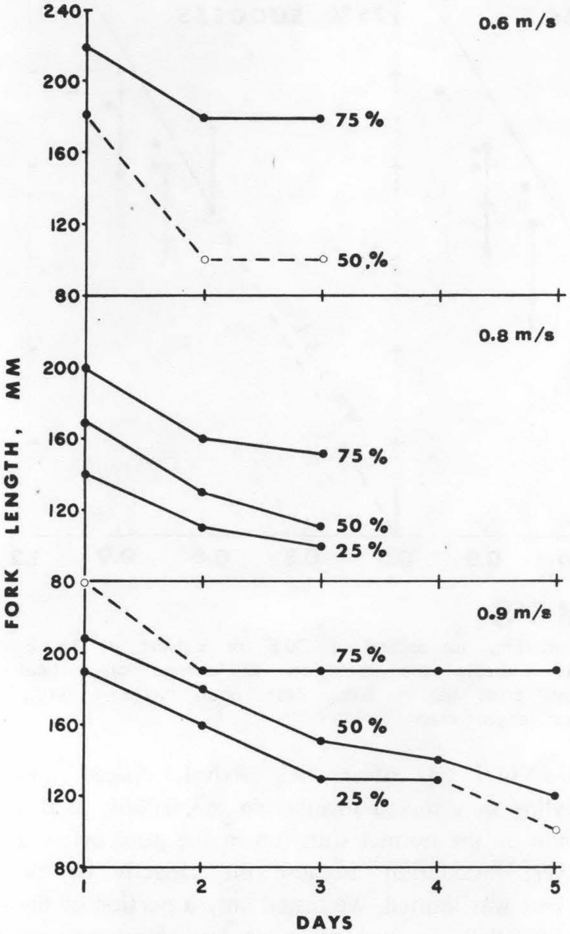

Figure 17. Cumulative effect of time on the length of grayling that ascended a 30.5 m culvert at the indicated percentage level of success. Hollow points and dashed lines indicate extrapolated data

improving our headbox operation. These changes in procedure reduced some of the inconsistencies observed in the 1973 data but did not result in a change in fish performance, or the general pattern of results.

We were able to distinguish the effect of temperature and, to a more limited extent, the effect of maturation and longer test periods on the swimming performance of grayling in 1974. However, we were not able to determine the possible effect of changes in volume of attraction water in the culvert on the swimming response of fish. Small discharges may have affected the results of our low velocity tests (0.6 to 0.9 m/s).

Ripe females were most successful in stemming the 30.5 m culvert during the latter half of the run. This suggests that the state of maturation influences the motivation of females to stem a culvert. Any delay in the migration of females at this time could be critical for optimum reproduction and survival of eggs and young. Thus, a strong drive to migrate upstream during the late stages of the run would have obvious survival value for the species.

Because the number of fish available each day for testing in 1973 was less than what would be statistically desirable, we used a moving average of three to verify our analysis (MacPhee and Watts, 1973). This method increased the reliability of judgement by allowing the size of adjacent length classes to weight the estimate of the lengths of the 25, 50, and 75% successes. However, datum points are lost at the ends of the series, resulting in fewer points for plotting. Also, because this procedure averaged lengths in a 60 mm length range, the

Table 16. Percentage of ripe grayling that sucessfully ascended a 30.5 m culvert in one day. Data for 5.0 m/s velocities are omitted because of few successful responses (5 out of 142 fish)

Starting date, May	Temperature range, Centigrade	Velocity range, meters per second	Percentage of ripe fish (261-360 mm) Males: Successes	Males: Failures	Females: Successes	Females: Failures
13, 14, and 15	3-6	0.6-1.2	88 (n=18)	81 (n=27)	-- (n=0)	-- (n=0)
17, 18, 19 and 20	4-9	0.6-1.2	97 (n=127)	68 (n=22)	31 (n=105)	51 (n=47)
22, 23, 24, 25, 26, and 27	9-13	0.8-1.1	80 (n=20)	60 (n=5)	76 (n=33)	67 (n=9)

determined lengths would sometimes represent two age groups. The length classes for performance level determined by either method were essentially similar, and so, our analysis with a moving average of three is not included in this report.

The culvert tests did not contain short enough grayling to obtain the 25% and 50% success lengths for the 18.3 m culvert at 0.6 m/s (6-7 C), and the 25% success length for the 30.5 m culvert at 0.6 m/s (13-16 C) in Tables 9 and 10. Extrapolation to the next lowest length class (81-100 mm) provides a conservative estimate of these critical lengths. Any plotting of these extrapolated lengths in Figure 14 would not bias the results. However, one should be cautioned against extrapolating to the next largest length class for critical lengths greater than those for which data are available, as much longer fish might be needed to attain the desired critical level of success.

An 87 mm grayling was the shortest fish captured in 1974. Thus, the lengths of grayling in the 81-100 mm class (35 fish) were not normally distributed and averaged 96 mm. Although not determined, the average of the 81-100 mm class in 1973 was probably about the same length and 96 mm instead of the 90 mm mean should be used for datum analysis.

The straight line relationships shown in Figure 14 indicate conservative estimates of sustained speed for grayling. The estimated speeds range from 3.5 L to 6.2 L (where L equals fork length) depending on the water temperature, length of the culvert and on the percent of success specified. Bell (1973) reported that sustained swimming speed for average adult grayling range from 0.8 to 2.2 m/s. Stanistaw and Stanistaw (1962) indicate that maximum velocity sustained by grayling in an experimental fishway at a dam on the Volkhov River in Russia was 2.3 m/s. According to the relationships shown in Figure 14 for an 18.3 m culvert, a 38 cm grayling could maintain a sustained speed ranging from 1.8 to 2.3 m/s so our data are consistent with data reported by Bell (1973), and Stanistaw and Stanistaw (1962).

Considering all aspects of the study, the number of secondary variables and the variations in the size classes in the runs, we are well-satisfied with the data. With few exceptions the data grouped rather well. The curved lines shown to the right of most of the data indicate a barrier type region to the right of the line. Any design criteria selected should be to the left of the curved line for any of the three specified levels of success.

The straight line to the left of most of the datum points represents a conservative linear equation for fork length versus flow velocity in the culvert. The positioning of the design curve, somewhere between the solid line and the barrier line (possibly a best fit curve through the datum points), and the selection of 25, 50 or 75% success as a design criterion are options of the planning agency. Judgement will be based on management philosophy and passage constraints imposed for the structure in question.

SWIMMING PERFORMANCE IN CIRCULAR CHANNEL

Introduction

The general purpose of the circular channel tests was to provide swimming performance data for variables that could not be systematically varied in the relatively short-term culvert study. An assessment of such variables would allow an interpretation of the ability of grayling to ascend culverts in situations other than that encountered at Poplar Grove site.

The specific objectives of the circular channel tests were as follows:

1) to determine the voluntary cruising speed and sustained speed of grayling in relation to temperature,
2) to determine the voluntary cruising speed and sustained speed of grayling in relation to fork length, and,
3) to determine the effect of upstream and downstream migratory behavior on the voluntary cruising speed and sustained speed of grayling and their motivation to swim.

Cruising speed has been defined by Brett, et al. (1958) as the rate that a fish can maintain for a period of one hour under strong stimulus without gross variation in performance. We determined the speed of fish for one-hour periods, but differentiated between voluntary and forced cruising speed according to the absence or presence of a wire screen to force fish to maintain station.

For this section of the report we define sustained swimming speed as the fastest rate which a fish can voluntarily maintain for a 10-minute period.

For voluntary cruising speed and sustained speed we patterned our tests after MacLeod (1967) and provided a water velocity which was slightly greater than the maximum swimming speed of the weaker or less motivated fish in a sample. This caused some fish to drift backwards even though swimming upstream. Swimming speed was calculated from current velocity, circumference of the channel, and the number of laps lost by fish during a specific time period.

Grayling Sources

Arctic grayling were obtained from Poplar Grove Creek and Town Lake by the town of Çhitina. The lake is small in area (0.16 km^2) and relatively shallow (6.4 m at maximum depth). Town Lake contained an abundance of small grayling, useful for measuring the effect of temperature on swimming speed. Poplar Grove Creek provided all sizes of fish in sufficient numbers to assess the effect of size on swimming performance in both the circular channel and culvert facility. As the same race of grayling was used in the two types of experiments, the results should be directly related.

Circular Swimming Channel

A circular swimming channel (0.2 m in width by 0.6 m in height by 8.7 m in median circumference) was constructed with a plywood bottom and outside wall and a clear plexiglass inside wall (Figures 18 and 19). An angle iron frame was used to hold the fiberglassed facility rigid. Four custom built aluminum water jets (3 mm in width by 45 cm in height) propelled water (50 cm in depth) in the channel clockwise at a speed regulated by valves in the pipe system.

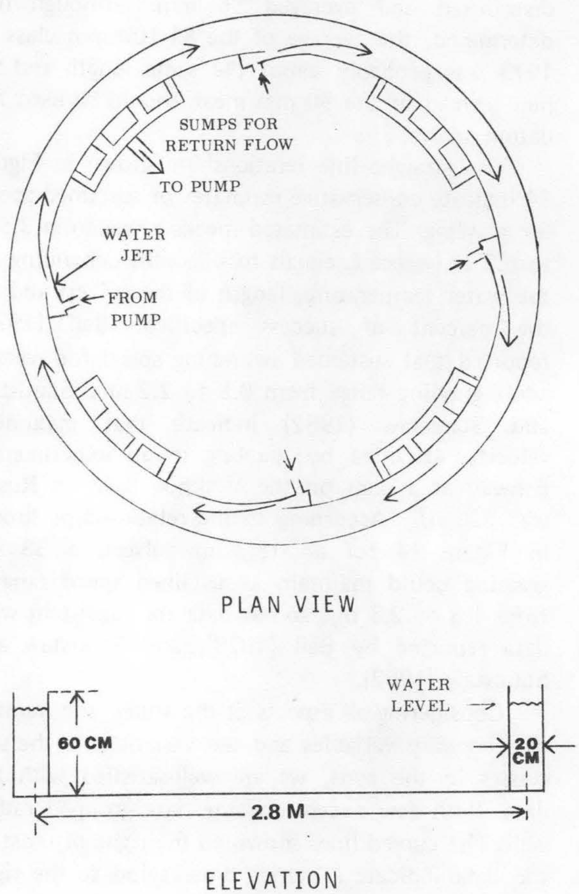

Figure 18. Plan and elevation of circular channel used in fish swimming performance tests. Pumps and hoses are omitted from the diagram

Two 7.6 cm ID (inside diameter) centrifugal pumps driven by 5 hp air-cooled engines forced water through two pairs of 3.8 cm ID hoses to the four jets. Each quadrant of the channel had four screened sumps (5.1 cm ID) that drained water into a 7.6 cm suction hose. Three suction hoses returned water to the pumps and one hose was used to regulate overflow.

Friction in the pumping system heated the water in the channel. To maintain a constant temperature in the channel, it was necessary to draw water continuously from the creek through one 3.8 cm hose. As a result of this procedure, water in the swimming channel was slightly warmer than the creek.

An Ott current meter was centered 20 cm above the bottom of the channel and clamped permanently into position.

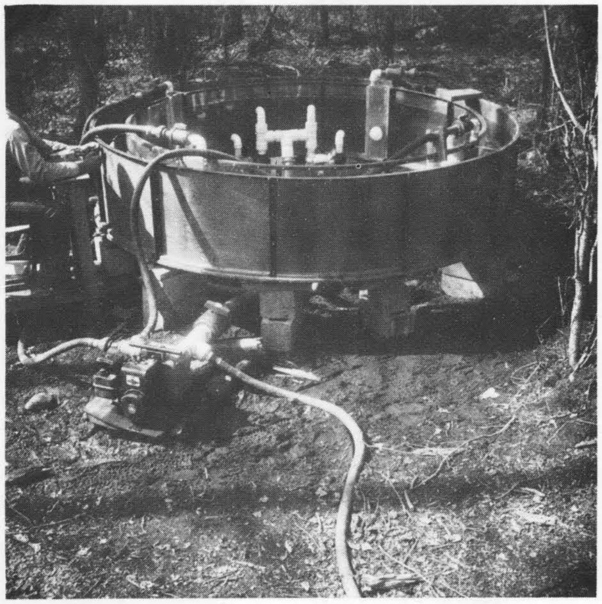

Figure 19. View of circular swimming channel with installed pumps and hoses

Experimental Procedure

The number of grayling tested in the channel at any one time ranged from 2 to 59 fish, depending on their size and availability. Tables 17 – 21 list the number, mean fork length, length range and source of each experimental lot.

Fish that were used in culvert tests were sorted into relatively uniform length-classes as they were measured. Other fish were sorted by eye to reduce handling injuries. Fish were acclimated at least overnight at stream temperature.

Most grayling stemmed the current or tried to maintain a station when placed in the circular channel. The weaker or non-motivated fish in a lot gradually lost ground tail-first when the water velocity was too fast for them. The velocity of the water had to be adjusted to match the swimming speed of the fish. Sometimes false starts occurred when many fish ceased to maintain station, and the velocity needed to be reduced.

A removable 13 mm square wire screen placed transversely across the channel was used to train those fish which did not promptly head into the current, stem the current or maintain their position. Untested fish were conditioned with the screen for at least one-half hour in experiments in April 1973, and for one hour for most of the remainder of the tests. Water velocities during the conditioning period were maintained at less than one-half test velocities. After conditioning, we removed the screen and increased the water velocity to a speed that most fish in a lot could voluntarily maintain for one hour (up to 1.3 m/s).

The number of times that unscreened fish passed an arbitrarily selected reference point clockwise and counterclockwise was recorded at 10-minute intervals for one hour and totaled. Current velocity, water temperature, and fish movements were recorded at 10-minute intervals and the data were averaged for one-hour tests.

If a group of fish was obviously not motivated to swim vigorously or if fish headed downstream, a screen was used to force the lot to maintain position and swim faster. In this case water velocity in the channel had to be changed to a speed that would not cause weaker fish to flatten against the screen. Forced swimming speeds (1 hr) were obtained for analysis for just those lots of fish that would not respond well without the use of a screen. Data from poorly motivated swimmers were omitted from analyses.

With few exceptions groups of fish were tested for two or three one-hour periods. Fish were permitted to rest a minimum of 30 minutes between experiments. Depending on the number of one-hour tests, 6, 12 or 18 sustained speeds were obtained with each lot of fish. However, only the maximum cruising and sustained speeds were selected for analyses. We considered that variation in swimming speed as occurred in repeat trails was due to experimental artifact and/or lack of motivation rather than exhaustion.

We measured the contrasting swimming performance of upstream and downstream migrating grayling from Poplar Grove Creek. We also measured the swimming performance of four lots of fish that succeeded and three lots that failed to stem the 18.3 m test culvert. We analysed the results of all tests for Poplar Grove and Town Lake grayling with the exception of tests that were discontinued before the elapse of one hour because of mechanical failure or because of the necessity of stopping the test to insert a screen to force fish to swim faster.

Table 17. The voluntary sustained speed (10 min) and crusing speed (1 hr) of Arctic grayling (107-172 mm) from Town Lake

Date month/ day	Test number	Temperature, degrees Centigrade	Number of fish	Fork length range, millimeters	Mean fork length millimeters	Swimming speed, meters/second		Water velocity meters/second
						10-minute	1-hour	
5-9-73	2	1	11	115-148	134	0.41	0.41	0.45
5-12-73	3	2	17	139-162	152	0.59	0.56	0.57
5-14-73	1	4	59	132-164	149	0.66	0.55	0.59
5-15-73	1	6	16	113-150	127	0.60	0.57	0.57
6-6-73	2	10	36	136-163	151	0.77	0.72	0.85
6-6-73	3	11	31	160-179	165	0.87	0.79	0.95
6-7-73	2	11	39	140-160	152	0.80	0.80	0.85
6-8-73	2	9	19	112-142	129	0.77	0.67	0.77
6-9-73	2	9	28	132-174	150	0.76	0.65	0.86
6-12-73	2	12	26	142-165	152	0.86	0.81	0.82
6-13-73	2	14	7	115-135	123	0.81	0.74	0.83
7-4-73	1	14	31	97-118	107	0.72	0.59	0.66
7-4-73	1	15	22	159-179	167	0.92	0.86	0.91
7-14-73	2	14	10	148-160	155	0.94	0.88	0.91
7-14-73	1	15	4	163-167	165	1.15	1.14	1.12
7-17-73	2	16	13	106-133	120	0.91	0.87	0.93
7-18-73	2	15-16	30	159-175	161	0.94	0.90	0.94
7-18-73	1	16	28	144-161	153	0.87	0.81	0.87
7-25-73	2	18	24	107-140	122	0.84	0.75	0.98
7-25-73	1	18	27	153-177	165	0.77	0.70	0.94
7-26-73	2	16	27	153-177	165	0.86	0.80	0.91
7-26-73	2	17	25	140-164	151	0.84	0.79	0.98
7-27-73	1	15-16	12	160-176	170	0.79	0.62	0.99
7-27-73	2	16-17	12	160-176	170	0.70	0.70	0.79
7-31-73	2	13	20	114-140	128	0.87	0.72	0.95
8-8-73	1	12	11	123-144	133	0.76	0.59	0.77
8-9-73	2	12	32	137-161	152	0.78	0.77	0.95
8-9-73	2	13	34	155-173	170	0.83	0.78	0.85
8-23-73	2	13	11	113-139	130	0.84	0.64	0.91
8-23-73	2	13	15	136-153	145	0.95	0.93	1.08
8-24-73	2	13	40	145-170	156	0.84	0.79	0.85
9-4-73	3	9	55	150-177	162	0.70	0.67	0.91
9-5-73	2	10	37	124-152	139	0.71	0.70	0.79
9-13-73	2	7-8	31	115-138	128	0.74	0.73	0.75
9-14-73	2	7	37	130-159	141	0.84	0.80	0.93
9-14-73	2	8	10	155-173	163	0.88	0.76	0.99
9-20-73	3	7	21	148-182	164	0.77	0.76	0.85
9-20-73	1	7-8	20	130-155	141	0.71	0.63	0.80
5-6-74	3	1	45	149-190	164	0.44	0.41	0.46
5-8-74	2	1	22	125-140	126	0.40	0.39	0.42
5-9-74	2	1	53	144-167	156	0.44	0.43	0.48
5-10-74	2	1	14	122-137	131	0.36	0.35	0.44
5-11-74	3	2	48	139-169	154	0.43	0.43	0.50
5-11-74	2	2	20	154-192	176	0.45	0.42	0.50
5-14-74	1	5	35	124-143	131	0.57	0.52	0.62

Table 18. The speed of Arctic grayling from Town Lake which were compelled by a wire screen to swim for one hour at a maximum rate (1973)

Date month/ day	Test number	Temperature, degrees Centigrade	Number of fish	Fork length range, millimeters	Mean fork length, millimeters	Fish swimming speed, meters/second	Water velocity, meters/second
6-29	2	15-16	12	99-128	117	0.66	0.66
7-2	2	14	15	132-160	146	0.68	0.68
7-2	2	16	38	150-169	165	0.75	0.75
7-3	2	14	18	138-162	151	0.68	0.68
7-3	2	14	17	144-174	167	0.95	0.95
7-4	2	14	31	97-118	107	0.75	0.75
7-6	2	16	27	144-164	154	0.91	0.91
7-7	2	16-17	36	142-163	157	0.87	0.87
8-1	3	13	29	140-160	152	0.90	0.90
8-1	2	13	27	162-186	172	0.95	0.95

Table 19. The voluntary sustained speed (10 min) and cruising speed (1 hr) of upstream migrating Arctic grayling from Poplar Grove Creek (1973). Four samples of grayling were selected on the basis of successfully passing (S) or failing to pass (F) upstream through an 18.3 m culvert

Date month/ day	Test number and category	Temperature, degrees Centigrade	Number of fish	Fork length range, millimeters	Mean fork length, millimeters	Swimming speed, meters/second 10-minute	1-hour	Water velocity, meters/second
5-15	1S	6	30	260-325	292	0.79	0.70	0.95
5-15	2	5	21	173-233	200	0.77	0.74	0.79
5-18	2S	7	21	266-332	294	0.94	0.91	0.93
5-18	3S	6	20	173-345	288	0.86	0.84	0.91
5-18	2S	8	20	265-366	311	1.07	0.96	1.04
5-19	2F	8	30	155-199	185	0.58	0.34	0.49
5-20	3F	7	30	159-191	167	0.52	0.52	0.52
5-21	1	7	20	258-283	270	0.92	0.91	0.91
5-22	2	6-7	50	125-158	140	0.54	0.54	0.54
5-23	1	8	15	293-340	304	0.97	0.87	1.04
5-24	3	9	15	202-238	215	0.61	0.56	0.63
5-25	2	8	15	272-333	293	0.91	0.84	0.95
5-26	2	7-8	11	256-281	272	0.98	0.94	0.95
6-4	2	10	44	101-128	115	0.42	0.39	0.36
6-21	1F	14	33	96-123	109	0.29	0.19	0.46

Table 20. The voluntary sustained speed (10 min) and cruising speed (1 hr) of downstream migrating Arctic grayling from Poplar Grove Creek (1973)

Date month/ day	Test number	Temperature, degrees Centigrade	Number of fish	Fork length range, millimeters	Mean fork length, millimeters	Swimming speed, meters/second		Water velocity, meters/second
						10-minute	1-hour	
5-31	3	10	7	268-349	323	0.93	0.79	1.04
5-31	1	11	10	275-295	284	0.99	0.58	0.93
6-1	1	11	27	176-199	189	0.38	0.26	0.38
6-5	2	11	18	162-222	202	0.59	0.34	0.63
6-5	2	11	22	128-144	134	0.34	0.28	0.42
6-14	2	14	11	298-321	309	0.95	0.84	1.06
6-18	1	13-14	20	210-244	227	0.56	0.52	0.68
8-14	1	10	14	200-223	213	0.65	0.57	0.99
8-21	1	14-15	11	203-220	212	0.67	0.52	0.99
8-22	1	12	5	195-200	197	0.56	0.43	0.87
8-27	1	12	20	220-245	228	0.71	0.38	0.87
8-28	1	11	21	195-221	211	0.66	0.48	0.87
8-28	1	11	3	308-325	315	0.97	0.52	1.04
9-6	2	10	25	197-228	213	0.86	0.68	1.03
9-6	1	9	11	197-240	229	0.90	0.54	0.98
9-7	1	9-10	5	248-268	257	0.85	0.66	0.91

Table 21. The speed of Arctic grayling from Poplar Grove Creek which were compelled by a wire screen to swim at a maximum rate for one hour. Most of the tests contained downstream migrants but three tests were made with upstream migrants that succeeded (S) or failed (F) to pass upstream through a 18.3 m test culvert

Date month/ day 1973	Test number and category	Temperature, degrees Centigrade	Number of fish	Fork length range, millimeters	Mean fork length, millimeters	Fish swimming speed, meters/second	Water velocity, meters/second
5-17	1S	6	20	173-345	288	0.89	0.89
6-19	4	13-14	20	210-244	227	0.77	0.77
6-20	3	14-15	28	190-219	208	1.02	1.02
6-21	3F	16	33	96-123	109	0.52	0.52
8-22	3	13	5	195-200	197	0.91	0.91
8-27	2	12	20	220-245	228	0.87	0.87
8-28	2	12	21	195-221	211	0.99	0.99
8-29	2	11	3	308-325	315	1.04	1.04

Calculations

The forced swimming speed of grayling equalled the water velocity as a screen prevented fish from circling the channel. The distance that grayling swam in one hour was determined by multiplying the velocity of water in meters per second by 3600 seconds.

For voluntary cruising speed a correction was made by multiplying the net revolutions in one hour that fish gained or lost by 8.7 m (circumference of mid-channel), and subtracting that value from the one-hour distance that the water travelled. The result divided by 3600 gave the voluntary cruising speed in meters per second. Voluntary sustained speed was calculated in the same manner except that units of 600 sec were used instead of 3600 sec.

Optimal water speeds for determining voluntary cruising speed required some loss of revolutions by the weaker or smaller fish of a test lot.

The stronger fish, if motivated, gained revolutions usually at the beginning of a test. If velocities were too high, considerable downstream drift occurred even though fish headed into the current.

Within limits, the velocity of the water and the number of revolutions lost by weaker fish and gained by stronger ones was compensatory. Data for eleven fish subjected for one hour to two different velocities on 9 May, 1973, illustrate this compensatory adjustment.

Test No. 1:

Water velocity: 0.45 m/s
Revolutions by fish: gained 5
lost 180
Difference: -175
Distance water traveled:
$0.45 \times 3600 = 1620$ m/hr/fish
Distance lost by fish:
$\frac{8.7 \text{ m} \times -175}{11} = -138$ m/hr/fish
Difference: 1482 m/hr/fish

Mean speed of fish: $\frac{1482}{3600} = 0.41$ m/s

Test No. 2:

Water velocity: 0.39 m/s
Revolutions by fish: gained 5
lost 16
Difference: -11
Distance water traveled:
$0.39 \times 3600 = 1404$ m/hr/fish
Distance lost by fish:
$\frac{8.7 \text{ m} \times -11}{11} = -8.7$ m/hr/fish
Difference: 1395 m/hr/fish

Mean speed of fish: $\frac{1395}{3600} = 0.39$ m/s

The two values 0.39 and 0.41 m/s are about the same.

Results

We determined the swimming performance of 56 separate lots of grayling (2,215 fish) from Town Lake and Poplar Grove Creek in 201 one-hour experiments between 9 May and 21 September, 1973 and 6 May and 24 May, 1974. During these periods the test temperature varied between 1 and 18 C. Tables 17-21 list only those tests in which grayling swam the fastest.

Swimming speeds of Town Lake grayling (107-139 mm and 141-172 mm mean length ranges) varied with changes in temperature (Figures 20 and 21). Data for forced swimming speed and voluntary speed were plotted in the same graphs as they did not vary significantly. Fish were forced to swim when they exhibited a low level of swimming performance and would not voluntarily maintain position. In this case, data for forced speeds (not voluntary speeds) were plotted in the graphs. For some lots of grayling the change in water temperature between tests was sufficient to warrant the inclusion of two datum points for the same lot of fish (connected by arrows in Figures 20 and 21).

To determine the approximate shape of the cruising speed versus temperature curves in Figure 20, the points of the 107-139 mm grayling were superimposed on those of the 141-172 mm fish by adding 0.09 m/s to the speeds of the 107-139 mm fish. A regression line common to both size groups was then shaped by eye and appropriately placed to best describe the data points for the separate graphs. A similar procedure was used for determining the slope and location of the regression lines for sustained speed (Figure 21).

The datum points for sustained speed (Figure 21) are distributed in a pattern similar to those for cruising speed (Figure 20). Points (hollow-circles) representing forced swimming speeds are included. The points correspond for temperature but not for speed in the sustained and cruising speed graphs. Points could occur any place below the regression lines, even lower than 0.3 m/s, depending on the motivation of the fish.

The voluntary sustained speeds of the two fork length classes of Town Lake grayling were 6.8% (141-172 mm fish) and 12.3% (107-139 mm fish) faster than their cruising speeds. The mean speed of the 141-172 mm fish increased from 0.73 to 0.77 m/s and that of the 107-139 mm fish from 0.63 to 0.71 m/s when their swimming periods were reduced from one hour to 10-minute intervals. (Data for forced swimming speeds were omitted from these calculations).

Maximum swimming speed occurred between 13 and 15 C for grayling. Mean cruising and sustained speeds of grayling (141-172 mm) increased about 80% with an increase in temperature from 0 to 14 C.

The largest graylings collected from Town Lake swam markedly faster at higher temperatures. Five grayling (mean fork length, 223 mm) voluntarily cruised at 0.70 m/s for one hour at 1 C on 10 May, and two grayling (mean fork length, 227 mm) voluntarily cruised at 1.31 m/s for one hour at 15-16 C on 22 June, 1973. This latter speed was equal to the water velocity in the channel and was the maximum water speed possible using two pumps. Data indicate that two larger fish (275 and 312 mm) tested the same day at 14-15 C could have maintained their position at velocities higher than 1.27 m/s. Except for these four fish, no grayling from any source attained a 1.22 m/s cruising or sustained speed in the circular channel.

The migratory behavior of Poplar Grove grayling governed their willingness to swim. Upstream migrants (Figure 22) swam faster than downstream migrants on a voluntary basis (Figure 23). The points that represent the swimming performance of well-motivated fish lie above the regression lines, and those that represent poorly motivated fish lie below the lines.

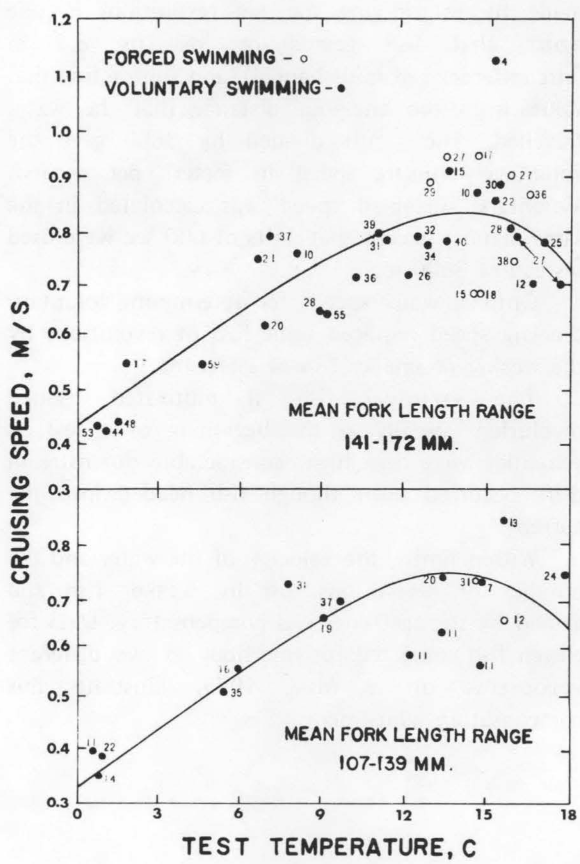

Figure 20. Cruising speed of grayling of two length classes (mean length, 125 and 157 mm) with respect to temperature. The numerals beside the points refer to sample size. Solid points = voluntary speed; hollow points = forced speed

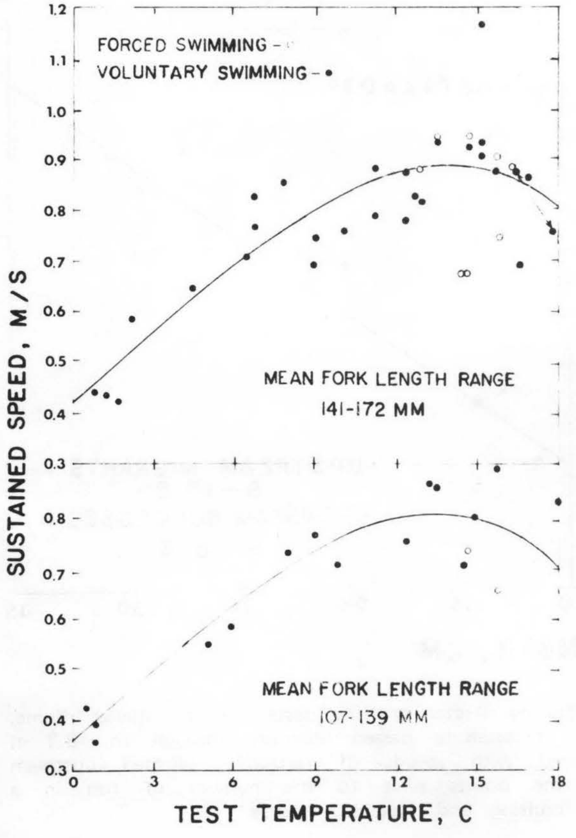

Figure 21. Sustained speed of grayling of two length classes (mean lengths, 125 and 157 mm) with respect to temperature. Solid points = voluntary speed; hollow points = forced speed

Voluntary sustained swimming speed was only slightly faster (6.6%) than cruising speed for upstream migrants from Poplar Grove Creek. This indicates that upstream migrants maintained a high level of motivation throughout the one-hour test period.

A single lot of Poplar Grove upstream migrants (27 fish) were tested for 3 one-hour periods on the 24 May, 1974. Their mean fork length was 125 mm (range, 112-132 mm). Water temperature was 12 C and mean water velocity was 0.77 m/s. The maximum cruising speed obtained was 0.72 m/s and the maximum sustained speed was 0.74 m/s. This was the fastest speed of fish of this class size obtained from Poplar Grove Creek and compares with Town Lake fish in Figure 20.

Downstream migration occurred at stream temperatures generally above 8 C in 1973. The level of voluntary performance of downstream migrants was considerably less than that of the upstream migrants in spite of the advantage of increased metabolism due to higher test temperatures. Thus, their downstream migratory behavior resulted in a low level of effort and their cruising speed was slow. However, the voluntary sustained speed was 37% faster than the cruising speed of downstream migrants, and was comparable to the voluntary cruising speed of the upstream migrants.

The voluntary swimming performance of three lots of upstream migrants that failed to ascend the culvert appeared to be similar to those of downstream migrants. However, these data were not used to determine the regression lines drawn in Figure 23. The slopes for sustained speed are slightly steeper than those for cruising speed but the difference between slopes may not be significant.

The insertion of a wire screen in the circular channel forced grayling that were poorly motivated to swim faster (Figure 24). The correlation between fork length and forced speed lacks significance at the 5% confidence level. The relative position of the regression line, however, suggests a higher level of effort than those obtained on a voluntary basis (Figure 25). Even when compelled by a screen to swim faster, Poplar Grove grayling failed to swim as fast as Town Lake fish of the same size.

Discussion

During the test runs, grayling tended to school together in the lower one-third of the channel mostly near the bottom. However, they avoided contact with the side and bottom. As measured with an Ott current meter, velocities at the inner side were 7% less and at the outer side, 2% less than those at mid-channel when the mid-channel current was 0.4 m/s. Sometimes small fish took shelter in the lee of jets and exhaust fittings which protruded about 1 cm from the inner wall. Such fish were omitted from the sample and calculations of swimming speed were suitably adjusted.

The size of the circular channel permitted the use of large samples of fish. Not only do large samples make results statistically more reliable, but in these tests large samples forced fish to shuffle position sufficiently to average the effect of cross channel variation in water velocity.

Voluntary and forced swimming speeds were about the same for small Town Lake fish that were well-motivated to swim (Figures 20 and 21). For larger Poplar Grove grayling forced swimming speed was markedly faster than voluntary speed even during the spawning run when grayling had a strong upstream migratory drive (Figure 25). The difference in voluntary and forced speed of larger Poplar Grove grayling as compared with smaller Town Lake grayling suggests that older fish could be more inhibited than younger fish by confinement in the circular channel. Thus, the difference between voluntary and forced swimming speed could be a measure of motivation. Likewise, the difference in the swimming performance of upstream and downstream migrants from Poplar Grove Creek reflects the motivation of the fish

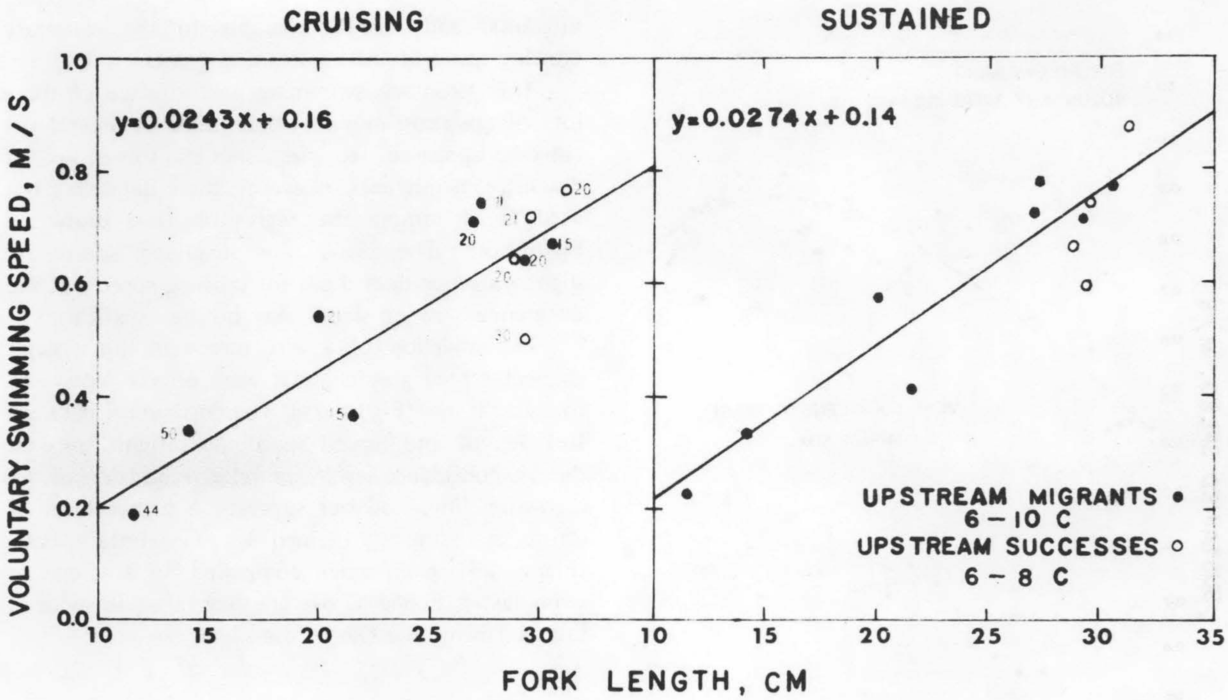

Figure 22. Cruising and sustained speeds of upstream migrating Arctic grayling tested in a circular flume. The mean speeds of fish (hollow points) that successfully passed upstream through an 18.3 m culvert at a flow of 1.3 m/s are compared with speeds of randomly selected upstream migrants (solid points). The numerals beside the points refer to the number of fish in a sample. The same lots of fish were used for cruising and sustained speeds

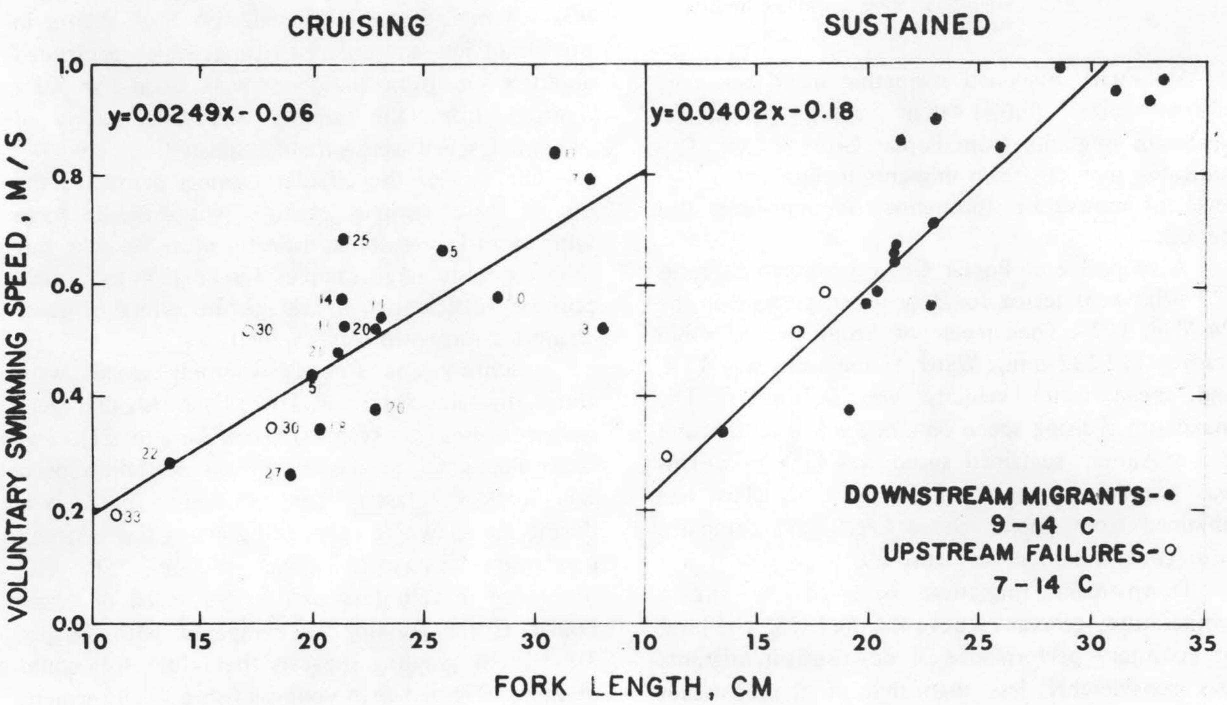

Figure 23. Voluntary cruising and sustained speeds of downstream migrating Arctic grayling tested in a circular flume. The mean speeds of upstream migrants (hollow points) that failed to pass through an 18.3 m culvert at flows of 1.1, 1.5 and 1.6 m/s are compared with speeds of downstream migrants. The numerals beside the points refer to the number of fish in a sample. The same lots of fish were used for cruising and sustained speeds

Table 22. Approximate swimming speeds of upstream migrating Arctic grayling determined under different experimental conditions

Type of test	Mean temperature, degrees, Centigrade	Fork length 150 mm	200 mm	250 mm	300 mm
Cruising speed (1-hour, Figure 22), m/s	8	0.52	0.65	0.77	0.89
Sustained speed (10-minute, Figure 23), m/s	8	0.55	0.69	0.82	0.96
Culvert speed (75% level of success, Figure 14)					
30.5 meters, m/s	7	0.53	0.70	0.87	1.05
	11	0.57	0.76	0.95	1.16
18.3 meters m/s	7	0.76	1.02	1.27	1.52

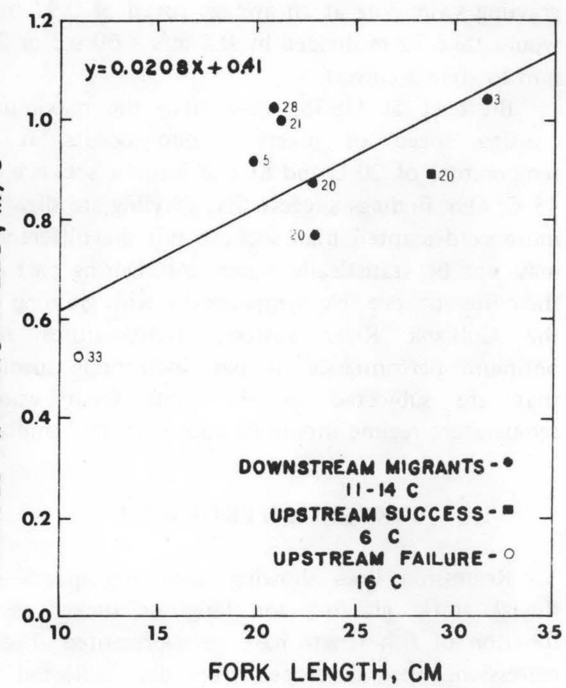

Figure 24. Swimming speed of Arctic grayling compelled by a wire screen to swim at a constant rate for one hour in a circular flume. The numerals beside the points refer to the number of fish in a sample

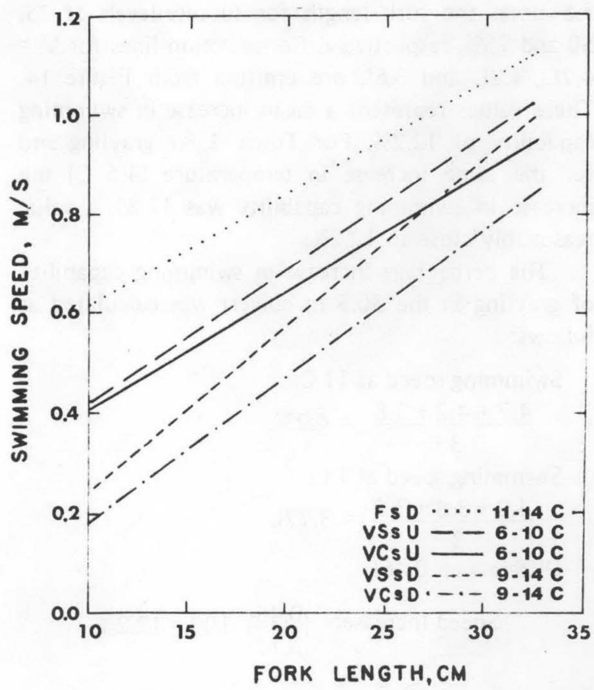

Figure 25. A comparison of swimming speeds of Arctic grayling obtained under different experimental conditions in a circular flume. Fs = forced speed, Ss = sustained speed, Cs = cruising speed, V = voluntary, U = upstream migrants, D = downstream migrants. The regression lines are the same as those in Figures 22-24

(Figure 25). The water velocity in the channel was generally slightly faster for the 10-minute interval in which fish swam the fastest than for the mean velocity of the 1-hour tests. However, water velocity was adjusted to maximize cruising speed and not sustained speed. Therefore, our sustained speed estimates are conservative in that slightly faster speeds might have been obtained if water velocity had been adjusted to maximize sustained speed.

The sustained speed of upstream migrating Poplar Grove grayling tested in the circular channel more closely approximates that of Poplar Grove grayling stemming the 30.5 m culvert than does the cruising speed (Table 22).

Voluntary sustained swimming speeds of upstream migrants (200 and 300 mm) were 0.69 and 0.96 m/s, respectively (Figure 22). Water velocities in 30.5 m culvert tests permitting 75% success for grayling (200 and 300 mm) were also 0.70 and 1.05 m/s (Figure 14). Apparently, 10-minute sustained speeds in the circular channel approach those required for 75% success in a 30.5 m long culvert.

At 7 C the sustained speed of Town Lake grayling (157 mm) was considerably faster (0.73 m/s) than that of Poplar Grove grayling of the same length (0.63 m/s at the 25% and 0.55 m/s at the 75% level of success). In this case, we compared the mean speed of Town Lake fish (Figure 21) with Poplar Grove grayling stemming a minimum "safe" water velocity in a 30.5 m culvert (Figure 14). Because fish have to swim faster than the current to ascend a culvert, grayling swimming speed has to be greater than water velocity.

For grayling in the 30.5 m culvert tests an increase in temperature of 4.5 C resulted in an increase in the swimming capability of grayling. "Safe" water velocities at 11.5 C were 4.7, 4.2 and 3.8 times the fork length for success levels of 25, 50 and 75%, respectively. Construction lines for V = 4.7L, 4.2L and 3.8L are omitted from Figure 14. These values represent a mean increase in swimming capability of 12.2%. For Town Lake grayling and for the same increase in temperature (4-5 C) the increase in swimming capability was 17.8% a value reasonably close to 12.2%.

The percentage increase in swimming capability of grayling in the 30.5 m culvert was calculated as follows:

Swimming speed at 11 C:

$$\frac{4.7 + 4.2 + 3.8}{3} = 4.23L$$

Swimming speed at 7 C:

$$\frac{4.0 + 3.8 + 3.5}{3} = 3.77L$$

Difference: 0.46L

Speed Increase: $(\frac{0.46}{3.77})\ 100 = 12.2\%$

The percentage increase in swimming capability of grayling tested in the circular channel was calculated as follows:

Swimming speed at 11.5 C:	0.86 m/s
Swimming speed at 7 C:	0.73 m/s
Difference:	0.13 m/s

Speed Increase: $(\frac{0.13}{0.73})\ 100 = 17.8\%$

A decrease in mean temperature from 7 to 3.5 C reduced the swimming capability of Poplar Grove grayling tested in the 30.5 m culvert to 3.2 and 2.7 times their fork length for success levels of 25 and 50%, respectively. This represents a mean decrease in swimming performance of 24.3%, a value based essentially on one sample (168 fish) (Figure 14). For Town Lake grayling in the circular channel a decrease in temperature from 7 to 3.5 C decreased the swimming capability of 157 mm grayling 20.5% (Figure 21).

The above camparisons are good evidence that temperature changes in the circular channel and in the 30.5 m culvert affect the swimming capability of grayling in a like manner. The comparisons also substantiate the assumption that sustained and cruising speeds in the circular channel may be used to predict temperature effects on swimming performance of grayling in culverts outside the temperature regimes of the culvert tests.

Voluntary cruising speed could probably be used as a "safe" estimate of swimming performance in culverts longer than 30.5 m. For a 72 m culvert with a water velocity of 0.92 m/s, for example, a grayling swimming at an average speed of 0.97 m/s would take 72 m divided by 0.5 m/s x 60 sec or 24 min to stem a culvert.

Brett et al (1958) show that the maximum cruising speed of juvenile coho occurs at a temperature of 20 C and that of juvenile sockeye at 15 C. Our findings suggest that grayling are slightly more cold-adapted than sockeye but the difference may not be statistically significant. During part of their life sockeye live sympatrically with grayling in the Gulkana River system. Temperatures for optimum performance of two indigenous species that are subjected to the same fresh water temperature regime should be approximately similar.

CONVERSION ESTIMATES

Regression lines showing swimming speeds of fluvial arctic grayling and longnose sucker as a function of fish length have been presented. These regressions were developed from data collected at essentially 5-8 C for an 18.3 m long culvert and 5-12 C for a 30.5 m long culvert. It is safe to assume that the design curves are conservative for culverts less than 30.5 m in length; however, it is logical that as culvert lengths are extended, swimming capability would decrease.

An examination of daily mean water temperatures in Table 11, when most successes ascended the culverts, indicates that the average water temperature of tests at 5-8 C was approximately 7 C. This allows for a 0.5 C correction for warmer temperatures between 1100 and 2300 hr. Thus, Figures 14 and 15 indicate swimming speeds versus lengths of fish for water temperatures of about 7 C.

The sustained speed of grayling swimming in the circular channel approximated that in the 30.5 m culvert. Accordingly, the data presented in Figure 21 is used for estimating sustained swimming speed such as is required in stemming culverts when water temperature is other than 7 C. Based on a mean curve drawn through a composite of datum points shown in Figure 21, it was apparent that mean sustained speed varies by a factor of about 6.2% per degree Centigrade for water temperatures of 0 – 7 C, and about 2.8% per degree Centigrade for temperatures of 7 – 11 C using 7 C as a pivotal point. Cruising and sustained speeds are essentially constant between 11 and 17 C, then speeds reduce significantly at higher temperatures in an unknown manner.

In our 1973 Progress Report, examples were given for estimating culvert swimming speeds at two temperatures from cruising speed data (Figure 20). For this report we substitute sustained speed (10-min) for cruising speed data using an 18.3 m culvert.

Problem 1: Estimate the potential swimming speed of a 240 mm grayling swimming at a temperature of 2 C where 75% passage through an 18.3 m culvert is required.

First step: Determine the basic swimming speed of the 240 mm length class graphically or from the formula V = 5.0L in Figure 14. The basic swimming speed is 5.0 x 240 mm or 1.20 m/s at a mean temperature of 7 C.

Second step: Calculate the corrected speed for a water temperature of 2 C. The calculation is as follows:
1.20 m/s - 0.062 (7-2 C) (1.20 m/s) = 0.83 m/s

Problem 2: Estimate the potential swimming speed of a 240 mm grayling swimming at a temperature of 10 C where 75% passage through an 18.3 m culvert is required.

First step: The basic swimming speed is 1.20 m/s at a mean temperature of 7 C.

Second step: The corrected swimming speed for a water temperature of 10 C is as follows:
1.20m/s + 0.028 (10-7 C) (1.20 m/s) = 1.31 m/s.

The maximum sustained speed attainable by this 240 mm design fish would be for water temperatures ranging from 11 – 17 C. This speed would be about 1.5 m/s.

The information presented in this report can be used for the design of moderate length culverts for fish passage. Appropriate design fish must be selected and the swimming speed of fish determined. The culvert must be designed so that velocities in the culvert are compatable with fish swimming capability at the time the fish must move through the culvert. In all circumstances the tailwater must be maintained at sufficient depth that fish can freely enter the culvert without jumping. This can be accomplished by constructing the invert of the culvert below stream gradeline, or by controlling the level of the pool at the outfall end of the culvert with some type of sill.

If flow conditions are such that velocities in the culvert exceed the swimming capability of fish that must ascend the reach, an alternate type of structure must be considered.

RECOMMENDATIONS

We recommend the following:

1) That five to seven duplicate one-day tests be made with the 30.5 m culvert facility in May 1975. These tests would: (1) assess the swimming performance of a repeat run of grayling, (2) increase the small sizes of the 1973 and 1974 samples, and (3) provide additional data on the effect of temperature regimes of Poplar Grove Creek during the spawning run in 1975.

2) That five to seven duplicate 2-day tests be made with the 30.5 m culvert in May 1975.

Our 1973 and 1974 results indicate that the spawning run of *mature* grayling in Poplar Grove Creek lasts approximately 10 days. An additional run of smaller essentially immature grayling continues after the spawning run for about 4 days. Two-day assays with the culvert facility would provide 5 to 7 sets of new 1- and 2-day data.

Our 1974 studies indicate that we obtained a higher level of success when we allowed immature grayling 2 days to ascend the 30.5 m culvert and respond to their migratory drive. To what degree a 2-day response interval affects mature grayling needs to be demonstrated.

We showed that the percentages of success are increased in 3- and 5-day trials for any given length class of immature grayling. However, the increase in response is relatively small after the second day. Moreover, any impediment that delays a spawning run for an extended period could seriously reduce the reproduction potential of grayling. Thus, we consider a 2-day period a maximum "safe" period for delay of fish based on the reported ripeness of the fish in the 1974 run. Therefore, culvert response trials should be limited to 2-day tests.

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