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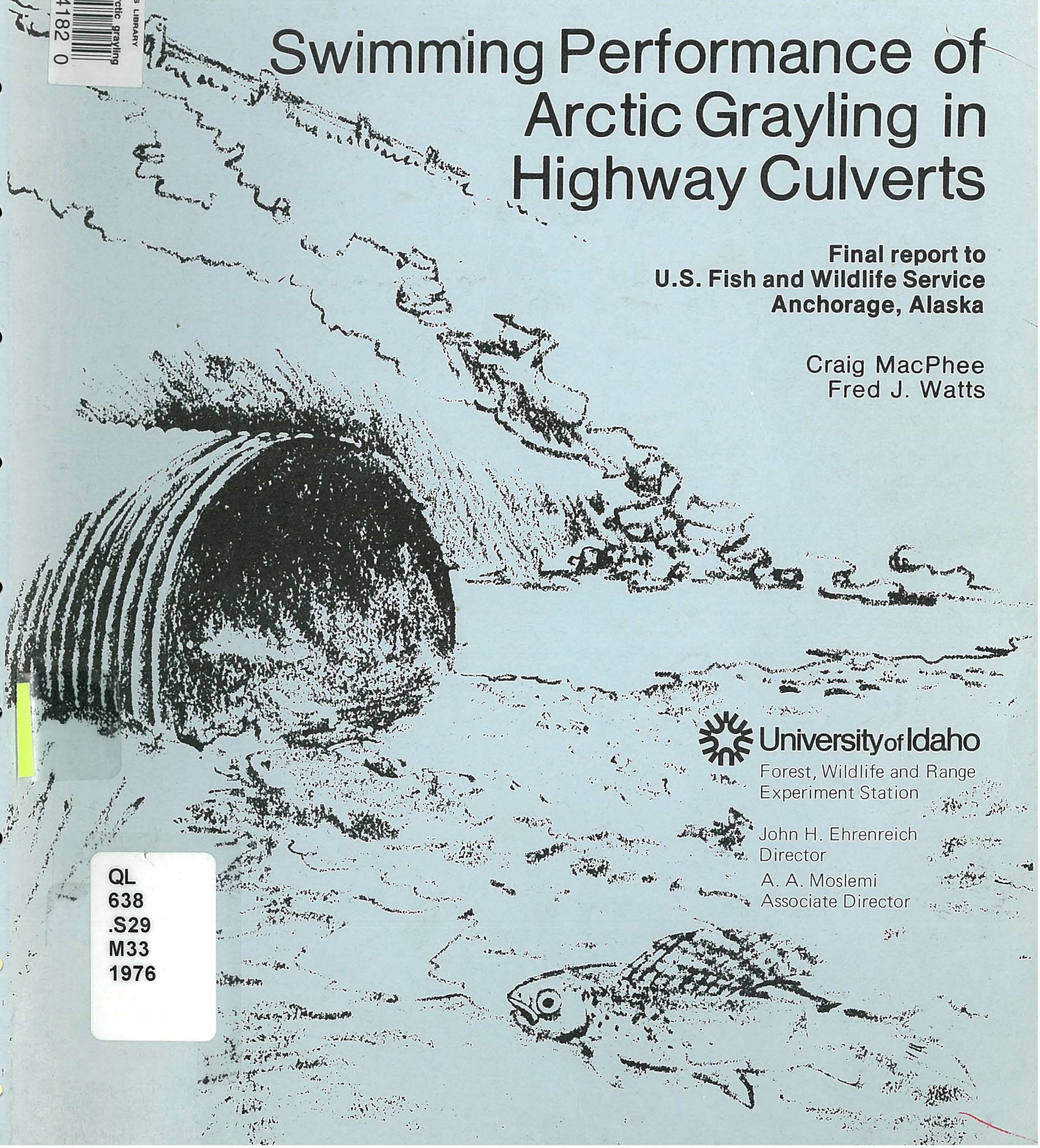
Swimming Performance of Arctic Grayling in Highway Culverts



Final report to
U.S. Fish and Wildlife Service
Anchorage, Alaska

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on

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SWIMMING PERFORMANCE OF ARCTIC GRAYLING IN HIGHWAY CULVERTS

Craig MacPhee
and
Fred J. Watts

INTRODUCTION

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

The original objectives of the study were:

1) 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.
2) to determine the cruising speed of various size-classes of grayling in a circular channel at prevailing stream temperatures, and,
3) 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). For our circular channel research, 1-hour intervals were used. 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-min 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 an inexpensive 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. Poplar Grove Creek was selected 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 specie, size, and body temperature. 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.

The effect of temperature on the swimming performance of grayling was determined at the site by the use of controlled temperature tests conducted in a circular flume. Water temperatures ranged from 0 to 17 C during the 1973 tests and from 0 to 16 C during the 1974 tests. This range was considered sufficient to determine the effect of temperature on swimming speed for the usual temperature range of Alaska grayling habitat; thus data from controlled bioassay laboratory tests were not needed to scale probable swimming velocities.

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 fortunate in that sufficient fish were available for this expanded study.

Initially, we designed our research to measure the swimming capability of grayling. However, our

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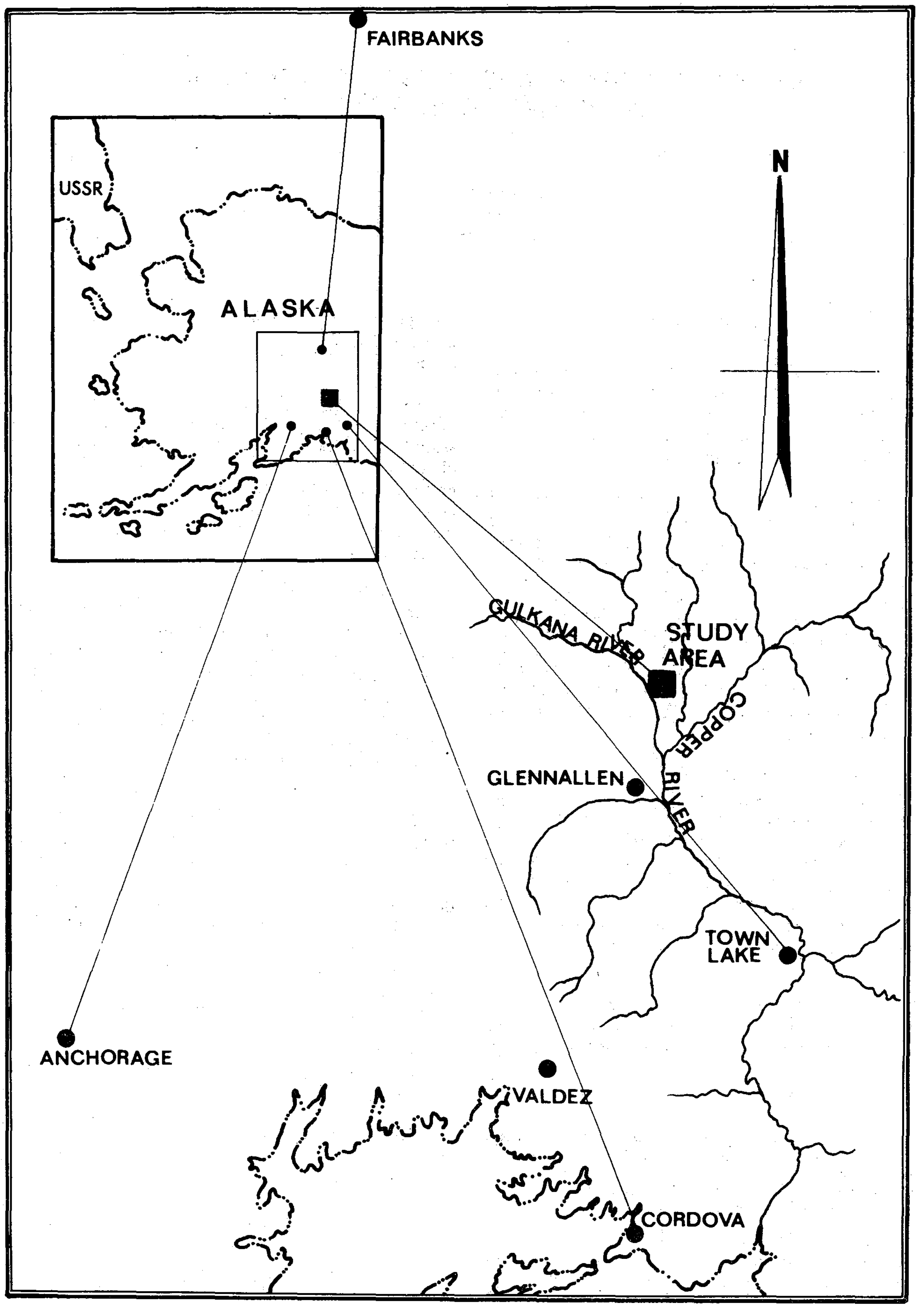

Fig. 1. Schematic map of the study region showing the location of the test site and collection areas.

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.

STUDY AREA

Topography

Poplar Grove Creek was selected for our study site. The 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 (Fig. 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 steep 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. In 1973, 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 (Fig. 2). Because of a 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. Flows were recorded between 2 May and 20 June 1974, and between 8 May and 2 June 1975. During these periods, discharges peaked at 4.2 m^3/s on 10 May 1974 (Fig. 3), and at 2.0 m^3/s on 14 May 1975 (Fig. 4). We estimated that discharge at times could range to 7.1 m^3/s at the study site.

Water Temperature

In 1973, water temperatures were monitored 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, then increased about 1 C per day for the next 4 days. The first grayling of the season were observed at 1700 of 14 May when the water temperature reached 4 C (Fig. 2). Between 15 May and 12 June, stream temperatures remained below 10 C. With the exception of 12 to 16 August, stream temperature was 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 near freezing. Water in the impoundment above the dam froze on 9 October. Minimum air temperature was minus 27 C on 22 October 1973.

Water temperatures averaged 3 C on 13 May 1974, and 2 C on 10 May 1975, when the first grayling of the run arrived. Afterwards, the average water temperature climbed fairly regularly to 15 C on 31 May 1974 and to 13 C on 1 June 1975, when the runs were essentially over (Fig. 3 and 4). Thus it is apparent that water temperatures measured during the test periods in 1974 and 1975 were somewhat higher than water temperatures measured in 1973.

Poplar Grove Creek was characterized by small diel variation in water temperature. Maximum temperatures occurred by late afternoon and minimum temperatures occurred 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.

During the spawning run the Gulkana River flowed considerably colder than Poplar Grove Creek (Table 1). 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.

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

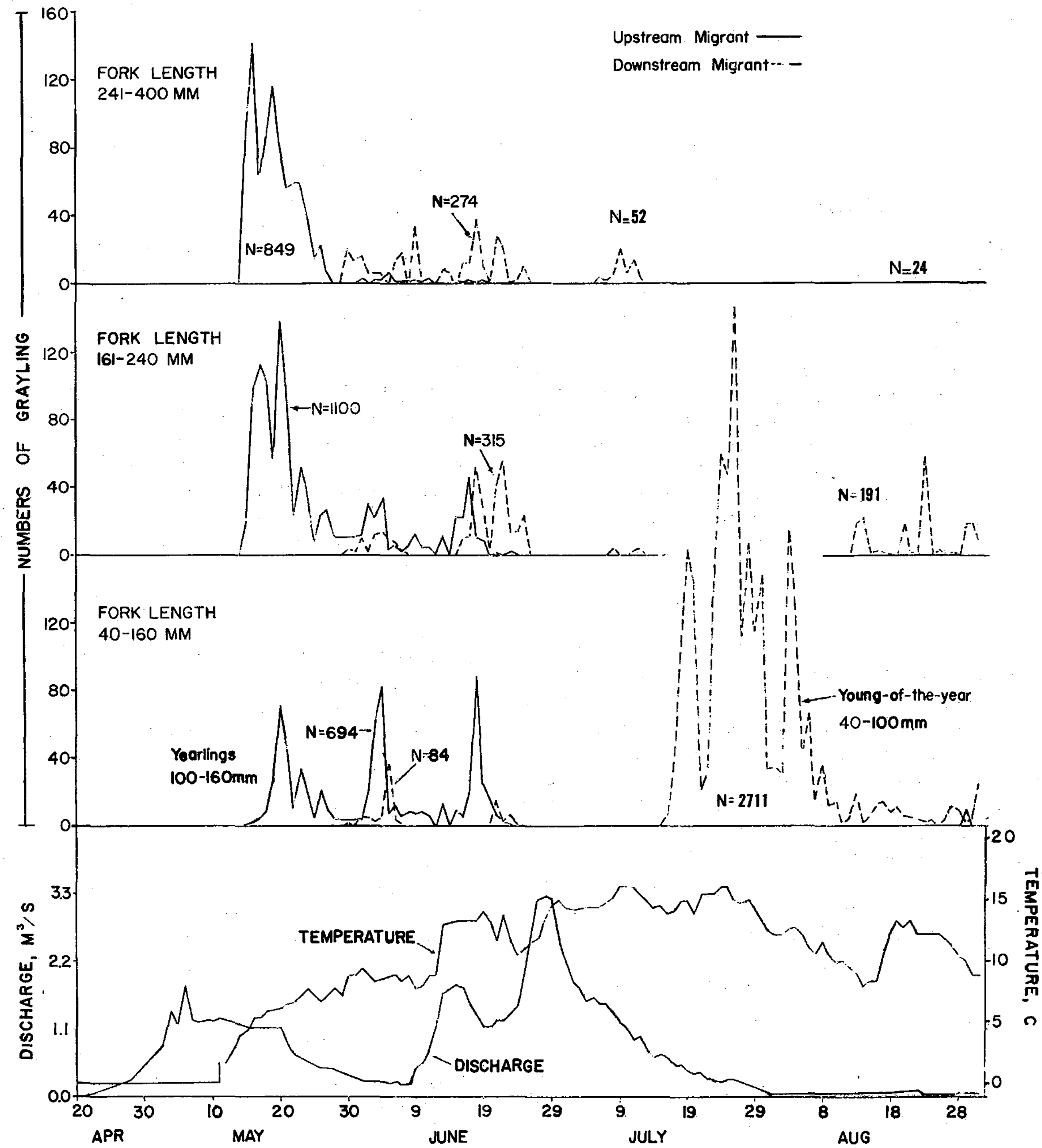

Fig. 2. Seasonal variation of discharge, mean water temperature, and counts of upstream and downstream migrating grayling in Poplar Grove Creek in 1973.

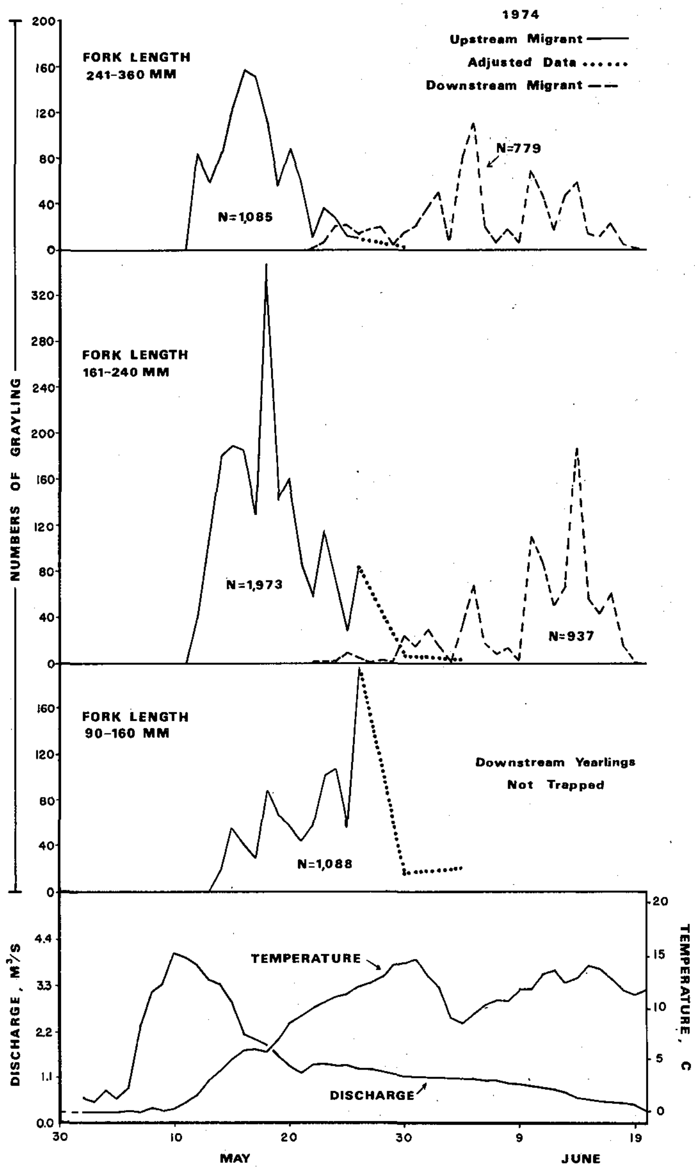

Fig. 3. Seasonal variation of discharge, mean water temperature, and counts of upstream and downstream migrating grayling in Poplar Grove Creek in 1974.

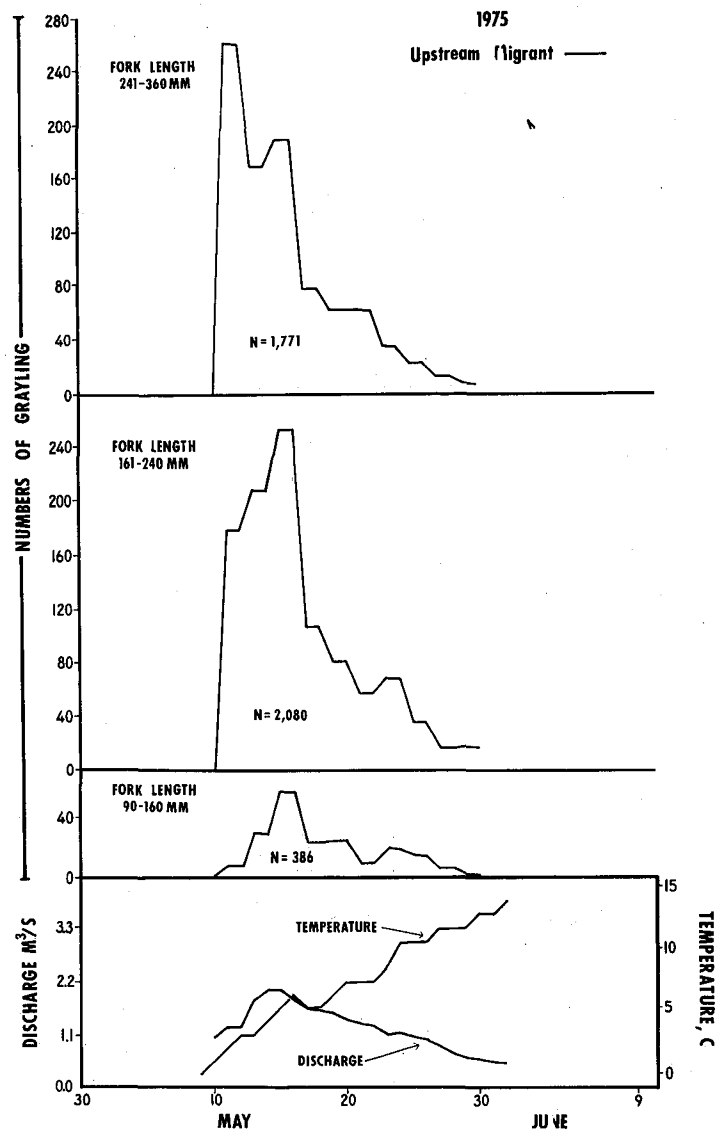

Fig. 4. Seasonal variation of discharge, mean water temperature, and counts of upstream migrating grayling in Poplar Grove Creek in 1975.

Table 1. Selected water temperatures in Poplar Grove Creek and the Gulkana River during the grayling spawning runs in 1973, 1974 and 1975.

		Temperature, C	
Date	Hr	Poplar Grove Creek	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
9 May, 1975	1230	0	0
11 May, 1975	1300	3	1
18 May, 1975	1700	6	3
25 May, 1975	1200	10	6
1 June, 1975	1300	14	8

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. This complex of factors motivates fish to swim against a current. Knowledge of the factors affecting migratory behavior is important because these factors affect the 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 (Fig. 5). 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 neither increased the daily catch greatly, nor altered 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.

On 20 May 1973, when the spawning run 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.

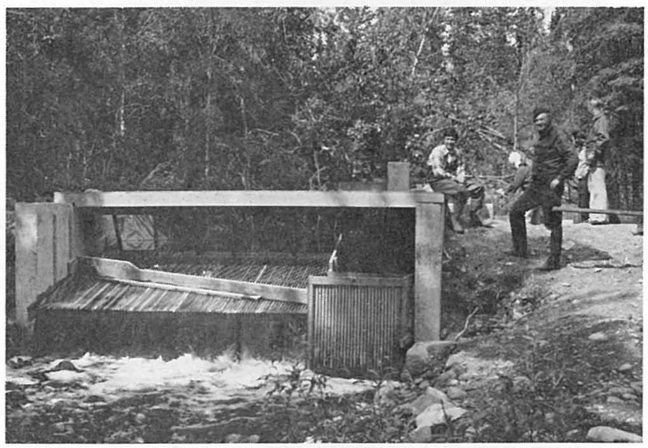

Fig. 5. View of dam with inclined plane trap installed for the collection of downstream migrants (1974).

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 and 1975 by sexing all grayling over 240 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 "ripe."

The number of ripe fish under 241 mm in length was noted. For analysis purposes, the percentages of ripe fish shorter than 241 mm were approximated by dividing the number of ripe fish of each sex by one-half the total number of fish in the size class. This procedure assumed an equal sex ratio, but because of the small number of ripe fish, a very unequal sex ratio would only slightly bias the data.

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

Between 22 May and 20 June 1974, we used an inclined plane trap to collect downstream migrants (Fig. 5). 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 about 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; we made no count of them.

For growth analysis of grayling, 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 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 the fork length of grayling at each annulus. Poplar Grove grayling captured from 15 May to 5 June 1973 (139 fish), 19 May to 1 June 1974 (21 fish), and 13-17 May 1975 (12 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 means of the fork lengths of each age class of 1973, 1974 and 1975 Poplar Grove grayling computed to the last annulus were 111, 194, 255, 289, 314, 337 and 339 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.

Table 2. Age and computed mean fork length in millimeters of Poplar Grove grayling in 1973, 1974 and 1975.

		Annulus						
Number	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			
21	V	78	170	241	282	314		
19	VI	80	162	224	277	308	337	
4	VII	75	157	227	265	302	320	339

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 was small and could bias the lengths of age classes I and II.

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

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 I+, II+, etc. The longest grayling captured in Poplar Grove Creek had a fork length of 408 mm.

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

Age	I	II	III	IV	V	VI	VII
Mean fork length, millimeters	116	199	266	295	326	351	354
Mean weight, grams	17	78	200	281	356	442	415
Number of fish	20	53	23	35	9	13	1

Based on a random sample of 50 fish, the mean fork length of young-of-the-year Poplar Grove grayling measured on 18 October 1973 was 102 mm (range 64-151mm). Selective over-winter mortality favoring the survival of larger fish, and/or the 8 months difference in age, could account for the difference between the October 102 mm and the June 111 mm mean length estimates.

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

In 1973, length-class frequencies of May upstream migrants had a bimodal distribution. The 221-240 mm length class contained relatively few fish and represented an intermode (Fig. 6).

In 1973, the mode of the length-class frequencies of early June upstream migrants was 121-140mm 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, the upstream migrants were separated into three groups, namely, 100-160 mm (mostly age I+), 161-240 mm (mostly age II+), and 241-400 mm (mostly age III+ to VII+) (Fig. 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 Fig. 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 contained the most fish (Fig. 7). For comparision, however, the 1974 data (Fig. 3) were grouped in the same length classes as those in 1973 (Fig. 2). The 1975 pattern of length-frequencies (Fig. 8) was very similar to that obtained in 1973 (Fig. 6).

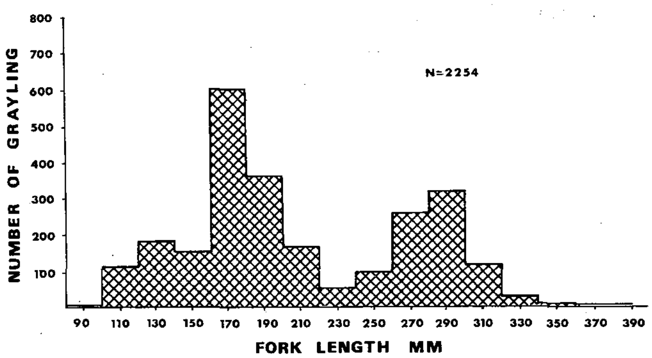

Fig. 6. Length-frequency histogram of the spring run of Poplar Grove grayling (15 May to 5 June 1973).

Upstream Migrants

A few grayling jumped at the dam in the late afternoon of 14 May 1973 (water temperature: 3 C at 1000, 4 C at 1430 of 14 May), but none appeared by 1230 of 12 May 1974 (water temperature: 2 C). We assume that some grayling arrived during the late afternoon of 12 May when observers were absent. The first grayling of the 1975 run surfaced below the dam on the evening of 10 May, when diel water temperatures were maximum (2 C).

In 1973 the first large group of grayling arrived at the dam site by 0800 of 15 May, with water temperatures of 3 C at 1000 and 6C at 2020. Water temperatures for subsequent year arrival dates were 2 C at 0900 and 3 C at 1715 of 13 May 1974, and 1 C at 0800 of 11 May 1975. Based on the first arrival of large numbers of fish, the 1974 and 1975 runs each arrived 2 days earlier than the run of the previous year.

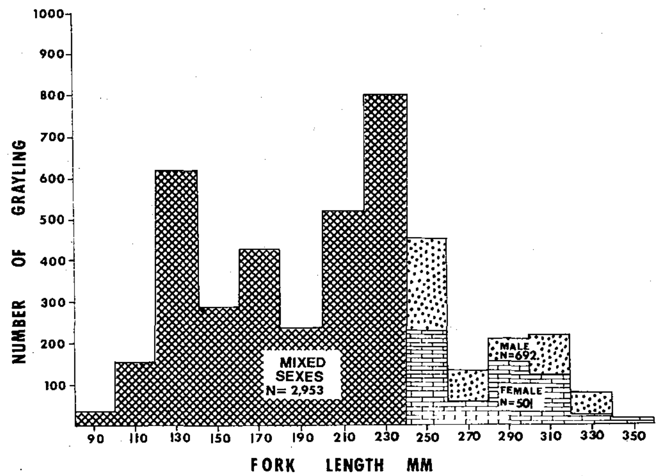

Fig. 7. Length-frequency histogram of the spring run of Poplar Grove grayling (13 May to 4 June 1974).

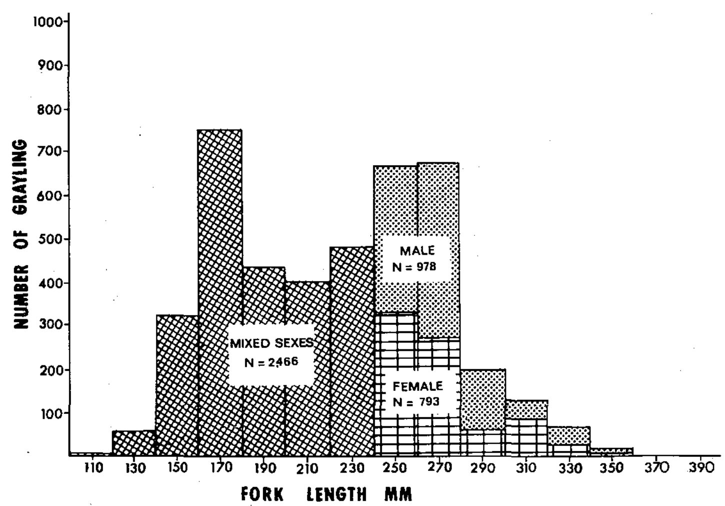

Fig. 8. Length-frequency histogram of the spring run of Poplar Grove grayling (10 May at 3 June 1975).

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 on 14 May, 121-140 mm on 15 May, and 101-120 mm on 16 May. This decrease in length with time was not apparent in 1975.

In 1973, grayling (161-400 mm) arrived at the dam site in two major groups, with peak numbers 3 days apart (Fig. 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 (Fig. 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.

In 1975 the peak number of 241-400 mm grayling (525 fish) was netted on 11 May, and the peak numbers of 101-160 mm grayling (121 fish) and 161-240 mm grayling (508 fish) on 15 May. These dates represent the 1st and 5th days of the run.

The percentage number of fish in each major length class (90-160, 161-240 and 241-400 mm) for each year compared rather well; so we averaged the percentages. For 1973 and 1974, 90-160 mm grayling formed 23 percent of the run; 161-240 mm fish, 45 percent; and 241-400 mm fish, 32 percent. In 1975, 100-160 mm grayling formed 9 percent of the spring run; 161-240 mm fish, 49 percent; and 241-400 mm fish, 42 percent.

In 1973, between 7 June and 30 August, we counted 255 small grayling (100-160 mm), 159 medium-sized grayling (161-240 mm), and only 10 large grayling (more than 240 mm) that moved upstream. No upstream migrants were observed after 30 August that year. No counts were taken after 4 June 1974 or after 3 June 1975, but we assume that the relative number of upstream migrants would be comparable to that noted in 1973.

The total spring run was 2,254 grayling by 5 June 1974, 4,146 grayling by 4 June 1974, and 4,237 grayling by 3 June 1975. After these dates, the upstream migration of fish longer than 160 mm had essentially ceased.

In 1974 and 1975 we noted the sex ratio and proportion of ripe fish in the spawning run. This was done to determine whether the state of maturity of the fish could influence the results of culvert tests. Grayling, though of a mature size, were not deemed "ripe" unless they readily yielded milt or eggs.

Ripe males (508 fish in 1974 and 497 in 1975) were much more numerous than ripe females (143 fish in 1974 and 19 fish in 1975). Presumably because the 1975 run was early we obtained fewer ripe females in 1975 than 1974.

The proportion of ripe fish in a given length class increased with the size of the fish. The 160-240 mm length class contained only 97 ripe males and 19 ripe females (1,973 fish) in 1974, and only 26 ripe males and 2 ripe females (2,078 fish) in 1975. The 241-360 mm length class contained 411 ripe males and 124 ripe females (1,085 fish) in 1974, and 471 ripe males and 17 ripe females (1,769 fish) in 1975. The two smallest ripe male and female graylings measured 177 and 176 mm, respectively.

The data for 1974 indicate that most potential spawners are generally more than 260 mm in length (Fig. 9). As over 94 percent of this size class had been captured by 24 May 1973, 22 May 1974 and 21 May 1975, the spawning run lasts essentially 10 days.

About 77 percent of the males in 1974 and 82 percent of the males in 1975 were ripe when the fish were first examined on 13-14 May of each year. By these dates no females were ripe either year, but in 1974 the percentage of ripe females generally increased each day of the main part of the run (Fig. 10). It is likely that many females classified as not "ripe" when examined in the early part of the runs spawned at a later time. Irregularities in Fig. 10 on 25 and 26 May 1974, could be due to small sample size or possibly to the presence of spent fish.

Downstream Migrants

A total of 66,870 grayling ~~was~~ were trapped while moving 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 percent of the yearlings and two-year-old fish, and 41 percent of the fish longer than 241 mm were captured as downstream migrants. Probably most of 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 in place.

During the 30 days in 1974 that we operated the inclined plane trap, 72 percent of the 241-360 mm upstream migrants (1,085 grayling) and 60 percent of the 181-240 mm upstream migrants (1,549 grayling) came back downstream (Fig. 3). The 160-180 mm length class (424 fish) was not trapped.

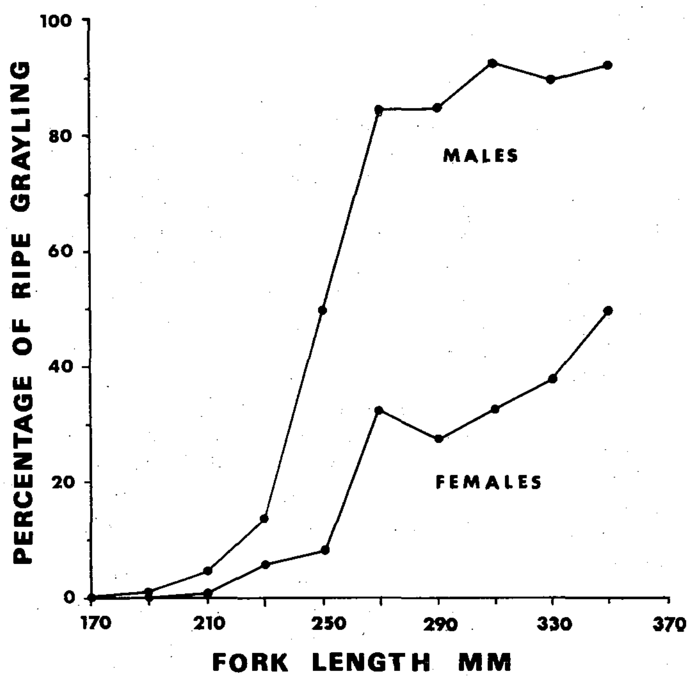

Fig. 9. Proportion of ripe grayling by length class in the spawning run of Poplar Grove Creek, 13 to 27 May 1974.

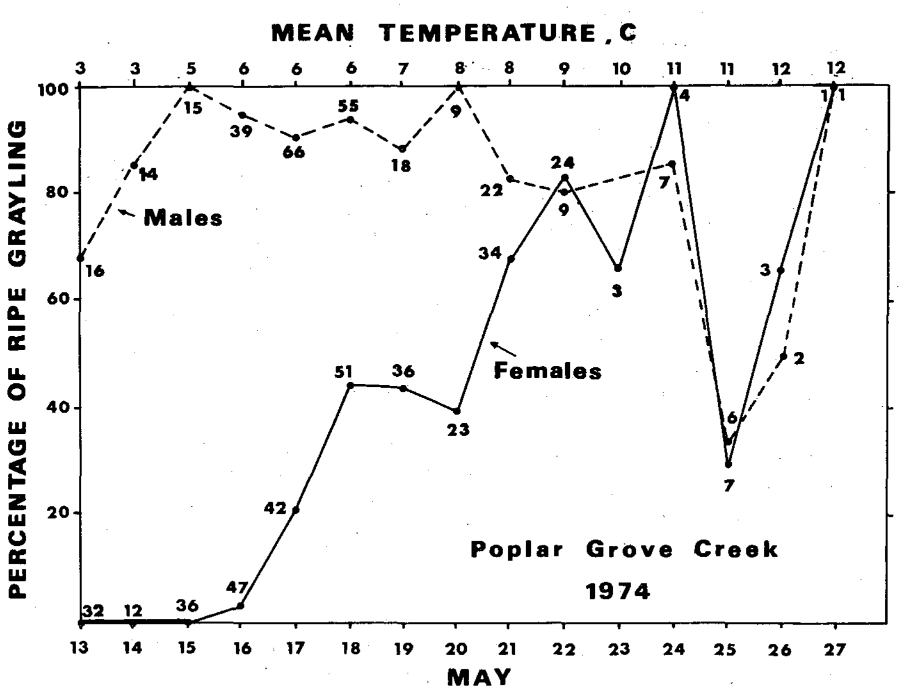

Fig. 10. Proportion of ripe grayling (261-360 mm) that occurred each day during the first 15 days of the 1974 spawning run in Poplar Grove Creek. Numerals by each point indicate total daily counts of ripe fish.

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

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

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 trapping was initiated on 17 July. Survival of these nomads is deemed poor, as they could be preyed upon easily 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 percent were caught after 11 September.

Young-of-the-year grayling had a mean fork length of 55 mm (16 fish) on 18 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 4 of a 20 fish sample of the same year class (more than 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. There is little opportunity for cannibalism because the older fish have left the creek by the time fry hatch.

Diel Movements

Schools of large grayling formed along the edge of the creek below the dam on the first morning of the 1973 and 1974 spawning runs. Except for these first arrivals, most grayling congregated below the dam in late afternoon (1600-1800) for the remainder of the runs.

In the mornings before our netting operation, few grayling were active, whereas in late afternoon, many fish surfaced and jumped. Maximum activity of grayling correlated with time of day and changes in water temperature (Fig. 11). Fish activity peaked about 1800, 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 upstream.

Most grayling from both the 181-240 mm and 241-360 mm classes returned downstream in late afternoon and early evening (Fig. 12). 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.

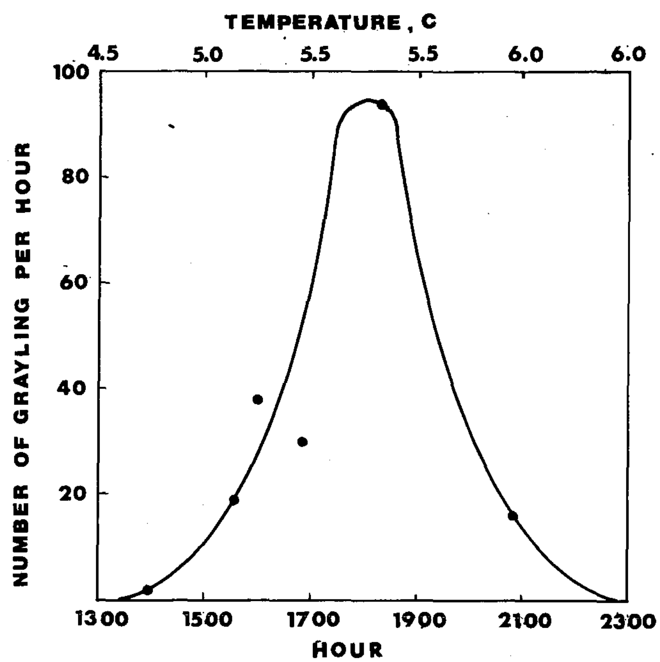

Fig. 11. Diel variation in the number of upstream migrating grayling that jumped or surfaced below the research dam on Poplar Grove Creek on 15 May 1974.

Discussion

This study details information on movements of the fluvial grayling in a small creek. Such movements can have managerial implications. The extent to which 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 the stream, on the timing and duration of spawning runs of mature fish, and on forage movements of immature fish.

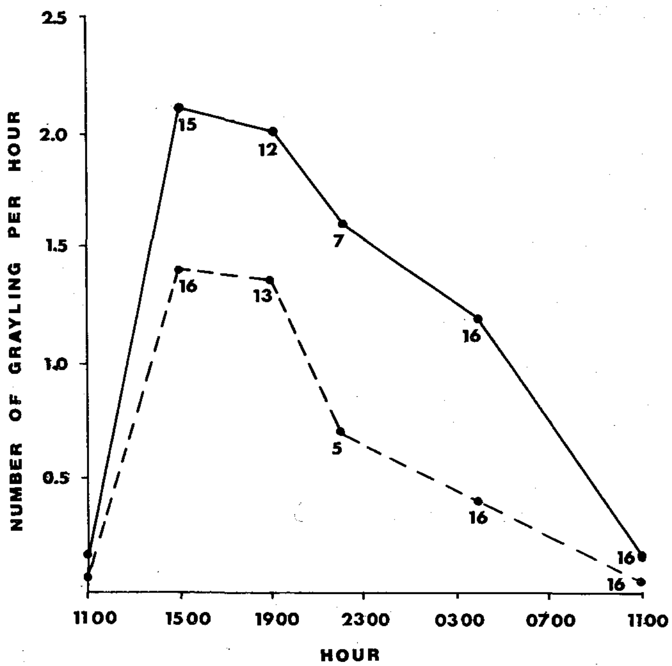

Fig. 12. Number of downstream migrating grayling captured per hour in inclined plane trap from 24 May to 8 June 1974. Numerals beside points indicate the number of days that observations were made. Broken lines represent 234 grayling 161-240 mm in fork length; solid lines, 444 grayling 241-360 mm in fork length.

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 - CULVERTS

Introduction

The general objective of the culvert tests was to determine the maximum allowable water velocity in a culvert of given length which would permit a specified length of grayling to pass upstream through the culvert.

The specific objective of the culvert tests was to determine the water velocities that would permit 25, 50 and 75 percent 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 determine their ability to swim up culverts, although 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. Most of the culverts are between 18 and 30 m in length. Thus, the range of culvert lengths chosen for this study is sufficient for most of the culverts along this route. 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 explored the impact of two minor factors that might influence migration through culverts, namely, 1) the effect of 3- and 5-day tests on the passage of foraging grayling collected at the end of the spring run, and 2) the effect of maturation on the swimming response of grayling.

In 1975, our primary objective was to determine the effect of 2-day tests on the ability of grayling to ascend a 30.5 m culvert. The tests differed from the 1974 multiple day tests in that we tested the whole run of fish rather than the foraging fish collected at the tail-end of the run. This enabled us to test large mature fish presumably with a strong migratory drive, and to test fish at lower water temperatures. A secondary objective was to increase the number of replicates for the 1-day tests which we had obtained in 1974 with the 30.5 m culvert.

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 stream temperature variation would be minimal. We did not expect or find any significant relationship between swimming performance in the culvert and temperature in 1973, when the daily mean temperature range was, with two exceptions 4 – 9 C. In 1974, however, the daily mean temperature range was 4 – 8 C for six tests, and 9 – 12 C for eight tests; in 1975, the daily mean temperature was 4 – 8 C for five tests and 9 – 12 C for three 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

The culvert facility constructed on Poplar Grove Creek consisted of 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 and 1975) tiltable, 0.6 m ID (inside diameter) culvert and a tailbox. The culvert could be set prior to each run to a slope ranging from 0 to 4 per cent. The tailbox was 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 and 1975. Fig. 13 and 14 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.

Fig. 13. Upstream view of the 18.3 m culvert facility showing the position of the headbox, tailbox and dam (1973).

Fig. 14. Downstream view of the 30.5 m culvert facility showing the position of the headbox, tailbox and dam (1974 and 1975).

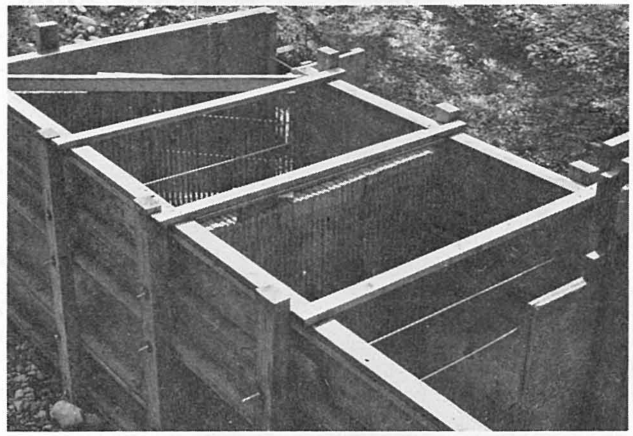

Fig. 15. Tailbox of the 30.5 m culvert facility showing the upstream experimental compartment (right) from which test fish could ascend the culvert and the downstream conditioning compartment (left) in which fish could recover overnight from any effects of netting.

In 1974, after the second test, and in 1975, a vertical slot fence was used to divide the tailbox into upstream and downstream compartments (Fig. 15). The downstream 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. After removal of failures from the upstream compartment, 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 measure the greater number of 1974 and 1975 test fish, and to change the slope of the 30.5 m 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 on a daily basis 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 cm for the 0 percent slope to about 30 cm for the 3.2 percent slope. The minimum depth of water in the tailbox was about 50 cm at 3 percent slope. The maximum depth was about 115 cm at 0 percent slope.

In 1974 and 1975, the depth of the pool below the invert of the culvert outfall varied from 160 cm for the 0 percent slope to about 80 cm for the 2.5 percent slope. The minimum depth of water in the tailbox was about 100 cm at 2.5 percent slope and the maximum depth was about 180 cm at 0 percent slope.

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.

Fish that succeeded in stemming the current were termed successes and collected in the headbox. They were removed from the headbox as necessary to prevent crowding, mostly at 2-hour intervals until upstream movements became minimal, usually after dark. The time interval of the experiments included the afternoon and evening periods when grayling were most active and when the water was warmest. Those fish which remained in the tailbox at the termination of the run were termed failures.

The daily procedure and approximate schedule for the experiments were as follows:
1973 and the first two runs of 1974

1. The slope of the culvert and headwater depths were set to obtain a specified water velocity. The velocity was verified with a current meter and/or block float (about 1000 and 1100 hour).

2. Fish were then netted and/or trapped and placed in the tailbox (about 1100 to 1300 hour). Fish were allowed at least 18 hours to ascend the culvert. The headbox was checked at about 2-hour intervals (from about 1500 to 2300) for fish which had ascended the culvert. These fish were removed from the headbox, counted, measured and returned to Poplar Grove Creek well upstream of our facility.

3. The next morning the culvert system was drained and the remaining fish were recovered from the headbox and the tailbox. These fish were counted, measured and returned to the stream (about 0800 to 1200 hour).

1974 (after the tailbox was partitioned)

1. The culvert slope and headwater depth were set to obtain a specified water velocity (about 1000 to 1100 hour).

2. Fish collected from the stream the previous day and confined overnight in the downstream holding pen of the tailbox were crowded forward into the upstream compartment of the tailbox (about 1100 hour). Fish were allowed 18 hours or more to ascend the culvert. The headbox was checked every 2 hours (from about 1300 to 2300) for fish which had ascended the culvert. These fish were removed from the headbox, counted, measured and returned to the stream.

3. New fish were netted from the creek (about 1300 to 1700 hour) and placed in the downstream holding pen and held overnight for the next experiment.

4. The next morning, the culvert system was drained and the fish that remained were removed from the tailbox and headbox, counted, measured and returned to the stream (about 0800 to 1100 hour).

1975 – Two-day test

1. The culvert slope and headwater depth were set to obtain a specified velocity (about 1000 to 1100 hour).

2. Fish collected from the stream the previous day and confined in the holding pen were driven forward into the tailbox (about 1100 hour). Fish were allowed roughly 44 hours to ascend the culvert. The headbox was checked about every 2 hours (from 1300 to 2300 the 1st day and from 0800 to 2200 the 2nd day) for fish which had ascended the culvert. These fish were removed from the headbox, counted, measured and returned to the stream.

3. On the 2nd day of the test, new fish (2 days accumulation) were netted from the creek (about 1300 to 1900 hour) and placed in the holding pen to be held overnight for the next experiment.

4. The next morning, the culvert system was drained and the remaining fish were removed from the tailbox and headbox, counted, measured and returned to the stream (about 0800 to 1100 hour).

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

Fork length, millimeters	Number of Grayling Successes	Failures		Percentage of success	Critical success point	Critical length, millimeters
81-100	0	20		0		
101-120	1	56		2		
121-140	11	81		14		
141-160	13	17		43	25%	140
161-180	11	4	47%	73	50%	170
181-200	5	11		31		
201-220	21	4		84	75%	200
221-240	24	5		83		
241-260	5	3		62		
261-280	0	0		--		
281-300	2	0		100		

Because of the small run in 1973, 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 421 mm in length was able to stem the 1.8 m/s water velocity. 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, we did not measure the retained fish 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 percent of the fish in a size class ascended the culvert (successes). The criteria 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 percent success), the shorter length class was selected as the data point. A tolerance of $\pm$ 5 percent was allowed when making this selection. Example: For the 50 percent level of performance, a range of 45 percent failures to 55 percent 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 percent success points for the test on 27-28 May 1974 are 140 and 200 mm, respectively, (Table 7).

3. An average length (to the nearest 10 mm) was calculated to attain a $\pm$ 5 percent tolerance limit where the percentages of consecutive sets of successes and failures oscillated. Example: The 50 percent 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 percent, which is within the 50 $\pm$ 5 percent 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.

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 percent, double dots = 50 percent and lower bar = 75 percent 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
101-120	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 distributions of Poplar Grove grayling (1973 upstream migrants) that were successful in ascending an 18.3 m culvert in 1-day tests at indicated water velocities. S = success, F = failure; upper bar = 25 percent, double dots = 50 percent and lower bar = 75 percent 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 distributions of Poplar Grove grayling (1974 upstream migrants) that were successful in ascending a 30.5 m culvert in 1-day tests at indicated water velocities. S = success, F = failure; upper bar = 25 percent, double dots = 50 percent and lower bar = 75 percent 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 69
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 9	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	9 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. Fork length class distributions of Poplar Grove grayling (1975 upstream migrants) that were successful in ascending a 30.5 m culvert in 1-day and 2-day tests at indicated water velocities. S = success, F = failure; upper bar = 25 percent, double dot = 50 percent and lower bar = 75 percent successful length class for each water velocity.

Velocity, meters per second	1.07	1.07	1.22	1.22	1.37	1.37	1.01	1.01	1.07	1.07	0.76	0.76	0.61	0.61	0.61	0.61	0.76	0.76	1.22	1.22
Slope, percent	1.0	1.0	1.5	1.5	1.7	1.7	0.9	0.9	1.0	1.0	0.5	0.5	0.0	0.0	0.0	0.0	0.5	0.5	1.5	1.5
Headwater depth / culvert diameter	0.60	0.60	0.56	0.56	0.54	0.54	0.60	0.60	0.55	0.55	0.60	0.60	0.60	0.60	0.6	0.6	0.6	0.6	0.52	0.52
Temperature, C	3-4	3-6	4-7	5-7	5-6	4-6	5-8	6-7	6-8	7-8	7-9	8-10	9-11	9-12	10-11	10-12	10-12	11-12	11-14	12-14
Date	May 13-14	13-15	15-16	15-17	17-18	17-19	19-20	19-21	21-22	21-23	23-24	23-25	25-26	25-27	27-28	27-29	29-30	29-31	May June 31-1	31-2
	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	S F	S F	S F
Fork length millimeters																				
101-120							0 1	0 1									0 1	0 1		
121-140	0 1	0 1	0 4	0 4	0 12	0 12	0 4	0 4	0 7	0 7	1 3	1 3	1 7	1 7	3-7	3-7	0 2	0 2		
141-160	0 13	0 13	0 55	0 55	0 109	0 109	0 40	1 40	0 41	0 41	1 13	1 13	8 17	9 16	6 9	6 9	2 3	2 3	0 2	0 2
161-180	0 104	0 104	0 151	0 151	0 193	0 193	2 84	3 83	0 72	0 72	6 25	6 25	16 40	19 37	16 11	16 11	6 4	6 4	0 11	0 11
181-200	0 61	1 60	0 70	1 69	0 119	0 119	8 45	9 44	1 37	1 37	12 18	12 18	16··14	17 13	7 5	7 5	5-0	5-0	0 9	0 9
201-220	2 86	7 81	1 85	1 85	0 91	1 90	13 26	14 25	3 21	3 21	5 8	6··7	17 8	18-7	9 4	10-3	5 0	5 0	2 3	2 3
221-240	6 99	22 83	3 107	5 105	0 105	0 105	19 15	21 13	8 18	13··13	18··18	18 18	16-6	19 3	16 2	16 2	11 2	11 2	3 5	3 5
241-260	21 156	60 117	26-100	35-91	2 122	4 120	40-11	44 7	34-13	37-10	53 10	54 9	32 2	32 2	20 4	21 3	17 1	17 1	4 2	4 2
261-280	63-168	149 82	49 71	58··62	14 115	16 113	63 4	64 3	38 9	41 6	32 8	32 8	22 2	22 2	10 3	10 3	2 0	2	2 0	2 0
281-300	27··31	48 10	28··25	35 18	6 32	7 31	18 1	18 1	9 1	9 1	9 0	9 0	5 1	5 1	3 0	3 0	2 0	2	0 1	0 1
301-320	12 19	22 9	12 9	12 9	9 33	10-32	11 2	12 1	13 0	13 0	6 0	6 0	2 0	2 0	1 0	1 0			1 0	1 0
321-340	9 11	15 5	13 1	13 1	6 12	6 12	3 0	3 0	2 3	4 1	3 1	3 1	1 0	1 0	0 1	0 1			1 1	1 1
341-360	2 4	6 0	3 1	3 1	4··4	5 3	0 1	1 0	1 0	1 0	1 0	1 0							1 0	1 0
361-380	1 1	2 0	0 0	0 0	0 1	0 1	0 0	0 0	0 0	0 0										
381-400									1 0	1 0										

Table 12. Summary of critical points for fork lengths of grayling which successfully ascended 18.3 and 30.5 m culverts in 1-day tests at indicated water velocities. The critical points were obtained from Table 8, 9, 10 and 11, and are plotted in Fig. 16.

18.3-meter culvert (1973)					30.5-meter culvert (1974)					30.5-meter culvert (1975)				
Velocity m/s	Mean temperature, C	Percentage of Success 25	50	75	Velocity m/s	Mean temperature, C	Percentage of Success 25	50	75	Velocity m/s	Mean temperature, C	Percentage of Success 25	50	75
1.4	4.0	240	280	310	0.9	3.0	290	330	-	1.07	4.0	270	290	-
1.3	5.0	160	200	220	0.6	3.5	240	270	-	1.22	6.0	250	290	320
1.5	5.5	200	210	220	1.2	5.0	240	260	-	1.37	5.5	320	350	-
1.6	6.0	200	210	240	1.5	5.5	-	-	-	1.01	7.0	200	220	250
1.9	6.5	300	330	350	0.9	5.5	210	220	240	1.07	7.5	220	240	250
0.8	6.5	150	190	290	1.2	6.0	240	300	330	0.76	8.5	180	230	240
1.8	6.5	270	290	-	0.6	7.0	130	190	230	0.61	10.5	140	190	230
0.6	6.5	-	-	130	1.1	8.0	210	240	260	0.61	11.0	130	160	220
1.8	7.5	290	300	-	1.5	9.5	-	-	-	0.76	11.5	140	160	190
1.7	7.5	220	270	330	1.1	10.0	190	220	240	1.22	13.0	200	240	260
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 13. Fork length class distributions of longnose sucker (1973 upstream migrants) that were successful in ascending an 18.3 m culvert in 1-day tests at indicated water velocities. S = success, F = failure; upper bar = 25 percent, double dots = 50 percent and lower bar = 75 percent 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 14. Fork length class distributions of longnose sucker (1974 upstream migrants) that were successful in ascending a 30.5 m culvert in 1-day tests at indicated water velocities. S = success, F = failure; upper bar = 25 percent, double dots = 50 percent and lower bar = 75 percent 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 15. Fork length class distributions of longnose sucker (1975 upstream migrants) that were successful in ascending a 30.5 m culvert in 1-day and 2-day tests at indicated water velocities. S = success, F = failure; upper bar = 25 percent, double dot = 50 percent and lower bar = 75 percent successful length class for each water velocity.

Velocity, meters per second	1.07	1.07	1.22	1.22	1.37	1.37	1.01	1.01	1.01	1.07	1.07	0.76	0.76	0.61	0.61	0.61	0.76	0.76	1.22	1.22
Temperature, C	3-4	3-6	4-7	5-7	5-6	4-6	5-8	6-7	6-8	7-8	7-9	8-10	9-11	9-12	10-11	10-12	10-12	11-12	11-14	12-14
Date, 1975	May 13-14	13-15	15-16	15-17	17-18	17-19	19-20	19-21	21-22	21-23	23-24	23-25	25-26	25-27	27-28	27-29	29-30	29-31	May-June 31-1	31-2
	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	S F	S F	S F
Fork length, millimeters																				
101-120																	0 1	0 1		
121-140															0 3	0 3	0 2	0 2		
141-160															0 1	0 1	0 2	0 2		
161-180															0 0	0 0	0 1	0 1		
181-200							<-	<-			<-	<-	<··	<··	1··1	1··1	0··0	0··0	0 1	0 1
201-220							2··0	2··0	0 2	1 1	<··	<··	2 0	2 0	2 1	2 1	2-0	2-0	0 2	0 2
221-240					0 1	0 1	1 0	1 0	0 3	0 3	3-0	3-0	4-2	5-1	10 2	11 1	13 0	13 0	0 14	1 14
241-260					0 7	0 7	2 3	3 2	1 24	1 24	8 0	8 0	29 8	30 7	17 10	22 5	10 1	11 0	2 16	2 16
261-280			0 3	0 3	0 26	0 26	1 5	2 4	8 45	9 44	22 9	25 6	54 7	56 5	29 0	29 0	18 3	21 0	13 33	15 31
281-300	<1	<1	0 3	0 3	0 28	0 28	14 7	18 3	26 51	30 47	56 6	57 5	47 5	49 3	39 4	40 3	19 0	19 0	9 29	9 29
301-320	0 1	0 1	0 1	0 1	0 24	0 24	17 2	17 2	15 55	17 53	39 5	41 3	39 5	42 2	30 4	32 2	16 0	16 0	6 21	6 21
321-340	1 0	1 0	0 1	0 1	0 28	0 28	13 2	13 2	25 50	28 47	50 12	54 8	50 0	50 0	39 3	39 3	10 1	11 0	10 14	11 13
341-360	> 1	> 1			0 14	0 14	12 3	14 1	37··46	53 30	65 6	69 2	66 5	69 2	52 6	53 5	16 0	16 0	10 8	10 8
361-380					0 12	0 12	10 0	10 0	26 34	34 26	76 10	80 6	59 7	64 2	76 6	81 1	11 1	12 0	5 14	5 14
381-400					0 6	0 6	8 1	8 1	22 28	25 25	31 4	32 3	41 5	42 4	35 5	38 2	9 0	9 0	4 9	5 8
401-420					0 8	0 8	2 2	3 1	5 19	5 19	20 3	20 3	11 6	16 1	20 1	20 1	6 0	6 0	0 7	0 7
421-440					0 2	0 2			1 2	2 1	2 0	2 0	3 0	3 0	4 0	4 0				
441-460					> -	> -			1-0	1 0										

Table 16. Summary of critical points for fork lengths of suckers that successfully ascended 18.3 and 30.5 m culverts in 1-day tests at indicated water velocities. The critical points were obtained from Tables 13, 14 and 15, and are plotted in Fig. 17.

18.3-meter culvert (1973)					30.5-meter culvert (1974)					30.5-meter culvert (1975)				
Velocity m/s	Mean temp-erature, C	Percentage of success			Velocity m/s	Mean temp-erature, C	Percentage of success			Velocity m/s	Mean temp-erature, C	Percentage of success		
		25	50	75			25	50	75			25	50	75
1.9	6.5	-	-	-	1.2	5.0	-	-	-	1.07	4.0	-	320	-
0.8	6.5	-	-	240	1.5	5.5	-	-	-	1.22	6.0	-	-	-
1.8	6.5	-	-	-	0.9	5.5	-	250	300	1.37	5.5	-	-	-
0.6	6.5	210	220	230	1.2	6.0	270	400	450	1.01	7.0	-	210	300
1.8	7.5	-	-	-	0.6	7.0	230	240	270	1.07	7.5	280	350	450
1.7	7.5	-	-	-	1.1	8.0	250	430	440	0.76	8.5	-	-	230
1.2	7.5	220	250	310	1.5	9.5	-	-	-	0.61	10.5	-	-	230
1.4	7.0	320	-	-	1.1	10.0	230	260	300	0.61	11.0	-	190	220
1.3	7.5	240	260	300	0.8	10.0	-	-	230	0.76	11.5	180	190	210
0.9[a]	8.5	160	230	250	0.8	11.0	-	220	250	1.22	13.0	260	340	-
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.

Results

The sizes and numbers of grayling available for culvert tests varied with the size of the run (Tables 9, 10 and 11). 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 percent 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 percent, respectively, in a 1.3 m/s current. The critical lengths of grayling thus determined in Tables 8, 9, 10 and 11 are summarized in Table 12 and plotted in Fig. 16. Likewise, the results of sucker tests are presented in Tables 13, 14, and 15, summarized in Table 16, and plotted in Fig. 17.

The > and < symbols used in Tables 8-11 and 13-15 require explanation. In some instances because of excessive water velocity or lack of fish in suitable size classes, 75 percent (or 50 or 25 percent) 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 percent success at 1.8 m/s; for the 22-23 May test the < symbols indicate that the fish in the sample were too long to determine 25 or 50 percent 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 and 1975 (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 12 and 16 represents an average of a maximum afternoon temperature and a minimum morning temperature taken daily between 0900 and 0900. The mean water temperatures between 1100 and 2300, 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 C.

In the 18.3 m culvert, the fastest flow tested (1.9 m/s) blocked 77 percent 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 out of 40 fish (4-7 C), and 2 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 percent 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 (430-450 mm max) at 4-7 C but not at 5-7 C or warmer (Tables 14 and 15). 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 (Fig. 16). 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 Fig. 17. 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 line represents a conservative relationship between fish length and water velocity in that it includes all well-motivated fish.

As the length of the culvert increases, the ability of the fish to ascend the culvert decreases. As an example, success data shown for 25 percent (grayling) in Fig. 16 indicate that 25 percent of the fish can ascend 18.3 m of culvert when the mean flow velocity is 6.2 times the length of the fish. For 30.5 m of culvert, the velocity must be limited to 4.0 times the fish length to obtain a similar passage of fish. For suckers the information for 25 percent success shown in Fig. 17 indicates that flow velocity must be limited to 4.3 times the fish length for passage through 18.3 m of culvert as compared to 2.6 times the fish length for 30.5 m of culvert. The data also indicate that for a specified success ratio, and a given culvert length and velocity of flow, the sucker must be about 1.5 times longer than the grayling.

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 positively to the migratory drive.

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 swimming performance of essentially immature grayling. 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 percent levels of success in 2-day tests were about 24 percent shorter than those attained in 1-day tests; and those attained in 3-day tests were about 8 percent shorter than those attained in 2-day tests (Table 17).

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 (Fig. 18). The straight line which bounds the lower velocity range of the fish at 5-8 C in Fig. 16 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 (Fig. 19). 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.

In 1975, the cumulative effect of 2-day versus 1-day tests had little to no effect on the response of grayling and sucker to stem the 30.5 m culvert (Table 11 and 15). The greatest increase of grayling successes (from 16 percent at the end of day 1 to 37 percent at the end of day 2) occurred during the first experiment when the maximum water temperature increased from 4 C on 13 May to 6 C on 14 May. After these dates the mean increase of successes between the 1st and 2nd day of the tests ranged from 0 to 7 percent for grayling and suckers.

In the first experiment on 13-15 May 1975, the length class of grayling at the 25, 50 and 75 percent levels were generally 30 mm shorter for the 2-day test than those for the 1-day test. Except for the first grayling experiment, the cumulative effect of 2-day versus 1-day tests for grayling and suckers did not significantly alter the length class distribution of successes. For this reason only the 1-day data are plotted on Fig. 16. The reader can easily verify the similarity in 1-day and 2-day results by examining the data in Table 11.

In 1974, we analyzed the effect of state of maturation on the motivation of grayling to ascend the 30.5 m culvert. Fish were classified 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 1974 grayling in any given length class varied with the size of the length class (Fig. 9). Only the large fish (261-360 mm) were used for analyses, as this group contained the highest and most consistent percentages of ripe fish (males, 89 percent; females 37 percent).

A large percentage of males was ripe at the beginning and during most of the run, whereas the percentage of ripe females increased with time (Fig. 10). Thus, we divided the females chronologically into three groups. These represented three levels of maturation (Table 18). 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.

For the total run, 88 percent of the successes and 70 percent 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 was not ripe (Fig. 10), there were fewer ripe females among the successes (31 percent) than among the failures (51 percent). For the latter part of the run (22-27 May) when a large percentage of the females was ripe, there were more ripe females in the successes (76 percent) than in the failures (67 percent). Thus the situation reversed itself.

Discussion

Most of the fish in the first wave of grayling were of spawning size. For the first test, fish remained in the tailbox several hours prior to attempting to ascend the culvert. During subsequent tests, more fish ascended the culvert at progressively earlier hours. It is assumed that water temperature and state of maturation regulated the timing of their upstream swimming response. During the first days, significant numbers of fish did not ascend the culvert until late afternoon, the time when water temperatures were maximum. On subsequent days as fish ripened and the weather and water warmed, grayling ascended the culvert earlier in the day.

Significant numbers of suckers arrived at the dam site on 19 May 1973 (6-7 C), 15 May 1974 (4-6 C) and 15-16 May 1975 (4-7 C). After their arrival, suckers and grayling were mixed together in the tailbox, as this would be the normal situation in a pool below a culvert installation. Because of the large number of fish and the limited capacity of the tailbox, only a portion of the suckers was tested. Moreover, culvert velocities were set to obtain specific data for grayling and not for sucker. Thus, for several tests, culvert velocities were too high for the sucker, resulting in fewer data for analysis.

The spawning run of grayling 241 mm and longer was essentially complete by 27 May of each year. After this date, the runs were 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

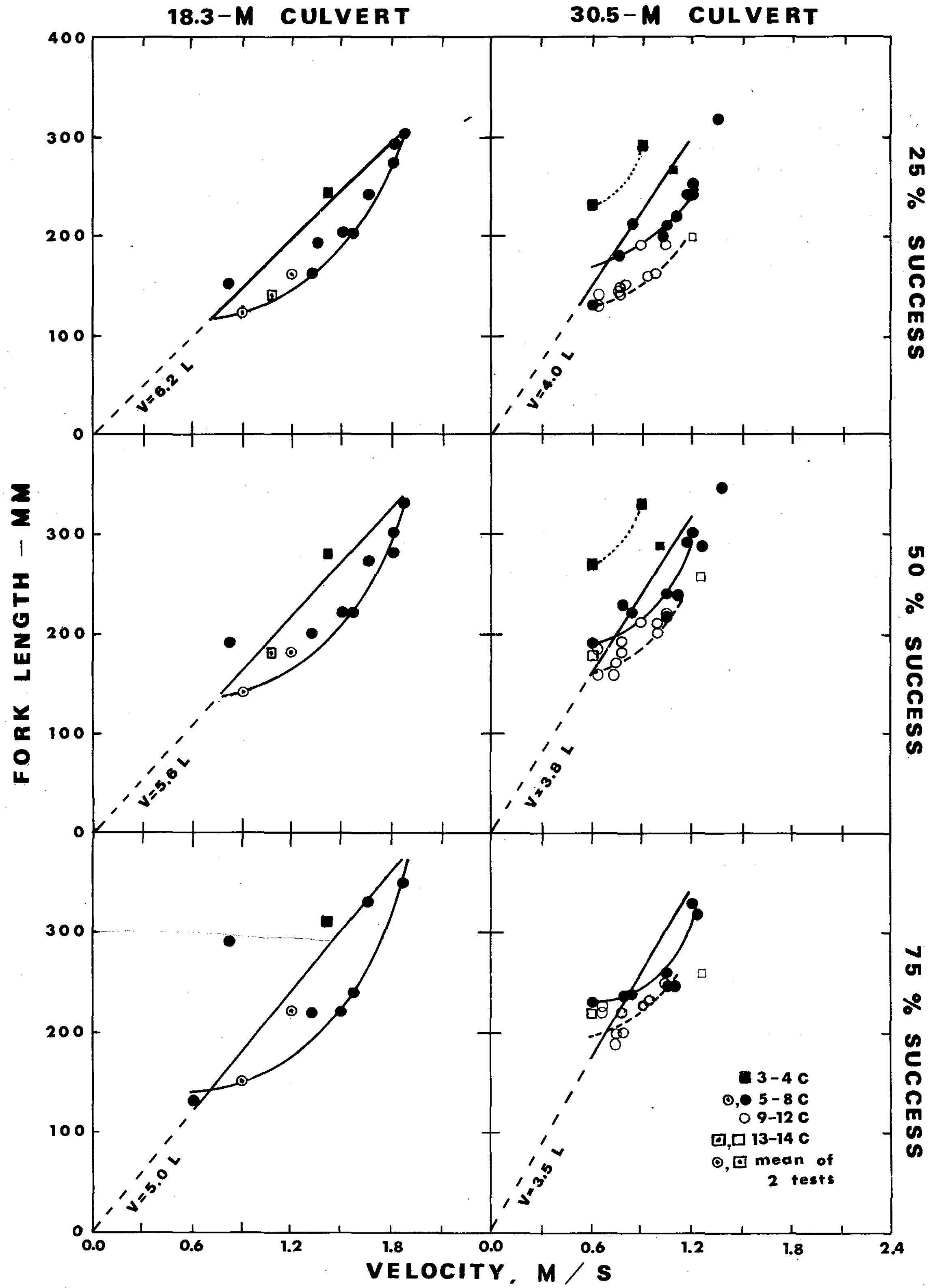

Fig. 16. Relationship between fork length and water velocities which permitted 25, 50 and 75 percent of Arctic grayling to ascend 18.3 and 30.5 m culverts in 1-day tests. Curved lines approximate "barrier" parameters (dotted, 3-4 C; solid, 5-8 C; dashed, 9-12 C). Straight lines represent maximum "safe" velocities.

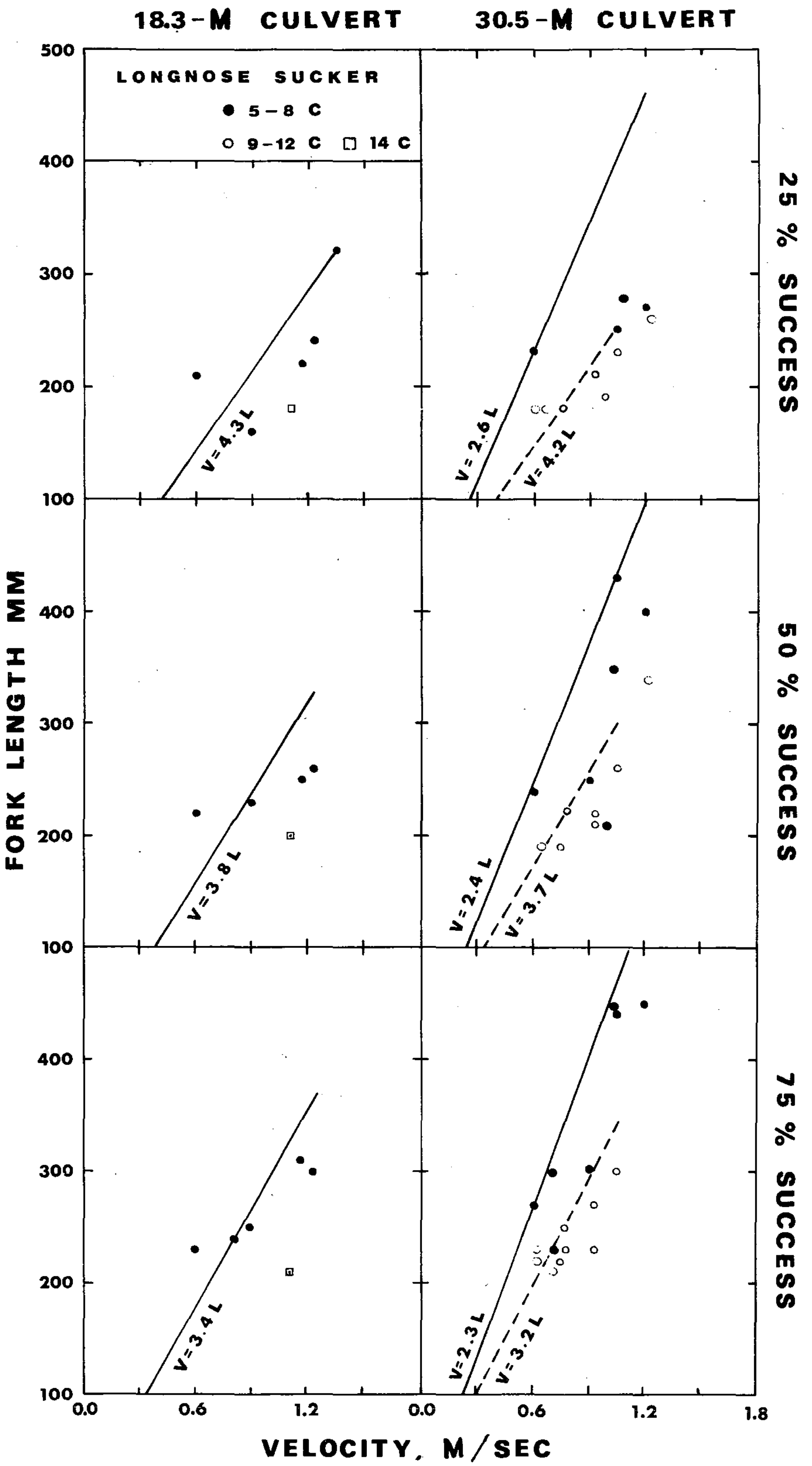

Fig. 17. Relationship between fork lengths and water velocities which permitted 25, 50 and 75 percent of the longnose suckers to ascend 18.3 and 30.5 m culverts in 1-day tests. Solid lines (5-8 C) and dashed lines (9-12 C) represent maximum "safe" velocities.

Table 17. 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 percent, double dots = 50 percent and lower bar = 75 percent 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					

Table 18. Percentage of ripe grayling that successfully ascended a 30.5 m culvert in 1 day. Data for 1.5 m/s velocity 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)

swimming performance is somewhat comparable to that of motivated spawners swimming at lower temperatures.

In 1974 and 1975 the culvert tests were stopped about 1.5 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 retrieving failures and altering the slope of the culvert was accomplished in the morning when water temperatures were low and fish were least active.

In 1974 and 1975 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) 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 maturation on the swimming performance of grayling in 1974 and the effect of temperature and longer test periods in 1974 and 1975. 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 ascending 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 ascend 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.

Grayling used in the culvert tests were too long to obtain the 25 and 50 percent success lengths for the 18.3 m culvert at 0.6 m/s (6-7 C) in 1973, and the 25 percent success length for the 30.5 m culvert at 0.6 m/s (13-16 C) in 1974 (Tables 9 and 10). Extrapolation to the next lowest length class (81-100 mm) provides a conservative estimate of these critical lengths. However, one should be cautioned against extrapolating to 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; 96 mm instead of the 90 mm mean should be used for datum analysis.

The straight line relationship shown in Fig. 16 indicates conservative estimates of sustained speed for

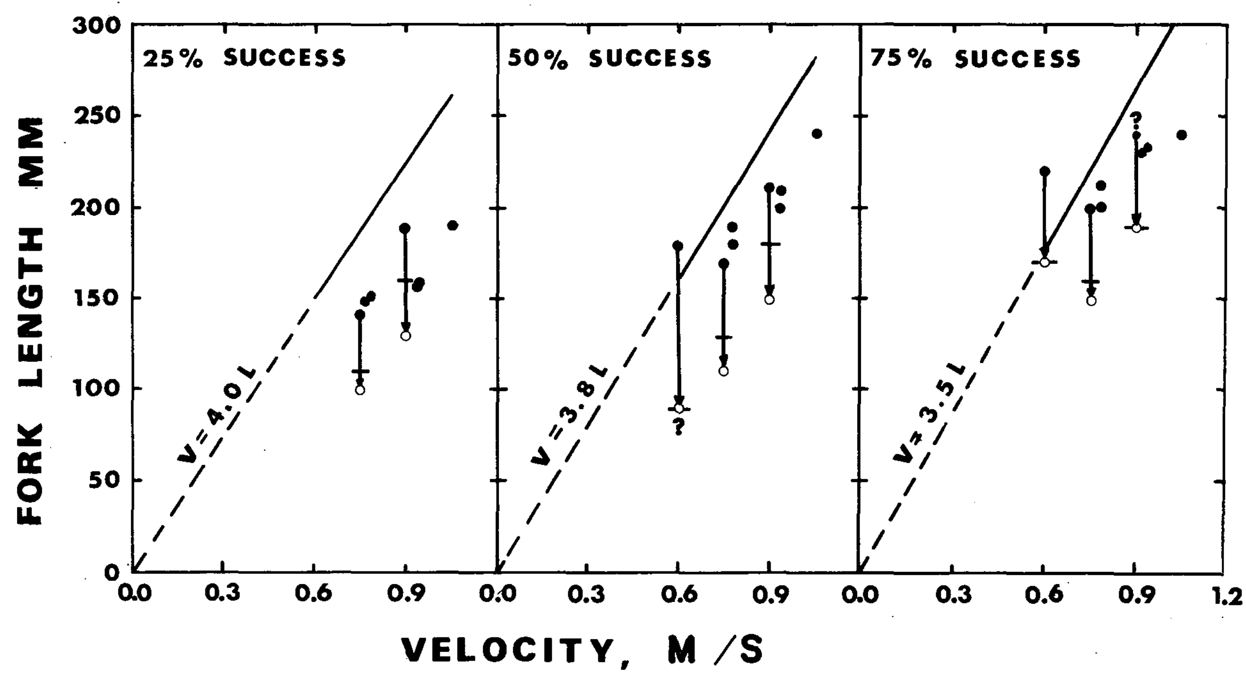

Fig.18. Effect of water velocity on the capability of grayling to ascend a 30.5 m culvert in 1-, 2- and 3-day trials (temperature, 9-16 C). Arrows indicate the direction of change of critical lengths for 3-day tests. Solid circle = 1-day test; cross bar = 2-day test; open circle = 3-day test; and a ? = extrapolated value to the next length class.

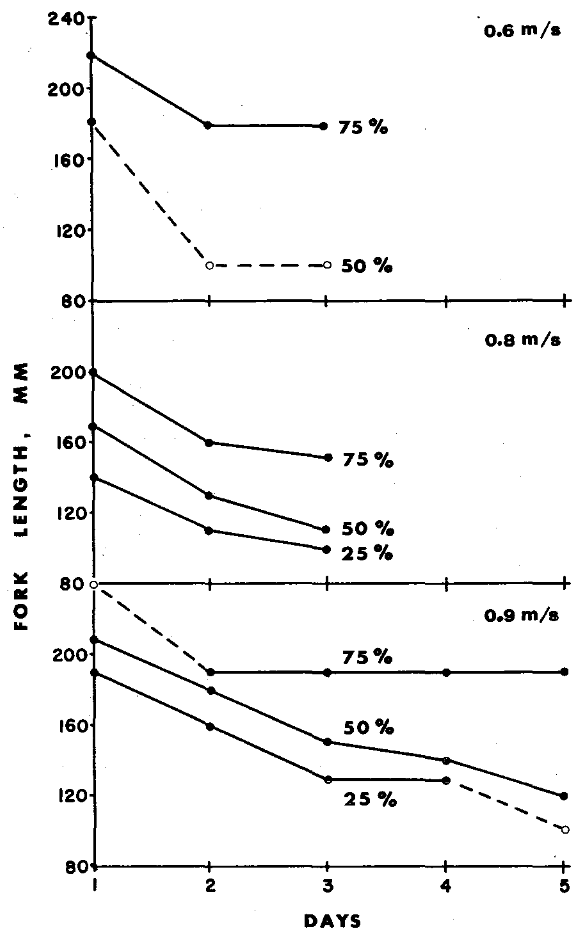

Fig. 19. Cumulative effect of time on the length of grayling that ascended a 30.5 m culvert at the indicated percentage level of success. Hollow points and dashed lines indicate extrapolated data.

grayling. Two-day tests did not materially alter these estimates. 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 ranges 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 Fig. 16 for an 18.3 m culvert, a 380 mm 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 data points represents a conservative linear equation for fork lengths 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 percent success as a design criterion are options of the planning agency. Judgment 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 those encountered at the Poplar Grove site.

The specific objectives of the circular channel tests were:

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 1 hour under strong stimulus, without gross variation in performance. We determined the speed of fish for 1-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-min 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 near the town of Chitina. 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 (Fig. 20 and 21). 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.

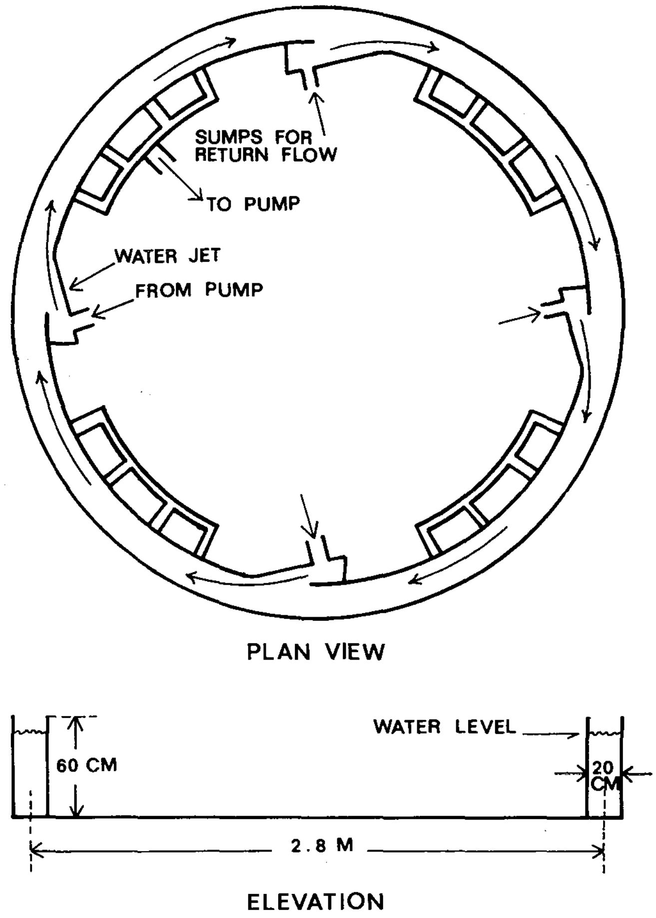

Fig. 20. Plan and elevation of circular channel used in fish swimming performance tests. Pumps and hoses are omitted from the diagram.

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

Table 19. The voluntary sustained speed (10 min) and cruising speed (1 hour) 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 10-minute	1-hour	Water velocity meters/second
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	155-179	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

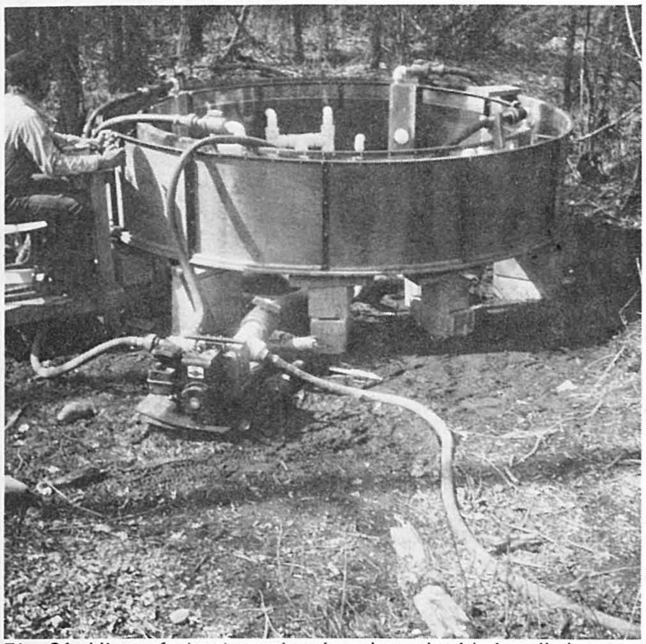

Fig. 21. View of circular swimming channel with installed pumps and hoses.

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.

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 19-23 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. This necessitated a restart at a lower velocity.

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 1 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 1 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-min intervals for 1 hour and totaled. Current velocity, water temperature, and fish movements were recorded at 10-min intervals, and the data were averaged for 1 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 hour) 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 1-hour periods. Fish were permitted to rest a minimum of 30 min between experiments. Depending on the number of 1-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 analysis. It was assumed that variation in swimming speed that occurred in repeat trials was due to experimental artifact and/or lack of motivation rather than exhaustion.

We measured the contrasting swimming performance of upstream and downstream migration 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. Results of all tests for Poplar Grove and Town Lake grayling were analyzed with the exception of tests that were discontinued before the elapse of 1 hour because of mechanical failure or because of the necessity of stopping the test to insert a screen to force fish to swim faster.

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 1 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 1 hour that fish gained or lost by 8.7 m (circumference of mid-channel), and subtracting that value from the 1 hour distance that the water traveled. The result divided by 3600 gave the voluntary cruising speed in meters per second. Voluntary

Table 20. The speed of Arctic grayling from Town Lake which were compelled by a wire screen to swim for 1 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 21. The voluntary sustained speed (10 min) and cruising speed (1 hour) 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		Water velocity, meters/second
						10-minute	1-hour	
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 22. The voluntary sustained speed (10 min) and cruising speed (1 hour) 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 10-minute	Swimming speed, meters/second 1-hour	Water velocity, meters/second
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 23. The speed of Arctic grayling from Poplar Grove Creek which were compelled by a wire screen to swim at a maximum rate for 1 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 an 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

sustained speed was calculated in the same manner except that units of 600 seconds were used instead of 3600 seconds.

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 11 fish subjected for 1 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 equals:		-175
Distance water traveled:	0.45 x 3600 = 1620 m/hour/fish	
Distance lost by fish:	$\frac{8.7 \text{ m} \times -175}{11}$ = -138 m/hour/fish	
Difference:	1482 m/hour/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 equals:		-11
Distance water traveled:	0.39 x 3600 = 1404 m/hour/fish	
Distance lost by fish:	$\frac{8.7 \text{ m} \times -11}{11}$ =-8.7 m/hour/fish	
Difference:	1395 m/hour/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 1-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 19-23 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 (Fig. 22 and 23). 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 Fig. 22 and 23).

To determine the approximate shape of the cruising speed versus temperature curves in Fig. 22, 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 (Fig. 23).

The data points for sustained speed (Fig. 23) are distributed in a pattern similar to those for cruising speed (Fig. 22). 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 percent (141-172 mm fish) and 12.3 percent (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 1 hour to 10-min intervals. (Data for forced swimming speeds were omitted from these calculation.)

Maximum swimming speed occurred between 13 and 15 C for grayling. Mean cruising and sustained speeds of grayling (141-172 mm) increased about 80 percent 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 1 hour at 1 C on 10 May, and two grayling (mean fork length, 227 mm) voluntarily cruised at 1.31 m/s for 1 hour

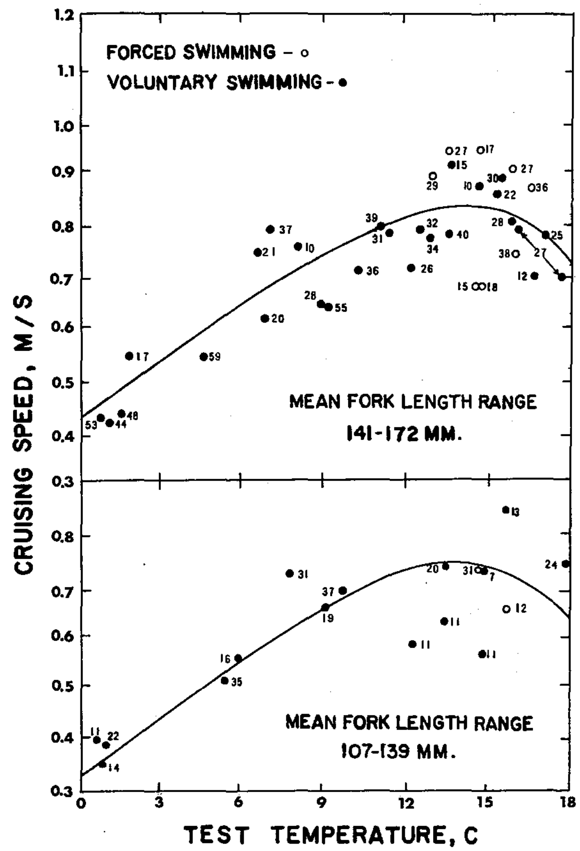

Fig. 22. Cruising speed of grayling of two length classes (mean lengths, 125 and 157 mm) with respect to temperature. The numerals beside the points refer to sample size. Solid points = voluntary speed; hollow points = forced speed.

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 (Fig. 24) swam faster than downstream migrants on a voluntary basis (Fig. 25). 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.

Voluntary sustained swimming speed was only slightly faster (6.6 percent) than cruising speed for upstream migrants from Poplar Grove Creek. This indicates that upstream migrants maintained a high level of motivation throughout the 1-hour test period.

A single lot of Poplar Grove upstream migrants (27 fish) was tested for three 1-hour periods on 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 Fig. 22.

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 percent faster than the crusing 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 Fig. 25. 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 (Fig. 26). The correlation between fork length and forced speed lacks significance at the 5 percent confidence level.

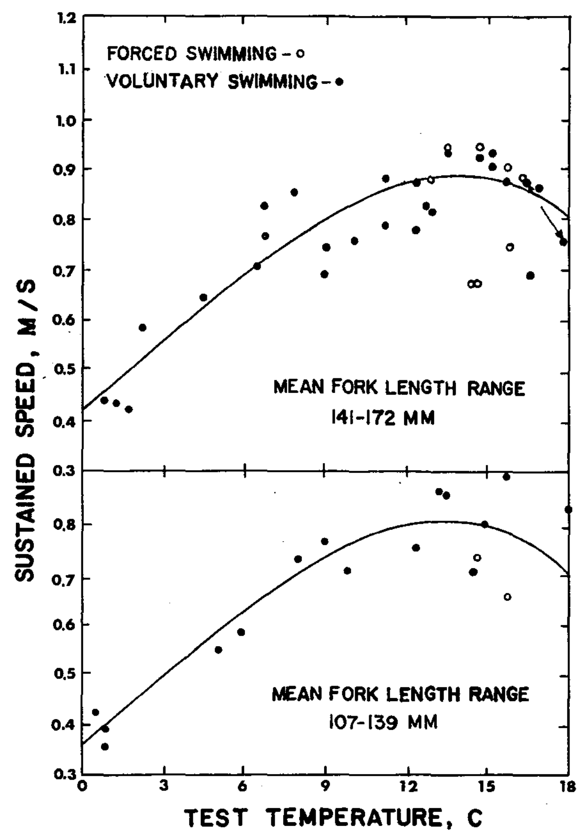

Fig. 23. Sustained speed of grayling of two length classes (mean lengths, 125 and 157 mm) with respect to temperature. Solid points = voluntary speed; hollow points = forced speed.

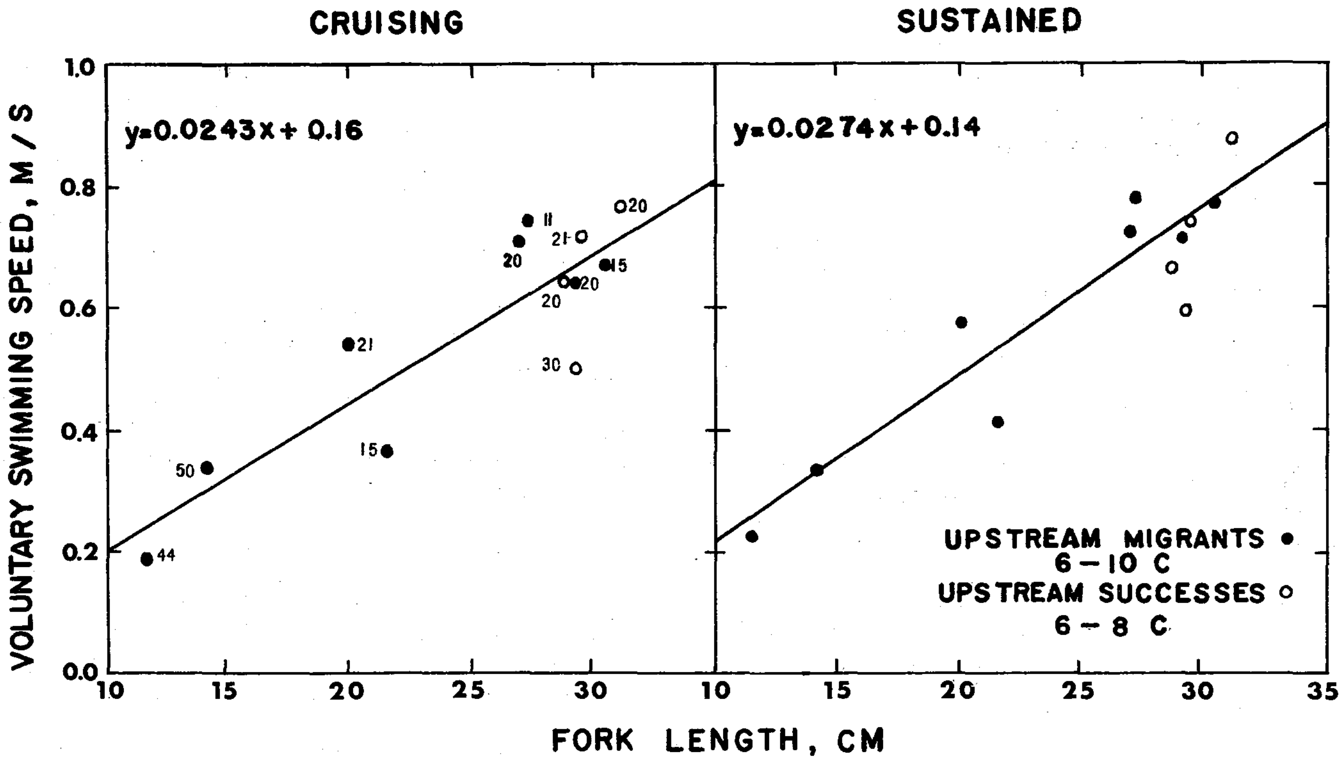

Fig. 24. Cruising and sustained speeds of upstream migrating Arctic grayling tested in a circular flume. The mean speeds of fish (hollow points) that successfully passed upstream through an 18.3 m culvert at a flow of 1.3 m/s are compared with speeds of randomly selected upstream migrants (solid points). 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.

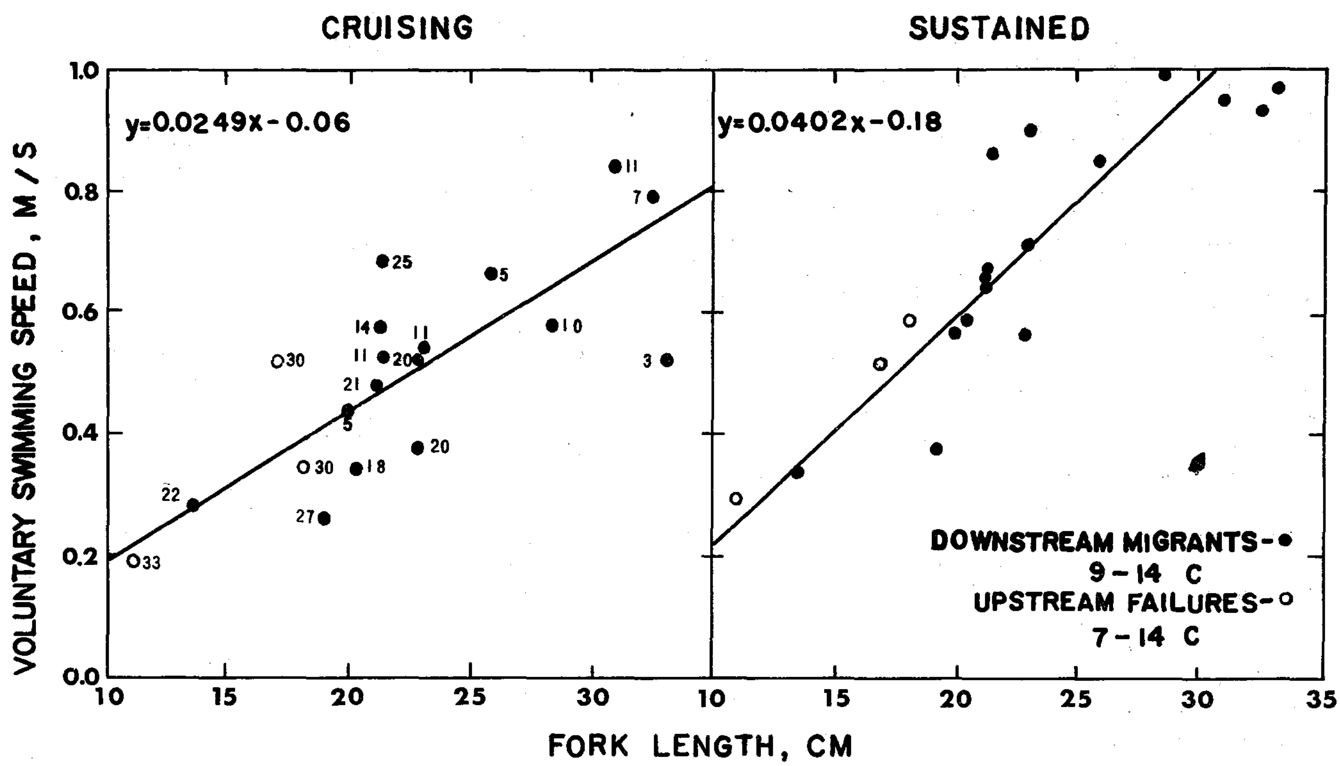

Fig. 25. Voluntary cruising and sustained speeds of downstream migrating Arctic grayling tested in a circular flume. The mean speeds of upstream migrants (hollow points) that failed to pass through an 18.3 m culvert at flows of 1.1, 1.5 and 1.6 m/s are compared with speeds of downstream migrants. The 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.

The relative position of the regression line, however, suggests a higher level of effort than those obtained on a voluntary basis (Fig. 27). 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. Measurements within the flume indicated that velocities at the inner side were 7 percent less and at the outer side 2 percent 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 (Fig. 22 and 23). 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 (Fig. 27). 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 (Fig. 27). The water velocity in the channel was generally slightly faster for the 10-min 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 the swimming speed of Poplar Grove grayling in the 30.5 m culvert than does the cruising speed (Table 24).

Voluntary sustained swimming speeds of 200 mm and 300 mm upstream migrants were 0.69 and 0.96 m/s, respectively (Fig. 24). Water velocities in 30.5 m culvert tests permitting 75 percent success for 200 mm and 300 mm grayling were 0.70 and 1.05 m/s (Fig. 16). Apparently, 10-min sustained speeds in the circular channel approach those required for 75 percent success in a 30.5 m long culvert.

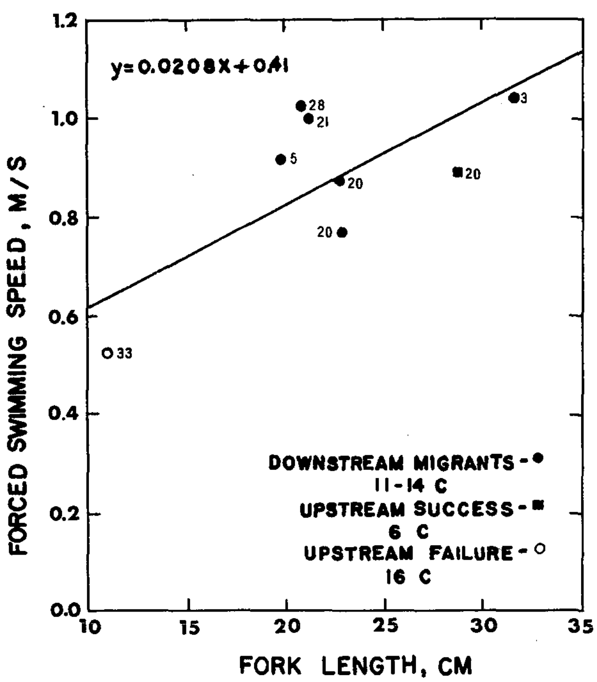

Fig. 26. Swimming speed of Arctic grayling compelled by a wire screen to swim at a constant rate for 1 hour in a circular flume. The numerals beside the points refer to the number of fish in a sample.

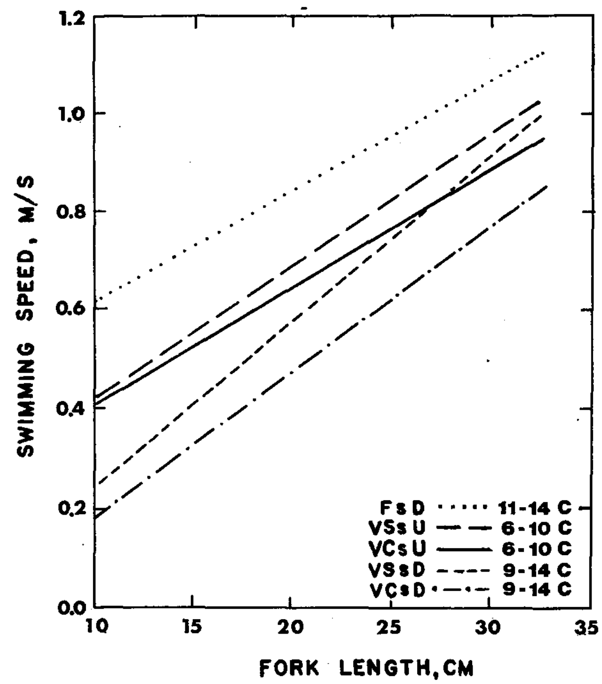

Fig. 27. A comparison of swimming speeds of Arctic grayling obtained under different experimental conditions in a circular flume. Fs = forced speed, Ss = sustained speed, Cs = cruising speed, V = voluntary, U = upstream migrants, D = downstream migrants. The regression lines are the same as those in Figs. 24-26.

Table 24. Approximate swimming speeds of upstream migrating Arctic grayling determined under different experimental conditions.

Type of test	Temperature C	Fork Length 150mm	200mm	250mm	300mm
Circular flume speed					
Cruising (1 hour)	8	0.52	0.65	0.77	0.89
Sustained (10 minute)	8	0.55	0.69	0.82	0.96
Culvert speed (75% level of success)					
30.5 meters	7	0.53	0.70	0.87	1.05
	11	0.57	0.76	0.95	1.16
18.3 meters	7	0.76	1.02	1.27	1.52

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 percent and 0.55 m/s at the 75 percent level of success). In this case, we compared the mean speed of Town Lake fish (Fig. 23) with a minimum safe swimming speed of Poplar Grove grayling in a 30.5 m culvert (Fig. 16). 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 percent, respectively. Construction lines at 11.5 C for deriving these velocities are omitted from Fig. 16. These values represent a mean increase in swimming capability of 12.2 percent. For Town Lake grayling and for the same increase in temperature (4-5 C) the increase in swimming capability was 17.8 percent, a value reasonably close to 12.2 percent.

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

Swimming speed at 11 C: $\frac{4.7 + 4.2 + 3.8}{3} = 4.23$ L

Swimming speed at 7 C: $\frac{4.0 + 3.8 + 3.5}{3} = 3.77$ L

Difference: 0.46 L

$$\left(\frac{0.46}{3.77}\right) 100 = 12.2\%$$

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

$$\left(\frac{0.13}{0.73}\right) 100 = 17.8\%$$

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 percent, respectively. This represents a mean decrease in swimming performance of 24.3 percent, a value based essentially on one sample (168 fish) (Fig. 16). 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 percent (Fig. 23).

The above comparisons 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 x60 seconds or 24 min to pass through the 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 12, 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 the hours of 1100 and 2300. Thus, Fig. 16 and 17 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 Fig. 23 are used for estimating sustained swimming speed as required for culverts when water temperature is other than 7 C. Based on a mean curve drawn through a composite of data points shown in Fig. 23, it was apparent that mean sustained speed varies by a factor of about 6.2 percent per degree Centigrade for water temperatures of 0-7 C, and about 2.8 percent 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; 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 (Fig. 22). 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 percent 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 Fig. 16. 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 percent 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: 1.20 m/s + 0.028 (10-7 C) (1.20 m/s) = 1.30 m/s.

The maximum sustained speed attainable by this 240 mm design fish would be for water temperature 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 these fish determined. The culvert must be designed so that velocities in the culvert are compatible 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 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.

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ABSTRACT

Both 18.3- and 30.5-meter tiltable highway culverts (0.6 m in diameter) were used for evaluating the swimming performance of Arctic grayling *(Thymallus arcticus)* and longnose sucker *(Catastomus catastomus)* at velocities ranging from 0.6 to 1.9 m/s. Fish migrating upstream during their annual 2-week spawning run were utilized for the culvert tests. In 1-day tests at water temperatures of 5-8 C, 25, 50 and 75 percent of the grayling succeeded in ascending a 30.5 m culvert at flows of 4.0, 3.8 and 3.5 times the fork length, respectively, and an 18.3 m culvert at flows of 6.2, 5.6 and 5.0 times the fork length of the fish, respectively. At 9-12 C, 25, 50 and 75 percent of the grayling succeeded in stemming a 30.5 m culvert at flows of 4.7, 4.2 and 3.8 times the fork length of the fish, respectively. For 2-day tests, a second day permitted only 0 to 7 percent more of the first day failures to stem a 30.5 m culvert, with the exception of the initial test of the series when stream temperatures were lowest. Suckers swam at about two-thirds the speed of grayling. The state of maturation of females affected the upstream drive of grayling. Volunteer swimming speeds for grayling for 10-min and 1-hour intervals were determined for various temperature regimes in a circular flume with controlled flows. The swimming capability of grayling (141-172 mm) increased about 80 percent with an increase in temperature from 0 to 14 C. At 8 C grayling attained mean sustained speeds (10 min) of 0.55, 0.69, 0.82 and 0.96 m/s for fork lengths of 15, 20, 25 and 30 cm, respectively. At 8 C grayling cruised (1 hour) at 94 percent of the sustained speed. Grayling migrating downstream were less motivated to swim vigorously than those migrating upstream.