Abstract.- The effects of delays on the spawning run of Arctic grayling in Fish Creek, a tributary of the Jack River, near Cantwell, Alaska were examined. Tagged grayling were delayed for 3, 6, or 12 days, and then released; control fish were released within 12 hours of capture. During the delays, a high proportion of females became ripe; most males were ripe before the delays and remained ripe over a longer period than females. Delayed and control fish were monitored by the recapture of tagged fish in upstream traps. Females released in a "running-ripe" condition migrated at higher rates, but failed to reach upstream areas in similar proportions as those of "less ripe" females. Reduction in distances traveled by grayling as a result of longer delays may lead to the use of non-preferred spawning habitats, underuse of spawning areas upstream, and decreases in recruitment. I recommend that spawning delays for Arctic grayling not exceed 3 days.

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Preface

When the present study embarked in May 1987, it sailed into uncharted waters. Fish migrations have been studied a great deal in the past, but the consequences of interrupted migrations had not been investigated. In the past, resource agencies have required engineers to facilitate fish passage through structures at instantaneous peak mean annual discharge. Alternative duration flow design criteria advocate designs based on average flow rates over specific periods of time- resulting in smaller, more cost effective culverts. These structures will provide passage during most of the open water season, but may delay upstream migrations for short periods. It was our goal to either support or reject the guiding hypothesis in null form:

> "Any delays, natural or artificial, experienced by Arctic grayling during their spawning run will have no effect on their subsequent spawning success."

The primary objectives selected for the study were to experimentally measure the biological effects of migrational delay on spawning success, and secondarily, to determine the maximum permissible delay which would not alter spawning success. Spawning success can be variously defined: the number of mature fish that spawn; the number that spawn in favorable areas; and the hatching percentage of egg deposition.

The objectives for the first (1987) field season proved to be ambitious, and elusive. Arctic grayling were captured at a weir just upstream of the culvert under study for fish passage. It was planned that both control (no delay) and delayed fish would be stripped of gametes and the eggs fertilized and incubated to evaluate the effect of delay on hatching success; however, no females were running-ripe at the time of initial capture, thus no valid controls were available. Eggs and milt were stripped from delayed fish, eggs counted, fertilized and placed in incubation chambers and held instream. However the chambers needed constant cleaning of sediment and debris. Nevertheless, an opportunistic fungus (Saprolegnia sp.) destroyed the eggs before "eyeing up" occured.

When the control and delayed fish were released, 289 were carrying large spaghetti tags inserted anteriorly to the dorsal fin. The tags were of various colors corresponding to the delay period they endured. The upstream progress and spawning of the different groups was to be monitored by streamside observation on routine stream surveys (post release). Characteristics of the Fish Creek watershed-- a complex of many ponds, deep channels, undercut banks, -periodic turbidity prevented successful observation. The only tag recaptures, a modest return of 3.4%, resulted through angling efforts.

The information gained during the first field season helped with the study design of the second field season. It would be necessary to recapture the migrating grayling upstream at several strategic locations in order to answer questions such as: How fast would grayling migrate after being delayed? What changes to maturity occur during migration? Where are the spawners distributed in the watershed after being delayed?

The 1988 field season began May 2, earlier than the 1987 season start on May 10 because of an earlier breakup. Several problems arose that reduced the useful data base. The stream was partially open with streamflow passing through channels cut in the ice. The weir was fishing by May 6 but relocated below the culvert. Concurrently, we readied the upstream fyke trap sites and prepared for the start of the spawning run. It was assumed that grayling do not ascend streams until the bulk of ice has left. However, unmarked grayling entered the upstream fyke nets as soon as the nets were set, indicating that grayling were already upstream. Some fish were transported to the downstream holding areas for delay: because the weir catches were low, and upstream catches were high, the bulk of the spawning run may have been missed. Eventually additional upstream migrants arrived at the weir.

On May 16, a large beaver dam was located between the two traps farthest upstream, blocking the migration of a large number of grayling. Declining upstream trap captures and a falling hydrograph were evidence that the fish could have been delayed for several days or more. A major effort to create a fish ladder over the dam ensued, and approximately 500 fish ascended the ladder and moved upstream. We removed the data on 444 fish from the study because of the unquantified delay.

On the morning of May 27th, we discovered that our holding pens had been vandalized; the nets were cut and all fish being delayed (69) and the weir catches of the previous evening (~80) removed. The authorities were notified immediately and an investigation began; no one has been arrested for the crimes. Because of the uncertainty surrounding the missing delay fish, all 69 were removed from the database of the spawner distribution study. Many of these fish were later captured in upstream traps; information was still collected and utilized in the investigations on maturity and migration speed. Despite these problems, the 1988 field season resulted in sufficient data to reach some conclusions about spawning run delay. This thesis, excluding preface and appendices, was presented to the Bioengineering symposium of the American Fisheries Society on October 27, 1988, and has been submitted for publication in the proceedings of the symposium.

The Alaska Department of Transportation and Public Facilities, and Federal Highways Administration funded this study. Appreciation is extended to Dr. Douglas L. Kane, Robert Gieck, and Dan Basketfield, Water Research Center, University of Alaska Fairbanks, Robert Clark and Robert F. McLean, Alaska Department of Fish and Game, and Michael D. Travis, Alaska Department of Transportation and Public Facilities, for technical guidance and field support; University of Alaska Fairbanks students Alan R. Burkholder, James B. Griswold, J.D. Johnson, Craig Monaco, and Kathleen Roush for field assistance. Additional thanks go to Dr. Pat Fox , Applied Statistics Department, University of Alaska Fairbanks.

Over the past two years at the Alaska Cooperative Fishery Research Unit (ACFRU), I have been amidst a cohort of great people. Many thanks go out to my chief advisor, Dr. Jim Reynolds, and my committee, which also included Dr. Jacqueline LaPerriere, Dr. Doug Kane, and Mike Travis, for assisting in many of the technical and review facets of this project. Ramona Salonka receives many special thanks for the magnitude of her assistance in logistics for field work, help in the office, and other uncountable instances that arose along the way. My fellow students and close friends have been the best, with many sweet hours of procrastinating work in favor of frenzied discussions over "Comps," recruitment and population models, "bum props," and the gauntlet to delayed gratification. They also helped me greatly while mired in parts of my study, and in learning a great many things that tuition just doesn't buy.

Introduction

The use of culverts as highway drainage structures at stream crossings is a mixed blessing. Culverts are less costly than bridges, but may block fish passage during high or low flows. Fish migration is of particular concern in northern environments where such behavior is essential to fish survival; northern species often have complex migration routes that link spawning, feeding and overwintering. The spawning strategy of Arctic grayling (*Thymallus arcticus*) may coincide with that of centrarchids and cyprinids described by Hall (1972): migration of spawners often results in their offspring being distributed in the more productive areas upstream at a time when most energy is available for feeding and growth.

In central and northern Alaska, Arctic grayling migrate from overwintering areas to their spawning grounds during the spring breakup, a period of near-peak stream flow from snowmelt. High water velocities through culverts are normal and may delay upstream spawning migration. Work by MacPhee and Watts (1976), on which the present highway design standards of the State of Alaska for fish passage are largely based, focused on swimming performance and the maximum culvert water velocities that would permit fish passage.

In the past, resource agencies have required engineers to facilitate fish passage through structures at instantaneous peak mean annual discharge. Alternative duration flow design criteria advocate designs based on average flow rates over specific periods of time- resulting in smaller more cost effective culverts. These structures will provide upstream passage during most of the open water season, but may delay upstream migrations for short periods. Duration flow design for the placement of culverts requires information on the maximum period of delay that Arctic grayling can withstand during spawning migration without significant reduction in spawning success (i.e., the critical delay period). Delays during spawning migrations have been recognized as an important aspect of fish passage, but have not received much scrutiny (Dryden and Stein 1975). The effects of spawning run delay must be evaluated in biological terms. Declines of chinook salmon (*Oncorhynchus tshawytscha*) in Columbia River may have resulted from the biological effects of spawning run delays caused by dams (Haynes and Gray 1980). Likewise, declines of the Montana grayling were thought to have been influenced by irrigation dams blocking migrations (Vincent 1962).

Our goal was to determine the effects of delay on migrant spawners in terms of spawning success. One measure of that success is the hatching percentage of the eggs deposited. The most direct approach would be to study the effect of delay on egg hatching. However, hatching fertilized eggs from delayed adults would not take into account the post-delay behavior of fish trying to reach their spawning grounds. Instead, our approach was to examine some indirect effects of delay: the chronology of maturation, migratory rates, and the distributions of spawners.

Study Area and Methods

The study was conducted on Fish Creek, a second-order tributary of the Jack River in the Alaska Range near Cantwell, Alaska, with a watershed area of 110 km^2 (Figure 1). The creek passes through a culvert (2.9 m diameter, 19 m long) on the Denali Highway (milepost 132.8). Each spring, several thousand Arctic grayling migrate upstream from overwintering areas in the Jack and Nenana rivers, through the culvert, to spawning and feeding habitats in upper Fish Creek. The stream was selected because of its small size and proximity to the Denali Highway. Fish Creek offers a variety of habitats; its lower sections include a series of small shallow interconnected lakes, and its headwaters comprise two branches: a warmer lake-fed branch and a cooler surface runoff branch. The lower watershed's deep stream channel meanders through areas of wet tundra; its course is very sinuous and substrates include silt, sand, and detritus (Weir to site A, Figure 1). Reaches further upstream are less sinuous, containing higher gradient segments of interspersed riffles and pools with coarser gravels and cobble bottom substrates within the main stem and surface runoff branch (above site D, Figure 1). The lake fed branch has a narrowly constricted, deep channel of moderate gradient flowing through roots and woody debris of encroaching wet tundra.

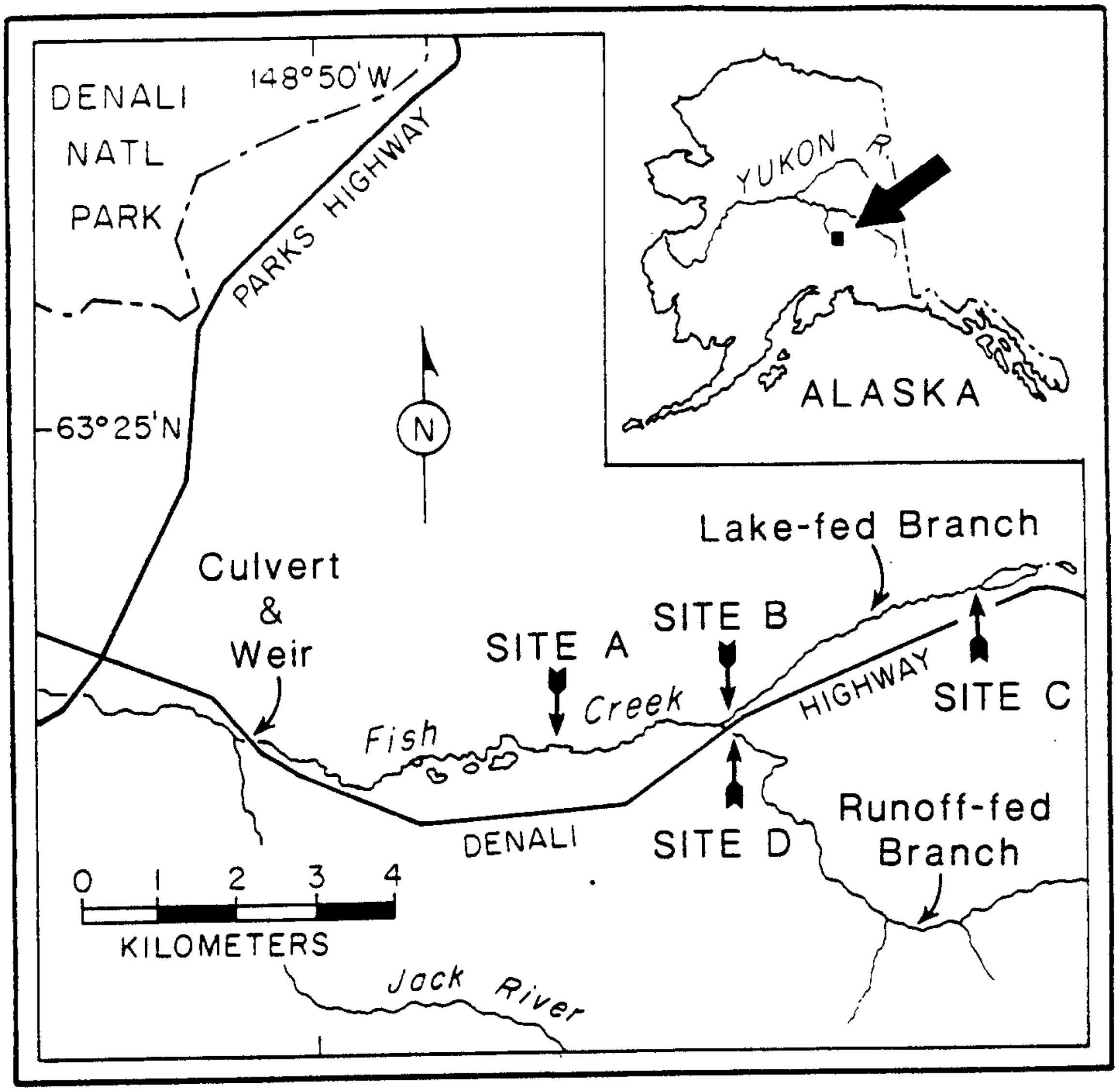

Figure 1. Fish Creek, along the Denali Highway, south of Fairbanks, Alaska, showing the location of the culvert and recapture sites (A,B,C,D).

Our primary approach was to capture adult grayling at a weir near and downstream of the culvert; tag them; delay randomly selected fish for 0, 3, 6, or 12 days; release them; and recapture them in several traps progressively farther upstream. Multiple recapture sites allowed greater opportunity to evaluate the maturation of the delayed and control (no-delay) fish, and to provide check-points with which to gauge upstream migratory performance and distribution as a function of delay.

An 18.5-m long weir was deployed downstream from the culvert on 6 May 1988 to capture upstream migrants. Fish were fin-clipped and tagged with serially numbered Floy™ FTSL-73 shrimp streamer tags[1], inserted along the anterior edge of the dorsal fin. The tags were tied to increase retention time. Fork lengths and states of maturity were recorded. Handling was done without anesthesia to minimize recovery time and effects on migratory behavior and performance.

Each fish was examined for protrusion of the urogenital pore and gently squeezed in an attempt to release eggs or milt. The ease and quantity of gametes released determined the maturity status of each individual:

Unknown sex : no gametes released; no evident sexual features.

Male

Partly-ripe: little milt released; urogenital pore not protruding.

Ripe: milt easily released; urogenital pore not protruding.

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[1] Use of trade names does not imply product endorsement.

Females

Partly-ripe: one or very few eggs released by gentle squeezing; urogenital pore often not protruding.

Ripe: numerous eggs easily released, but not streaming; urogenital pore often protruding

Running-ripe: eggs streamed out freely upon handling, with little or no pressure applied; urogenital pore protruding.

Spent: no, or few, eggs released; swollen and protruding urogenital pore; usually a flaccid abdomen.

Fish considered for the delay study had fork lengths greater than 270 mm, a minimum length applied to ensure that all fish in the sample were sexually mature.[2] Fish were sampled over the entire run (about 25 days) to reduce the effect of unknown differences in early- or late-run migrants. Of 233 adult grayling captured at the weir, 111 were used for the delay treatments and 122 were used as controls; the latter were released within 12 hours of capture upstream of the culvert to avoid any additional delay resulting from high discharge through the culvert. Release times and tag numbers were recorded for all released fish. Sample sizes for the delay groups were 41 3-day delay; 39 6-day delay; and 31 12-day

2 Length at maturity based upon findings by the Alaska Department of Fish and Game on Fish Creek grayling in 1987.

delay. Balanced sex ratios within samples were not possible because of a high incidence of fish of unknown sex captured at the weir.

Delayed fish were held in three separate (by treatment) net pens (1.2 m by 3.1 m constructed of 10 mm mesh) staked in water 0.5 m deep and covered with tarpaulins. At the end of the delay period, fish to be released were removed from the holding pens and re-evaluated for maturity status before release.

Four fyke nets were placed at upstream sites and fished continuously from 13 May to 11 June to monitor the progression of the run (Figure 1). Site A was 9 km upstream from the weir; sites B and D (confluence of the branches) 12 km; and site C 18 km. The traps were checked four times each day. Data recorded at the upstream sites were tag number, maturity status, time of release, and water temperature. No tagged grayling were held in a fyke net more than 8 hours. Trapping efficiencies were estimated by calculating the proportion of tagged fish caught in a trap as compared to the number of tagged fish encountering the trap, including escapees captured further upstream. Individual efficiency estimates and their 95% binomial confidence intervals were estimated for each delay or maturity release group at each fyke trap. Catches were adjusted to reduce bias by dividing observed catches by the group-specific efficiency estimate; upper and lower catch limits were similarly calculated using the binomial confidence intervals.

Nonparametric methods such as log likelihood ratio goodness of fit tests, contingency table tests for independence, and Mann-Whitney U tests comprised most of the data analysis. Proportions were also transformed using the arcsine root transformation to yield approximately normally distributed variables for regressions. Cochran's chi-square for linearity was calculated to support conclusions of linear relations when only several proportions were regressed (Cochran 1954). Ridit analysis (Fleiss 1981) was adapted to compare distributions of migrating fish relative to each other along the continuum of the watershed. Ridit analysis depends on a probability relative to a reference distribution as a means of revealing differences between compared distributions. All statements of statistical significance were based on P=0.95 unless otherwise stated.

Results

Maturity

At initial capture 74% of the males were ripe and 52% of the females were ripe or running-ripe. After delay in the holding pens the maturity status of 68 to 85% of the females changed from the condition initially observed; while only 23 to 35% of the males showed changes (includes increases toward, and decreases from, peak spawning condition; Figure 2). Among groups of delayed females, there were no statistically significant differences in the proportion of those with changed maturities; there also were no significant differences among proportions of delayed males showing changed maturity as well. Clearly, more females changed maturity while being delayed than did males. Significant changes to maturity occured between 0 and 3 days. Of the delayed females, 37 to 64% advanced in gonadal maturity, the percent increase proportional to the period of delay (Figure 3); 65 to 75% of the delayed males remained unchanged (Figure 4). However, these proportions among delay groups were not statistically significant. Maturity status in some individuals of both sexes decreased during delay as a result of gamete release, accompanied perhaps by spawning while captive. Overall, 50% of the females ripened after a mean delay duration of 6.4 days; 11% of the males after 6.7 days.

Control fish recaptured upstream also advanced in maturity status with the passage of time and migratory behavior, but significant

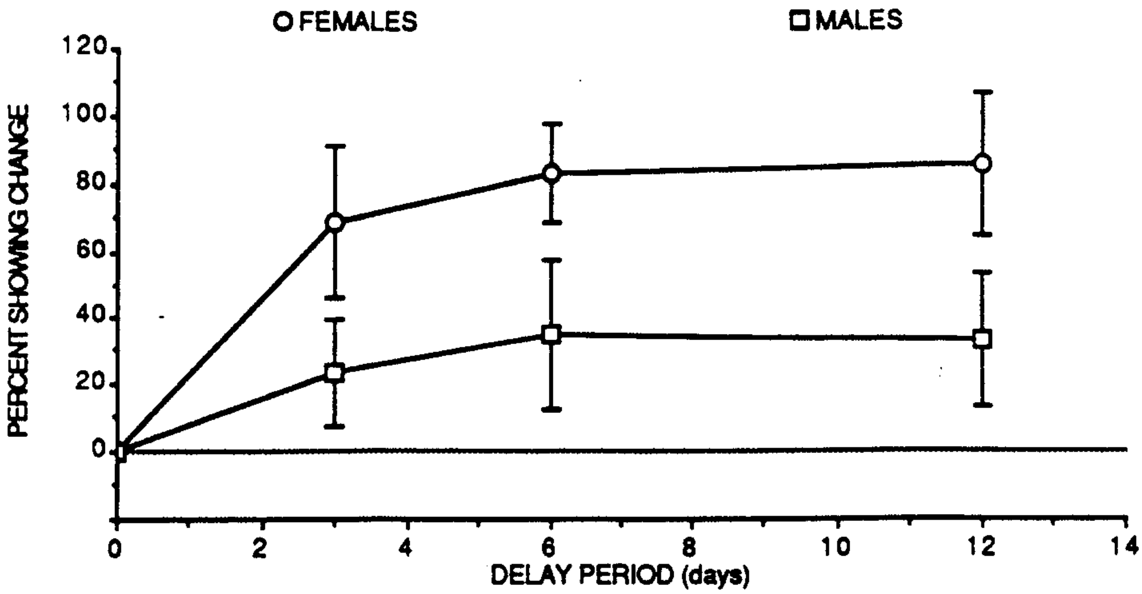

Figure 2. Percent of delayed females and males showing change from initially observed maturity. Vertical bars represent 95% confidence intervals.

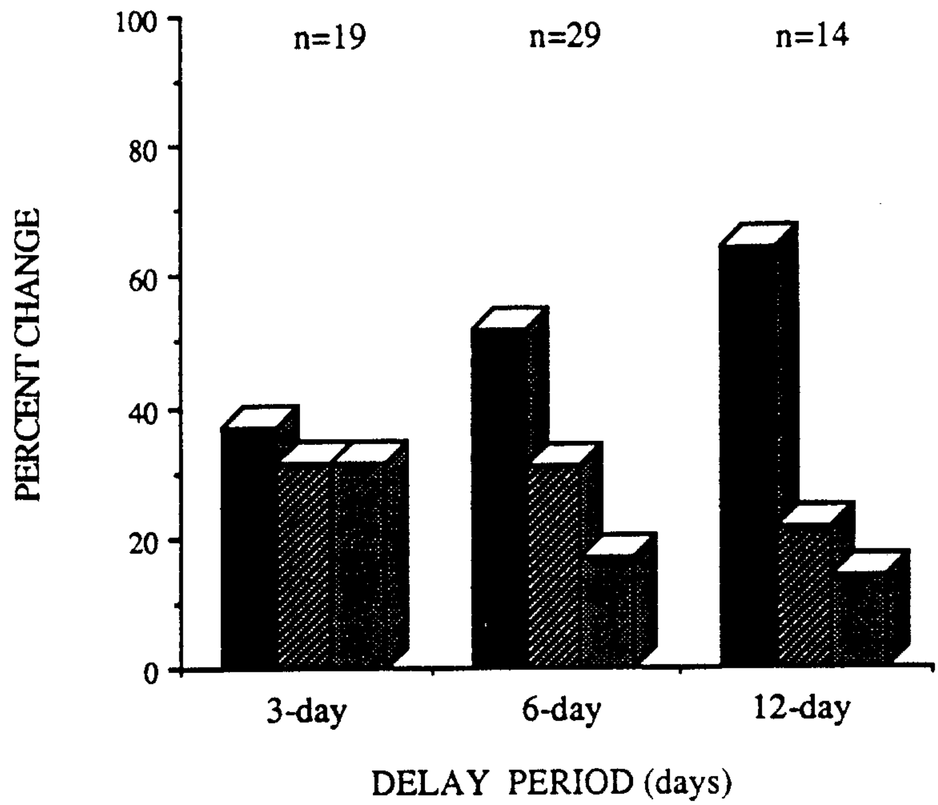

Figure 3. Percent change in stage of maturity [increased (black), decreased (cross hatched), or unchanged condition (grey)] of females delayed in holding pens as a function of delay period.

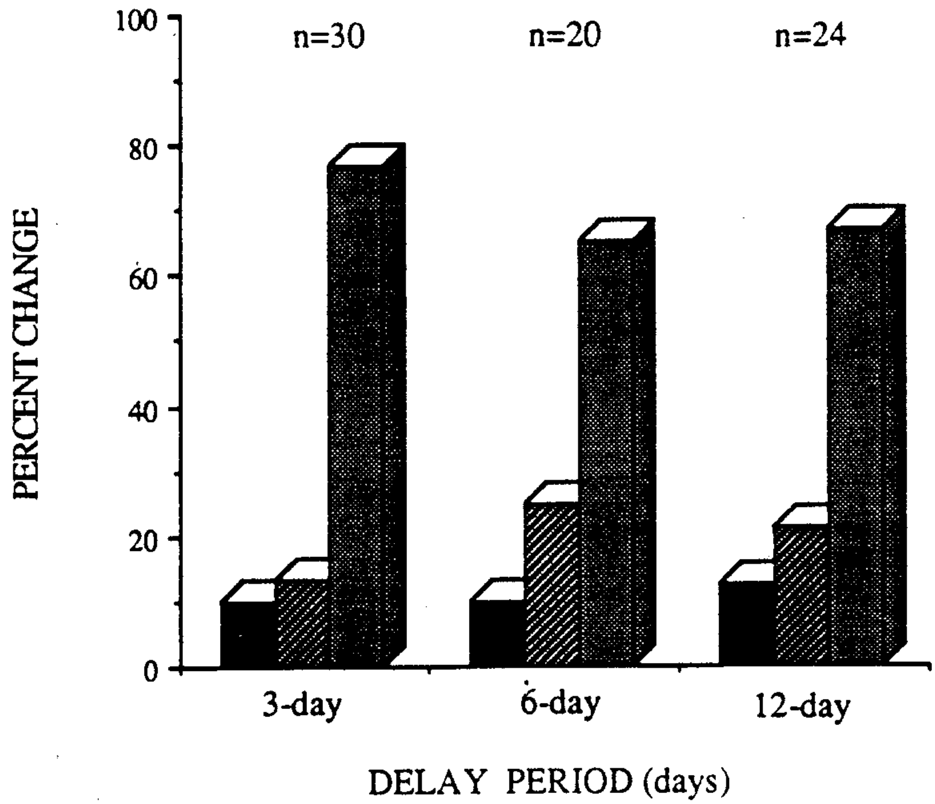

Figure 4. Percent change in stage of maturity [increased (black), decreased(cross hatched), or unchanged condition (grey)] of males delayed in holding pens as a function of delay period.

differences in estimates of change among each sex were not detected except between females at sites A and C (Figure 5). The natural processes of maturation in control females and males were significantly different. Upon recapture farther upstream, some delayed females and males (Figure 6) showed additional changes in maturity (advances or loss of gametes) compared to that observed at time of release from the holding pens. Sample sizes of recaptured fish were too small to compare proportions of maturity changes among delay treatments for significant differences.

Migratory Performance

Migratory rates, calculated by using release and recapture times and stream distances between capture sites were calculated for different segments along the migration route (Table 1). Water temperatures ranged from 0°C to 11°C during the study period but were not factored into migratory performance. Pooled median migratory rates (both sexes and all treatments) were 0.22, 0.22, and 0.05 km/h corresponding to migration from the weir to site A; from the weir to site B (because site B was fishing before site A); and from site B to site C. The migratory rate from the weir to site A was significantly higher than that of site B to site C (Mann-Whitney U, $P < 0.0001$); also the rate from the weir to site B compared to that from site B to site C (Mann-Whitney U, $P < 0.0001$). The median migration rate between the weir and site A was not significantly different from that between the weir and site B.

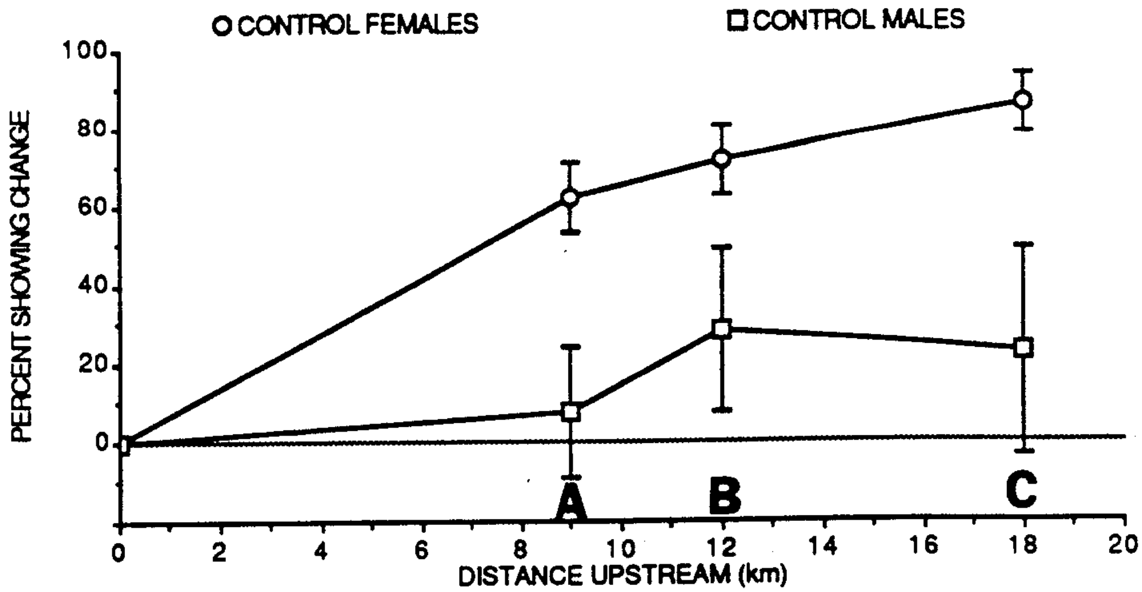

Figure 5. Percent of control females and males showing change from initially observed maturity upon recapture at upstream sites (A, B, C). Vertical bars represent 95% confidence intervals.

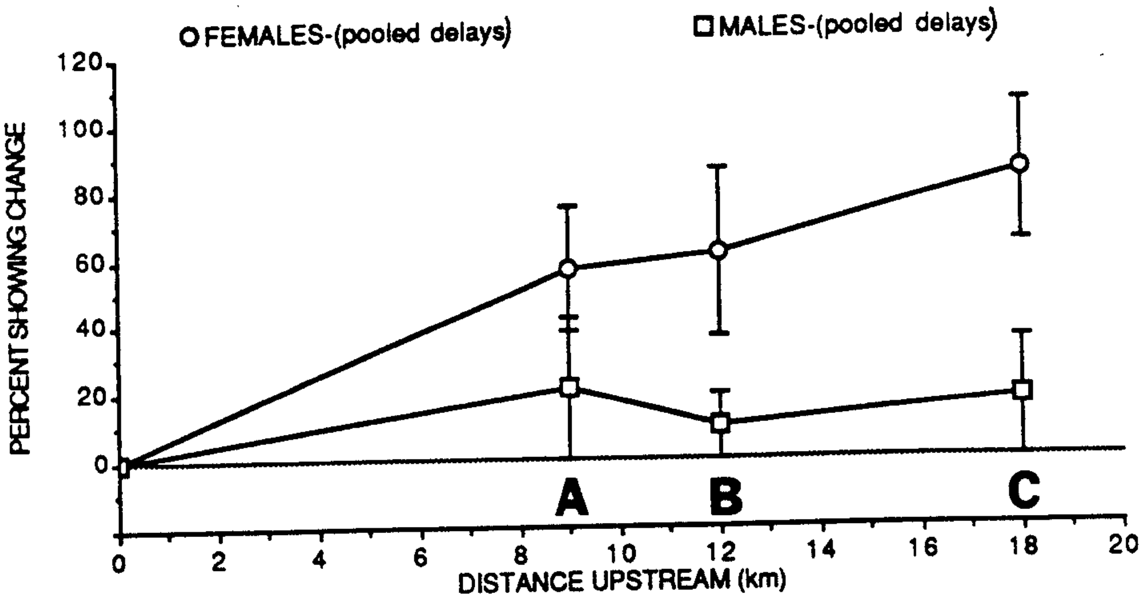

Figure 6. Percent of pooled delay females and males showing change from initially observed maturity upon recapture at upstream sites (A, B, C). Vertical bars represent 95% confidence intervals.

Table 1. Median migration rates (km/hr) and variances for various groups.

Category	Median	Variance
Stream Segment		
W to A	0.22	0.039
W to B	0.22	0.021
B to C	0.05	0.0015
Delay Group		
0-day	0.37	0.027
3-day	0.18	0.071
6-day	0.26	0.021
12-day	0.3	0.014
Sex and Maturity		
RRF*	0.33	0.007
RF**	0.25	0.021
RM***	0.22	0.041

* Running-Ripe Female
** Ripe Female
*** Ripe Male

Migration rates, analyzed by delay and sex, were calculated for fish recaptured at site A. Median values for the delay groups were 0.37, 0.18, 0.26, and 0.30 km/h, corresponding to the control, 3, 6, and 12 days of delay. Individual rates ranged from 0.02 to 1.29 km/h. Comparisons of migration rates by Mann-Whitney U tests showed significant differences between control and 3-day delay (P=0.02). Median rates by sex and maturity were 0.33 , 0.25 , and 0.22 km/h, for running-ripe females, ripe females, and ripe males, respectively. Running-ripe females had a significantly higher migration rate than ripe females (Mann-Whitney U, P=0.045) with a variance significantly smaller than variances from all other groups.

Distributions of Spawners

Recapture analysis of the control and delay groups of male and female grayling (Table 2) suggests that duration of delay did not clearly or consistently affect final spawner distribution. A regression (pooled males and females) of the fraction recaptured at upstream locations showed an inverse relation between distance upstream and the estimated percentage remaining within the run (Figure 7). This relation was significant according to Cochran's chi-square for linearity test. Confidence intervals (P=0.95) of the slope indicated that between 1 and 8% of those released "dropped-out" in each 1 km of stream. Regression of Arcsine root transformed fractions recaptured was also performed to satisfy requirements of normality and did not affect the findings (Zar 1984).

Table 2. Estimated number (upper) and percent (lower) of grayling reaching upstream fyke trap locations by delay period. Confidence intervals (P=0.95) are in parentheses.

Fyke Trap and Upstream Distance (km)	Delay Period (days) and Sample Size			
	0* (122)	3 (41)	6 (39)	12 (31)
Remote site A	79 (65-99)	34 (27-41)	17 (15-21)	15 (10-25)
(9)	65 (53-81)	83 (66-100)	43 (38-54)	48 (32-81)
Lake branch site B	45 (41-51)	13 (12-16)	7 (6-9)	9 (8-9)
(12)	37 (34-42)	32 (29-39)	18 (15-23)	29 (26-29)
Lake outlet site C	33 (29-47)	5 (4-7)	6 (5-8)	9 (8-9)
(18)	27 (24-38)	12 (10-17)	15 (13-20)	29 (26-29)

*Control group

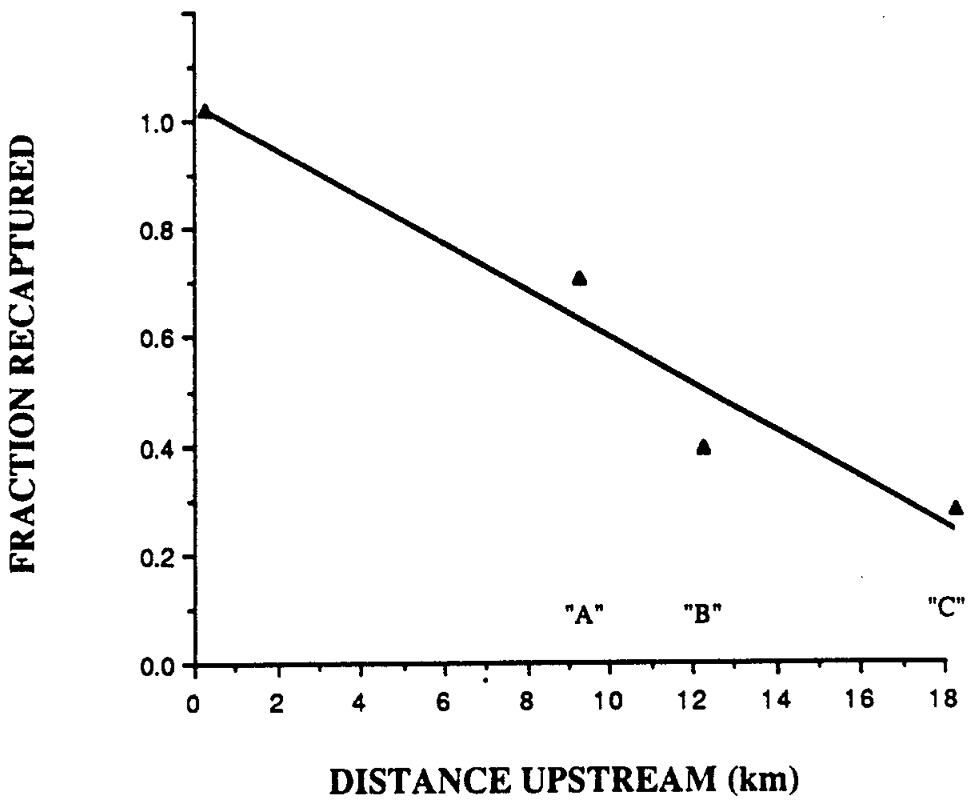

Figure 7. Fraction of grayling recaptured (pooled treatments) at upstream recapture sites (A, B, C) as a function of distance upstream of release point (culvert). The fitted regression line: Y= 1.0015- 0.0433X (r^2=0.88, P=0.04) where Y= fraction recaptured and X= distance upstream.

Slopes non-significantly different from zero and low coefficients of determination precluded comparison of slopes, or "drop-out" rates[3], among the control and delay groups.

Pooled samples of ripe males and females in various stages of maturity were plotted by using the fraction recaptured as a function of upstream distance. The estimated drop-out rate was 4.5% for ripe males and 4.0% for ripe females. Running-ripe females dropped out at a mean rate of 5.0% (r^2=0.90, P=0.035); and partly-ripe females at 3.1% (r^2=0.997, P=0.001). Drop-out rate increased with the status of maturity in females (Table 3; Figure 8); the difference between running-ripe and partly-ripe females was significant (Students t, ($0.01<P<0.025$)). Drop-out rates calculated using the Arcsine root transformed fractions resulted in similar findings.

Estimated final distribution of spawners (Tables 4 and 5, Figures 9 and 10) indicated that a large portion of the run remained in the lower watershed. Only 3% of the released fish entered the branch fed by surface runoff and were recaptured at site D. Data on these fish were removed from the study to clarify further analysis.

Final distribution was dependent on delay period according to contingency table analysis ($P<0.0002$), and was independent of sex and maturity at downstream release. Log likelihood ratio goodness of fit tests showed heterogeneity (two-tailed test) among all group

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[3] "Drop-out" rate implies the fraction of initially released fish that remain resident or no longer migrate, per kilometer of stream. This is calculated by regression of the recapture fraction against the recapture site distance.

Table 3. Estimated number (upper) and percent (lower) of grayling reaching upstream fyke trap locations by sex and maturity at time of downstream release. Confidence intervals (P=0.95) are in parentheses.

Fyke Trap and Upstream Distance (km)	Weir Release Sex and Maturity with Sample Sizes PRF* (14)	RF** (41)	RRF*** (28)	RM**** (80)
Remote site A	10 (8-14)	27 (19-41)	18 (17-22)	57 (46-74)
(9)	71 (57-100)	66 (46-100)	64 (61-78)	71 (57-92)
Lake branch site B	9 (8-14)	17 (15-22)	7 (6-10)	28 (26-32)
(12)	64 (57-100)	41 (37-54)	25 (21-36)	35 (32-40)
Lake outlet site C	6 (5-8)	13 (12-18)	4 (3-5)	19 (17-27)
(18)	43 (36-57)	32 (29-44)	14 (11-18)	24 (21-34)

* Partly-ripe females
** Ripe females
*** Running-ripe females
**** Ripe males

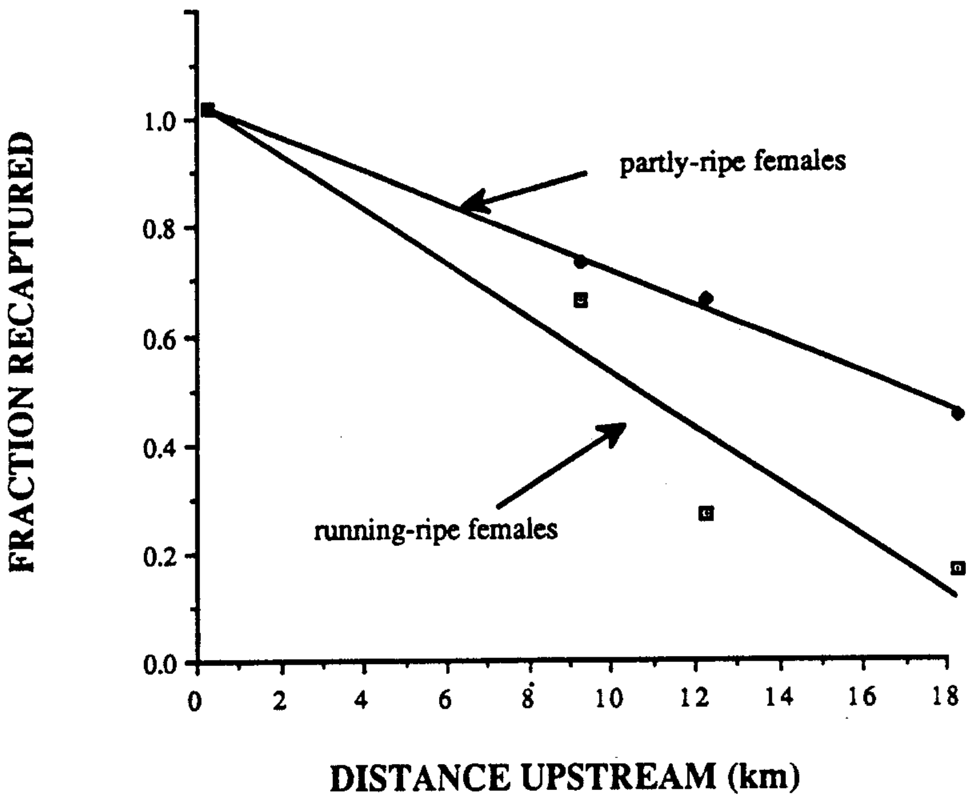

Figure 8. Fraction of running-ripe (squares) and partly-ripe (diamonds) females at upstream recapture sites (A, B, C) as a function of distance upstream of release point (culvert). The fitted regression line for partly-ripe females was $Y=1.0027-0.0314X$ ($r^2=0.99$, $P=0.001$). The fitted regression line for running-ripe females was $Y=0.9995-0.0503X$ ($r^2=0.896$, $P=0.035$). In both cases Y= fraction recaptured and X= distance upstream.

Table 4. Estimated number (upper) and percent (lower) of grayling distributed within various stream segments as a function of delay period. Confidence intervals (P=0.95) are in parentheses.

Stream Segment and Upstream Distance (km)	Delay Period (days) and Sample Size 0* (122)	3 (41)	6 (39)	12 (31)
W to A	43 (23-57)	7 (0-14)	22 (18-24)	16 (6-21)
(0-9)	35 (19-47)	17 (0-34)	56 (46-61)	52 (19-67)
A to B	34 (14-58)	21 (11-29)	10 (6-15)	6 (1-16)
(9-12)	28 (11-47)	51 (27-71)	25 (15-38)	19 (3-52)
B to C	12 (0-22)	8 (5-12)	1 (1-4)	0 (0-1)
(12-18)	10 (0-18)	19 (12-29)	3 (3-10)	0 (0-3)
above C	33 (29-47)	5 (4-7)	6 (5-8)	9 (8-9)
(18-20)	27 (24-38)	12 (10-17)	15 (13-20)	29 (26-29)

* Control group

Table 5. Estimated number (upper) and percent (lower) of grayling distributed within various stream segments as a function sex and maturity at time of release downstream. Confidence intervals (P=0.95) are in parentheses.

Stream Segment and Upstream Distance (km)	Weir Release Sex and Maturity with Sample Sizes PRF* (14)	RF** (41)	RRF*** (28)	RM**** (80)
W to A (0-9)	4 (0-6) 29 (0-43)	14 (0-22) 34 (0-54)	10 (6-11) 36 (21-39)	23 (6-34) 29 (7-42)
A to B (9-12)	1 (0-6) 7 (0-43)	10 (0-26) 24 (0-63)	11 (7-16) 39 (25-57)	29 (20-48) 36 (25-60)
B to C (12-18)	3 (0-9) 21 (0-64)	4 (0-10) 10 (0-24)	3 (1-7) 11 (3-25)	9 (0-15) 11 (0-19)
above C (18-20)	6 (5-8) 43 (36-57)	13 (12-18) 32 (29-44)	4 (3-5) 14 (11-18)	19 (17-27) 24 (21-34)

* Partly-ripe female
** Ripe female
*** Running-ripe female
**** Ripe male

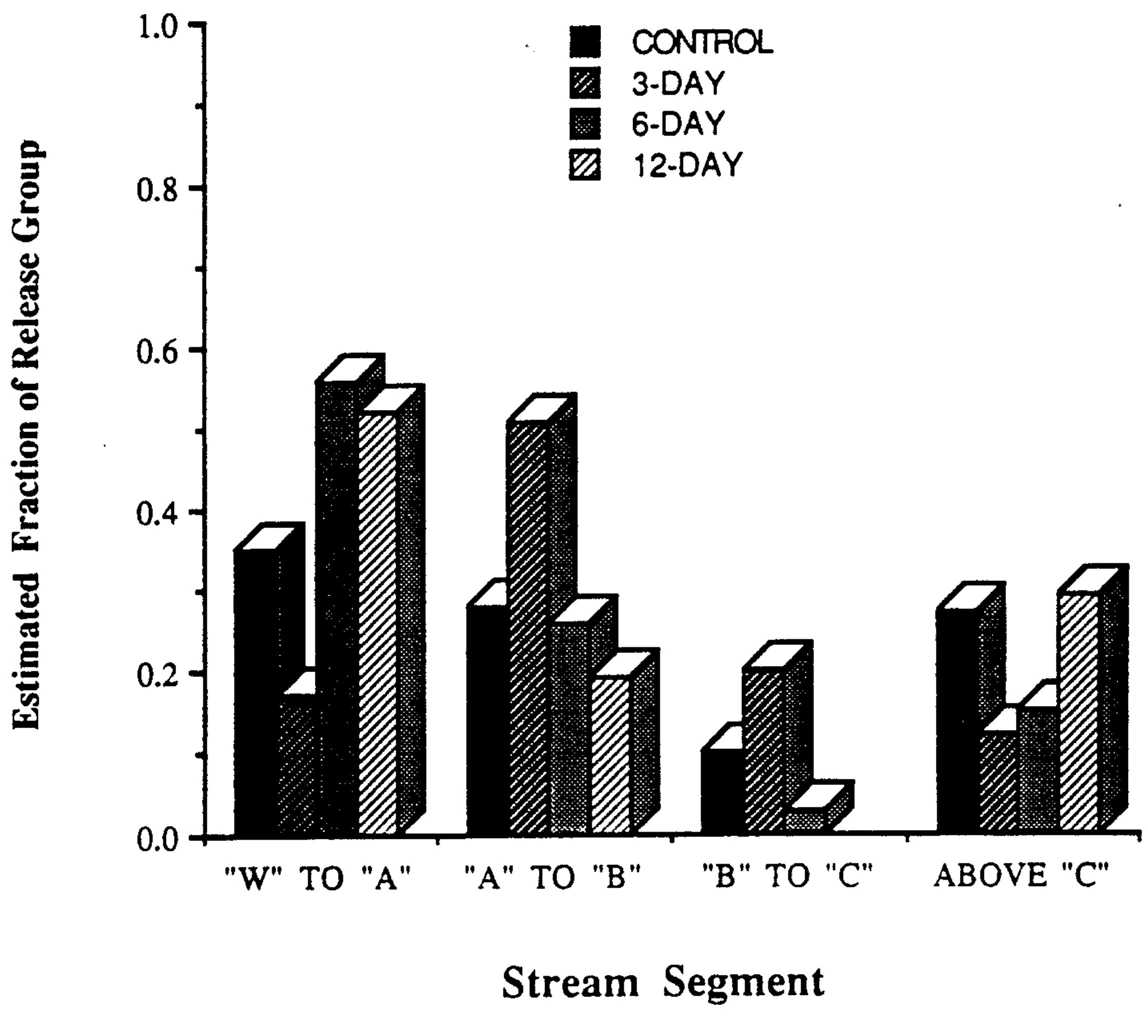

Figure 9. Distribution of grayling throughout the length of the study area at the end of the study as a function of delay.

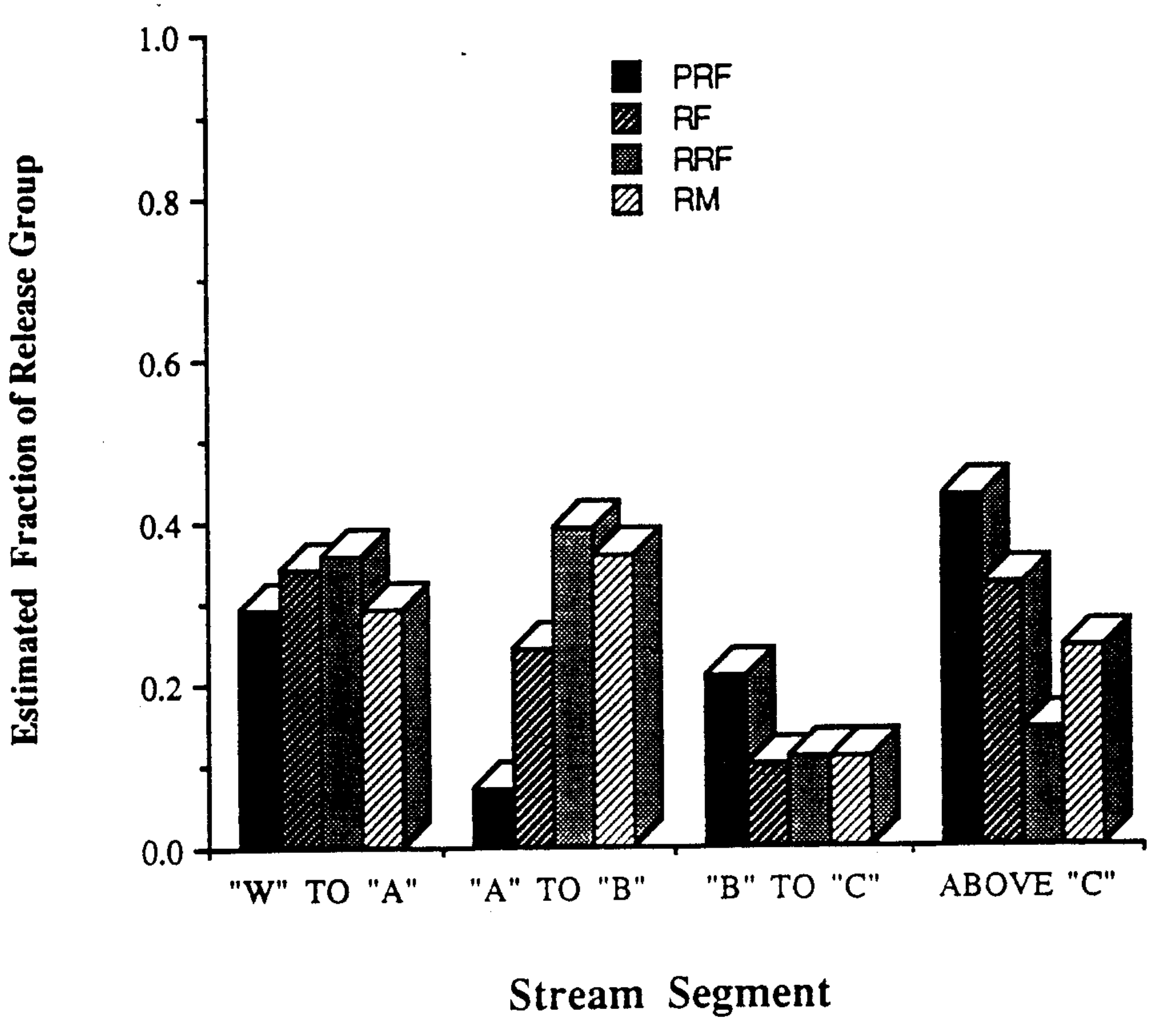

Figure 10. Distribution of grayling throughout the length of the study area at the end of the study as a function of sex and maturity at time of downstream release.

comparisons with exceptions that distributions of 12- and 6-day fish were not different, as were running-ripe and ripe-females.

The use of ridit analysis (Fleiss 1981) allowed spatial observation and a one-tailed comparison of delay and sex-maturity group distributions relative to each other. Comparison of mean ridit scores (Table 6 and Figure 11) showed that the probability of a randomly chosen 6-day delayed fish would be significantly downstream of similarly chosen 3-day fish (P=0.003) and control fish (P=0.009). Running-ripe females would more likely be downstream of partly-ripe females (P=0.08, Table 7 and Figure 12).

Table 6. Mean ridit probabilities for reference and comparison group distributions (by delay treatments) with associated differences and probabilities. Positive differences denote upstream distribution of comparison group relative to reference group; negative differences denote downstream distribution.

Comparison groups (Reference v. Comparison)	Ridit Score Probabilities: Reference 0.5	Comparison	Difference	P-value
6-day v. 12-day	0.5	0.548	0.048	0.46 N.S.
3-day v. 12-day	0.5	0.399	-0.101	0.13 N.S.
3-day v. 6-day	0.5	0.322	-0.178	0.003 **
control* v. 12-day	0.5	0.437	-0.063	0.23 N.S.
control v. 6-day	0.5	0.37	-0.13	0.009 **
control v. 3-day	0.5	0.52	0.02	0.17 N.S.
control v. pooled delays	0.5	0.446	-0.054	0.05 **

* 0-day delay
** statistically significant

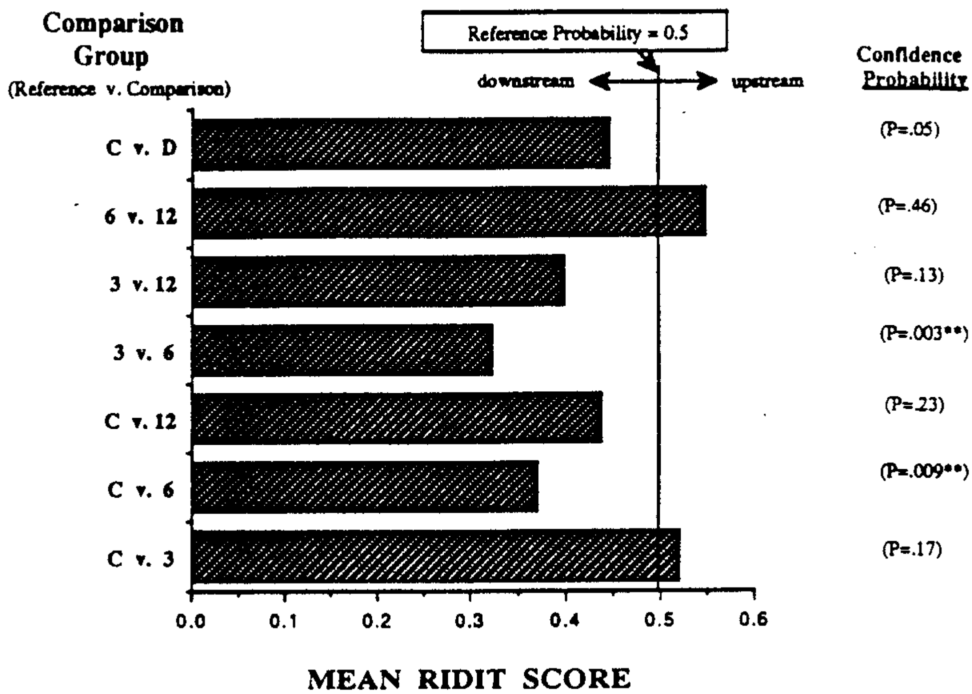

Figure 11. Pairwise comparisons of the upstream-downstream distribution of delay groups, relative to each other, using mean ridit probability scores.

Table 7. Mean ridit probabilities for reference and comparison group distributions (by sex and maturity at time of release downstream) with associated differences and probabilities. Positive differences denote upstream distribution of comparison group relative to reference group; negative differences denote downstream distribution.

Comparison groups (Reference v. Comparison)	**Ridit Score Probabilities** Reference 0.5	Comparison	Difference	P-value
males (pooled) v. females (pooled)	0.5	0.502	0.002	~1.0
running-ripe females v. ripe males	0.5	0.563	0.063	0.3
ripe females v. ripe males	0.5	0.49	-0.01	0.85
ripe females v. running ripe f's	0.5	0.431	-0.069	0.31
partly-ripe f's v. ripe males	0.5	0.396	-0.104	0.2
partly-ripe f's v. ripe females	0.5	0.42	-0.08	0.36
partly-ripe f's v. running ripe f's	0.5	0.34	-0.16	0.08

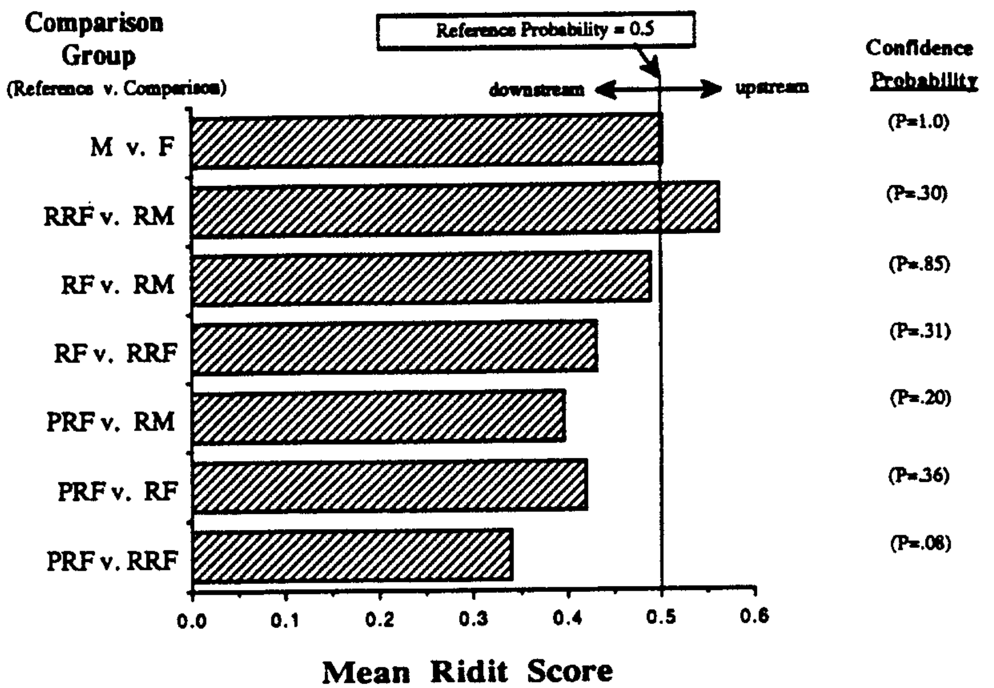

Figure 12. Pairwise comparisons of the upstream-downstream distribution of sex and maturity groups, relative to each other, using mean ridit probability scores.

Discussion

During the 1988 spring migration, adult grayling showed a high degree of difference between proportion of ripe males and females; about 74% of the males and 52% of the females were ripe upon initial interception at the weir. In 1987, when Fish Creek grayling were also captured during their spawning run a similar proportion of males were ripe, but only 5% of the females were ripe (R. McLean, ADFG, Fairbanks, personal communication); in the two years of observation, the chronology of female maturation varied greatly. Evaluation of grayling stocks for hatchery egg-takes in interior Alaska have demonstrated the need to allow females additional time in holding pens to reach the running-ripe status necessary for artificial fertilization (Parks et al. 1986) MacPhee and Watts (1976) found spawning runs to initially consist of high percentages of ripe males and low percentages of ripe females at the one interception point along Poplar Grove Creek, Alaska, in 1974 and 1975. They found a linear relation between the increasing mean daily water temperature and the fraction of daily captured female grayling that were ripe; within 9 days greater than 80% were ripe in 1974. Comparison of these data with that of a 1986 study (Behlke et al. 1988) showed a similar relationship: within 6 days, 47% of females checked were ripe; no fish were checked after 6 days. Correlation analysis of female fraction ripe against mean daily water temperature resulted in significant correlations (r=0.86) in each study.

Regression of mean daily water temperature against time during the 1974 and 1986 spawning runs, following breakup, resulted in similar rates of warming, approximately 0.6°C per day. Tilsworth and Travis (1986), who studied fish passage at Poplar Grove Creek in 1985, found nearly all adults ripe by the third day of a spawning run delay below a highway culvert. During that study the approximate warming rate was 1.25°C per day- double the rates of other Poplar Grove Creek migration studies. High water velocities delayed fish passage for 8 days in which an estimated 50% of the spawning run was removed by anglers.

High variation in female maturity during migration is also apparent in Fish Creek. Among females captured in 1987, 5% were ripe initially and 25% of the penned females showed additional ripening after a mean delay period of 6.6 days. In 1988, 52% of weir captured females were initially ripe and 50% of the penned females showed additional ripening after a mean delay of 6.4 days. Warming rates calculated for 1987 and 1988 in Fish Creek were 0.20°C and 0.26°C per day, but no significant difference was found between years. These rates were approximately one-third that of Poplar Grove. Explanations for the slower rate of warming may be differences in watershed area (110 km^2 v. 31 km^2), water content of the snowpack, climatic differences, presence of permafrost, or other topographical differences.

During the 1988 spawning run in Fish Creek, delayed females underwent substantial changes in state of maturation within the first 3 days of delay, and control (no-delay) females showed similar changes when examined after migrating 9 km upstream. Males showed much less change, and a significantly different pattern of maturation. A relation between condition of females and passage of time and temperature suggests that the timing and extent of delay is more critical in females than in males. The delay of some females resulted in maturation that would otherwise have occurred during further migration or while the fish were at upstream spawning areas. The changes in maturity status of delayed females (Figure 3) showed that, although spawning condition was advancing in many females, others were losing condition; egg loss or untimely spawning may have occurred during delay or between recapture sites. Some control and delayed fish failed to show signs of ripening until they were recaptured upstream later in the spawning run, indicating that some fish mature and spawn much later in the season than others. The presence of both young-of-the-year grayling and running-ripe females late in the study also corroborated the existence of early and late spawners in Fish Creek during 1988. We do not know if spawning was late because of delays created by our study.

The arrival of pre-spawning adults to spawning areas may not always be synchronized with sexual maturity. Ripe and unripe fish were present at site C by 13 May and spawning was first observed 17 May when the temperature was 5°C. Tack (1972) found nonspawning adult grayling in spawning areas at the outlet of Mineral Lake for 6 days before spawning; spawning began when the water temperature first reached 4°C. He attributed this condition to sub-optimal water temperatures for spawning; perhaps the time and temperature were necessary to mediate final maturation by females not yet ripe. Other investigators have also suggested that shifts in temperature mediate the final stages of female maturation (ovulation) in other species (Billard et al. 1981; Dodson et al. 1985; Morrison and Smith 1986; Beacham and Murray 1988) Within a species, some stocks of Pacific salmon vary greatly in gonadal maturation in relation to migration distance (McKeown 1984). Grayling, being salmonids, may vary similarly. Differences in migratory distance in different watershed populations may also create variation in rate of maturation. Until maturation of grayling are characterised under different stream warming patterns and differing length migrations are studied or compared in a similar manner, future recommendations on critical delay periods would need to be limited to watersheds and migration distances similar to those studied at Fish Creek.

Migratory performance

Migratory performance of delayed grayling may be depressed, as seen in comparison of the 3-day group to the control group. On the other hand, when we analyzed the data by release condition, running-ripe females showed a significantly higher migration rate than either ripe females or ripe males, suggesting greater urgency. The extremely low variance in migratory rate of running-ripe females, relative to all other groups, suggests that the urgency to migrate may overcome environmental controls over swimming (e.g. water temperatures and velocities). MacPhee and Watts (1976) found that ripe females were more successful in negotiating a 30.5-m culvert than their non-ripe counterparts later in the run. We found a high variability in transit times and rates in groups other than running-ripe females, much of which may be accounted for by temperature mediated control on swimming speed, other instream delays, multiple-event spawning, or entry into the lakes or ponds of the lower watershed. Overall, the Fish Creek grayling migration rate (0.196 km/hr; pooled average weir to site C) differed significantly from grayling in other grayling migration studies (0.037 km/hr, Tilsworth and Travis 1986; 0.04 km/hr, Behlke et al. 1988). Plausible explanations may be based on longer migrations of Fish Creek grayling, or perhaps lower average water velocities because of topographic differences. Methods to better study migratory rates over distances might use several physically different stream types, or migration studied over uniform stream sections of similar habitat to learn if migratory behavior changes according to habitat and thermal regimes.

Distribution of spawners

Final distributions of male and female grayling were dependent on delay treatment. The overall final distribution (Figure 9) showed an abundance of spawners in the lower watershed, and fewer spawners reaching the headwaters of the lake. The final distribution of females was significantly related to maturity status at release. Running-ripe females had a higher drop-out rate per kilometer traveled than partly-ripe females. Regression plots (Figures 7 and 8) indicated that a linear relation existed between distance upstream and the percentage of migrants continuing upstream. We do not know if the drop-out rate (1-9%/km) would be similar in watersheds of differing size and habitat type.

Ridit analysis (Table 6, Figure 11) showed that a randomly chosen 6-day grayling would migrate to a lesser extent than both control (no delay) and 3-day fish. In the 3-day versus 6-day comparison (reference group versus comparison group) the 3-day group has an 18% higher probability of migrating further than the 6-day group. Likewise, the control group has a 13% higher probability of migrating further than the 6-day group.

The pattern seen in figure 11 does not show a drop-out of the delay distributions inversely related to delay duration as one might expect if delay were detrimental :

12-day < 6-day < 3-day < Control

downstream----------------------------------upstream

Instead, interpretation of the mean ridit scores results in the distribution ordering :

6-day < 12-day < Control < 3-day

downstream--------------------------------upstream

Interpretation of this pattern was possible when sex and maturity composition data were added. Earlier analysis found no drop-out differences between male and females, and found significant effects when partly-ripe and running-ripe females were compared. It was logical to look at the relative abundance of females (partly-ripe/running-ripe) within the delay treatment groups ordered by ridit analysis:

0.2 < 0.50 < 0.58 < 1.0

6-day < 12-day < Control < 3-day

downstream--------------------------------upstream

The ordering of the delay group distributions is more related to the ratios of partly-ripe to running-ripe females, than the duration of delay. We can think of the partly-ripe females as an upstream push on streamwide distribution of females, and running-ripe females as a downstream pull, resisting migration upstream.

Maturity as affecting migration and distribution

State of maturity appears to create significant distributional differences among the females we monitored. Migrating in a running-ripe state may occur naturally on occasion but is not consistent with the common migration strategy that adults reach spawning areas in the correct physiological condition (Northcote 1978). The change from non-ripe to a running-ripe state (post-ovulation) in females may signal a commitment to spawn; our results indicate that the "drop-out" rate increases when this change occurs. However, a portion of females that were running-ripe upon release migrated to upstream areas (site C), and some still had eggs when they arrived there; possible causes are homing to natal sites, or learned behavior as a subadult. Tack (1980) found through mark-recapture that fidelity to a feeding stream a year or more after tagging exceeded 96%. The migration of grayling in Fish Creek showed indications of homing with the near-total avoidance of the runoff fed branch monitored by fyke trap at site D (Figure 1). This branch was colder on average, but its maximum temperature often exceeded that of the lake fed branch; yet it did not attract adult prespawning grayling theorized to seek warm areas. Northcote (1978) offers the idea that if a parental stock was successful in utilizing a particular site, then probably its offspring will find it suitable upon reaching maturity. It is likely that the lower-than-average snowfall during the previous winter accounted for the warmer temperatures seen during 1988, and likely that the shallow lake outlet area is predictably warmer with less variation from year to year; hence, more environmental stability might lead to its repeated use by spawners.

A remaining question is, "Do these delayed females released in a running-ripe state reach upstream areas with viable eggs?" Bry (1981) found that viability dropped significantly after gravid rainbow trout (*Oncorhynchus mykiss*, formerly *Salmo gairdneri*) were held 6 days past ovulation before artificial fertilization, and viability plummeted in eggs of females held 9 days. Sakai et al. (1975) investigated the over-ripening process of eggs with rainbow trout and found the percentage of hatching decreased and deformed and weak alevins increased in fish held past peak maturity. Extrapolation of these results to field studies on Arctic grayling would be regretable because unlike the laboratory studies, stream temperatures are not constant. No such information is yet available for grayling.

Conclusions

The longer delays caused females to ripen significantly, and those in running-ripe condition had high migration rates, yet on the average did not ascend as far as "less-ripe" females. The effects of reduced upstream migration and distributions could include the use of lower quality spawning habitat and underuse of available upstream habitat, and as a result, reduced recruitment. The potential for reduced spawning success is clearly greater when either high proportions of females are ripe upon arrival at a delaying structure, or rapid stream warming elicites sudden changes in maturity. Although a general goal of fisheries management is one of population stability, the delay of spawning runs such as those in Fish Creek may lead to population instability. Further studies should include other streams of differing sizes and types, the effect of stream warming upon maturation, and the effect of delay on egg viability under more natural conditions. Until such information is available for consideration, spawning runs by Arctic grayling should not be artificially delayed more than 3 days because (in Fish Creek):

1. most female grayling ripened in 3 days or less after entering their spawning stream, and coupled to this, females in spawning condition failed to migrate as far as their less-ripe counterparts.

2. ripe females lost maturity status while being delayed, even for only 3 days, and egg viability past peak maturity is not known for grayling.

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Appendix A. Spawning Run Timing and Weir Catches of Adult Grayling.

A weir was operated by the Alaska Department of Fish and Game to catch the entire spawning run of Arctic grayling in Fish Creek during May 1987 and May 1988.

In 1987 the weir operated during May 13-25 about 100 m upstream of the culvert at milepost 132.8 on the Denali Highway; a total of 1074 grayling were captured. The run was expected to consist of both randomly distributed sizes and sexes over time, and that the captured adults would be in a near-spawning condition, i.e. ripe. The number of adult sized-grayling captured decreased over the time the weir was in operation (Figure A-13). Of the total catch there were 301 male and 208 female grayling with fork lengths greater than 260 mm available for the delay study following capture (1987 delay study considered use of grayling ≥260mm.) Only 5% of the females and 26% of the males were near spawning condition when first captured. Cantwell residents suggested that a large portion of the spawning run had already ascended Fish Creek prior to deployment of the weir. High flows through the culvert may have influenced the size composition of the weir-caught grayling by allowing large fish to pass upstream earlier than smaller fish.

In 1988 the weir was in place about 100 m downstream of the culvert and fishing by May 5; different patterns were observed in the run timing. The weir was operated until May 30, and captured a total of 1753 grayling. The catch included many grayling ≤100 mm in fork length that were thought to be age 1 grayling (Figure A-14) Numbers of grayling ≥270 mm captured each day are shown in Figure A-15. It was apparent that there was an earlier and more gradual breakup than in 1987, which may have accounted for the earlier arrival of fish in 1988. The early presence of many untagged adults in upstream areas, after the weir was in place, indicated that the run timing was bimodal. In 1988 we captured 297 fish with fork

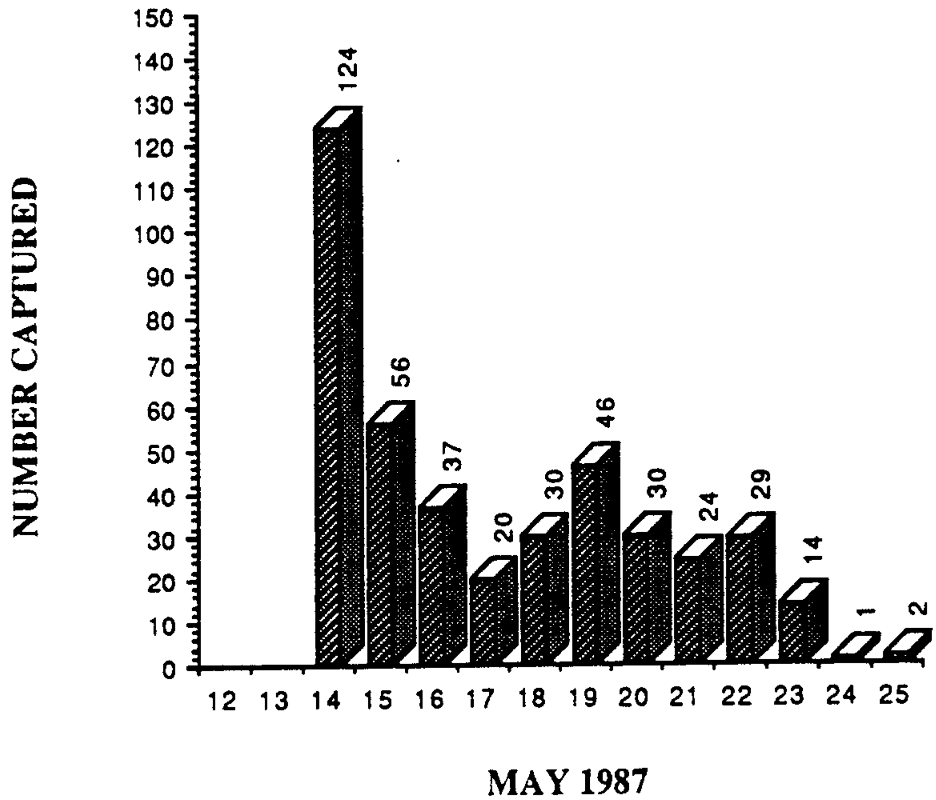


Figure A-13 Number of grayling (≥ 270 mm) captured by weir in Fish Creek during May1987.

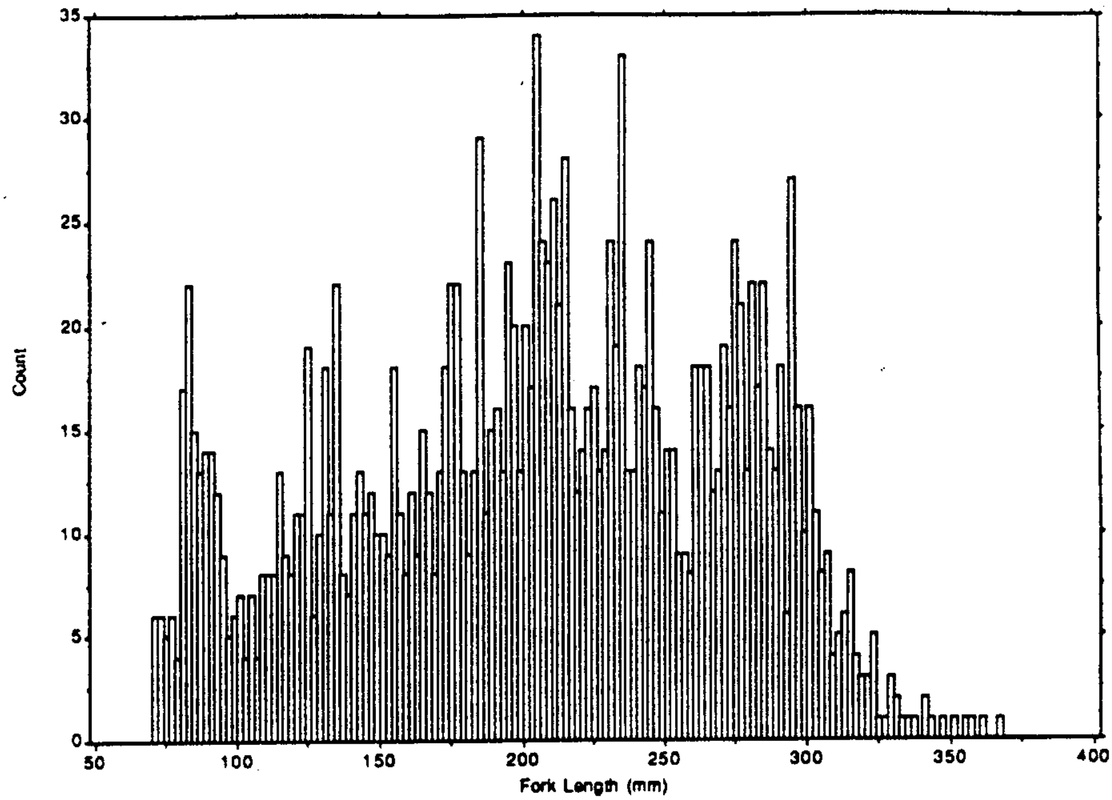


Figure A-14 Length frequency of grayling captured in downstream weir May 1988 (n=1753).

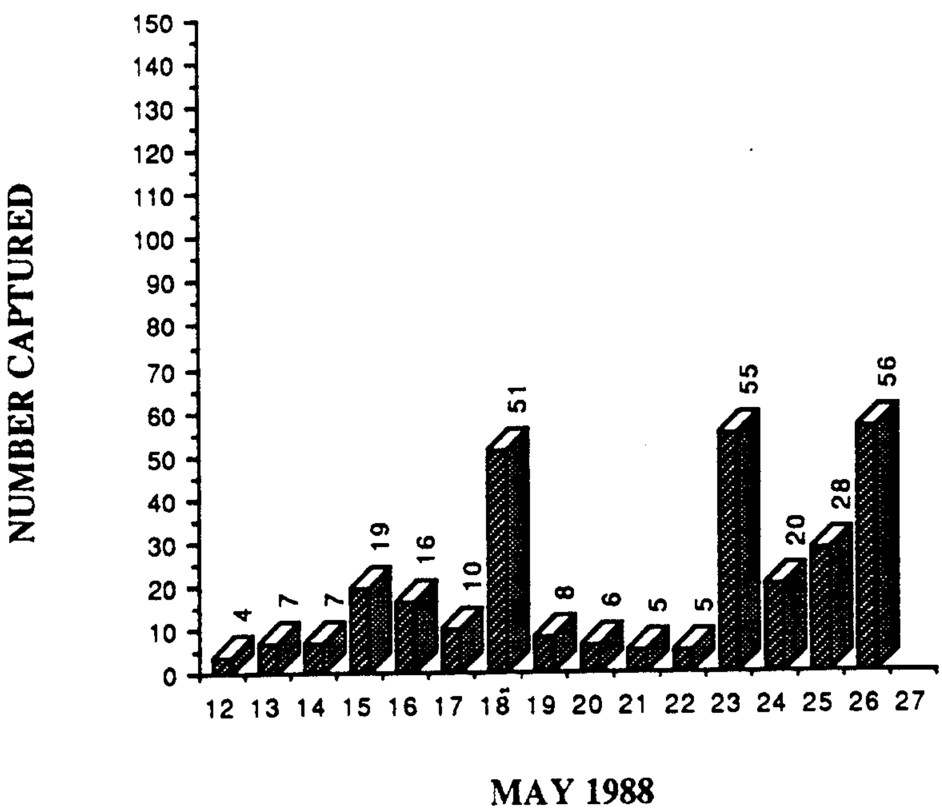


Figure A-15 Number of grayling (≥ 270 mm) captured by weir in Fish Creek during May 1988.

lengths greater than 270 mm at the weir, out of which there were 150 females and 145 males available for the study. Upon initial capture, approximately 52% of the females and 74% of the males were in near spawning condition- a much larger proportion than in 1987.

Appendix B. Fyke Trap Efficiency Estimation and Adjustments to Catch.

Although the fyke traps appeared to be fishing very effectively, tag recapture analysis showed that some fish tagged at the weir passed through one or more trapping sites without being captured. In order to draw conclusions about the resident distributions of fish throughout the watershed, fyke trap catches needed to be corrected for inefficiency, e.g. failure to capture all passing fish. This was accomplished for the site A fyke trap by:

1. Pooling all tag numbers that originated at the weir and caught at site A.
2. Pooling all tag numbers that originated at the weir caught at sites B, C, and D.
3. Estimating the proportion of tags that site A captured out of all weir tagged and released fish that were captured upstream of site A.
   (This was accomplished by cross referencing tag numbers; then the number of weir tags caught at site A was divided by the total number of weir tags caught above site A at sites B,C,D.)
4. The 95% binomial confidence interval for the proportion was calculated.
5. Catch was then adjusted through division by the efficiency point estimate and lower and upper endpoints of the efficiency interval estimate, yielding a point estimate of adjusted catch as well as its upper and lower limits.

We found that there were some differences among delay and sex/maturity group trap efficiencies and therefore it was necessary to calculate efficiencies for each delay group and sex/maturity release group at each recapture site. Efficiency was also calculated for each of the upstream traps in a similar manner with exception of Sites D (fish not used in distribution study) and site C. Site C's efficiency was based on a sample of spawning adults captured by dipnet in a tributary to the lakes- because the sample was small (28 tags total) only a single estimate could be generated (Table B-8). The efficiency estimates and resulting adjusted catches (by group and trapping site) were then used to determine upstream distributions

Table B-8. Fyke trap efficiency interval estimates and adjustments to catches for specific trapping sites and release groups.

		FYKE TRAP EFFICIENCY ESTIMATES			ESTIMATED ABUNDANCES OF TAGGED GRAYLING PASSING TRAPPING SITES		
site-group	Raw Catch	Lower	Midpoint	Upper	Lower E.P.	Midpoint	Upper E.P.
A-12+	6	0.237	0.414	0.609	10	15	25
A-6++	14	0.672	0.818	0.918	15	17	21
A-3+++	20	0.436	0.595	0.743	27	34	41
A-0++++	38	0.382	0.481	0.583	65	79	99
B-12	4	0.428	0.652	0.837	5	6	9
B-6	6	0.670	0.844	0.947	6	7	9
B-3	12	0.757	0.928	0.991	12	13	16
B-0	38	0.740	0.842	0.916	41	45	51
C-12	8	0.600	0.840	0.955	8	10	13
C-6	5	0.600	0.840	0.955	5	6	8
C-3	4	0.600	0.840	0.955	4	5	7
C-0	28	0.600	0.840	0.955	29	33	47
A-PRF*	2	0.043	0.200	0.481	4	10	14
A-RF**	12	0.275	0.444	0.622	19	27	41
A-RRF***	17	0.764	0.929	0.991	17	18	22
A-RM****	31	0.417	0.547	0.671	46	57	74
B-PRF	8	0.548	0.846	0.981	8	9	14
B-RF	14	0.630	0.821	0.939	15	17	22
B-RRF	6	0.586	0.833	0.984	6	7	10
B-RM	25	0.773	0.896	0.965	26	28	32
C-PRF	5	0.600	0.840	0.955	5	6	8
C-RF	11	0.600	0.840	0.955	12	13	18
C-RRF	3	0.600	0.840	0.955	3	4	5
C-RM	16	0.600	0.840	0.955	17	19	27

+ 12-day delay
++ 6-day delay
+++ 3-day delay
++++ 0-day delay (control)

* Partly-ripe females
** Ripe females
*** Running-ripe females
**** Ripe males

Appendix C. Fish Creek Water Temperature Measurement and Analysis.

In 1987, with a very limited number of water temperature measurements, we found that the lake-fed and runoff fed branches differed greatly in thermal regimes. The lake fed branch was always warmer, as much as 10°C warmer. In meeting with local townspeople we learned that early in the season grayling were not angled in the runoff fed branch, but were caught exclusively in the lake fed branch. It has been hypothesized that pre-spawning grayling will seek out the warmer stream areas to spawn in. During 1988 an attempt was made to carefully document thermal differences between the two branches, and the preferences of grayling for one branch over the other. A data logger was deployed with thermocouples located in the lake branch, the runoff branch, downstream of the confluence, and in ambient air. Temperature data was charted for the early part of the spawning run (Figure C-16 and C-17) and analyzed using comparison of the means (Z-test). Although temperature differences were not as great as in 1987, the lake-fed branch was significantly warmer than the runoff branch. Daily variation in water temperature of the lake-fed branch was less extreme; perhaps the lake-fed branch offers a more buffered thermal environment for egg development than the runoff fed branch.

Temperature measurements (hand held thermometers) were also made on an irregular basis at recapture sites A, B, and C (Figure C-18). Lake outlet water temperature (site C) was significantly greater than that of sites A and B (one-tailed students t-test). No significant differences were found between Sites A and B.

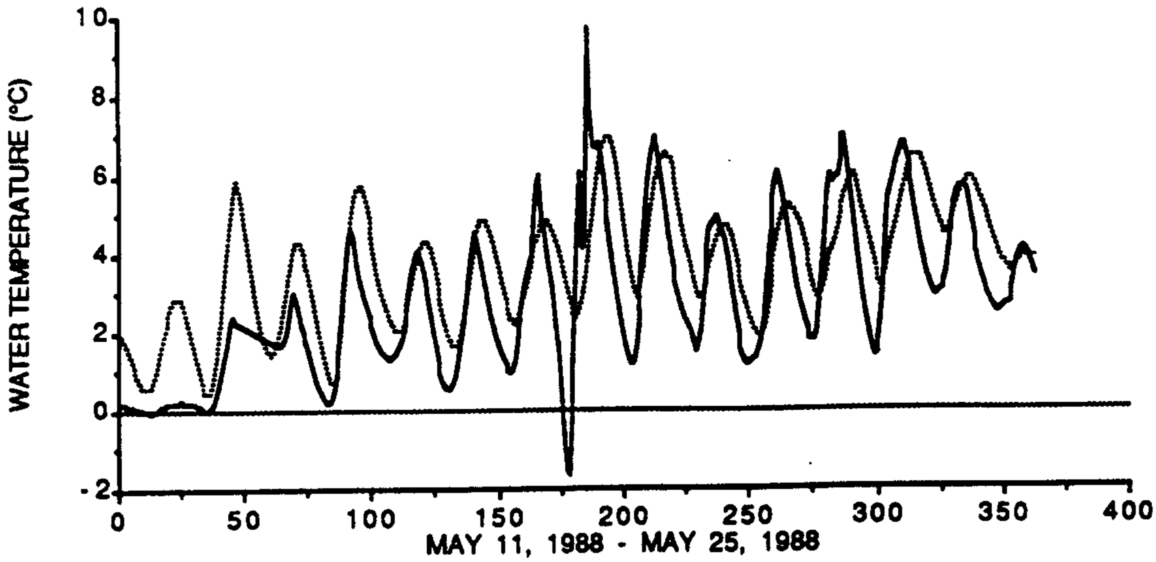


Figure C-16 Water temperature of lake (dashed line) and runoff fed (solid line) branches (sites B and D) during spawning run of grayling.

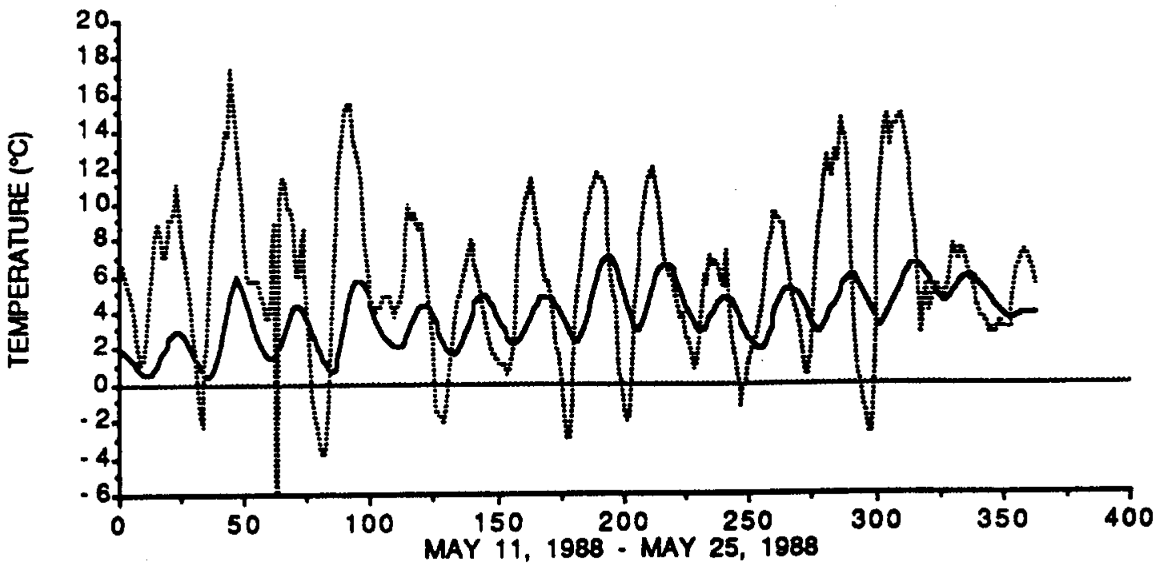
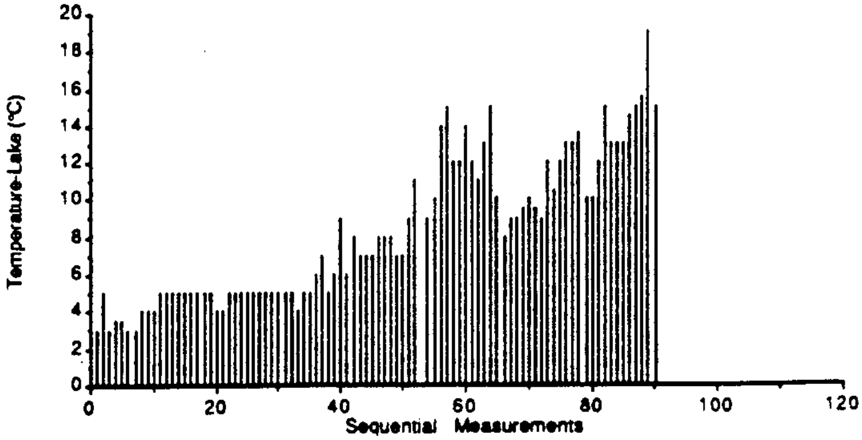
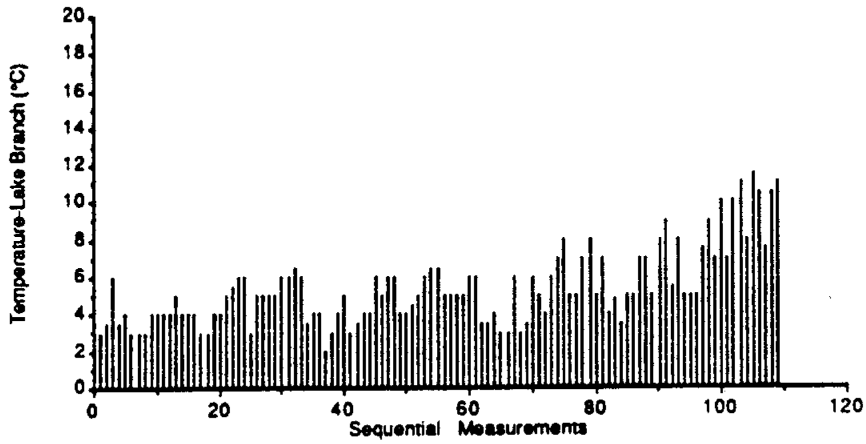


Figure C-17 Air temperature (dashed line) and lake fed branch water temperature (solid line) take at site B during spawning run of grayling.





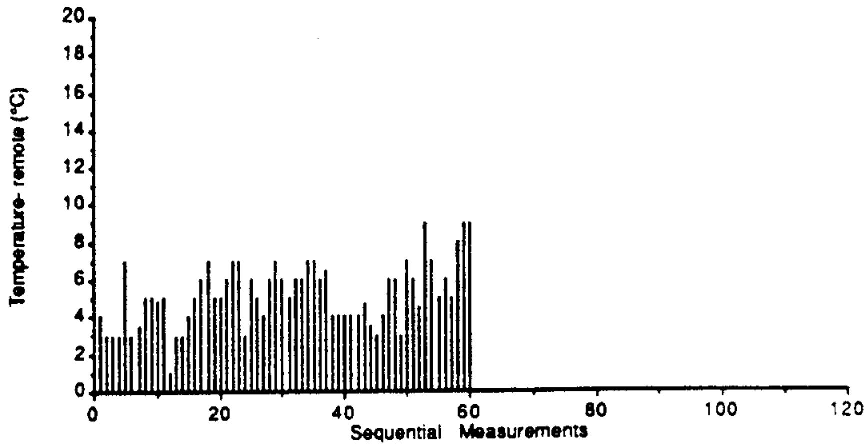


Figure C-18 Water temperatures taken at recapture sites C (top), B (middle), and A (bottom) with stream thermometer between May 13 and June 11, 1988.

Appendix D. Data collected on Adult Grayling used for Analysis of Upstream Distribution and Migration Rates.

Table D-9. Information on tagged adult grayling used in study of spawner distribution.

TAG NUMBER	TRAP LOCATION	CAPTURE DATE (MAY)	CAPTURE TIME	FORK LENGTH (mm)	WT. (g)	SEX/ MATURITY (CODED RANKING)	DELAY LENGTH
99	weir	14	1745	355	460	RM (ripe male)	3
783	weir	23	1610	331		RRF (running-ripe female)	3
560	weir	29	1045	324		RM	3
789	weir	23	1520	322	310	U (unknown sex)	3
951	weir	18	1300	321	378	RF (ripe female)	3
984	weir	20	1150	320	320	RM	3
992	weir	21	1530	317	290	U	3
791	weir	23	1520	315	350	RRF	3
943	weir	18	1150	314	324	RM	3
58	weir	16	1330	313	300	U	3
851	weir	23	1430	311		RRF	3
976	weir	19	1115	310	270	RM	3
37	weir	14	1300	305	290	RM	3
95	weir	14	1745	305	280	RM	3
938	weir	18	1136	302	282	RM	3
61	weir	17	1200	300	304	RF	3
995	weir	22	1100	300		RRF	3
49	weir	15	1240	299	300	F	3
580	weir	28	1030	298		U	3
930	weir	18	1100	298	264	PRF (partly-ripe female)	3
850	weir	23	1430	295		RM	3
79	weir	16	1330	294	255	RM	3
87	weir	14	1745	294	260	RM	3
57	weir	16	1330	293	263	RM	3
39	weir	14	1300	285	240	M (male)	3
781	weir	23	1610	285		RF	3
934	weir	18	1100	285	252	RM	3
569	weir	29	1045	284		RM	3
797	weir	23	1430	282		RM	3
955	weir	18	1300	282	238	RM	3
577	weir	28	1030	281		RM	3
777	weir	23	1610	281		RM	3
36	weir	14	1300	280	240	RM	3
959	weir	18	1400	280	242	RF	3
91	weir	14	1745	276	240	RF	3
581	weir	28	1030	275		U	3
849	weir	23	1430	275		U	3
963	weir	18	1400	275	200	U	3
988	weir	20	1150	275	198	U	3
947	weir	16	1300	273	220	U	3
14	weir	12	1130	273	206	R-M	3
82	weir	16	1330	350	317	RM	6
563	weir	29	1045	337		U	6
28	weir	14	1300	335	400	RM	6
788	weir	23	1520	329	339	RF	6
582	weir	28	1030	317		RF	6
572	weir	29	1045	313		U	6
46	weir	15	1240	310	308	RM	6
571	weir	29	1045	309		PSF = partly-spent female	6
928	weir	18	1100	304	310	RF	6
562	weir	29	1045	303		RM	6
25	weir	14	1300	300	294	U	6
45	weir	14	1300	300	300	F	6
66	weir	17	1300	300	286	U	6

Table D-9. (Continued)

TAG NUMBER	TRAP LOCATION	CAPTURE DATE (MAY)	CAPTURE TIME	FORK LENGTH (mm)	WT. (g)	SEX/ MATURITY (CODED RANKING)	DELAY LENGTH
55	weir	16	1330	296	266	F	6
579	weir	28	1030	296		RM	6
931	weir	18	1100	295	250	RM	6
977	weir	19	1115	295	274	PRF	6
948	weir	18	1300	294	280	PRF	6
956	weir	18	1400	294	276	RM	6
960	weir	18	1400	291	224	RM	6
59	weir	16	1330	290	265	F	6
94	weir	14	1745	285	260	RF	6
985	weir	20	1150	285	220	U	6
952	weir	18	1300	284	240	RM	6
73	weir	16	2300	282	224	U	6
77	weir	16	1330	282	220	RM	6
44	weir	14	1300	278	230	F	6
86	weir	14	1745	277	240	F	6
944	weir	18	1150	277	230	PRF	6
48	weir	14	1300	276	220	U	6
62	weir	17	1200	275	188	RM	6
935	weir	18	1100	275	230	PRF	6
981	weir	19	1115	275	200	RM	6
573	weir	28	1030	273		RF	6
90	weir	14	1745	272	200	RM	6
53	weir	15	1240	271	210	U	6
98	weir	14	1745	270	234	RF	6
939	weir	18	1136	270	200	U	6
16	weir	13	1215	277	230	U	6
982	weir	19	1115	367	454	RM	12
32	weir	14	1300	317	330	RM	12
26	weir	14	1300	315	320	M	12
40	weir	14	1300	313	300	RM	12
29	weir	14	1300	307	320	RM	12
61	weir	16	1330	305	314	RM	12
88	weir	14	1745	304	270	RM	12
990	weir	21	1100	302	260	U	12
67	weir	17	1300	300	284	RM	12
929	weir	18	1100	300	272	RM	12
965	weir	18	1420	300	300	RM	12
986	weir	20	1150	298	280	RM	12
24	weir	14	1010	295	320	U	12
83	weir	14	1745	295	260	RM	12
945	weir	18	1150	295	250	RM	12
76	weir	16	1330	290	248	RM	12
978	weir	19	1115	287	228	RM	12
941	weir	18	1136	286	258	PRF	12
31	weir	14	1300	285	240	RM	12
96	weir	14	1745	265	270	RF	12
63	weir	17	1200	284	250	U	12
936	weir	18	1136	283	240	U	12
949	weir	18	1300	282	250	RM	12
71	weir	17	1200	281	220	RM	12
846	weir	22	1100	280		RM	12
52	weir	15	1240	278	235	F	12
60	weir	16	1330	278	228	U	12
953	weir	18	1300	276	224	PRF	12
72	weir	16	2300	275	240	U	12
92	weir	14	1745	275	240	RF	12
962	weir	18	1400	273	220	RF	12
578	weir	28	1030	293		RM	O (control)
70	weir	17	1200	360	480	RM	O (control)
900	weir	23	1130	340		RRF	O (control)

Table D-9. (Continued)

TAG NUMBER	TRAP LOCATION	CAPTURE DATE (MAY)	CAPTURE TIME	FORK LENGTH (mm)	WT. (g)	SEX/ MATURITY (CODED RANKING)	DELAY LENGTH
710	weir	25	1100	332		U	O (control)
872	weir	23	1230	330		RM	O (control)
974	weir	18	1420	318	300	RM	O (control)
624	weir	26	1100	315		RM	O (control)
743	weir	24	1120	315		RM	O (control)
887	weir	23	1200	315		PRF	O (control)
885	weir	23	1200	312		RF	O (control)
883	weir	23	1200	307		RF	O (control)
80	weir	16	1330	304	280	RM	O (control)
536	weir	31	1200	300		F	O (control)
987	weir	20	1150	300	298	RF	O (control)
570	weir	29	1045	299		U	O (control)
85	weir	14	1745	298	250	RM	O (control)
654	weir	26	1100	297		RRF	O (control)
745	weir	24	1120	297		F	O (control)
867	weir	23	1230	297		RM	O (control)
871	weir	23	1230	297		RM	O (control)
876	weir	23	1200	296		RM	O (control)
940	weir	18	1136	296	250	RM	O (control)
51	weir	15	1240	295	275	RM	O (control)
93	weir	14	1745	295	250	RM	O (control)
704	weir	25	1100	295		U	O (control)
858	weir	23	1230	295		U	O (control)
859	weir	23	1230	295		RM	O (control)
888	weir	23	1200	295		PRF	O (control)
968	weir	18	1420	295	304	RF	O (control)
796	weir	23	1520	294		RRF	O (control)
875	weir	23	1200	294		RM	O (control)
879	weir	23	1200	294		RRF	O (control)
74	weir	16	1330	291	256	RF	O (control)
972	weir	18	1420	291	258	PRF	O (control)
731	weir	25	1000	290		RF	O (control)
751	weir	24	1120	290		U	O (control)
882	weir	23	1200	290		RF	O (control)
933	weir	18	1100	290	274	PRF	O (control)
970	weir	18	1420	290	264	PRF	O (control)
68	weir	17	1300	289	262	RF	O (control)
800	weir	23	1430	289		RRF	O (control)
896	weir	23	1130	289		RF	O (control)
873	weir	23	1230	288		RF	O (control)
966	weir	18	1420	288	276	PRF	O (control)
973	weir	18	1420	288	240	PRF	O (control)
698	weir	25	1100	287		PRF	O (control)
749	weir	24	1120	287		RRF	O (control)
946	weir	18	1300	287	235	RM	O (control)
34	weir	14	1300	286	240	RM	O (control)
721	weir	25	1000	286		U	O (control)
942	weir	18	1136	286	230	RM	O (control)
89	weir	14	1745	285	260	RF	O (control)
661	weir	26	1100	285		RM	O (control)
971	weir	18	1420	285	240	U	O (control)
631	weir	26	1100	284		RM	O (control)
877	weir	23	1200	284		RF	O (control)
658	weir	26	1100	283		RM	O (control)
860	weir	23	1230	282		RF	O (control)
862	weir	23	1230	282		RF	O (control)
870	weir	23	1230	282		U	O (control)
897	weir	23	1130	282		U	O (control)
653	weir	26	1100	281		RRF	O (control)
684	weir	25	1100	281		RF	O (control)

Table D-9. (Continued)

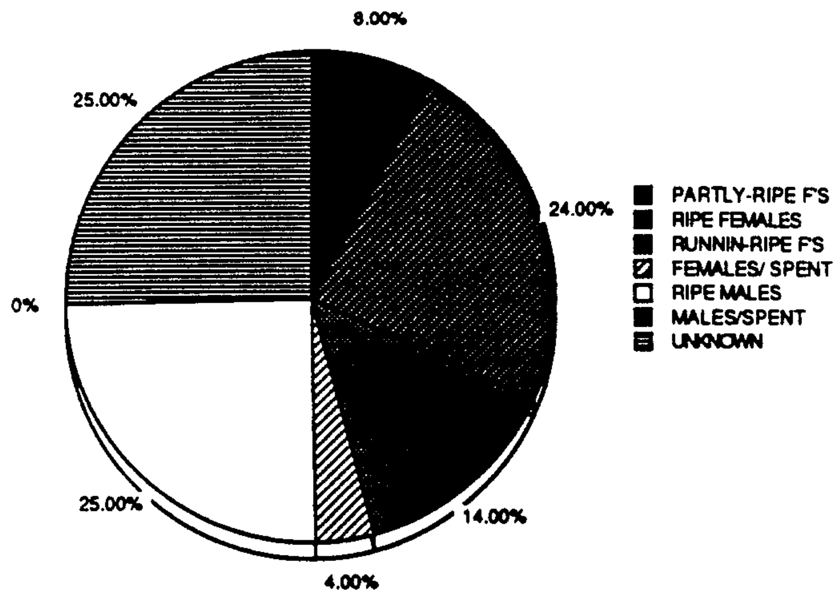
TAG NUMBER	TRAP LOCATION	CAPTURE DATE (MAY)	CAPTURE TIME	FORK LENGTH (mm)	WT. (g)	SEX/ MATURITY (CODED RANKING)	DELAY LENGTH
752	weir	24	1120	281		U	O (control)
950	weir	18	1300	281	228	PRF	O (control)
707	weir	25	1100	280		U	O (control)
742	weir	24	1120	280		RF	O (control)
884	weir	23	1200	280		RF	O (control)
979	weir	19	1115	280	240	U	O (control)
673	weir	26	900	279		RF	O (control)
620	weir	26	1100	278		U	O (control)
864	weir	23	1230	278		RRF	O (control)
534	weir	31	1200	277		U	O (control)
649	weir	26	1100	277		U	O (control)
676	weir	26	900	277		RF	O (control)
735	weir	24	1120	276		U	O (control)
937	weir	18	1136	276	252	PRF	O (control)
746	weir	24	1120	275		U	O (control)
958	weir	18	1400	275	250	RF	O (control)
967	weir	18	1420	275	216	RM	O (control)
994	weir	22	1100	275		RF	O (control)
861	weir	23	1230	274		U	O (control)
880	weir	23	1200	274		U	O (control)
617	weir	26	1100	273		U	O (control)
621	weir	26	1100	273		RRF	O (control)
961	weir	18	1400	273	220	RF	O (control)
633	weir	26	1100	272		RF	O (control)
726	weir	25	1000	272		RF	O (control)
561	weir	29	1045	271		RF	O (control)
863	weir	23	1230	271		RF	O (control)
646	weir	26	1100	270		RF	O (control)
666	weir	26	900	270		RF	O (control)
701	weir	25	1100	270		RM	O (control)
750	weir	24	1120	270		U	O (control)
969	weir	18	1420	270	190	RM	O (control)
983	weir	20	1100	270	220	U	O (control)
991	weir	21	1100	270	190	F	O (control)
22	weir	13	1540	323	318	R-M	O (control)
594	weir	26	1150	322		RRF	O (control)
605	weir	26	1150	297		RM	O (control)
607	weir	26	1150	297		U	O (control)
18	weir	13	1215	295	250	U	O (control)
601	weir	26	1150	294		RRF	O (control)
602	weir	26	1150	290		RM	O (control)
604	weir	26	1150	289		RRF	O (control)
12	weir	12	1130	288	245	F	O (control)
15	weir	12	1130	286	250	R-F	O (control)
23	weir	13	1620	285	270	U	O (control)
608	weir	26	1150	285		RRF	O (control)
596	weir	26	1150	280		RM	O (control)
598	weir	26	1150	278		RRF	O (control)
600	weir	26	1150	278		RRF	O (control)
21	weir	13	1215	277	208	U	O (control)
603	weir	26	1150	277		RM	O (control)
593	weir	26	1150	276		RRF	O (control)
591	weir	26	1150	275		U	O (control)
599	weir	26	1150	275		RRF	O (control)
592	weir	26	1150	273		U	O (control)
5	weir	10	1610	272	-	U	O (control)
954	weir	18	1300	271	192	U	O (control)
13	weir	12	1130	270	240	F	O (control)
606	weir	26	1150	270		RM	O (control)

Table D-10. Delay groups composition by sex and maturity at time of downstream release. Proportions are in parentheses.

RELEASE SEX AND MATURITY	DELAY DURATION 0-days*	3-days	6-days	12-days
partly-ripe females	10 (0.08)	2 (0.05)	1 (0.03)	1 (0.03)
ripe-females	29 (0.24)	6 (0.15)	3 (0.08)	3 (0.10)
running-ripe females	17 (0.14)	2 (0.05)	5 (0.13)	2 (0.06)
female/spent female	5 (0.04)	2 (0.05)	9 (0.23)	1 (0.03)
ripe males	31 (0.25)	20 (0.49)	12 (0.31)	15 (0.48)
males/spent males	0 (0.00)	3 (0.07)	3 (0.08)	5 (0.16)
unknown	30 (0.25)	6 (0.15)	6 (0.15)	4 (0.13)
total(s)	122 (1.00)	41 (1.00)	39 (1.00)	31 (1.00)

*control

CONTROL GROUP SEX AND MATURITY AT RELEASE (n=122)



3-DAY DELAY GROUP SEX AND MATURITY AT RELEASE (n=41)

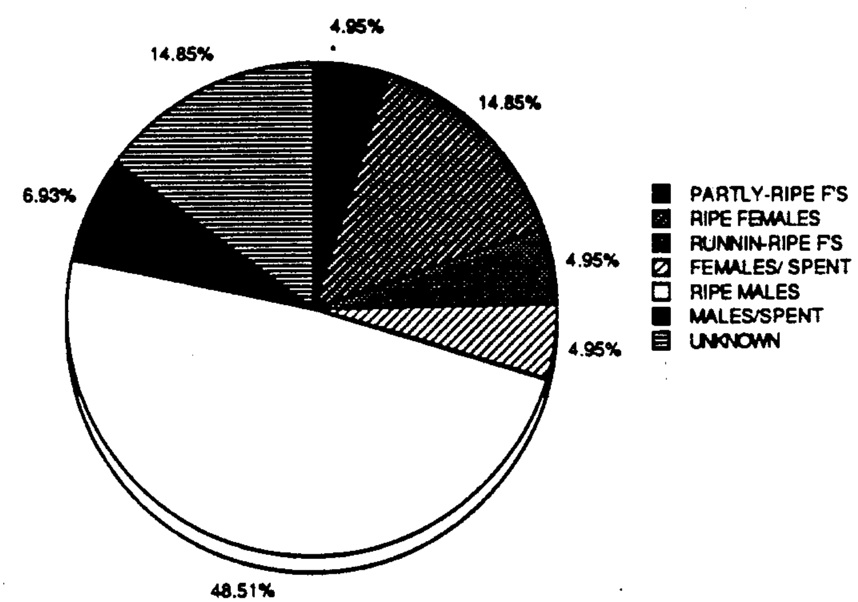
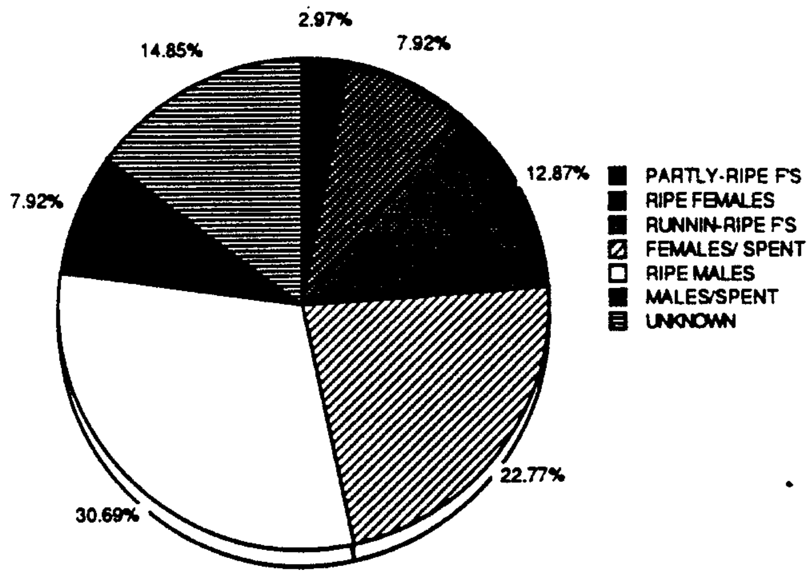


Figure D-19 Sex and maturity compositions within control group (top) and 3-day delay group (bottom) used in distribution analysis.

6-DAY DELAY GROUP SEX AND MATURITY AT RELEASE (n=39)



12-DAY DELAY GROUP SEX AND MATURITY AT RELEASE (n=31)

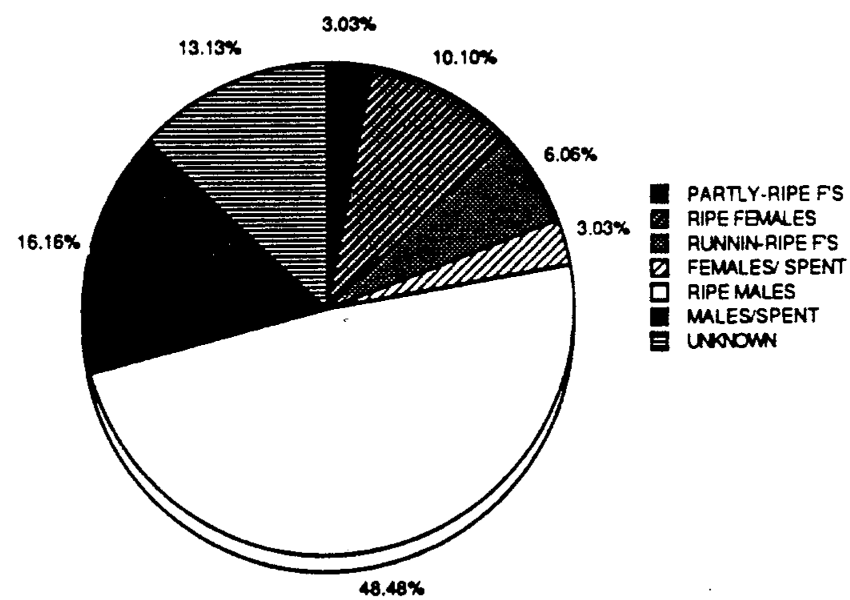


Figure D-20 Sex and maturity compositions within 6-day delay group (top) and 12-day delay group (bottom) used in distribution analysis.

Table D-11. Recaptured adult grayling by delay treatment at upstream sites A, B, C.

Site A (9km)				Site B (12km)				Site C (18km)			
tag number	length delay	site A sex/mat	weir sex/mat	tag number	length delay	site B sex/mat	weir sex/mat	tag number	length delay	site C sex/mat	weir sex/mat
37	3	RM	RM	36	3	RM	RM	36	3	RM	RM
39	3	M	RM	49	3	F	PRF	95	3	RM	RM
58	3	-	RM	58	3	-	RM	791	3	RRF	RF
79	3	RM	RM	61	3	RF	RF	934	3	RM	RM
87	3	RM	RM	87	3	RM	RM	44	6	F	-
95	3	RM	RM	91	3	RF	RF	46	6	RM	RM
560	3	RM	RM	95	3	RM	RM	55	6	F	F
777	3	RM	RM	99	3	RM	RM	931	6	RM	RM
778	3	RM	-	791	3	RRF	RF	944	6	PRF	RRF
791	3	RRF	RF	850	3	RM	RM	24	12		RM
797	3	RM	RM	934	3	RM	RM	63	12	-	RF
927	3	PRF	RRF	943	3	RM	RM	67	12	RM	RM
934	3	RM	RM	16	6		PRF	71	12	RM	-
943	3	RM	RM	46	6	RM	RM	72	12	-	-
947	3	-	F	55	6	F	F	88	12	RM	RM
951	3	RF	RRF	90	6	RM	RM	96	12	RF	PRF
955	3	RM	RM	931	6	RM	RM	936	12	-	-
980	3	PRF	RRF	977	6	PRF	RRF	12	C		F
984	3	RM	SM	24	12		RM	23	C		
992	3	-	-	26	12	M	RM	34	C		RM
16	6		PRF	88	12	RM	RM	51	C		RM
25	6		RF	941	12	PRF	RF	74	C		RF
44	6	F	-	74	C		RF	591	C		U
46	6	RM	RM	80	C		RM	603	C		RM
55	6	F	F	598	C		RRF	604	C		RRF
82	6	RM	MISSING	599	C		RRF	631	C		RM
90	6	RM	RM	603	C		RM	654	C		RRF
98	6	RF	RF	605	C		RM	658	C		RM
928	6	RF	RRF	621	C		RRF	666	C		RF
931	6	RM	RM	624	C		RM	673	C		RF
935	6	PRF	RRF	649	C		U	860	C		RF
939	6	-	-	684	C		RF	867	C		RM
944	6	PRF	RRF	701	C		RM	873	C		RF
977	6	PRF	RRF	707	C		U	887	C		PRF
24	12		RM	742	C		RF	946	C		RM
29	12	RM	RM	745	C		F	950	C		PRF
52	12	F	-	796	C		RRF	958	C		RF
54	12	F	-	860	C		RF	961	C		RF
88	12	RM	RM	864	C		RRF	968	C		RF
932	12	RM	RM	867	C		RM	969	C		RM
51	C		RM	871	C		RM	970	C		PRF
68	C		RF	873	C		RF	973	C		PRF
93	C		RM	884	C		RF	979	C		-
598	C		RRF	896	C		RF	983	C		U
599	C		RRF	933	C		PRF	987	C		RF
601	C		RRF	937	C		PRF				
603	C		RM	940	C		RM				
604	C		RRF	946	C		RM				
605	C		RM	950	C		PRF				
606	C		RM	961	C		RF				
607	C		U	966	C		PRF				
621	C		RRF	968	C		RF				
624	C		RM	969	C		RM				
653	C		RRF	970	C		PRF				

Table D-11. (Continued)

Site A (9km)				Site B (12km)				Site C (18km)			
tag number	length delay	site A sex/mat	weir sex/mat	tag number	length delay	site B sex/mat	weir sex/mat	tag number	length delay	site C sex/mat	weir sex/mat
654	C		RRF	971	C						
658	C		RM	973	C		PRF				
661	C		RM	974	C		RM				
726	C		RF	979	C		-				
731	C		RF	983	C		U				
735	C		U	987	C		RF				
742	C		RF								
743	C		RM								
745	C		F								
749	C		RRF								
796	C		RRF								
862	C		RF								
864	C		RRF								
867	C		RM								
871	C		RM								
873	C		RF								
880	C		U								
883	C		RF								
884	C		RF								
888	C		PRF								
896	C		RF								
942	C		RM								
979	C		-								
991	C		F								

Table D-12. Recaptured adult grayling by sex and maturity at time of downstream release at upstream sites A, B, C.

Site A (9km)				Site B (12km)				Site C (18km)			
tag number	length delay	site A sex/mat	weir sex/mat	tag number	length delay	site B sex/mat	weir sex/mat	tag number	length delay	site C sex/mat	weir sex/mat
778	3	RM	-	979	C		-	44	6	F	-
992	3	-	-	55	6	F	F	71	12	RM	-
44	6	F	-	745	C		F	72	12	-	-
939	6	-	-	49	3	F	PRF	936	12	-	-
52	12	F	-	16	6		PRF	979	C		-
54	12	F	-	933	C		PRF	55	6	F	F
979	C		-	937	C		PRF	12	C		F
947	3	-	F	950	C		PRF	96	12	RF	PRF
55	6	F	F	966	C		PRF	887	C		PRF
745	C		F	970	C		PRF	950	C		PRF
991	C		F	973	C		PRF	970	C		PRF
82	6	RM	MISSING	61	3	RF	RF	973	C		PRF
16	6		PRF	91	3	RF	RF	791	3	RRF	RF
888	C		PRF	791	3	RRF	RF	63	12	-	RF
791	3	RRF	RF	941	12	PRF	RF	74	C		RF
25	6		RF	74	C		RF	666	C		RF
96	6	RF	RF	684	C		RF	673	C		RF
68	C		RF	742	C		RF	860	C		RF
726	C		RF	860	C		RF	873	C		RF
731	C		RF	873	C		RF	958	C		RF
742	C		RF	884	C		RF	961	C		RF
862	C		RF	896	C		RF	968	C		RF
873	C		RF	961	C		RF	987	C		RF
883	C		RF	968	C		RF	36	3	RM	RM
884	C		RF	987	C		RF	95	3	RM	RM
898	C		RF	36	3	RM	RM	934	3	RM	RM
37	3	RM	RM	58	3	-	RM	46	6	RM	RM
39	3	M	RM	87	3	RM	RM	931	6	RM	RM
58	3	-	RM	95	3	RM	RM	24	12		RM
79	3	RM	RM	99	3	RM	RM	67	12	RM	RM
87	3	RM	RM	850	3	RM	RM	88	12	RM	RM
95	3	RM	RM	934	3	RM	RM	34	C		RM
560	3	RM	RM	943	3	RM	RM	51	C		RM
777	3	RM	RM	46	6	RM	RM	603	C		RM
797	3	RM	RM	90	6	RM	RM	631	C		RM
934	3	RM	RM	931	6	RM	RM	658	C		RM
943	3	RM	RM	24	12		RM	867	C		RM
955	3	RM	RM	26	12	M	RM	946	C		RM
46	6	RM	RM	88	12	RM	RM	969	C		RM
90	6	RM	RM	80	C		RM	944	6	PRF	RRF
931	6	RM	RM	603	C		RM	604	C		RRF
24	12		RM	605	C		RM	654	C		RRF
29	12	RM	RM	624	C		RM	591	C		U
88	12	RM	RM	701	C		RM	983	C		U
932	12	RM	RM	867	C		RM	23	C		
51	C		RM	871	C		RM				
93	C		RM	940	C		RM				
603	C		RM	946	C		RM				
605	C		RM	969	C		RM				
606	C		RM	974	C		RM				
624	C		RM	977	6	PRF	RRF				
658	C		RM	598	C		RRF				
661	C		RM	599	C		RRF				
743	C		RM	621	C		RRF				

Table D-12. (Continued)

Site A (9km)				Site B (12km)				Site C (18km)			
tag number	length delay	site A sex/mat	weir sex/mat	tag number	length delay	site B sex/mat	weir sex/mat	tag number	length delay	site C sex/mat	weir sex/mat
867	C		FM	796	C		RRF				
871	C		FM	864	C		RRF				
942	C		FM	649	C		U				
927	3	PRF	RRF	707	C		U				
951	3	RF	RRF	983	C		U				
980	3	PRF	RRF	971	C						
928	6	RF	RRF								
935	6	PRF	RRF								
944	6	PRF	RRF								
977	6	PRF	RRF								
598	C		RRF								
599	C		RRF								
601	C		RRF								
604	C		RRF								
621	C		RRF								
653	C		RRF								
654	C		RRF								
749	C		RRF								
796	C		RRF								
864	C		RRF								
984	3	RM	SM								
607	C		U								
735	C		U								
880	C		U								

Table D-13. Adult migration times (hrs) and rates (km/hr) from the weir site to recapture site A (9 km) by delay treatment.

Delay Treatment							
0-days*		3-days		6-days		12-days	
time	rate	time	rate	time	rate	time	rate
165	0.05	407	0.02	168.45	0.05	118.3	0.08
117.94	0.08	238.15	0.04	142.8	0.06	66.1	0.14
59.1	0.15	165.7	0.05	127.3	0.07	54	0.17
52.85	0.17	138	0.07	92	0.1	43.37	0.21
52.85	0.17	118	0.08	45	0.2	30	0.3
47	0.19	102.2	0.09	43.7	0.21	30	0.3
45	0.2	90.1	0.1	43	0.21	29.37	0.31
36.3	0.25	89	0.1	43	0.21	22	0.41
36.3	0.25	54.3	0.17	41	0.22	20.85	0.43
34	0.26	52.55	0.17	41	0.22		
31.1	0.29	49.3	0.18	39	0.23		
29.3	0.31	49.15	0.18	39	0.23		
28.8	0.31	48	0.19	35	0.26		
28.8	0.31	43	0.21	35	0.26		
28.8	0.31	41	0.22	34.85	0.26		
27.45	0.33	41	0.22	34	0.26		
27.45	0.33	40.45	0.22	29.45	0.31		
27.45	0.33	24	0.38	28.7	0.31		
26.95	0.33	22.45	0.4	28.7	0.31		
25	0.36	19.37	0.46	26.1	0.34		
23	0.39	19.15	0.47	25.15	0.36		
23	0.39	19	0.47	24	0.38		
23	0.39	17	0.53	23.15	0.39		
22.7	0.4	7	1.29	19.37	0.46		
22.5	0.4			19.37	0.46		
22.5	0.4			19	0.47		
22.5	0.4			17	0.53		
22.5	0.4			15.15	0.59		
22.5	0.4			15.15	0.59		
22.5	0.4						
22.5	0.4						
22.1	0.41						
22	0.41						
22	0.41						
22	0.41						
21.7	0.41						
21.7	0.41						
21.7	0.41						
7.9	1.14						
94	0.1						
23	0.39						
19.7	0.46						

Data summary

0-days*		3-days		6-days		12-days	
means=		means=		means=		means=	
35.1	0.341	78.9	0.263	44.63	0.295	45.9	0.261
medians=		medians=		medians=		medians=	
24	0.375	48.6	0.185	34.8	0.26	30	0.3
variances=		variances=		variances=		variances=	
810	0.027	7908	0.071	1475	0.021	962	0.014
n=		n=		n=		n=	
42	42	24	24	29	29	9	9

*control

Table D-14. Adult migration times (hrs) and rates (km/hr) from the weir site to recapture site A (9 km) by sex and maturity at time of release.

Sex and maturity at release					
Running-ripe females		Ripe females		Ripe males	
time	rate	time	rate	time	rate
17	0.53	22.45	0.4	52.55	0.17
24	0.38	22	0.41	28.8	0.31
22	0.41	92	0.1	27.45	0.33
34	0.26	36.3	0.25	41	0.22
19.7	0.46	165	0.05	49.3	0.18
41	0.22	22.7	0.4	17	0.53
30	0.3	21.7	0.41	54	0.17
27.45	0.33	45	0.2	102.2	0.09
34.65	0.26	25	0.36	49.15	0.18
31.1	0.29	22.1	0.41	43.37	0.21
22.5	0.4	41	0.22	118.3	0.08
19	0.47	36.3	0.25	22.5	0.4
22.5	0.4	168.45	0.05	21.7	0.41
28.8	0.31			21.7	0.41
27.45	0.33			52.85	0.17
34	0.26			28.7	0.31
22.5	0.4			20.85	0.43
28.7	0.31			52.85	0.17
45	0.2			7.9	1.14
22.5	0.4			407	0.02
23	0.39			19.15	0.47
				117.94	0.08
				138	0.07
				41	0.22
				24	0.38
				23	0.39
				23	0.39
				165.7	0.05
				48	0.19
				40.45	0.22
				23	0.39
				22.5	0.4
				127.3	0.07
				26.95	0.33
				22.7	0.4

Data summary					
Running-ripe females		Ripe females		Ripe males	
means=		means=		means=	
27.5	0.348	55.4	0.27	59.4	0.285
medians=		medians=		medians=	
27.4	0.33	36.3	0.25	40.5	0.22
variances=		variances=		variances=	
53	0.007	2801	0.02	5208	0.041
n=		n=		n=	
21	21	13	13	35	35

Appendix E. Use of Radio Telemetry to locate Spawning Areas

During the course of the 1987 and 1988 spawning migrations, adult grayling were fitted with internal radio transmitters in order that fish could be followed and located at spawning areas by airplane or on foot.

Tag weights were ≤2% of the adult body weight with frequencies in the 40 Mhz range. The tags were tied to the lower jaw with surgical nylon (attached to the tags) and slid down the esophagus into the stomach. Fish were held for a 15 minute recovery period before release in culvert's scour pool.

The tagged fish movements to upstream spawning areas were monitored on several occasions using a directional paddle antenna. Radio-tagged fish could be monitored at distances up to 20 m (65 feet). Most tagged fish were located within the lower reaches of Fish Creek, particularly within the lower ponds.