The biology and status of the Arctic grayling in Sunnyslope Canal, Montana
by Scott Alan Barndt

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Biological Sciences
Montana State University

Abstract:
The Arctic grayling (Thymallus arcticus) in Sunnyslope Canal were studied to examine factors limiting this population. Population characteristics, fish movements, winter habitat conditions, survival beneath ice cover, spawning, movements and habitat use of age-0 fry, and the presence of other species were examined. Results of this study confirm that Arctic grayling in the upper, 9 km of the Sunnyslope Canal represent a self-sustaining population that reproduces successfully in this unusual habitat, and that survives in remnant pools sustained by water leaking through the gates at Pishkun Reservoir and from springs along the canal during an extended, seven-month period when water does not flow through the canal. Reproduction within the canal was confirmed by a combination of observations: young fry were captured in drift nets 5.8 km downstream from the dam, but not at the outlet at Pishkun Reservoir; age-0 young were both visually observed and captured by seining within the canal; and spawning behavior was seen and developing embryos subsequently collected at a site within the canal. Fish seined in remnant pools, before pools froze over in autumn and then after ice-cover thawed in spring, indicated that overwinter survival was high (at least 75.4% through the winter of 1994-95, 89.5% in 1995-96). Dissolved oxygen concentrations remained high beneath ice cover, from 3.4 to 13.1 mg/l. Locations of recaptured fish and telemetry of radio-tagged fish indicated that they remained in the same pools through the winter. Recaptures of fish marked during the summer flow period and telemetry of radio-tagged fish indicated that fish moved upstream in the canal as water flows were reduced and then stopped at the end of the irrigation season. Concentrations of age-0 young within the upper part of the canal, including within the outlet tunnel beneath the dam, strongly suggested that they also move upstream as flows diminish. Telemetry of larger fish and downstream captures of age-0 and older fish suggested that many fish move down during summer flows and appear to be the source of grayling found in irrigation ditches diverted from the canal and in pools remaining at the lower drop structures after flows cease. During the summer flow period, canal grayling appeared to thrive, with good condition factors and among the fastest growth rates of any population in Montana. Success of grayling in the canal appears related to a combination of their ability to spawn under the flow and substrate conditions present, the ability of age-0 young to maintain position and survive within the upper canal, the tendency of both age-0 and older fish to move upstream as flows are reduced at the end of the irrigation season, their ability to overwinter in a few, remnant pools in the upper canal, the apparent habitat suitability of the canal for grayling during the summer flow period, and the apparent unsuitability of the canal for the principal, non-native potential competitors and predators present-rainbow trout (Onchorhyncus mykiss) and northern pike (Esox lucius). Numbers of fish (not including early age-0 grayling) remained low throughout the two-year study period, with about 62 to 120 estimated present from spring of 1995 to spring 1996. The loss of thousands of age-0 fish into the reservoir in fall 1994 during repair work at the dam, and continuing, apparently natural, downstream loss of fish have contributed to continuing low numbers, but other factors limiting the population are not known.

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Scott Alan Barndt

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

The Arctic grayling (*Thymallus arcticus*) in Sunnyslope Canal were studied to examine factors limiting this population. Population characteristics, fish movements, winter habitat conditions, survival beneath ice cover, spawning, movements and habitat use of age-0 fry, and the presence of other species were examined. Results of this study confirm that Arctic grayling in the upper, 9 km of the Sunnyslope Canal represent a self-sustaining population that reproduces successfully in this unusual habitat, and that survives in remnant pools sustained by water leaking through the gates at Pishkun Reservoir and from springs along the canal during an extended, seven-month period when water does not flow through the canal. Reproduction within the canal was confirmed by a combination of observations: young fry were captured in drift nets 5.8 km downstream from the dam, but not at the outlet at Pishkun Reservoir; age-0 young were both visually observed and captured by seining within the canal; and spawning behavior was seen and developing embryos subsequently collected at a site within the canal. Fish seined in remnant pools, before pools froze over in autumn and then after ice-cover thawed in spring, indicated that overwinter survival was high (at least 75.4% through the winter of 1994-95, 89.5% in 1995-96). Dissolved oxygen concentrations remained high beneath ice cover, from 3.4 to 13.1 mg/l. Locations of recaptured fish and telemetry of radio-tagged fish indicated that they remained in the same pools through the winter. Recaptures of fish marked during the summer flow period and telemetry of radio-tagged fish indicated that fish moved upstream in the canal as water flows were reduced and then stopped at the end of the irrigation season. Concentrations of age-0 young within the upper part of the canal, including within the outlet tunnel beneath the dam, strongly suggested that they also move upstream as flows diminish. Telemetry of larger fish and downstream captures of age-0 and older fish suggested that many fish move down during summer flows and appear to be the source of grayling found in irrigation ditches diverted from the canal and in pools remaining at the lower drop structures after flows cease. During the summer flow period, canal grayling appeared to thrive, with good condition factors and among the fastest growth rates of any population in Montana. Success of grayling in the canal appears related to a combination of their ability to spawn under the flow and substrate conditions present, the ability of age-0 young to maintain position and survive within the upper canal, the tendency of both age-0 and older fish to move upstream as flows are reduced at the end of the irrigation season, their ability to overwinter in a few, remnant pools in the upper canal, the apparent habitat suitability of the canal for grayling during the summer flow period, and the apparent unsuitability of the canal for the principal, non-native potential competitors and predators present-rainbow trout (*Onchorhyncus mykiss*) and northern pike (*Esox lucius)*. Numbers of fish (not including early age-0 grayling) remained low throughout the two-year study period, with about 62 to 120 estimated present from spring of 1995 to spring 1996. The loss of thousands of age-0 fish into the reservoir in fall 1994 during repair work at the dam, and continuing, apparently natural, downstream loss of fish have contributed to continuing low numbers, but other factors limiting the population are not known.

INTRODUCTION

Historically, relict populations of Arctic grayling (Thymallus arcticus) (hereafter interchangeably referred to as "Arctic grayling" or "grayling") occurred in two regions within the lower 48 states of North America, within the present states of Michigan and Montana. These populations were geographically isolated as the southernmost populations of Arctic grayling by the Wisconsin glaciation, and both have undergone severe declines within the last century. The Michigan population became extinct by 1936, and the Montana populations have declined until the species persists in its native habitat only in the Big Hole River and Red Rock Lakes (Vincent 1962, Kaya 1992). Both of these populations are reduced from their former numbers. The Big Hole population retains the important distinction of being the only fluvial (entirely riverine) population remaining in the lower 48 states. This is a change from historic grayling distribution in Montana, as fluvial grayling were once widespread and locally common in the upper Missouri River drainage above the Great Falls whereas the Red Rock Lakes (and possibly nearby Elk Lake) contained the only adfluvial (stream spawning, lake dwelling) population in the state. In contrast to fluvial populations, lacustrine populations have become more common by stocking mountain lakes, both in Montana and other states (Kaya 1990).

The decline of the Arctic grayling in its native habitat is attributed to three factors: (1) degradation of habitat, especially by dewatering for irrigation; (2) interactions with non-native salmonids; and (3) overharvest (Vincent 1962, Kaya 1992). Recent studies have focused on determining important factors limiting native fluvial grayling (i.e., Magee and Byorth 1994, Jeanes 1996). Such studies could have important applications to current recovery and reintroduction efforts.

A population of Arctic grayling located in an unusual habitat, the Sun River Slope Canal (Sunnyslope Canal), offered a unique opportunity to study factors which can affect the species. In 1971, Montana Department of Fish, Wildlife and Parks (FWP) biologist Bill Hill determined that Arctic grayling were present in the Sunnyslope Canal. This canal begins at the dam forming Pishkun Reservoir, and these fish occupy a fluvial habitat, at least during the four to five month irrigation season. During this period, the canal carries up to 47.5 cubic meters per second (m^3/s) or about 1680 cubic feet per second (cfs). During the remaining seven months, the canal is completely dewatered, with the exception of intermittent pools extending for about 5.8 km from the dam, and isolated pools at the base of concrete "drop structures" further downstream.

Arctic grayling were stocked in Pishkun Reservoir at least seven times in 1937, 1939, 1942 and 1943 (Everett 1986, Hill 1988, Kaya 1990). Records do not clearly indicate the source of these grayling but they likely originated from Madison River/Ennis Reservoir stocks (Everett 1986, Kaya 1990). Grayling subsequently became established in Sunnyslope Canal apparently from passage through the outlet of fish from these stockings, or their progeny. Some people report the presence of grayling in the canal since the 1940's (L. Vincent, Greenfields Irrigation District (GID), pers. comm.), and they have certainly been present since 1971, when Hill observed their presence. Arctic grayling apparently no longer exist in the reservoir, as the last reported catches of grayling were in 1971 and 1981 (Hill pers. comm.). Grayling in the canal have attracted some angler interest. In the past, anglers reportedly lined up below the reservoir outlet "shoulder-to-shoulder" to catch grayling (T. Tabor pers. comm.) and would "fill buckets" with their catch (L. Vincent pers. comm.).

The Sunnyslope Canal Arctic grayling are genetically distinct from all other Montana grayling populations (Everett 1986, Leary 1990). Despite their likely derivation from Madison River/Ennis Reservoir stock, as well their relatively short existence in the canal, Everett found that the Sunnyslope Canal population shows significant separation from both Red Rock Lake stocks and stocks descendent from the Madison River/Ennis Reservoir population (Everett 1986). Further, Sunnyslope grayling show similar separation from the Big Hole River population (Figure 1).

This present study was initiated in 1994 to determine the conditions under which this population persists within the unusual environment of this seasonally intermittent canal. The purpose of the study was to determine whether there is a self-sustaining population of Arctic grayling in Sunnyslope Canal, adapted to inhabiting the canal and reproducing during summer flow and surviving non-flow conditions, including during winter. This hypothesis was tested by examining:

(1) population abundance, age-size distribution, and individual growth rates;

(2) fish movements, during flow and after;

(3) winter habitat conditions and survival of grayling beneath ice cover;

(4) spawning times, substrates, and locations; and

(5) distribution, movement, and habitat use of age-0 fry and juveniles.

(6) presence of potential competing species.

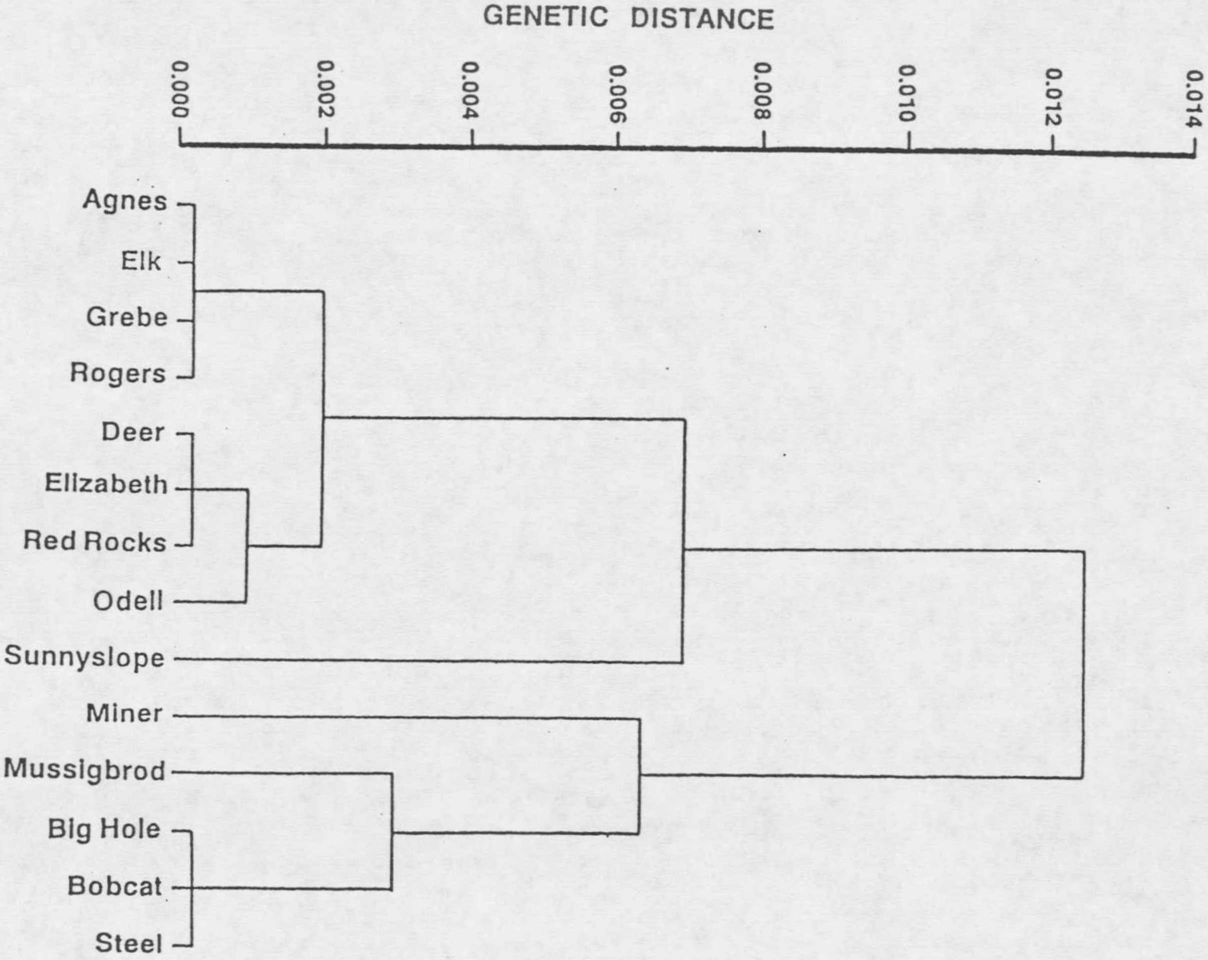

Figure 1. Dendrogram produced by cluster analysis of Nei's genetic distance based on information from 39 protein loci analyzed in Montana and Wyoming Arctic grayling populations (reproduced from Leary 1990).

STUDY SITE DESCRIPTION

Sunnyslope Canal is part of the Sun River Project, constructed by the United States Bureau of Reclamation, and administered by the Greenfields Irrigation District (GID). The canal originates at Pishkun Reservoir (elevation 1341 m) near the Rocky Mountain Front, west of Highway 287 between Choteau and Augusta, Montana (Figure 2). The canal and Pishkun Reservoir are physically separated by a steel, 2.5 cm mesh fish screen located on the reservoir side of the outlet. Pishkun Reservoir is filled by water diverted from the Sun River and transported through Pishkun Supply Canal (Figure 2).

Sunnyslope Canal is the major source of water for the Fairfield bench, irrigating over 32,376 hectares (ha) (about 80,000 acres) of agricultural land. Flow usually begins in early May and continues until early September. At full discharge, the canal carries over 47 m^3/s; upon cessation of flow, nearly the entire canal goes dry except for the upper 5.8 km immediately below the reservoir. In these 5.8 km, a small flow of water (< 0.06 m^3/s) from gate seepage and springs sustains 13 pools which persist until onset of flow the following May and provide overwintering habitat for grayling. Additionally, a series of concrete flumes ('drops') starting about 50 km downstream (Table 1, Figure 3) retain water in the settling pools at their bases; some of these also maintain fish overwinter. These drops are impassable to upstream movement by fish. Excess water not used in irrigation drains into Muddy Creek to the north and east, and into the Sun River to the south (Figure 2). The first potential barrier to upstream movement is a 1.6 km concrete-lined section of canal 9 km below the reservoir.

Table 1. Major physical features on Sunnyslope Canal and their distance downstream from Pishkun Reservoir.

Feature	Distance (km)
Dam	0
Boadle Bridge	5.8
Highway 287	19.0
Upper Turnbull drop	50.0
Lower Turnbull drop	52.8
9-foot drop	54.7
A (Fairfield) drop	60.6

Sunnyslope Canal represents very unnatural habitat. The canal flows through porous glacial till, which results in the rapid dessication of all pools not fed by seepage through the reservoir gates or by springs after discharges end. The channel bottom is kept free of flow impeding, and potential cover forming, objects such as woody debris or large rocks. Vegetation is sparse on the banks of the canal, and consists mostly of a variety of grasses.

During flow conditions, the canal best represents a glide or run habitat type because of its uniform, trapezoidal channel. A small area (<5%) of backwater habitat, as defined by Bisson et al. (1982), is present along canal margins. However, at higher discharges (over 30 m^3/s) backwaters form well beyond the canal margins and may represent 10% of the habitat in the upper 5.8 km. Thalweg water depths during flow conditions range from 1 to 3.5 m depending on discharge and location.

When flow ends, habitat in the upper 5.8 km consists of 1% riffles, 14% pools (lateral scour pools except for a pool in the concrete tunnel

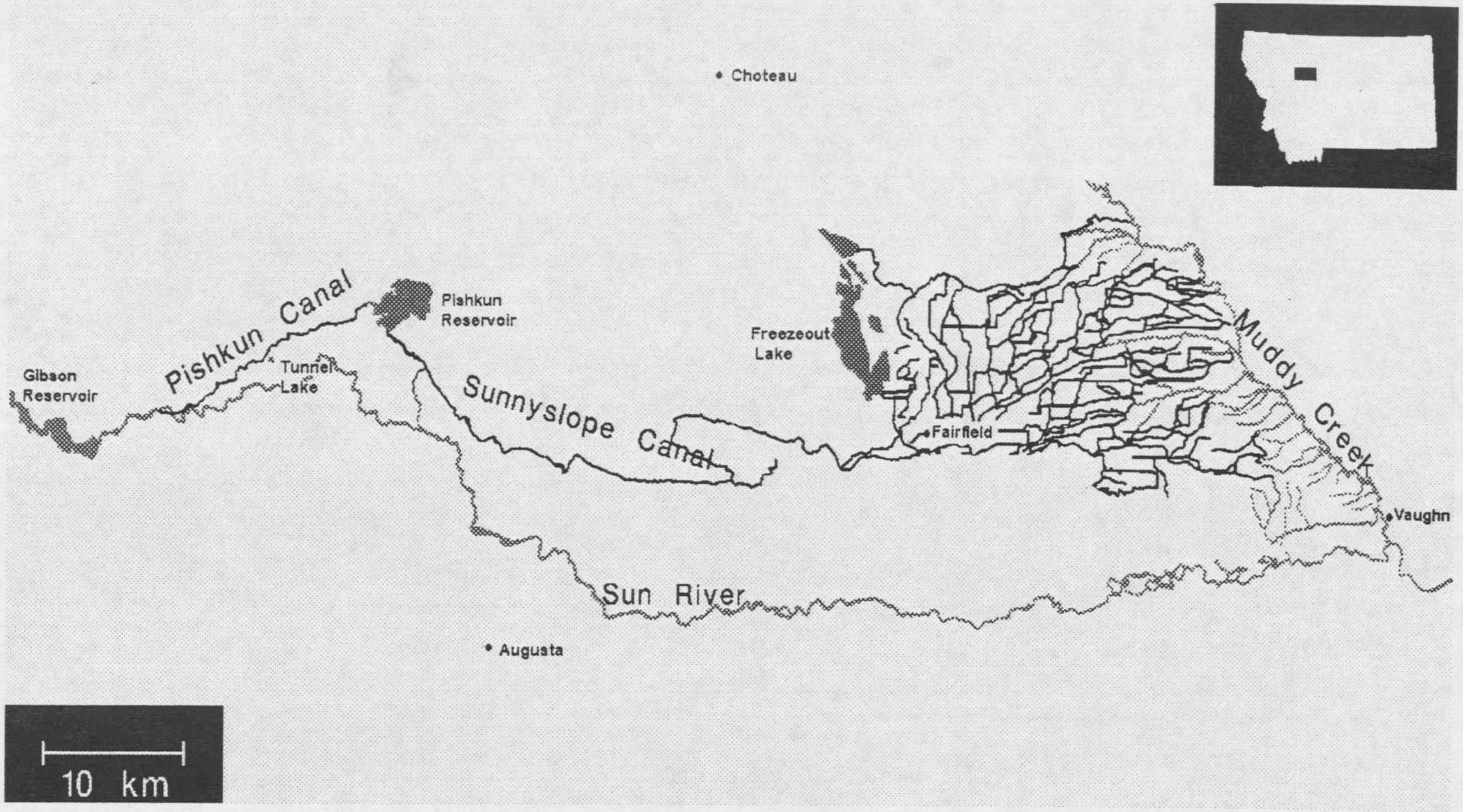

Figure 2. Watershed map of Greenfields Irrigation Project, from the Pishkun Supply Canal to discharge into the Sun River and Muddy Creek.

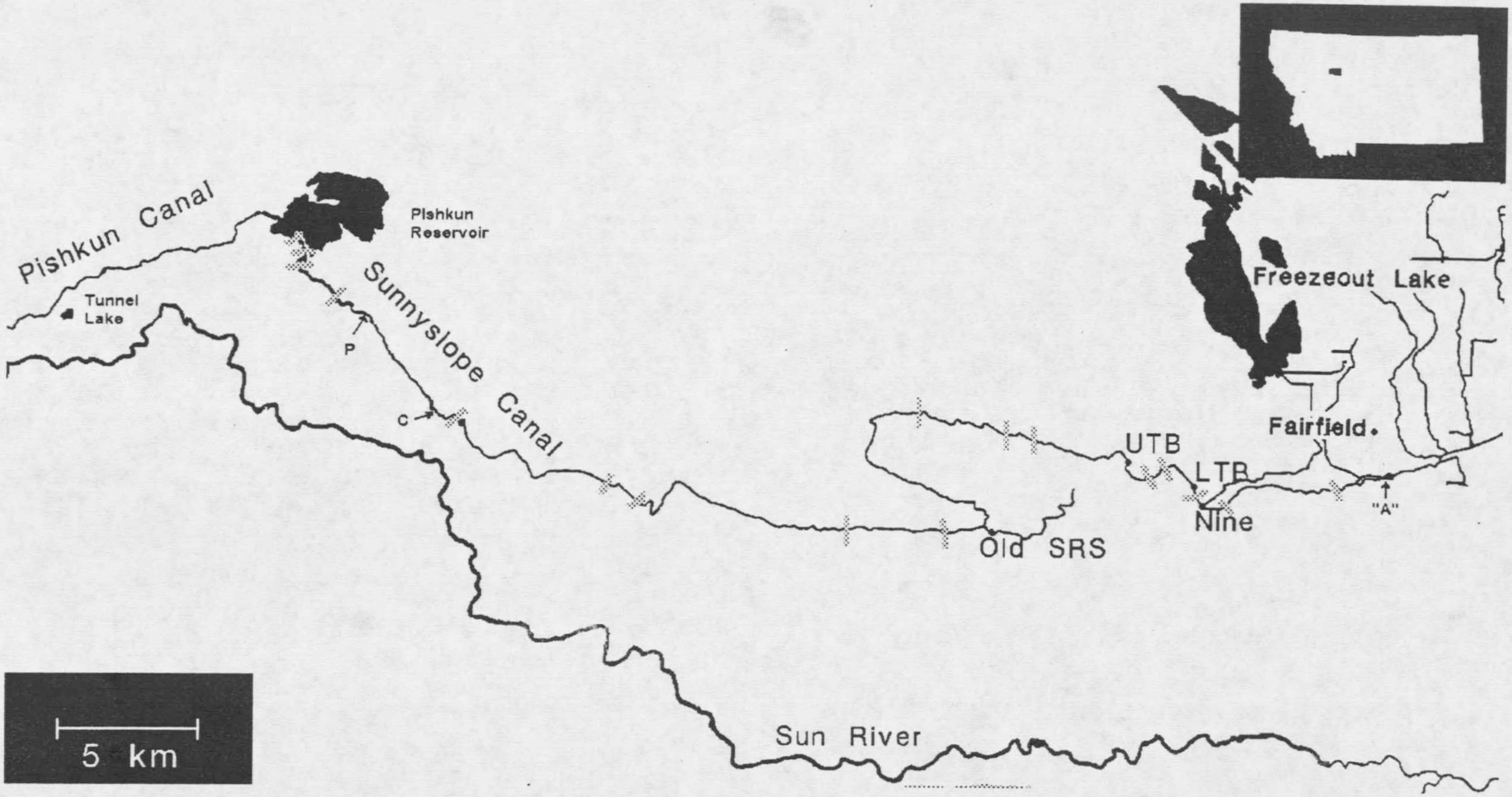

Figure 3. Watershed map of the Sunnyslope Canal study area from Pishkun Reservoir to Fairfield, MT, showing five drop structures (Old SRS, UTB, LTB, Nine, "A") and 17 fry survey transects (short gray stippled lines bissecting canal). The C denotes the beginning of concrete lining which is the first obstacle to upstream movement of grayling. The P shows the downstream extent of post-flow habitat.

beneath the dam closing Pishkun Reservoir), and 85% runs (habitat types from Bisson et al. 1982). During extended freezing conditions, ice formation is complete in riffles and shallower runs.

METHODS

Canal Flow and Water Quality

Physical habitat characteristics were measured during summer flow conditions to evaluate potential limiting factors to grayling during this period. Temperatures were measured on any visit to the canal, using a laboratory-grade mercury thermometer. Temperatures taken in the summer of 1995 were taken in mid-afternoon to evaluate higher daily temperature. Also in summer of 1995, pH, dissolved oxygen, and alkalinity were measured every 2 or 3 weeks with a Hach water quality kit. Conductivity readings were taken with a YSI 3000 TLC conductivity meter concurrent with other water quality measurements. Canal discharges were obtained from GID.

Capture and Analysis Techniques

Abundance, age-size distributions, individual growth rates, and movements were determined from grayling usually captured by seining, although trap nets (1.3 cm mesh), experimental gill nets, backpack electrofishing gear, and angling gear were also used occasionally. Typically, one seine was used as a blocking net, while another was pulled through the selected stretch of canal. Drop structures were seined by encircling the settling pool and hauling the seine to the shallow end of the pool.

Total length (mm) and weight (g) were measured on, and scales collected from, captured grayling for evaluating age-size distributions, condition factors, individual ages, and backcalculating lengths. Scales were taken from below the posterior edge of the dorsal fin (Jearld 1983).

Data were analyzed by micro-computer. Summary statistics and statistical analyses were calculated on the program Quattro Pro 5.0 (Borland 1994).

Age and Growth

Population size structure and age groupings were resolved from length-frequency distributions. Ages of grayling were determined from cellulose acetate scale impressions prepared by Wayne Black of FWP. Impressions were analyzed by microfiche at 48X (Jearld 1983). Lengths were backcalculated using the computer program LGMODEL (Weisberg 1989). Assigned ages were verified by two independent readers, and by recaptures of individually marked fish.

Condition Factors and Sex Ratios

Fulton's condition factor (K) (Anderson and Gutreuter 1983) was computed for all Arctic grayling for comparison with other populations:

$$K = \frac{100000\ W}{L^3}$$

where K= condition factor

W= total weight (g)

L= total length (mm)

The sex of mature fish was determined by examination of the length, shape, and color of the dorsal fin. Male Arctic grayling, especially mature fish, have a long dorsal fin which when depressed reaches nearly to the adipose fin, whereas the depressed dorsal fin of female grayling usually does not approach the adipose fin (Hop 1985).

Population Estimates

Population estimates were generated for the grayling population in the upper 5.8 km, beginning in the spring of 1995, from fish captured by seining during spring and fall sampling periods. All sampling occurred when the gates at Pishkun Reservoir were closed, and all 13 pools in the upper 5.8 km were seined as were five 50 m reaches of run habitat. Different 50-m reaches were seined each sampling period. One marking run was followed by one recapture occasion. These runs were separated by at least four hours for an individual site, and were usually separated by 24 hours. Population estimates were calculated using the program MRPE, which incorporates mark-recapture data to generate the maximum likelihood estimate (MLE) using Bayesian statistical methods (Gazey and Staley 1986, D. L. Gustafson, Montana State University, pers. comm.). Separate estimates were made for mature-sized (age 2 and older) and immature fish (age 0 or age 1).

Movements

Grayling movements were monitored in two ways: (1) by visual observation of recaptured, physically marked fish; and (2) by radio-telemetry. All age-1 and older grayling captured were physically marked with individually numbered visible implant (VI) tags in the adipose tissue behind the left eye, as well as by a fin clip specific to the location of the capture (right pelvic in the 5.8 km below the dam, for example). Grayling observed stranded in ephemeral pools post-flow were captured using seines or a backpack electrofishing unit, checked for marks, marked or remarked, and transported to the nearest wintering area. For example, age-0 grayling stranded in a shallow pool below "A" drop were netted and transferred to that drop. Twelve adult and 183 age-1 grayling captured in the fall of 1994 and spring of 1995 were moved from Ninefoot drop to a pool in the upper canal to supplement grayling remaining in the upper 5.8 km and to monitor their movements to see if they were more likely to move downstream than fish captured post flow in the upper end.

Radio transmitters were surgically implanted into 24 adults using a modified Ross and Kleiner shielded needle technique (J. Garrett, University of Idaho, pers. comm.). Incisions were made just ahead of and above the pelvic girdle. External antenna wires were trailed behind the pelvic girdle. The internal organs were shielded with a groover (trough-shaped metal instrument) while a hypodermic needle was inserted behind the pelvic girdle, moved along the groover, and out the incision. The antenna wire was then threaded through the hypodermic needle which was then withdrawn along with the groover. Incisions were sutured using 2-0 Vicryl material with an FS-1 cutting edge needle. Upon completion of implantation, fish were held in a recovery tank until full activity was regained, and then released. Full activity was considered to be regained when a fish was actively swimming and responding to my presence.

This technique was first practiced on about 18 rainbow trout at a hatchery (large, hatchery grayling were not available). Some of these practice fish were implanted with dummy transmitters. With other fish, the surgical procedure was performed, but transmitters were not left in. These trout were held for two to four weeks after surgery to monitor the effects of the procedure on the fish. Among these fish, all but two survived through the post-operative observation periods, and incision sites appeared to be healing well (one early mortality occurred when a specimen jumped out of the holding tank).

In the spring of 1994 (April 22 and 29), 15 adult fish (seven males and eight females) were implanted with 90-day Custom Telemetry (Watkinsville, GA) radio transmitters, 10 with external antennas and five with internal antennas. Because the maximum tag weight was 5.4 g, each tagged fish was 268 grams or larger so that transmitters were two percent or less of the body weight of a grayling (Winter 1983; J. Garrett, University of Idaho, pers. comm.). Tagged grayling averaged 360.4 mm (range, 317-463 mm) in length and 403.8 g (268-748) in weight. Radio tags were implanted into nine grayling captured within the 5.8 km below the reservoir and six grayling from two different drop structures (Upper and Lower Turnbull).

In 1995, seven male and two female grayling averaging 417.0 mm (375-461) and 623.4 g (509-718) were implanted with 150-d Advanced Telemetry System (ATS; Isanti, Minnesota) transmitters, all in the upper 5.8 km of canal. Six tags were implanted during spring (April 13-14, 20-21) and one on July 26. The two female grayling were implanted with the same type of tags on November 16. The transmitters ranged in weight from 4.2 to 4.8 g, and all fish were larger than 240 g, so that transmitter weights were again less than 2% of fish weights.

Radio-telemetry

Radio-tagged fish were tracked using an ATS receiver and a hand-held, bi-directional, 60 x 61 cm loop antenna. Approximate locations were found by driving along the canal road with the receiver scanning the appropriate frequencies (preprogrammed into the receiver's memory) until a signal was heard. The loop antenna was then manipulated by hand to triangulate the signal, and a visible description of the habitat of the site was recorded, as was the location on the appropriate USGS quadrangle map. In 1995, a truck-mounted whip antenna was used to find the general location of a transmitter, and the loop antenna was then used to localize the signal. In both years, during flow conditions, the entire canal was driven at least weekly from the reservoir to Fairfield. Reaches closer to the reservoir were surveyed three to five times a week during the same period. Most locations were made during daylight hours (0500-2100 h). However, all fish except those in extreme downstream reaches were located at night (2100-0500) at least twice. All telemetry gear was checked for accuracy prior to use by locating transmitters placed in streams at various depths and distances. Due to the small size of the ATS transmitters, fluctuating water temperatures caused frequencies to shift (ATS, pers. comm.), usually downward with a decrease in temperature. For example, transmitter 49.610 (khz) would be found at 49.614 khz at 10 °C while at 1 °C it would signal at 49.608 khz. Once this relationship was determined, an unused transmitter was used to evaluate the proper frequencies to scan each day.

Sexual Maturation and Spawning

Sexual maturity was determined through observations of spawning fish and by internal examination of gonads of radio-tagged fish. Spawning was determined by visual observation of areas in which concentrations of radio-tagged fish gathered, and other areas in which suitable spawning substrate was identified during pre-flow periods. These areas included pool margins and pre-flow riffles, and any areas of the canal sides and bottom which could be reasonably observed during flow conditions. However, because of water depth and turbidity, much of the canal bottom is not visible when water is flowing in the canal. In 1995, measurements of substrate, channel width, depth, and velocity were made at a site where spawning activity was observed and where fertilized eggs were subsequently collected. Substrate was classified using a modified Wentworth classification (Cummins 1962): bedrock (unbroken, solid rock), boulder and cobble (>50 mm), pebble (10-50 mm), gravel (2-15 mm), and fines (<2 mm). The timing and duration of spawning was back-calculated from swimup times and fry sizes by using published hatching times at temperature (Kaya 1990, Northcote 1995).

Distribution, and Habitat of Early, Age-0 Young

Emergence and distribution of grayling fry (fish less than 25.4 mm or 1 inch, in length as defined by Piper et al. 1982) were examined in two ways: (1) by visual observations along the water edge; and (2) by conical drift nets with 1 mm mesh, suspended from the Boadle Bridge about 5.8 km below the reservoir. In 1995, additional nets were set 100 m downstream of Pishkun reservoir, one on each side of the canal. Each net had a 0.9 m diameter opening, was 1.5 m long, and ended with a slotted PVC cup lined with aluminum screen. The cup was held to the net with metal clamps and could be opened by unscrewing the endcap. In 1994, positions of the three nets at the bridge were: (1) at the surface at midstream, (2) in shallow water directly adjacent to the bank, and (3) on the bottom (about 1.5 m deep) two meters from the bank. The nets were held in place by nylon ropes attached to various locations on the bridge. In 1995, nets were again set in positions 2 and 3. The two nets at the reservoir outlet were placed at a depth of 1 m, and about 2 m from the bank. Additionally, in 1995 a drift net with 0.5 mm mesh and attached to a 30 kg weight and towing frame was lowered to the bottom in the thalweg at the bridge prior to fry swimup (the stage when fry first start to swim freely and swim up from the substrate) in an effort to detect bottom-drifting eggs, egg-sac fry, or pre-swimup fry. These nets were set at daybreak and nightfall, beginning the first week of June each year, and were checked at those same times by retrieving each net and emptying the contents of the cup into an 18.5 L bucket for inspection. The nets were set at least three entire days (and nights) of each subsequent week through the end of June, for a total of 12 days each year. A sample of grayling fry were kept for length measurements.

Visual observations for grayling fry were conducted from June 4 to July 28 in 1994. Only the shallow areas along the margins of the canal were able to be surveyed, so the presence of fry grayling using deeper water was unable to be determined. Grayling fry were identified by their distinct silhouettes and vigorous swimming motions, with identifications verified by captured fry. At locations where grayling fry were seen, qualitative notations were made of the microhabitat being used, such as whether the fry was in current, behind some kind of obstruction, in shallow or deep water, and the type of associated substrate. In 1995, the locations where fry were seen in 1994 were again surveyed from June 1 to July 11. In 1995, measurements were taken of habitat occupied by fry, including focal point depth and velocity, distance from cover, distance from the bank, substrate in the 0.25 m^2 under the fish, and total depth at that location. Total lengths were measured on all fry which could be netted. Further, the 60.6 km of canal from Pishkun Reservoir to Fairfield (A drop; Table 1, Figure 3) was divided into five sections: (1) Pishkun Reservoir to Boadle Bridge (5.6 km); (2) Boadle Bridge to Upper Turnbull drop (43.3 km); (3) Upper Turnbull to Lower Turnbull (2.72 km); (4) Lower Turnbull to Ninefoot drop (1.92 km); and (5) Ninefoot drop to A drop (3.7 km). Survey reaches were then chosen from these sections by randomly choosing a pre-determined number of 1 km units, and then marking the 100 m within these units which held the greatest chance of holding young grayling (based on 1994 observations). A total of 17 reaches were surveyed (Figure 3). These reaches were surveyed weekly from June 15, one week after grayling fry were first seen, to June 27, when grayling fry were no longer visible, to evaluate longitudinal distribution of fry. Transects were not surveyed the week of June 8, when a single swimup grayling was first observed near the spawning area, due to the inaccessibility of most transects. Reaches were surveyed along the bank bordered by the road by walking the 100 m section very slowly, stopping every 3-4 steps and examining the immediate area carefully for presence of grayling fry. The reaches were surveyed starting from opposite ends of the canal on alternate weeks, beginning with reservoir to Fairfield the first week. I attempted to capture (dip net) and measure any fry detected, and took habitat measurements in the manner described previously. Habitat measurements were taken whether or not the individual fry was netted. Seines were also used in 1995 and 1996 to sample backwater locations for presence of grayling fry. The features used for identifying different species of fry, from observation and identification keys, are illustrated in Appendix A, Figure 1 (Kaya 1994, unpublished).

Habitat Use by Juveniles and Adults

Habitat use by both adult and juvenile grayling during flow conditions was monitored by the observation of feeding fish. Such habitat was characterized by measuring velocity transects on July 11, 1995 at three locations where grayling were most commonly seen or captured during both summer flows and in winter pools. The first two locations were 50 m apart, 1 km below Pishkun reservoir. The third was 4.5 km downstream from the reservoir. At each site, a 12.7 mm (0.5 inch) diameter nylon rope, graduated every meter, was stretched across the canal perpendicular to the current. A Montedoro-Whitney PVM-2A electronic current meter attached 10 cm above a 1 kg sounding weight was suspended by a cable, graduated at 0.5 m intervals, from a canoe. Velocity measurements were made every 2 m along the transect rope, except for the three closest to each bank, which were measured every meter. At each increment, velocity was noted at the surface, and at 0.5 m intervals until the weight touched bottom, where a final velocity was measured (10 cm above the bottom).

Habitat conditions during winter were characterized through the winters of both 1994-95 and 1995-96. Ice thickness, water depth, and dissolved oxygen concentration (using a YSI Model 54 dissolved oxygen meter) were measured both at pools known to contain grayling and some of the remaining pools in the upper canal for which grayling use was possible but unknown. At these and all other pools in the upper canal, length, width, maximum depth, and water volume were measured on March 8, 1996, to estimate the dimensions of winter habitat available. Relative volume was approximated by multiplying the average maximum depth along the thalweg of a pool by half of the average width and by the total length of the pool. The length of the pool was measured along the thalweg. Widths and depth were measured at 50 m intervals.

Other Species of Fish in the Canal

Sympatric fish species were identified and their relative abundances noted to evaluate potential competitors and predators of Sunnyslope Canal grayling. These species were captured during sampling for grayling.

RESULTS

Canal Flow and Water Quality

Discharge was variable between years, with flows generally peaking at about 45.9 to 47.6 m^3/s during June and early July (Figure 4). In 1994, water was released from Pishkun Reservoir into Sunnyslope Canal from May 6 to September 14. In 1995, discharge began April 22, halted from May 5 to May 20, then restarted until September 22. Initial flows both years exceeded 2.7 m^3/s, and were usually over 6.8 m^3/s (Figure 4). Flows began to decrease in mid-July in both 1994 and 1995. This decrease continued through August in 1994, but in 1995 there was a second peak at 37.5 m^3/s early in the month. When the irrigation season ended, the reservoir gates were shut and then later sealed with sand to reduce leakage to minimal (0.03-0.06 m^3/s) levels.

In 1994, GID conducted maintenance on the gates and tunnel on the reservoir side of the dam after flows ended September 14. Before the gates at the outlet were closed, only a small volume of water was flowing into the canal because the reservoir was drawn down to nearly minimum pool, close to the bottom of the outlet tunnel. During this week, the fish screen in front of the outlet gate at the reservoir was removed for repairs. To isolate the canal from the reservoir and to prevent fish passage, two coffer dams (one on the reservoir side of the fish screen and one below the outlet tunnel) were built. However, these coffer dams failed on September 15 and 20, allowing free passage of both water and fish through the dam.

Mean values of conductivity (285.1 umhos/cm; 222-365), alkalinity (133.1 mg/l $CaCO_3$; 112-146), pH (8.4; 8.0-8.5) and temperatures (4.7 °C to

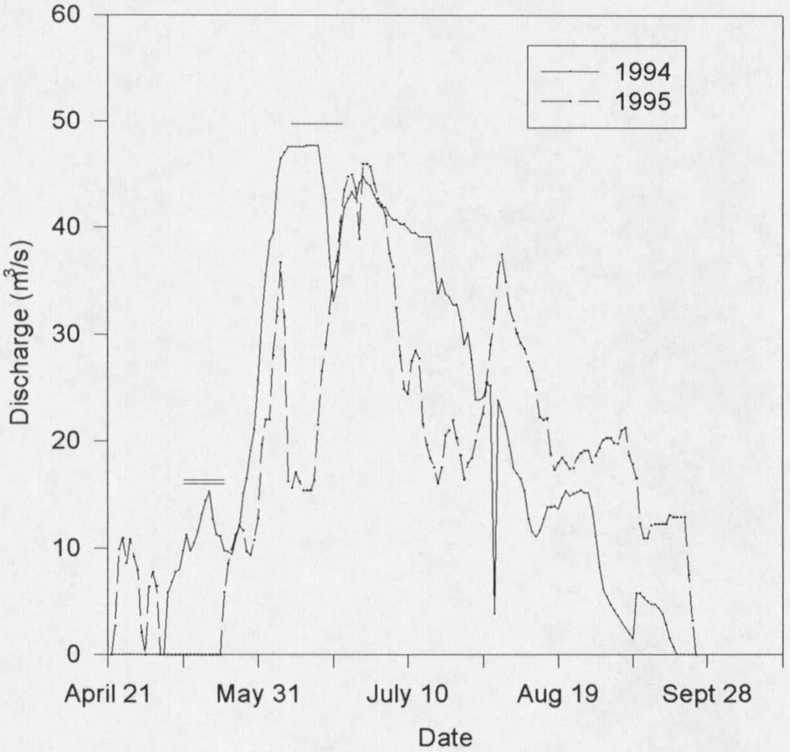

Figure 4. Discharge profiles for Sunnyslope Canal, 1994-95. Double bar indicates approximate spawning times while the single bar denotes fry swimup.

Table 2. Mean, (standard deviation), and range of physical and chemical habitat measurements for upper Sunnyslope Canal during the ice-free period, April 13-November 16, 1995. Conductivity is reported at 25°C.

	Temperature (°C)	Conductivity (umhos/cm)	Alkalinity (mg/l $CaCO_3$)	Dissolved Oxygen (mg/l)	pH
Mean	10.9	285	133	12.2	8.4
sd	(2.9)	(49.7)	(12.4)	(3.4)	(0.2)
Range	4.7-16.0	222-365	112-146	8.6-17.9	8.0-8.5

14.2 °C) for 1995 are presented in Table 2. Dissolved oxygen levels ranged from 8.67 to 17.9 ppm, and reached supersaturation of up to 17.9 ppm in early August. The maximum value (17.9 mg/l) was measured on August 8, 1995 at a water temperature of 13.2 °C. Saturation at this temperature is about 9.6 mg/l, indicating a high level (186%, or 252 mm Hg) of oxygen supersaturation. By August 23, dissolved oxygen dropped to 9.35 mg/l at 16 °C (saturation is 8.5 mg/l). Supersaturation was detected up to 6 km below Pishkun Reservoir.

Age and Growth

The oldest fish captured in Sunnyslope Canal were two age-7 females. Only one male reached age 6 (Table 3). In the first sampling period, spring 1994, 74% of fish captured (32 of 43) were age 3, with total lengths from 341 to 379 mm (Table 3). At the same time, only six grayling (14%) were age 2, ranging from 300 to 322 mm. Male grayling tended to grow faster than females, resulting in longer mean total lengths of males in all age classes through age five, when males were disappearing from the population.

Younger Sunnyslope Canal grayling grew more rapidly than older fish. Both observed lengths-at-annuli and backcalculated lengths (Table 4) show rapid growth in the first two years and a decrease in growth rate during

Table 3. Numbers and mean total lengths (MTL) in millimeters for each age class, by sex and age, of mature Arctic grayling captured in Sunnyslope Canal, spring sampling periods, 1994-96.

Age	Males		Females		Combined	
	Number(%)	MTL (sd)	Number(%)	MTL(sd)	Number(%)	MTL(sd)
			1994			
II	1 (4)	315 (0)	5 (26)	305 (32.0)	6 (14)	307 (29.1)
III	21 (88)	362 (9.0)	11 (58)	358 (13.6)	32 (74)	361 (10.8)
IV	1 (4)	426 (0)	2 (11)	384 (4.9)	3 (7)	397 (24.8)
V	1 (4)	463 (0)	0		1 (2)	463 (0)
VI	0		1 (2)	438 (0)	1 (0)	438 (0)
VII	0		0		0	
Total	24(100)		19(100)		43(100)	
			1995			
II	1 (7)	292 (0)	6 (30)	305 (21.2)	7 (21)	303 (20.0)
III	1 (7)	381 (0)	1 (5)	365 (0)	2 (6)	373 (11.3)
IV	10 (71)	413 (8.7)	8 (40)	401 (16.5)	18 (53)	408 (13.8)
V	2 (14)	449 (17.7)	2 (10)	409 (0.71)	4 (12)	429 (25.3)
VI	0		2 (10)	447 (7.1)	2 (6)	447 (7.1)
VII	0		1 (5)	440 (0)	1 (3)	440 (0)
Total	14(100)		20(100)		34(100)	
			1996			
II	27 (77)	312 (8.3)	64 (77)	300 (12.2)	91 (77)	303 (12.6)
III	3 (9)	372 (15.0)	3 (4)	356 (7.0)	6 (5)	364 (14.0)
IV	0		2 (2)	397 (19.8)	2 (2)	397 (19.8)
V	4 (11)	433 (10.8)	11 (13)	424 (11.8)	15 (13)	427 (11.9)
VI	1 (3)	450 (0)	2 (2)	420 (7.1)	3 (3)	430 (18.0)
VII	0		1 (1)	450 (0)	1 (1)	450 (0)
Total	35(100)		83(100)		118(100)	

year three and especially after year four. Calculated mean growth is 158 mm in the first year, and 144 mm in the second, while observed growth rates were 160 and 141 mm. A negative growth rate is evident in calculated lengths between age 5 and age 6. This reflects the fact that only one male grayling older than age 6 was captured, and male grayling grew faster to age 5 than females (Tables 3, 4).

Table 4. Average calculated lengths at succeeding annuli and annual increments of growth for Arctic grayling captured in Sunnyslope Canal in the springs of 1994-96.

Age	Number(%)	Mean length at Capture (sd)	range	Back-calculated length at each age 1	2	3	4	5	6	7
			1994							
I	13 (28)	172 (7.6)	133-194	168						
II	3 (7)	312 (11.2)	300-322	166	320					
III	27 (57)	363 (11.4)	341-379	158	310	365				
IV	2 (4)	403 (32.5)	380-426	170	315	368	407			
V	1 (2)	463 (0)	---	157	314	359	396	436		
VI	1 (2)	438 (0)	---	171	314	372	401	439	423	
VII	0 (0)									
Total	47 (100)									
Average				162	312	366	403	437	423	
Increment				162	149	54	37	35	-13.9	
			1995							
I	33 (49)	155 (9.8)	136-171	154						
II	9 (13)	303 (17.6)	280-335	153	302					
III	1 (1)	365 (0)	---	154	302	367				
IV	17 (25)	404 (13.1)	348-432	148	297	361	407			
V	5 (8)	429 (21.9)	408-461	151	295	360	404	432		
VI	2 (3)	447 (7.1)	440-452	144	290	350	395	422	431	
VII	1 (1)	440 (0)	---	154	293	356	395	424	431	428
Total	68 (100)									
Average				152	298	360	405	429	431	428
Increment				152	172	37	45	24	2	-2.4
			1996							
I	7 (9)	163 (10.3)	154-185	162						
II	50 (65)	300 (13.0)	250-320	162	300					
III	4 (5)	358 (7.4)	349-365	162	300	356				
IV	2 (3)	403 (27.6)	383-422	162	300	357	403			
V	12 (16)	432 (10.7)	415-450	161	299	355	402	433		
VI	1 (1)	415 (0)	---	162	298	355	401	433	413	
VII	1 (1)	450 (0)	---	159	297	352	398	430	410	444
Total	77 (100)									
Average				162	300	356	401	433	411	444
Increment				162	138	56	46	32	-22	33
Grand average				158	302	361	404	432	429	439
Increment				158	144	59	42	28	-2.5	9.7
Number				192	139	77	45	24	6	2
Observed average				160	301	362	403	433	437	445
Increment				160	141	61	41	30	4	8

Both calculated and observed growth rates show that Sunnyslope grayling grow little after age 5. Two recaptured female grayling illustrate the slow growth of older fish as they grew little between their sixth and seventh years, averaging 4 mm (2-6 mm) (Appendix A, Table 1). Correspondingly, little change was seen in scale annulus formation, with one of these fish laying down only one observable circulus over this time and the other female showing a few tightly packed circuli. These scales, as well as those from other fish, showed evidence of reabsorption, which makes it difficult to accurately age older fish. Without scales from previous years, the ages of these fish would have been underestimated by at least one year. During this study, the ages of all fish over age 5 were verified by scale samples from previous years.

Table 5. Comparison of summer and winter growth (mm) for 11 recaptured, VI-tagged Sunnyslope Canal Arctic grayling, 1994-96. W94= winter of 1994-95; S95= summer of 1995; W95= winter of 1995-96.

Sex	Age at First Capture	Length Fall 1994	Spring 1995	Fall 1995	Spring 1996	Growth Increments W94	S95	W95	Mean Increment W94	S95	W95
F	1	315	335	384	390	20	49	6	20	49	6
F	2	356	365	409	411	9	44	2			
F	2	---	280	349	349	--	69	0	9	57	1
F	3	406	405	436	442	-1	31	6			
F	3	392	384	420	425	-8	36	5	-4.5	33.5	5.5
M	4	---	417	429	430	--	12	1			
F	4	---	408	422	424	--	14	2			
M	4	---	402	429	420	--	27	-9			
M	4	---	409	428	425	--	19	-3	---	18	-2.3
F	5	---	408	418	415	--	10	-3	---	10	-3.0
F	6	---	442	446	450	--	4	4	---	4	4

Most growth occurs in the months between spawning in June and the following season of ice formation in November (Table 5). Older fish (age-3 and older) show practically no growth during the winter months. Negative values indicated for some older fish probably reflect measurement error.

Length-Frequency Distributions

Length-frequency distributions illustrate that grayling recruitment fluctuated widely before and during this study. Very few fish shorter than 330 mm were captured in 1994 (Figure 5) indicating weak year classes for 1993 and 1992. This relative scarcity in spring 1994 of smaller, age-1 and age-2 fish was alleviated with the appearance of age-0 young produced during 1994 and present as yearlings in spring 1995 (Figure 6). This 1994 year class was conspicuous in the spring of 1996 as age-2 fish ranging from about 280-320 mm (Figure 7). The 1994 year class of grayling was clearly stronger than either the 1993 or 1995 year classes, and the 1995 year class appeared to be somewhat larger than the 1993 year class.

The range of lengths in each year's length-frequency distributions were similar as total lengths ranged from 160 to 463 mm, 132 to 461 mm, and 154 to 450 mm total length in the spring sampling periods of 1994, 1995, and 1996 (Figures 5, 6, 7). The length-frequency distributions of males peaked at longer lengths than for females, suggesting that the males grew faster than females. The relationship was less pronounced in 1996 as fewer older males remained in the population.

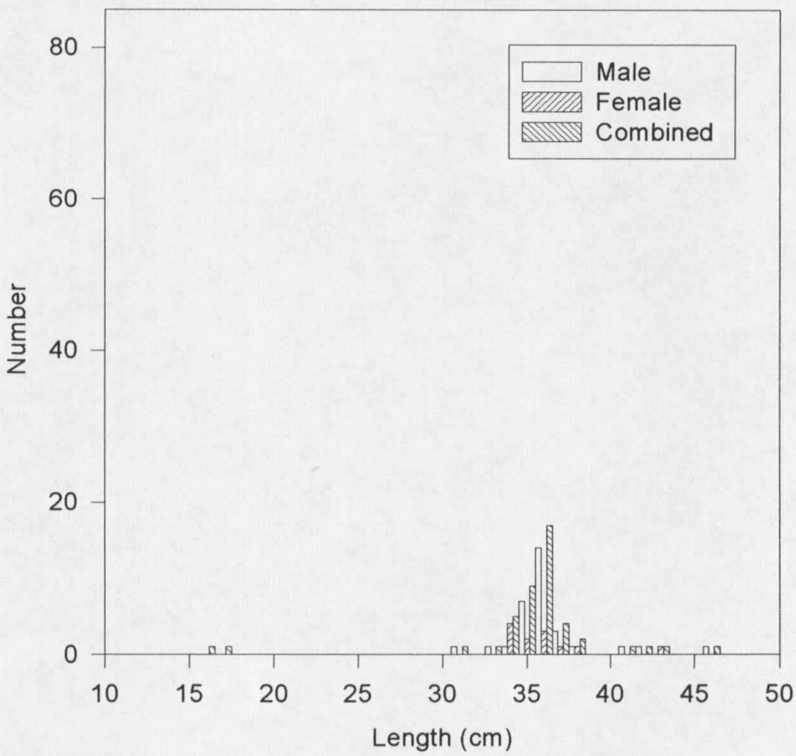

Figure 5. Length-frequency distribution of Arctic grayling in upper Sunnyslope Canal, in spring 1994.

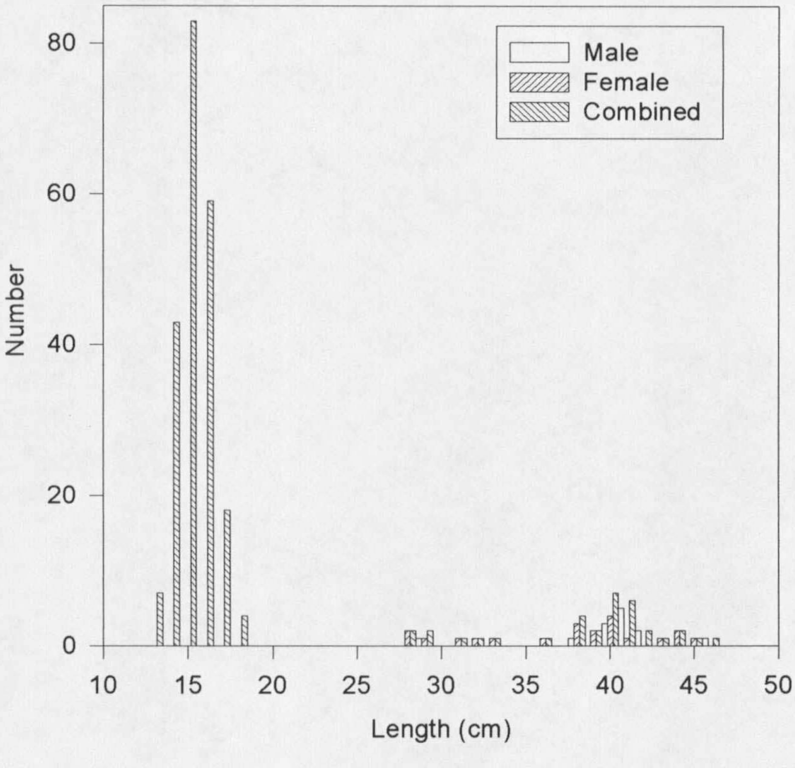

Figure 6. Length-frequency distribution of Arctic grayling in upper Sunnyslope Canal, in spring 1995.

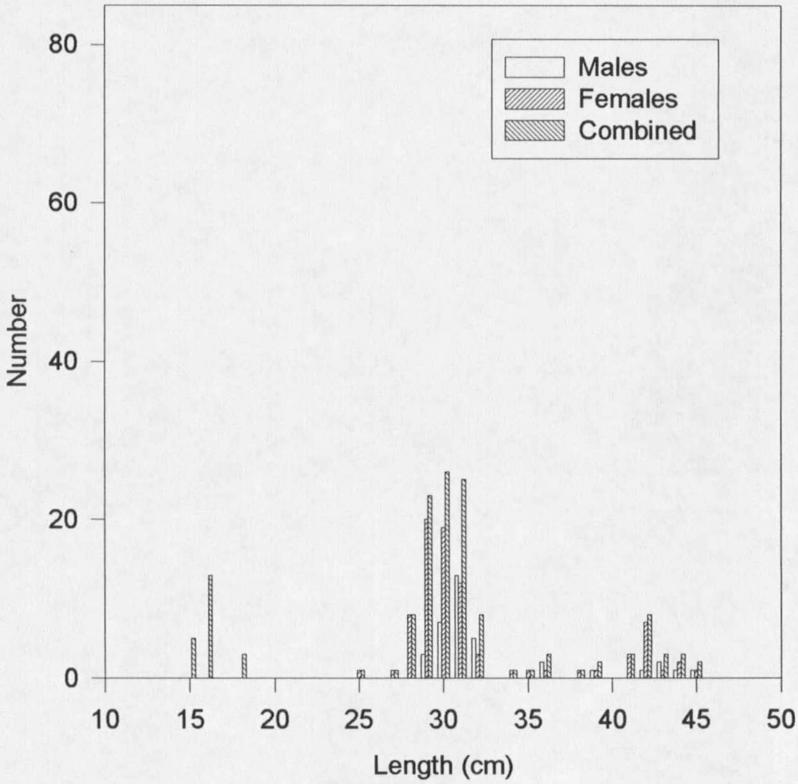

Figure 7. Length-frequency distribution of Arctic grayling in upper Sunnyslope Canal, in spring 1996.

Condition Factors and Sex Ratios

The adult-sized grayling (age 2 and older) captured in the canal generally increased in mean lengths and weights from the spring of 1994 until fall of 1995. However, in the spring of 1996, both mean lengths and weights of the adults decreased as the 1994 year class reached their second year (Table 6) and comprised the largest segment of this subpopulation. Males exceeded females in mean total lengths, and in three of the four sampling periods during which weights were measured, also had higher mean weights. The largest grayling, both in length (470 mm) and weight (1255 g) were males.

Condition factors for Sunnyslope Canal grayling were very similar across the sampling periods, with mean condition factors of females greater than that of males (Table 6). In the spring of 1996, mean condition factor of males was higher than at previous sampling times, and was very close to that of females (0.93 for males, 0.94 for females). Overall, condition factors were highest in spring 1996, even though the preceding winter habitat conditions seemed to have been more severe in 1995-96 than the winter of 1994-95. Age-0 (young of the year) grayling had lower condition factors during the springs of 1995 and 1996 than in the spring of 1994, whereas values for length and weight were higher in 1994 and 1996 than 1995. However, far fewer age-0 grayling were present in 1994 and 1996 than in 1995.

Sex ratios shifted from 1.7 : 1 (M : F) in the spring of 1994 to 1 : 1.1 by the following fall, and remained in favor of females through spring of 1996 (Table 6). The final sex ratio was the most heavily weighted towards females (1 : 3.3).

Table 6. Numbers, sex ratios, and means and ranges of total length (mm), weight (g), and condition factor (K) for male and female adult (age 2 or older) and for juvenile (age 0 and age 1) Arctic grayling captured in Sunnyslope Canal, 1994-96.

	Spring			Fall		
	Males	Females	Age 1	Males	Females	Age 1
1994						
Total Number	34	20	22	14	15	102
Sex Ratio(M:F)	1.7	1		1	1.1	
Length (mm)	365.0	351.1	166.7	389.6	339.3	125.8
(s.d.)	(26.5)	(37.1)	(13.6)	(60.8)	(60.6)	(8.8)
range	315-463	248-438	133-194	288-470	237-406	109-146
Weight (g)	388.7	390.3	39.6	509.9	366.3	---
(s.d.)	(83.4)	(99.2)	(9.5)	(189.5)	(163.7)	---
range	284-748	268-664	24-62	195-824	152-604	---
Mean K	0.80	0.86	0.86	0.82	0.87	---
(s.d.)	(0.08)	(0.06)	(0.28)	(0.10)	(0.06)	---
range	0.71-1.2	0.79-0.99	0.6-2.0	0.72-1.1	0.75-0.97	---
1995						
Total Number	14	21	234	23	51	37
Sex Ratio (M:F)	1	2		1	2.2	
Length (mm)	407.1	371.3	155.2	322.2	329.5	156.5
(s.d.)	(37.9)	(54.9)	(10.1)	(46.5)	(57.3)	(5.4)
range	292-461	280-452	132-183	275-429	244-446	143-169
Weight (g)	556.9	519.3	30.8	---	---	---
(s.d.)	(127.6)	(191.7)	(6.6)	---	---	---
range	178-718	217-795	20-48	---	---	---
Mean K	0.81	0.92	0.77	---	---	---
(s.d.)	(0.07)	(0.07)	(0.09)	---	---	---
range	0.7-0.95	0.81-1.1	0.61-1.0	---	---	---
1996						
Total Number	34	83	25	---	---	---
Sex ratio (M:F)	1	3.3		---	---	---
Length (mm)	334.8	324.6	168.4	---	---	---
(s.d.)	(46.4)	(50.6)	(13.2)	---	---	---
range	294-450	250-450	154-200	---	---	---
Weight (g)	372.6	353.6	39.8	---	---	---
(s.d.)	(217.9)	(227.0)	(17.2)	---	---	---
range	206-1255	147-1108	26-80	---	---	---
Mean K	0.93	0.94	0.79	---	---	---
(s.d.)	(0.19)	(0.14)	(0.14)	---	---	---
range	0.77-1.7	0.73-1.6	0.64-1.2	---	---	---

Population Estimates

Grayling abundance remained at low levels throughout the study. Population size was first estimated in the spring of 1995 at 62 age-2 and older fish (95% confidence interval, 37-230) (Table 7). In fall 1995, the estimated number of age-1 and older grayling was 69 (95% C.I., 62-85), which did not include 20 age-1 grayling moved to the upper canal from a desiccating pool 10.7 km below the reservoir. In the following spring, 1996, the estimated number of fish age 2 and older was 120 (95% C.I., 116-129). This increase partially reflected the addition of the 20 age-1 (age-2 in spring 1996) grayling moved upstream in the fall of 1995, but likely was also influenced by increased capture efficiency since more grayling were captured. During spring, seining is more efficient in the canal as water levels in the remnant pools are lower than in fall. This final population estimate was the highest for adult grayling throughout the

Table 7. Population estimates for Sunnyslope Canal, 1995-1996.

Year	Age	n_1	n_2	m	Nmle	STD	N_o	Nlow	Nhi
S95	1	69	78	20	269	52.95	127	204	390
S95	2+	8	31	4	62	85.73	35	37	230
F95	0	24	16	13	29	3.76	27	27	38
F95	1+	37	47	25	69	6.52	59	62	85
S96	1	19	15	11	25	4.18	23	23	36
S96	2+	77	105	67	120	3.54	115	116	129

n_1= number marked on first capture occasion
n_2= number caught on second capture occasion
m= number of marked fish caught on second capture occasion
Nmle= maximum likelihood estimator
STD= standard deviation
N_o= minimum population number
Nlow= lower confidence limit
Nhi= upper confidence limit

course of the study. The estimated numbers of juvenile, age-1 grayling were highest in spring, 1995, reflecting the strength of the 1994 year-class. Conversely, the 1995 year-class of young grayling was relatively small, as indicated by low estimated numbers of age-0 fish in fall 1995, and of age-1 fish in spring 1996.

Movements

Mortality and Transmitter Performance of Radio-tagged Grayling

Overall, 16 (67%) of the 24 radio-tagged grayling were successfully tracked until transmitter expiration. Six of the 24 implanted fish either were found dead or appeared to have dropped their transmitters based on the presence of the radio signal in locations which did not appear to be suitable habitat (areas with extreme velocity or where the transmitter remained in a completely dessicated location after the irrigation season). Two additional transmitters were not relocated after the second week following tagging in 1994, one because of strong local signal interference and the other apparently because of illegal angling. Some of the other transmitters were repeatedly located in the same locations, with no apparent movements from those places, perhaps indicating that either the radio-tags were dropped or that the fish had died. However, a male grayling (VI tag CA3) which was tracked for two years (1995 and 1996) did not make any noticeable movements from his summer feeding location for up to five weeks in the summer of 1995, and certain fish were recaptured by angling at the same locations (within 50 m) within a three-week period in the summer of 1995, indicating that these grayling move very little under summer conditions. Therefore, I am unable to confirm the status of the tagged fish which remained stationary in 1994, since none of them were recovered, and their transmitters expired well before flows ceased in the canal. Only two of the 24 radio-tagged fish were recaptured during sampling periods later than a week after initial tagging.

The maximum transmitter duration the first study season (1994-95) was 84 days. Minimum duration could not be determined. The maximum duration the second study season (1995-96) was 14 months, and the minimum known duration was 122 days.

Radio Telemetry, 1994

In 1994, grayling radio-tagged in the upper canal were most likely to move downstream out of the upper 9 km of canal. I was able to track five fish (of nine originally radio-tagged), for more than two weeks (Figure 8; Appendix B, Figures 1-4). All five grayling made initial downstream movements from their overwintering locations when flows began on May 6, and four of the five fish (CJ6, CB6, CB2, and CJ9) moved downstream between 40 and 60 km within 3 weeks of the beginning of water discharge from Pishkun Reservoir (Appendix B, Figures 1-4). The remaining fish (CD6) remained within 1.5 km of the reservoir (Figure 8). During this period, radio-tagged fish did not form long-lasting aggregations suggestive of large groups of spawning fish, although two males (CJ6 and CB6) were located together once at a site with substrate which appeared to be suitable for spawning (Appendix B, Figures 1, 2).

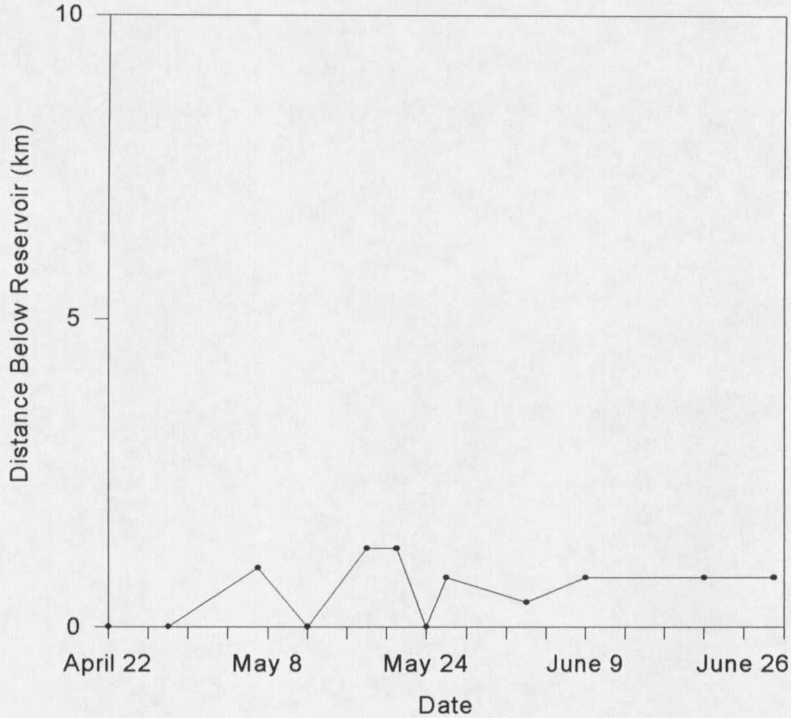

Figure 8. Movements of radio-tagged grayling CD6 (radio-frequency 49.054 mhz) during the spring and summer of 1994, from tagging until transmitter expiration.

Grayling overwintering in drop structures did not remain close to these structures after canal discharge began. All six grayling radio-tagged in the drop structures in 1994 (F12, F08, CJ0, CJ1, CH5, and CH6; Appendix B, Figures 6-11) moved downstream between 1.6 and 3.2 km and over at least one drop structure within three weeks of the beginning of canal discharge.

Within a month of the beginning of discharge, most of the grayling still being tracked (6 of 8) began holding at discrete locations where they were repeatedly located until their transmitters failed. For example, the fish remaining in the upper canal (CD6) was repeatedly located 0.8 km below Pishkun Reservoir at a location where fish clearly identifiable as grayling were often seen rising to feed on surface insects (Figure 8). None of these radio-tagged grayling used available backwater locations. Additional observations of individual grayling are presented in Appendix B.

Radio Telemetry, 1995-1996

In 1995 and 1996, radio-tagged grayling in the upper canal showed a three- or four-stage pattern of movements. I was able to track three fish (of six originally radio-tagged) for more than five weeks (Figure 9). Two of these three grayling (F42, F57, and CA3) made initial downstream movements of between 4.3 and 5.6 km after canal discharge began on April 22, 1995 (Figure 9). Both fish moved upstream in response to decreasing flows at the beginning of the 2 week temporary shutdown. All three fish then moved upstream between 1.2 and 3.7 km in mid-May, apparently for spawning. As will be described later, these fish apparently participated

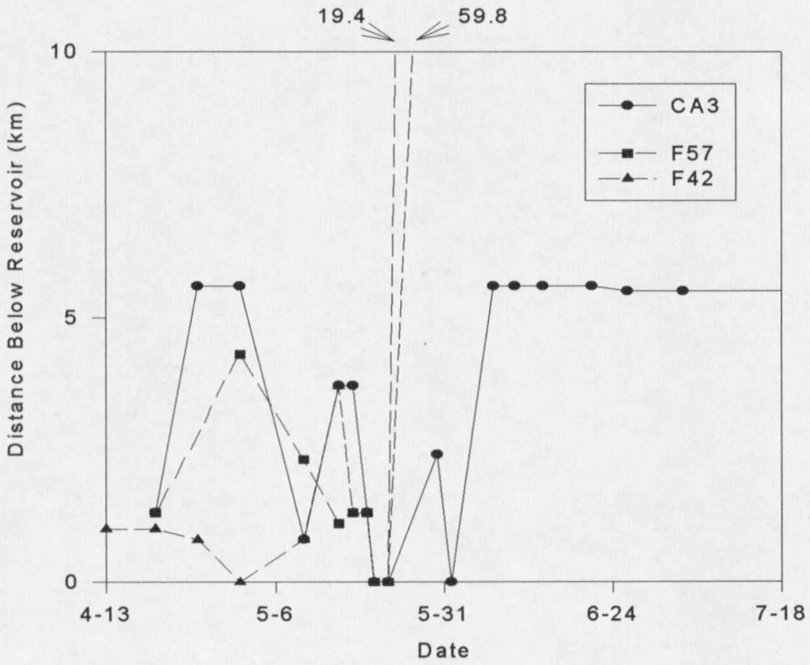

Figure 9. Movements of three radio-tagged male Arctic grayling during spring and summer, 1995, in Sunnyslope Canal.

in spawning activities I observed in the upper canal. After spawning, two fish made downstream movements of between 19.4 and 59.8 km out of the upper canal. One fish (F57) was later found dead and another (F43) dropped its tag or died. The remaining fish (CA3) moved downstream 5.6 km below the reservoir where it remained throughout the summer, moved upstream 4.1 km to overwinter at the same location where he had been tagged, and then repeated the same pattern of movements in 1996 from beginning of discharge through spawning (Figure 10). Also in 1996, another grayling (F30) moved downstream 2.6 km from its wintering pool to a point 6.3 km below Pishkun Reservoir. It remained there through spawning, then moved downstream 1.5 km to a location 7.3 km below Pishkun Reservoir where it had been captured by angling the previous summer.

Radio-tagged grayling did not move between overwintering pools during the non-flow period during the autumn and winter of 1995 and 1996. Both CA3 and F30 remained in separate pools from the time discharges ended in 1995 and began in 1996.