STATUS AND BIOLOGY OF THE SPAWNING POPULATION OF RED ROCK LAKES ARCTIC GRAYLING

by

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APPROVAL

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VITA

James Tory Mogen, son of Ron and Patti Mogen, was born in Forsyth Montana, August 1, 1969. He graduated from Forsyth High School in May, 1988 and attended Eastern Montana College, Billings, the following September, where he completed two years in the biology program. In September 1990, he transferred to Montana State University-Bozeman. He married Robyn Marie Hayden, also of Forsyth, in August of 1992, and received a Bachelor of Science degree in Fish and Wildlife Management at Montana State University-Bozeman the following December. He began graduate studies in January, 1993 at Montana State University-Bozeman.

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ABSTRACT

The population of lacustrine Arctic grayling (*Thymallus arcticus*), historically large in Red Rock Lakes, Montana, has declined substantially in recent years. The goal of this study was to determine the current status of the Red Rock Lakes grayling and provide the biological basis for directing management and future restoration efforts of this native population. The spawning population of Arctic grayling in Red Rock Lakes system was monitored during the springs and summers of 1994 and 1995. A cross-channel weir was installed in both years in Red Rock Creek, the primary spawning tributary for these fish, in an attempt to capture all migrants. In both years, grayling began their spawning migrations prior to ice-off of the Upper Lake, while flows were increasing and daily mean temperatures were near 6.0 C. The peak of upstream movement occurred 4-11 May in 1994 and 14-23 May in 1995. Stream residency for adult grayling captured on both upstream and downstream migration averaged 17.7 d (sd 11.3) for females and 34.8 d (sd 10.2) for males and were significantly different ($p<.001$). Total numbers of spawners captured in Red Rock Creek were 241 in 1994 and 85 in 1995. Only 20 (8.3%) of the grayling captured in 1994 were recaptured in 1995. Average lengths, weights, and condition factors were greater in 1994. Females outnumbered males in the spawning runs by a ratio of 1.8 to 1.0 in 1994 and 2.1 to 1.0 in 1995. Red Rock grayling mature at ages II and III. A shift in age structure was observed between the 2 years. Spawning runs were composed of ages II-VII in 1994 and ages II-VI in 1995. Ages II-III made up 27 and 63 percent of the runs while ages V+ made up 51 and 15 percent of the runs in 1994 and 1995, respectively. In 1994, a weir was also installed in Odell Creek, another historically important spawning tributary. Only 12 grayling were captured from this stream. During the study, no grayling were observed in any of the other 10 historic spawning tributaries for this population. Fry emigration was monitored in Red Rock Creek in 1994. Age-0 grayling first appeared in the stream approximately 32 d after initial spawning activity and resided in the stream 10-15 d before emigration. Mean lengths ranged from 12.3 mm at swim-up to 28.5 mm on the last day of stream residence.

INTRODUCTION

Within North America, Arctic grayling (Thymallus arcticus) are distributed throughout Alaska and in Canada to the Hudson Bay. Additionally, two genetically distinct populations of grayling occurred in the contiguous United States, apparently as glacial relicts (Vincent 1962; Lynch and Vyse 1979; Everett and Allendorf 1985). These geographically isolated populations existed in Michigan and Montana. Since the turn of the century, Arctic grayling have become extinct in Michigan and have progressively declined in Montana (McAllister and Harington 1969; Kaya 1992).

Two distinctly different life-history forms are indigenous to Montana. The fluvial form (residing entirely within lotic systems) and the lacustrine form (spawning in streams, but residing in lentic systems) are genetically different from each other, as well as from Alaskan and Canadian populations (Lynch and Vyse 1979; Everett and Allendorf 1985). Fluvial grayling, once abundant and distributed intermittently throughout the headwaters of the Missouri River upstream from Great Falls, now occur only in the upper Big Hole River (Shepard and Oswald 1989; Kaya 1992). These fish represent the last remaining population of fluvial Arctic grayling in the contiguous United States and have recently been petitioned for listing as endangered. Efforts to reestablish other fluvial populations have thus far been unsuccessful.

The only native lacustrine population of Arctic grayling in the contiguous United States exists in Red Rock Lakes of extreme south-western Montana (Kaya 1992). While the distribution of lacustrine grayling has been greatly expanded through introduction into lakes of many western states, little is known about the origin of these fish except that they came indirectly from Madison River or Red Rock Lakes stocks. The Red Rock Lakes grayling, while greatly reduced in numbers, have maintained themselves without artificial propagation.

Red Rock Lakes and much of the surrounding area lie within the boundaries of Red Rock Lakes National Wildlife Refuge making more complete management of this unique population possible. However, numbers have progressively declined over the past 100 years (USFWS 1978; Unthank 1989). A number of factors appear to have contributed to this decline including excessive habitat degradation both on and off the refuge, siltation of critical habitats, water diversions, and competition with and predation by native and introduced fishes (Unthank 1989). Concern for the continued existence of this population has recently increased. Recent observations indicate that numbers have declined to low levels suggestive of imminent extinction (Neithammer, USFWS, pers. comm.).

According to early settlers, grayling were once abundant in the Centennial Valley. Homesteaders first moved into the valley around 1876, using the area primarily as summer cattle range (Unthank 1989). In the late 1800's the waters of the area supplied anglers with superb fishing, with trout and grayling present in great numbers (Brower 1896). As early as the 1890's, grayling from Red Rock Lakes were being used as a source for introduction into other waters (Unthank 1989). In the early 1940's, spawning grayling were so plentiful that Jim Hanson, a rancher in the Red Rock Creek drainage, reported that he could "scoop them out of his irrigation ditch with a pitch fork," and that "fishermen used to limit in an hour from his ditch." Refuge Manager Hull reported that sections of Red Rock Creek in late May 1942 "looked more like a fish hatchery than a natural stream with so many grayling" (USFWS 1978). Local ranchers reported that Elk and Picnic creeks were also once "thick with grayling, with as many as 50-75 grayling per hole" (USFWS 1978). In the early 1950's Nelson (1954) observed spawning grayling throughout Red Rock Creek and in the lower reaches of its tributaries and in Elk, Battle, Tom, and Odell creeks. A fish weir spanning Red Rock Creek during the spawning runs of 1962-1966 captured an average of 704 upstream migrating grayling per year during its 5-year existence (USFWS 1978). Overall, grayling spawning runs were documented in at least 12 of the small tributaries of the upper Centennial Valley (Figure 1)(Brown 1938, Nelson 1954, USFWS 1978, and Unthank 1989).

In early June of 1976, grayling populations of Upper and Lower Red Rock lakes and several tributaries were investigated by the Montana Department of Fish and Game (MDFG). "Large" numbers of spawners were observed in Red Rock and Odell creeks, while only four females were captured in Tom Creek. No grayling were found in any of the other tributaries including, Elk, Grayling, Shambow, East Shambow, Moose, and East Nye creeks (MDFG 1977). Two gill nets set overnight in each of the Red Rock Lakes in August of 1976 yielded 23 grayling from the upper lake and only one from the lower lake. Two grayling captured in the upper lake had been tagged the previous June in Odell Creek, indicating that grayling could negotiate the "river marsh" between the lakes and that the primary year-around residency for grayling was in the upper lake (MDFG 1977).

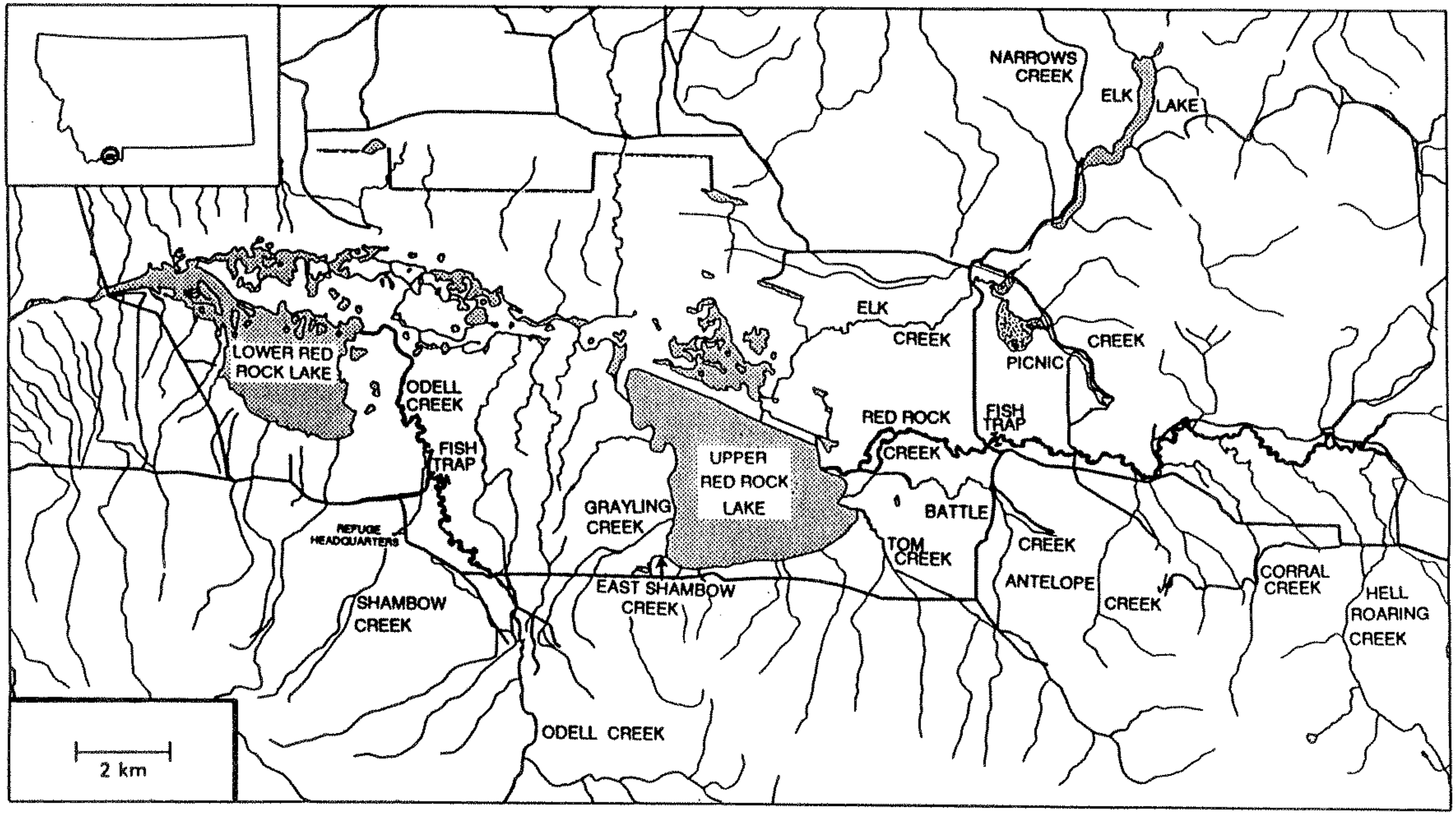


Figure 1. Watershed map of upper Centennial Valley (Beaverhead County, Montana) showing historic Arctic grayling spawning streams and approximate locations of adult fish traps in Red Rock Creek and Odell Creek during the study.

Recent observations indicate that grayling numbers are declining towards a seriously low level. Since 1976, grayling have only been observed in Red Rock and Odell creeks (Unthank 1989). Fish population surveys conducted in late-May to early-June since the late 1970's revealed small numbers of grayling in these two streams (Unthank 1989). Furthermore, in 1992 and 1993 no grayling were captured in a fish trap spanning Odell Creek (Neithammer, USFWS, pers. comm.).

Documentation of the current status of the native Red Rock Lakes Arctic grayling is critical and was the goal of my study. Specific objectives were: (1) determine the abundance, age and sex ratios of the spawning population of Red Rock Lakes Arctic grayling, (2) determine the timing of upstream and downstream spawning migration, (3) determine the distribution and residence time of age-0 grayling in Red Rock Creek, (4) locate and quantify characteristics of spawning habitat, and (5) determine if grayling use any of the other historic spawning tributaries. This study will help provide the biological basis for directing management and future restoration efforts of this unique grayling population.

DESCRIPTION OF STUDY AREA

Lying at over 2,000 m in elevation, only a few kilometers north of the continental divide, Red Rock Lakes National Wildlife Refuge is part of the greater Yellowstone ecosystem. It is located in the eastern portion of the Centennial Valley of extreme southwestern Montana, approximately 65 km west of Yellowstone National Park. The refuge was established in 1935 for the protection and management of the trumpeter swan (Cygnus buccinator) and administers over 16,000 ha, much of which is lake and marsh.

The Centennial Mountains, which rise abruptly to over 1,000 m above the valley floor, form the southern boundary of the valley with some of their heavily timbered slopes extending a short distance into the refuge. The northern boundary is formed by the gently rounded, sagebrush-covered foothills of the Gravelly Range. The valley is about 80 km long and 12 km wide and is drained by the Red Rock River which flows into Lima Reservoir to the west. Elevation at the headwaters of Red Rock Creek is approximately 2745 m. The Red Rock River leaves the valley at about 1966 m in elevation.

The Centennial Valley hosts the longest winters in the nation, excluding Alaska (Fischer 1976). Snowfall averages over 350 cm annually and frost can occur in every month of the year (USFWS 1973). Annual precipitation has averaged 48.0 cm since 1980 (USFWS, unpublished data 1995). The timbered slopes and rocky basins of the area capture the heavy winter snows and provide a constant supply of water for the 5,700 ha of lakes, marshes, and streams within the valley (USFWS 1978).

Two large shallow lakes, Upper and Lower Red Rock lakes, dominate the valley floor and lie entirely within the Refuge (Figure 1). The upper lake is approximately 4.3 km long by 3.2 km wide, encompasses 893 ha, and has a maximum depth of less than 2.0 m. The lower lake is approximately 2.7 km long by 2.6 km wide, encompasses 456 ha and has a maximum depth of about 0.5 m (USFWS 1978). Both lakes have uniform basins with aquatic vegetation throughout and bottoms of mud, peat, and detritus. The lakes are bordered by extensive marshes, meadowlands, and smaller open water areas. The remaining valley is grassland and sagebrush, much of which is privately owned and used for grazing.

The four major streams of the valley form the most remote headwaters of the Missouri-Mississippi River system. Red Rock, Elk, and Tom creeks are the principal tributaries of the upper lake while Odell Creek is the primary tributary of the lower lake. In addition, many small, spring-fed streams feed the lakes, most of which have been altered by beaver and irrigation diversions. Arctic grayling and other fish species are dependent upon Red Rock and Odell creeks for spawning and possibly juvenile rearing habitat. Considerable deterioration of these drainages has occurred over the past century due to various activities including excessive overgrazing of riparian vegetation and dewatering of the streams (USFWS 1978, Unthank 1989, and USFWS 1993). It recent years, however, the streams have shown signs of improvement.

Red Rock Creek, for most of its length, is a typical meandering mountain valley stream. It flows in a series of alternating riffles and pools for approximately 20.9 km to the upper lake while maintaining an average gradient of 0.6% and an average width of 9.5 m (USFWS 1978).

Red Rock Creek's streambed is very unstable, frequently shifting and cutting new channels through past alluvial deposits and forming bars of fine gravels. Riffle areas are dominated by gravels and pools have finer substrates. Except for much of the heavily grazed private lands east of the Refuge where siltation, degraded streambeds, and a lack of riparian vegetation is evident, and the lower 2-3 km of the stream, which are dominated by deeper, slow-moving water and substrates of fine sediment, Red Rock Creek appears to contain an abundance of suitable spawning habitat.

Odell Creek is approximately 19.3 km long and maintains an average gradient of 6.9% in its upper 8 km until it exits the mountains where it becomes similar to Red Rock Creek, winding its way 11 km to the lower lake with an average gradient of 1.0% and an average width of 6.5 m (USFWS 1978). The streambed in this stretch contains a greater proportion of larger materials (pebble-cobble) than that of Red Rock Creek, however the lower 5 km which are dominated by deep pools, slow water, and substrates of fine sediment are similar to lower Red Rock Creek. The private lands bordering Odell Creek above the refuge, appear to be in better condition than those in the Red Rock drainage. Livestock have been fenced out of riparian areas and habitat enhancement projects are currently underway.

Many native species of fish coexist with Arctic grayling in the study area, including mountain whitefish (Prosopium williamsoni), burbot (Lota lota), white sucker (Catostomus commersoni), longnose sucker (Catostomus catostomus), longnose dace (Rhinichthys cataractae), mottled sculpin (Cottus bairdi), and westslope cutthroat trout (Oncorhynchus clarki lewisi). Introduced species include brook trout (Salvelinus fontinalis), Yellowstone cutthroat trout (Oncorhynchus clarki bouveri), rainbow trout (Oncorhynchus mykiss) and rainbow-cutthroat trout hybrids.

The wide range of habitat found in the valley also creates a variety of niches for many species of wildlife including moose (Alces alces), elk (Cervus elephus), mule deer (Odocoileus hemionus), whitetailed deer (Odocoileus virginianus), pronghorn antelope (Antilocapra americana), coyote (Canus latrans), river otter (Lutra canadensis), and beaver (Canadensis canadensis). Bird life is especially abundant, with over 200 species identified, including bald eagle (Haliaeetus leucocephalus), osprey (Pandion haliaetus), pelican (Pelecanus erythrorhynchos), gulls (Larus sp.) and the trumpeter swan.

METHODS

Fish Trapping

Traps were installed to capture adult grayling entering and leaving Red Rock Creek in the spring of 1994 and 1995. In both years the trap was located just above the Elk Lake Road bridge (Figure 1), approximately 6.0 river km upstream from the mouth of Red Rock Creek. This was the location with the furthest downstream access below historic spawning areas. In 1994 a box trap with wings was installed. The box trap measured 1.5 m long, 1.2 m wide, and 0.9 m high, and was of a two-way design, capturing fish moving both directions. It had a 2.5 cm steel, square-tubing frame, 1.3 cm mesh galvanized hardware screen walls and bottom, and a plywood lid. The wings were constructed with 1.0 m lengths of 1.3 cm metal conduit cabled together and spaced at 1.9 cm. The trap enclosed the entire width of the stream, approximately 11.0 m.

In 1995 the Red Rock Creek trap was upgraded to a modified resistance board weir type (Tobin 1994) which also included the wings and two-way box trap used in 1994. Three resistance board weir panels were used, each 3.0 m long and 1.5 m wide. The panels were composed of 27 pickets evenly spaced at 2.5 cm. Pickets were constructed from 3.0 m lengths of 2.5 cm schedule 40 electrical PVC conduit which were capped at both ends to maintain buoyancy. Pickets were held together and evenly spaced by redwood stringers and a single aluminum stringer at the upstream end. The aluminum stringer of each panel contained hooks which hooked over a 6.0 mm cable and acted as a hinge (Figure 2). The cable was anchored to the stream bottom and spanned the width of the weir.

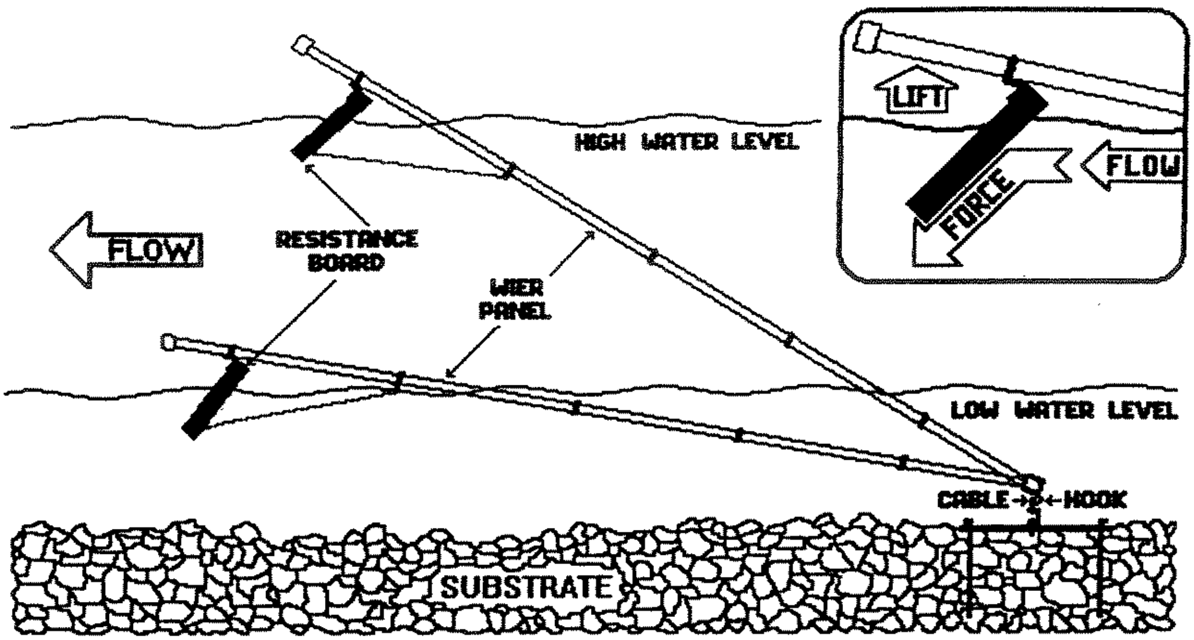


Figure 2. Lateral view of an installed resistance-board weir panel showing adaptability to fluctuating water levels (not drawn to scale). Inset depicts how lift is generated as the resistance board reacts to the hydrodynamic force exerted by flow.

Three resistant boards, measuring 0.4 m wide, and 1.5 m long, were constructed from 3.8 cm waterproof styrofoam (blueboard) laminated and bolted between two sheets of 6 mm plywood and coated with marine enamel paint. They were attached to a wooden stringer on the downstream end of each weir panel with hinges. The angle of each board was maintained by a chain fastened at one end to the resistant board and at the other to a hook on the adjacent upstream wood stringer. As water flowed against the resistant boards, it pushed them up, forcing the weir panels up out of the water (Figure 2). Bulkheads, constructed from 1.2 X 2.4 m sheets of 1.9 cm plywood coated with marine enamel paint, provided the terminus for the weir panel assembly. These thin vertical walls were supported by posts driven into the substrate. As the weir panel adjacent to each bulkhead rose and fell with fluctuating water levels, a consistent gap was maintained between the two providing a fish-tight terminus at a variety of water levels. The resulting barrier prevented adult fish movement, yet allowed water to pass through. Together, the two bulkheads and three panels formed 4.5 m of floating weir which attached to the trap box. The wings spanned the remainder of the stream.

In 1994, the Red Rock Creek box trap was installed 28 April, during ice break-up on the upper lake, and removed 15 July, after downstream movement of spawners appeared to have ended. During the peak flow period (9 through 15 May), the trap was completely breached. In 1995, the resistance board weir and box trap were installed 4 May, 6 d prior to complete ice-off of the upper lake and removed 5 August, after downstream migration had ceased. Despite extremely high flows in 1995, the trap was maintained throughout the runoff. However, fish passage around and sometimes over the trap was often possible from early June to mid-July due to over-bank flow.

A box trap was installed to capture adult grayling entering Odell Creek in the spring of 1994. Despite many attempts, the trap could not be maintained in this stream in 1995 due to extremely high flows. The 1994 trap was located approximately 5.0 river km upstream from the mouth of Odell Creek (Figure 1), just above the airstrip road bridge. This was the furthest, accessible, downstream location below all available spawning habitat. This trap was similar to the one used in Red Rock Creek in 1994, except that it was of a one-way design, only capturing fish moving upstream. The trap box measured 1.2 m long, 1.2 m wide, and 0.9 m high and was composed of the same materials as the Red Rock Creek trap box. The wings consisted of 1.5 m rigid panels composed of 1.0 m lengths of 1.0 cm aluminum pipe spaced at 1.9 cm. The trap enclosed the entire width (about 7.0 m) of the stream.

The Odell Creek trap was installed 25 April, during ice break-up on the lower lake and left in place until 30 June, well after the upstream migration of grayling had ceased. During the peak flow period (8 through 15 May) about one third of the weir was breached.

All traps were checked once to many times per day depending on the intensity of fish movement. In addition to fish captured in the traps, Montana Department of Fish, Wildlife and Parks (MDFWP) personnel electroshocked a section of Red Rock Creek a few kilometers upstream from the trap on 10 and 16 May, 1994, to obtain grayling gametes for transplanting into Roger's Lake of northwest Montana. All fish captured in the traps and by MDFWP were identified to species, classified to sex, weighed and measured (TL). All adult grayling and most adult cutthroat trout were marked with adipose fin clips and visual implant (V.I.) tags behind the left eye. Scales were taken from grayling from an area posterior of the dorsal fin above the lateral line for age and growth analysis. All fish were released in the direction of travel.

Water temperature was continuously recorded during the trapping periods in Odell Creek in 1994 and in Red Rock Creek in 1994 and 1995 with HOBO® thermographs placed near the traps.

Age, Growth, and Condition

Impressions of scales were made on sheets of cellulose acetate and examined using a NMI® 14 microfiche projector at 32.5 X magnification.

Back-calculated lengths of fish at each age were determined using LGMODEL computer program (Weisberg 1989), which is based on a linear approach to back-calculating fish growth.

Growth rates, regressions, and other calculations were performed on QUATTRO PRO® 4 computer software program. Fulton's condition factor (K) was computed for all Arctic grayling (ages I-VII) and adult cutthroat trout using the formula described by Nielsen and Johnson (1983):

$$K = \frac{100\,W}{L^3}$$

where K = condition factor

W = total weight (g)

L = total length (cm)

Age-0 Grayling

Distribution and residence time of 1994 age-0 grayling within Red Rock Creek were determined through visual observation and with the use of two drift nets and a seine. A fry-sampling area was established in Red Rock Creek near the adult fish trap which began at the Elk Lake Road Bridge and extended to a point approximately 0.7 km upstream. Beginning 11 June, the stream margins and backwater areas of this section were searched daily for the presence of fry. When fry were encountered, a 0.8 X 1.2 m, 1 mm meshed seine was used to capture specimens to verify identification and to measure total length. Distribution and relative abundance were also noted. Several other areas were occasionally examined for the presence of age-0 grayling including the spawning area and the mouth of Red Rock Creek. Most measurements were made in the field and live fry were released. Some samples were preserved in 10% formalin for later measurement.

Two 1.0 m-long stationary drift nets were secured in the thalweg of the stream in an attempt to sample downstream-drifting fry. One was located directly upstream from the adult fish trap and the other was located further upstream, just below the spawning area. Each was constructed of 0.5 mm nylon mesh, had a 30 X 60 cm opening and tapered down to a 1 mm mesh collection box with baffles. They were installed 5 June, checked daily, and removed 8 July. Fry were separated from debris, identified, counted, and measured for total length. Live fry were released below the trap.

Spawning Habitat

The only spawning area known to be used by Red Rock lakes grayling in recent years is a stretch of Red Rock Creek approximately 0.5 km long and located about 13.5 km above the upper lake, between the confluences of Corral Creek and Antelope Creek. This stretch has been a very important spawning area in the past for both Arctic grayling and cutthroat trout (Dick Oswald, MDFWP, and Ken Niethammer, USFWL, pers. comm.) and was determined both visually and through electroshocking to be used in 1994 and 1995. This stretch will be referred to as the "spawning area."

Evaluation of spawning habitat was limited to determining and quantifying substrate composition at the spawning area. A more thorough investigation was planned for 1995 but was not possible because of high flows and turbidity during the spring and early summer.

The spawning area was surveyed on 12 September, 1994, 4 months after spawning activity had ceased. Substrate composition was determined by visually estimating the diameter of the substrate type along transects. Transects were run perpendicular to flow at 10 m intervals along a 250 m stretch of the spawning area. Diameters of both the dominant and subdominant substrate types were recorded along each transect at 0.5 m intervals. Bottom materials were classified according to a modified Wentworth classification system (Cummins 1962) as bedrock (unbroken, solid rock), boulder (>256 mm), cobble (64-256 mm), pebble (16-64 mm), gravel (2-16 mm), and fines (<2 mm).

Historic Spawning Streams

During the study all historically important spawning streams of the upper Centennial Valley were examined for the presence of Arctic grayling (Figure 1 and Table 1). In addition, several other small, unnamed tributaries were examined, including a few small spring creeks along the south shore of the Upper Lake. Investigations consisted of walking the streams from their mouths to their sources or points considered to be impassable by fish and visually searching for grayling. All streams were examined at times coinciding with the 1994 and 1995 Red Rock Creek spawning runs as well as various times throughout both summers. Red Rock Creek, Corral Creek, and Odell Creek were also examined with a back-pack electrofishing unit.

Table 1. Historic Arctic grayling spawning tributaries of the upper Centennial Valley.

Stream	Approximate length (km)	Tributary to	Last documented occurrence of grayling
Red Rock	20.9	Upper Red Rock Lake	1993 (Neithammer[1])
Hell Roaring	10.5	Red Rock Creek	1952 (Nelson 1954)
Corral	4.8	Red Rock Creek	1993 (Neithammer[1])
Antelope	4.8	Red Rock Creek	1952 (Nelson 1954)
Battle	7.2	Red Rock Creek	1952 (Nelson 1954)
Elk Springs	8.9	Upper Red Rock Lake	1961 (USFWS 1978)
Picnic	1.4	Elk Springs Creek	1954 (USFWS 1978)
Tom	7.7	Upper Red Rock Lake	1976 (MDFG 1977)
East Shambow	1.3	Upper Red Rock Lake	?? (USFWS 1978)
Grayling	1.6	Upper Red Rock Lake	?? (USFWS 1978)
Odell	19.3	Lower Red Rock Lake	1991 (Neithammer[1])
Narrows	1.9	Elk Lake	1993 (Neithammer[1])

[1] Ken Neithammer, USFWS, Personal Communication, 1994

RESULTS

Trapping Conditions

The field seasons of 1994 and 1995 were very different, with neither year considered "normal" for the area (USFWS, unpublished data). Upper Red Rock Lake became free of ice on 26 April, 1994, and the Red Rock Creek fish trap was installed on 28 April. Due to unseasonably warm weather in early May, flows increased rapidly resulting in large debris loads and highly erodible substrates. These conditions made maintenance of a fish-tight weir difficult. Small blow-outs under the weir occurred daily until the trap was completely breached on 9 May. Six days later (15 May), after flows had receded, the trap was reinstalled. Grayling migration appeared to be peaking just before the trap was blown out and therefore, considerable fish movement probably occurred during the breach period. The trap was removed on 15 July, after downstream movement appeared to have ended. Drought conditions occurred throughout the remainder of the summer.

In 1995, the resistance-board weir and trap were installed 4 May and the upper lake became free of ice on 10 May. Frequent storms and cool spring temperatures helped slow runoff, but by mid-May water levels had begun to rise. Flows steadily increased, not peaking until mid- to late-June. At times the entire trap was submerged. Overbank flow continued for nearly 40 d, during which, most fish movement occurred. The trap was maintained throughout this period, however fish passage was often possible over and around the weir. The trap was removed 5 August after downstream movement had ceased. During the trapping period, water levels never returned to pre-runoff conditions.

Stream temperatures in Red Rock Creek varied markedly between the trapping periods of 1994 and 1995 (Figure 3). Daily mean stream temperatures during grayling upstream migration ranged from 6.0 to 10.3 °C in 1994 and from 2.6 to 9.0 °C in 1995. Downstream migration occurred over daily mean temperatures ranging from 5.0 to 17.5 °C in 1994 and from 4.4 to 11.0 °C in 1995. The maximum and minimum temperatures recorded during the 1994 trapping season were 22.5 (22 July) and 3.0 °C (14 May), while the maximum and minimum temperatures recorded during the 1995 season were 15.8 (7 July) and 0.8 °C (6 May).

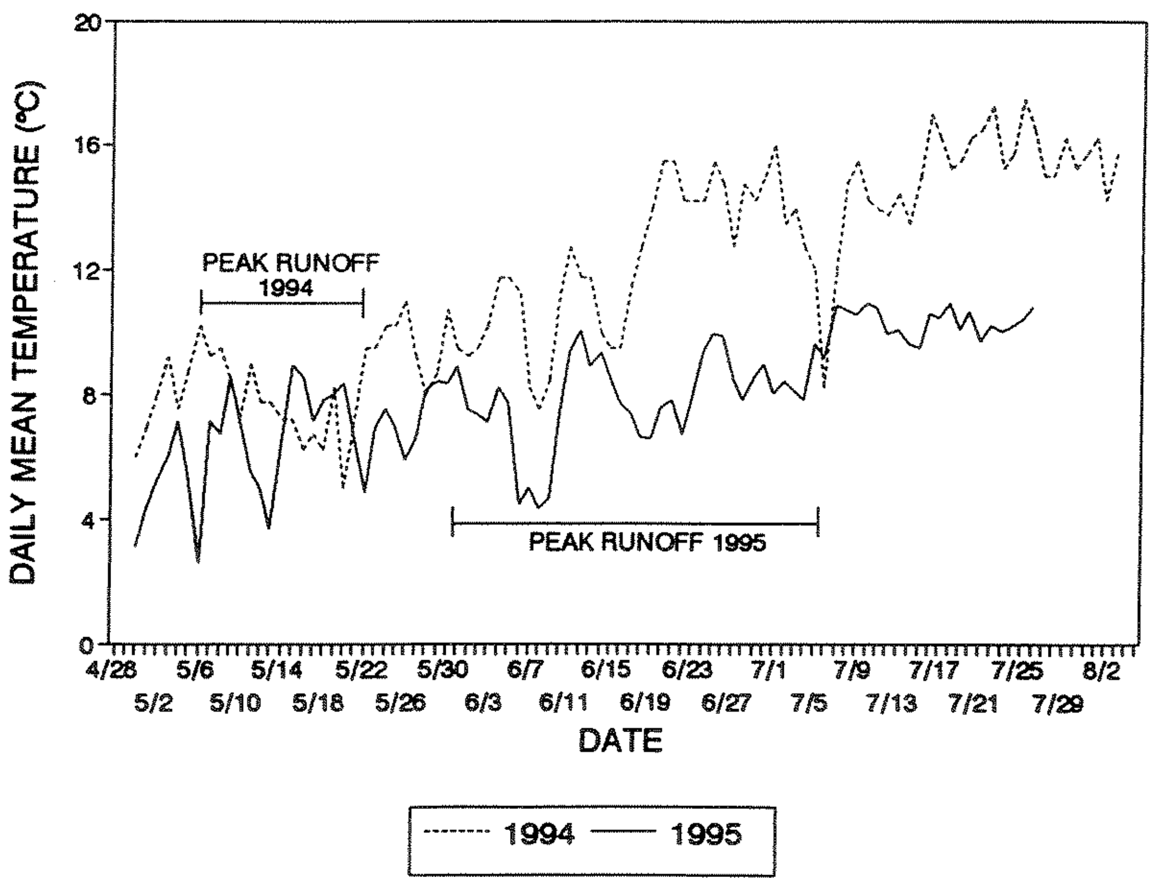


Figure 3. Mean daily temperatures (°C) in Red Rock Creek, May-July, 1994 and 1995.

Stream temperatures in Red Rock Creek peaked in the late afternoon, while peak flows and the coolest temperatures occurred in the early morning.

Conditions in Odell Creek during the study were similar to Red Rock Creek. Except during the peak runoff period, 8-15 June, a trap was maintained from 25 April to 30 June, 1994. Daily mean stream temperatures in Odell Creek varied from 3.3 to 15.5 °C (Figure 4). Upstream migration of grayling occurred over daily mean temperatures ranging from 6.0 to 14.0 °C. The maximum and minimum temperatures

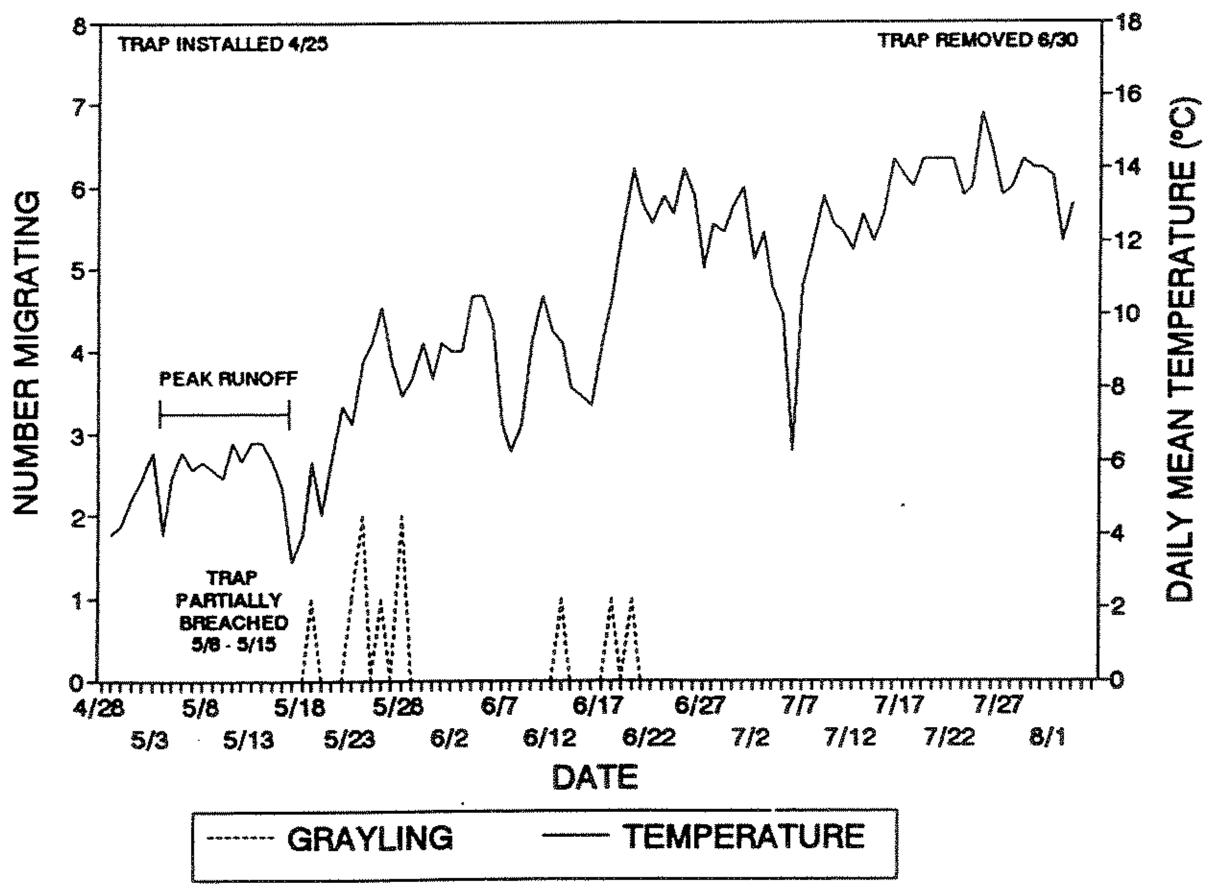


Figure 4. Chronology of Arctic grayling upstream movement and corresponding mean daily temperatures (°C) in Odell Creek, May-July, 1994.

recorded in Odell Creek during the 1994 field season were 19.5 (21 July) and 0.5 °C (30 April). Due to extremely high flows in 1995, a trap could not be maintained in Odell Creek.

Spawning Migrations

Chronology of the 1994 Red Rock Creek Spawning Run

In 1994, Arctic grayling moving upstream in Red Rock Creek were first captured on 1 May, 3 d after the trap was installed and 5 d after complete ice-off of the upper lake. Grayling began upstream movement as stream temperatures and flows increased, and first appeared at the trap when the mean daily stream temperature was 6.5 °C (Figure 5). Migration peaked with the capture of 37 grayling on 7 May. Upstream movement ended during the peak flow period, sometime between 9 and 15 May (while the trap was breached). Actual spawning activity occurred 9-25 May at daily mean temperatures ranging from 5.0 to 11.0 °C (maximum temperatures ranging from 6.0 to 15.0 °C). The first downstream migrant was captured 16 May, 1 d after the trap was reinstalled (Figure 5). Downstream movement increased daily and peaked around 23 May. Most outmigration occurred between 16 May and 6 June, signaling the completion of spawning activity. A number of grayling, however, remained in the stream throughout the summer as evidenced by angling and visual observation.

On 10 and 16 May, 1994, Montana Department of Fish, Wildlife and Parks (MDFWP) electroshocked the spawning area to obtain grayling gametes for transplanting. On 10 May, 35 grayling were captured, however few fish were ripe. Daily mean stream temperature was 7.2 °C.

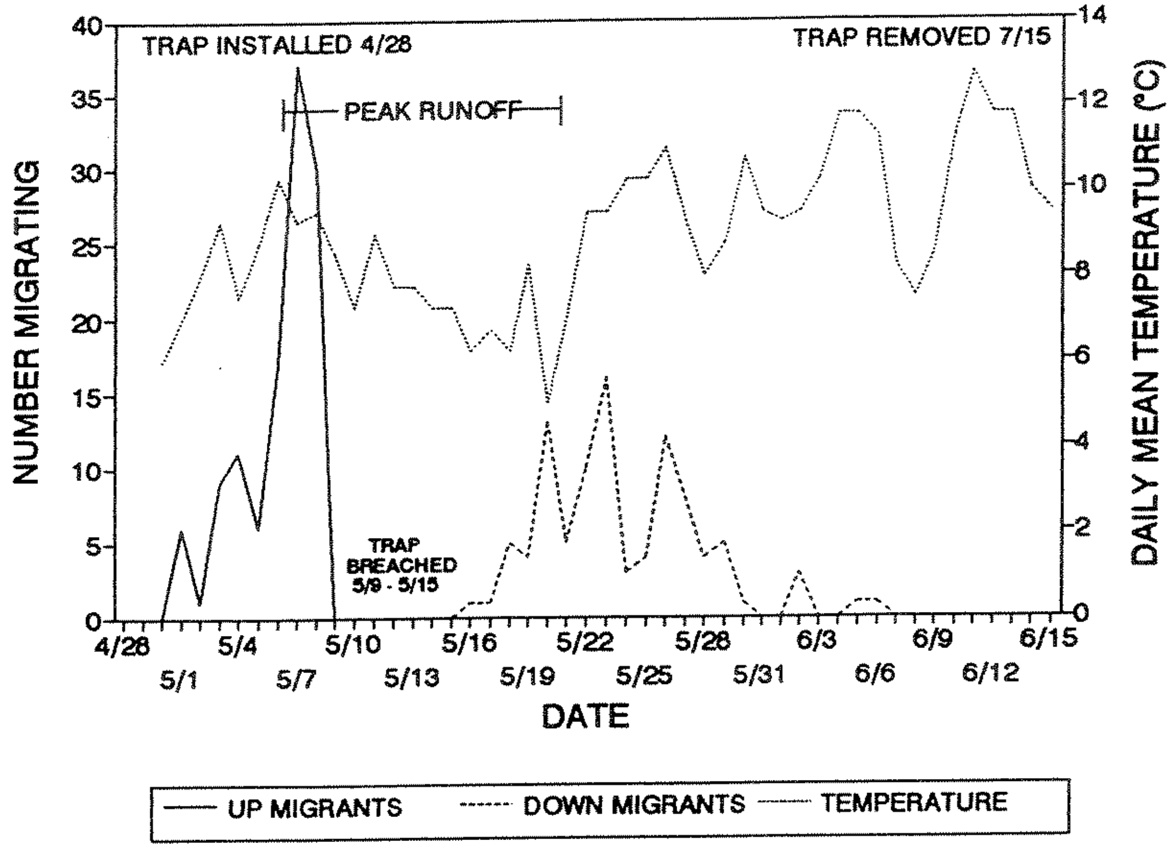


Figure 5. Chronology of Arctic Grayling spawning migrations and corresponding mean daily temperatures (°C) in Red Rock Creek, 1994.

On 16 May, when the mean daily temperature was 6.5 °C, 64 grayling were captured and most were ripe.

<u>Chronology of the 1995 Red Rock Creek Spawning Run</u>

Spawning movements of grayling in 1995 began approximately 13 d later and ended approximately 30 d later than in 1994. The first upstream migrant was captured 5 May, 1 d after the trap was installed and 5 d before the lake had become ice-free; most upstream movement

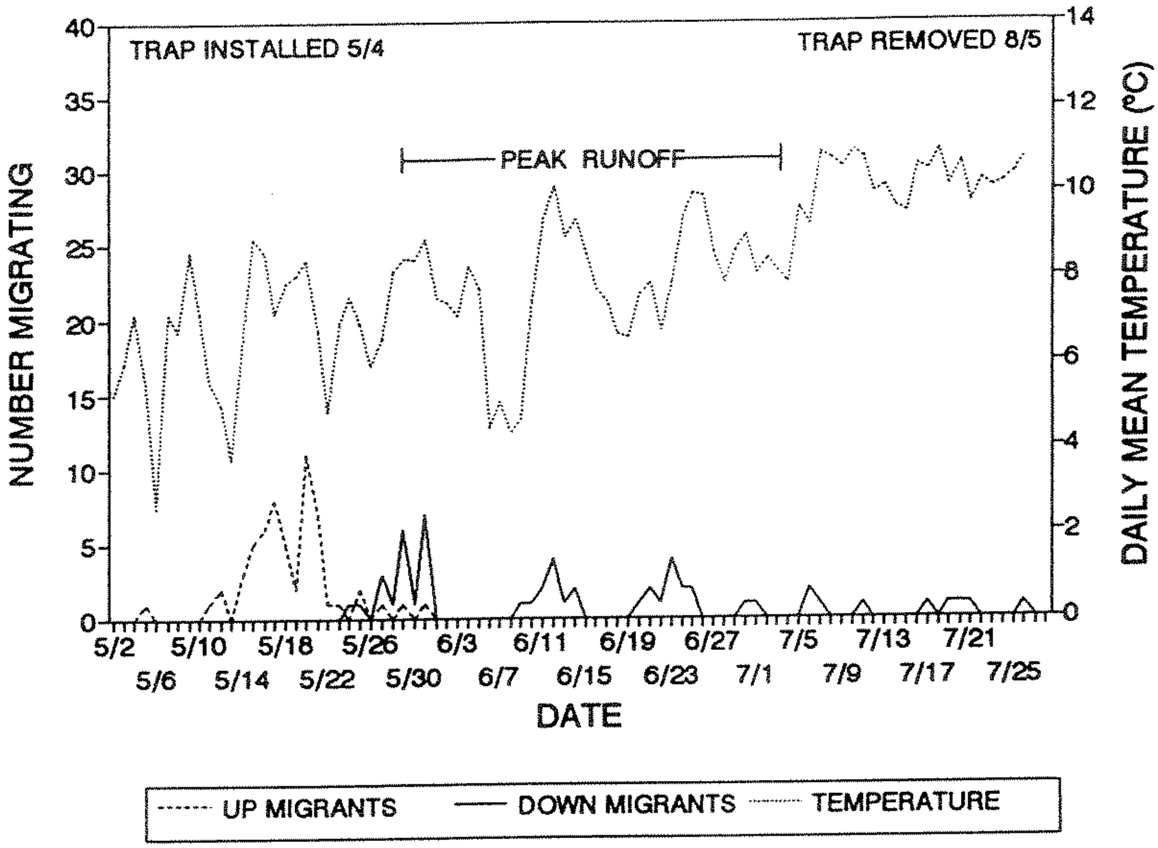


Figure 6. Chronology of Arctic Grayling spawning migrations and corresponding mean daily temperatures (°C) in Red Rock Creek, 1995.

occurred after 10 May (Figure 6). Grayling began their spawning migration as temperatures and flows increased and first appeared at the trap when the mean daily stream temperature was 5.5 °C. Upstream migration peaked around 20 May and ended 31 May. Downstream movement of post-spawn grayling began on 24 May and appeared to end in late July (Figure 6). Because high and turbid flows continued through most of the summer, angling and visual observation of grayling in the stream were not effective. Actual spawning activity was not observed in 1995, however it appears to have occurred in late-May through mid-June as evidenced by timing of up- and downstream migration. Daily mean temperatures during this period ranged from 4.5 to 10.1 °C (maximum temperatures ranged from 5.8 to 15.0 °C).

A diel pattern of movement was observed in both years. In general, most upstream migration occurred in the late afternoon and evening when stream temperatures were greatest and flows were at a minimum, while the majority of downstream movement occurred during the night and early morning associated with increasing flows and decreasing temperatures. Upstream migration was generally accelerated by warmer temperatures and inhibited by cooler temperatures.

Timing of outmigration in Red Rock Creek appeared to differ between sexes with males generally remaining in the stream longer than females (Figure 7). Stream residency calculated for grayling captured on both upstream and downstream migration averaged 17.7 d (sd 11.2) for females and 34.8 d (sd 10.2) for males during the study and were significantly different (two-sample t-test, $P<.001$). Of the first 55 downstream migrants captured in 1994, only one was a male. By the time the trap was removed, well after outmigration had peaked, a total of 85 out-migrating females had been captured as compared to only 12 males. This ratio of 7.1 females to 1.0 male was very different than the 1.7 to 1.0 ratio (73 F : 44 M) observed during upstream migration. In 1995, only 2 of the first 21 outmigrants captured (24 May to 9 June) were males. However, by the end of the trapping period 38 female and 16 male outmigrants had been captured. This ratio of 2.4 females to 1.0 male was similar to that observed during upstream migration (41 F : 17 M). Differences may have been greater had the trap been installed sooner and

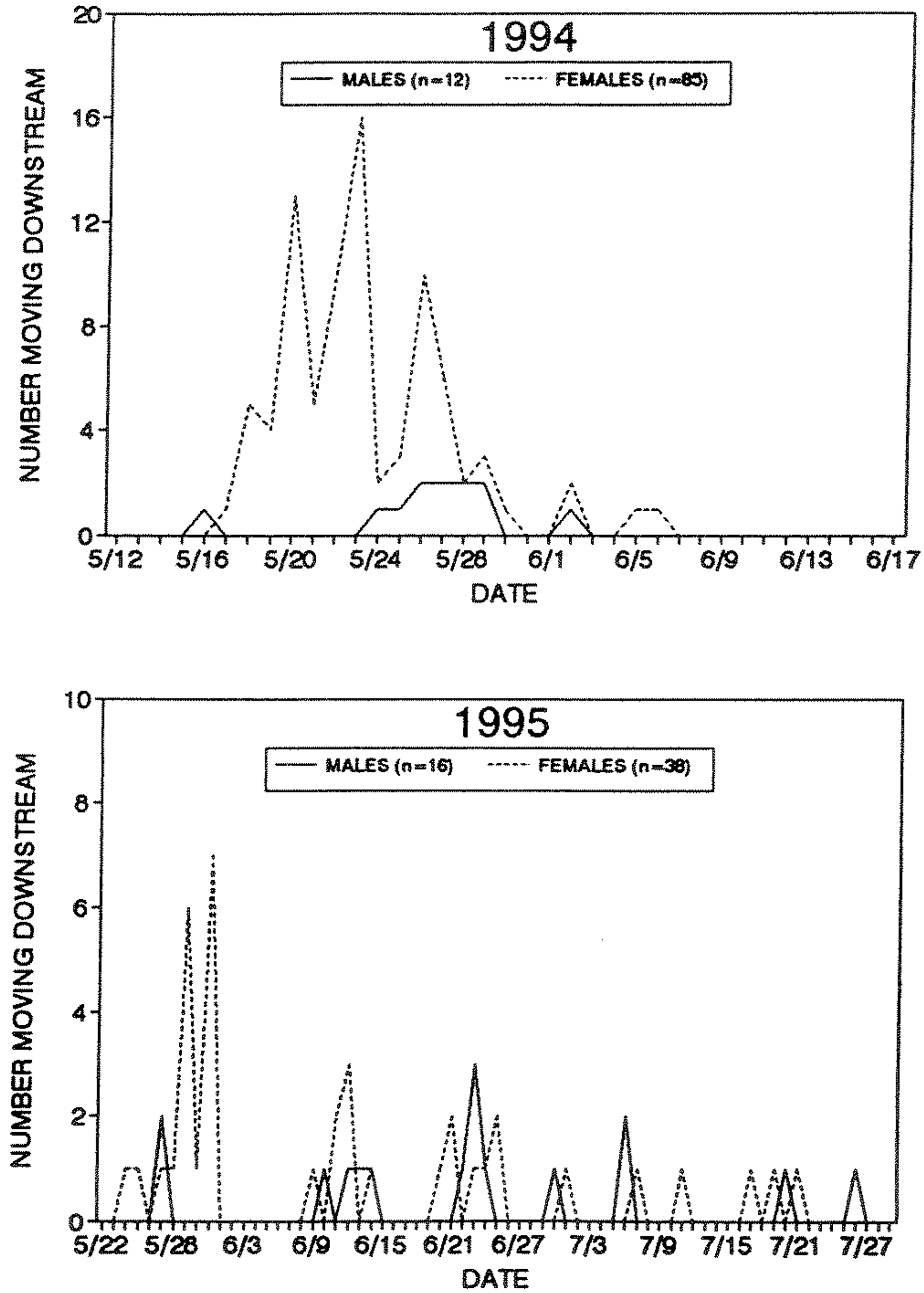


Figure 7. Downstream movements of Arctic grayling by sex in Red Rock Creek, 1994 and 1995.

maintained throughout the summer in both years. Many males captured on their downstream migration were not marked, suggesting that they may have entered the stream before the traps were installed. Males were also more commonly found in the stream throughout the summer of 1994, as evidenced by angling and visual observation.

Red Rock Creek Catch Statistics

A total of 241 adult grayling was captured in Red Rock Creek in 1994 compared to 85 in 1995 (Table 2). Grayling females outnumbered

Table 2. Numbers, sex ratios, and means and ranges of total length (mm), pre-spawning weight (g) and condition factor (K), and post-spawning weight and condition factor of all adult Arctic grayling captured in Red Rock Creek, 1994 and 1995.

	1994			1995		
	Male	Female	Combined	Male	Female	Combined
Total Number	86	155	241	27	58	85
Sex Ratio (M:F)			1:1.8			1:2.1
Mean Length	378	392	387	357	357	357
(s.d.)	(38.2)	(37.9)	(32.6)	(34.5)	(42.0)	(38.0)
range	300-430	311-436	300-436	297-426	263-425	263-426
Pre-spawn Conditions						
Number measured	43	73	116	15	39	54
Mean Weight	638	767	719	510	521	518
(s.d.)	(156.8)	(118.8)	(147.9)	(98.0)	(170.1)	(153.6)
range	255-865	290-990	255-990	305-710	225-860	225-860
Mean K	1.07	1.19	1.15	0.97	1.07	1.04
(s.d.)	(0.12)	(0.10)	(0.12)	(0.06)	(0.11)	(0.11)
Post-spawn Conditions						
Number measured	7	61	68	18	36	54
Mean Weight	499	523	520	410	431	424
(s.d.)	(113.7)	(113.3)	(113.6)	(100.2)	(117.6)	(112.5)
range	305-650	290-690	290-690	246-555	225-660	225-660
Mean K	0.99	0.96	0.96	0.96	0.94	0.94
(s.d.)	(0.10)	(0.10)	(0.10)	(0.08)	(0.11)	(0.10)

males in the runs by ratios of 1.8 to 1.0 in 1994 and 2.1 to 1.0 in 1995. The average size of adult grayling declined from 1994 to 1995. The overall mean total length, pre-spawn weight, and post-spawn weight were 30 mm, 201 g, and 96 g less, respectively, in 1995 than in 1994. On average, males were 21 mm shorter and 89 g lighter in 1995 than 1994, while females were 35 mm shorter and 92 g lighter in 1995 than 1994.

All fish appeared to be in excellent condition. Mean condition factors, however, declined in 1995, probably due to changes in size distribution (Table 2). Within each year, mean condition factor decreased from pre-spawn condition to post-spawn condition for both sexes of grayling. Male grayling declined from 1.07 to 0.99 in 1994 and from 0.97 to 0.96 in 1995. Female grayling showed more pronounced declines; from 1.19 to 0.96 in 1994 and from 1.07 to 0.94 in 1995.

Chronology of the 1994 Odell Creek Spawning Run

Only 10 grayling were trapped in Odell Creek in 1994. The first migrant was captured 19 May, 4 d after flows had peaked, when mean daily stream temperature was 6.0 °C. Although no peak in migration was detected, movement was most pronounced between 23 and 28 May (mean daily temperatures ranging from 7.0 to 10.3 °C), during which 6 of the 10 grayling were captured (Figure 4). The last upstream migrant was captured on 20 June. In addition to grayling, 14 cutthroat trout (Table 3), 10 brook trout (Table 3), 235 white suckers, 1 burbot, and 1 longnose dace were captured in the Odell Creek trap.

On 30 June, the day the Odell Creek trap was removed, grayling were observed feeding on the surface of the first pool above the trap. From this pool, 7 grayling and 2 brook trout were caught by angling. Of the 7 grayling, 2 were unmarked bringing the total number of grayling captured in Odell Creek in 1994 to 12. Eleven of the 12 grayling appeared to be sexually mature. A male to female sex ratio of 1.00 : 1.75 was observed and age-classes I to VI were represented. Adult grayling lengths ranged from 310 to 421 mm while weights varied from 255 to 830 g (Table 3). All fish appeared to be in excellent condition.

Table 3. Numbers and means and ranges of total length (mm), weight (g), and condition factor (k) of adult Arctic grayling and cutthroat and brook trout captured in Odell Creek, 19 May to 30 June, 1994.

	Arctic grayling			Cutthroat trout	Brook trout
	Males	Females	Combined		
Total number	4	7	11	14	10
Sex ratio (M:F)			1.00:1.75		
Mean length	386	362	371	232	242
(s.d.)	(45.9)	(39.0)	(41.1)	(56.2)	(24.4)
range	320-421	310-414	310-421	168-330	208-284
Mean weight	570	534	547	132	154
(s.d.)	(193.3)	(223.0)	(203.2)	(100.6)	(51.4)
range	290-720	255-830	255-830	25-340	80-250
Mean K	0.96	1.06	1.02	0.84	1.04
(s.d.)	(0.16)	(0.17)	(0.16)	(0.13)	(0.06)
range	0.83-1.21	0.78-1.30	0.78-1.30	0.71-1.08	0.89-1.09

Length Frequencies

Arctic grayling ranged from 178 to 436 mm and from 155 to 426 mm total length in 1994 and 1995, respectively. Although total numbers were much lower in 1995, a shift in age structure from older, longer fish to younger, shorter fish occurred (Figure 8). In 1994, 60% of the

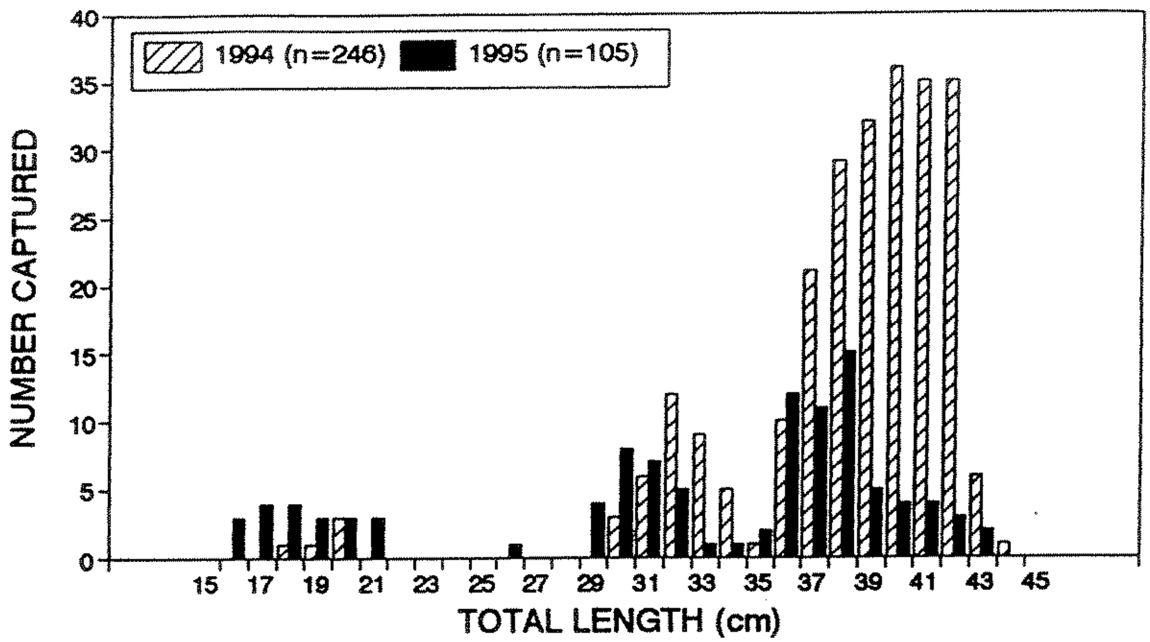
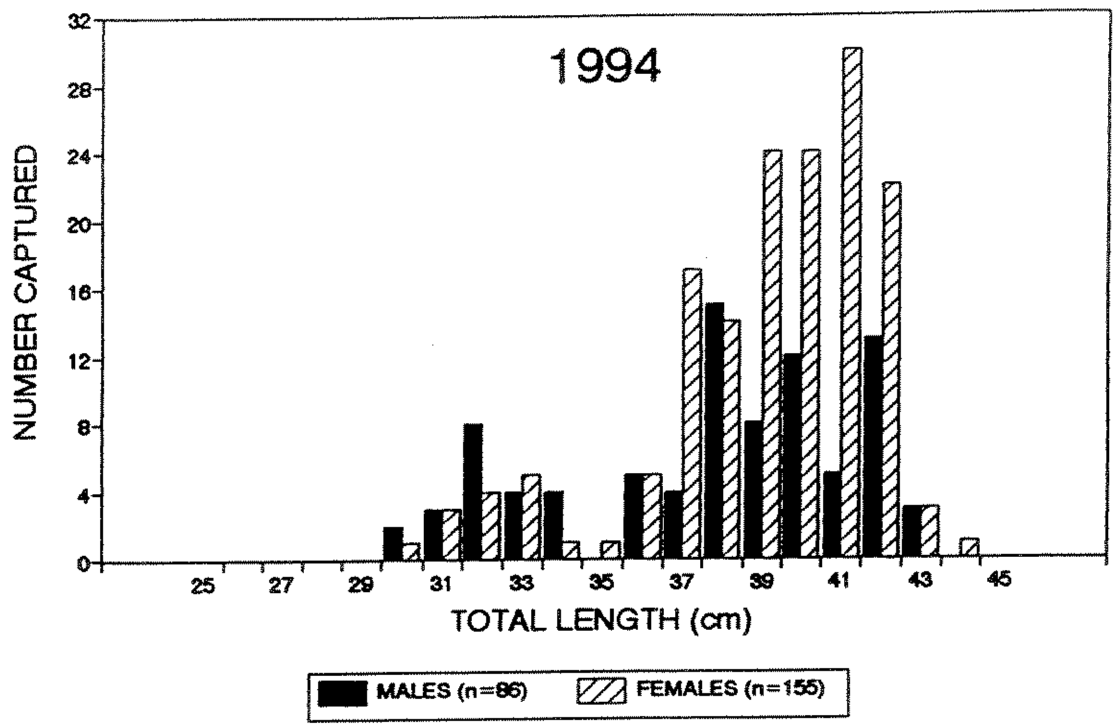


Figure 8. Length frequencies by year of all Arctic grayling captured during spawning migrations in Red Rock Creek, 1994 and 1995.

spawning run was composed of grayling with total lengths greater than 385 mm as compared to only 21% in 1995. Female lengths ranged 311 to 436 mm in 1994, while males ranged from 300 to 430 mm. In 1995, female lengths varied from 263 to 425 mm, and males ranged from 297 to 426 mm. Proportionally more females made up the larger size classes in both years (Figure 9). In 1994, the mean length of females (392 mm) was 14 mm greater than males (378 mm), with 67% of the females greater than 385 mm, as compared to only 47% of the males. In 1995, 26% of the females were larger than 385 mm, as compared to only 11% of the males (Figure 9). Mean lengths, however, were identical (357 mm) for the sexes in 1995. Juvenile (age-I) grayling lengths ranged from 178 to 203 mm in 1994 and from 155 to 211 mm in 1995 (Figure 8).



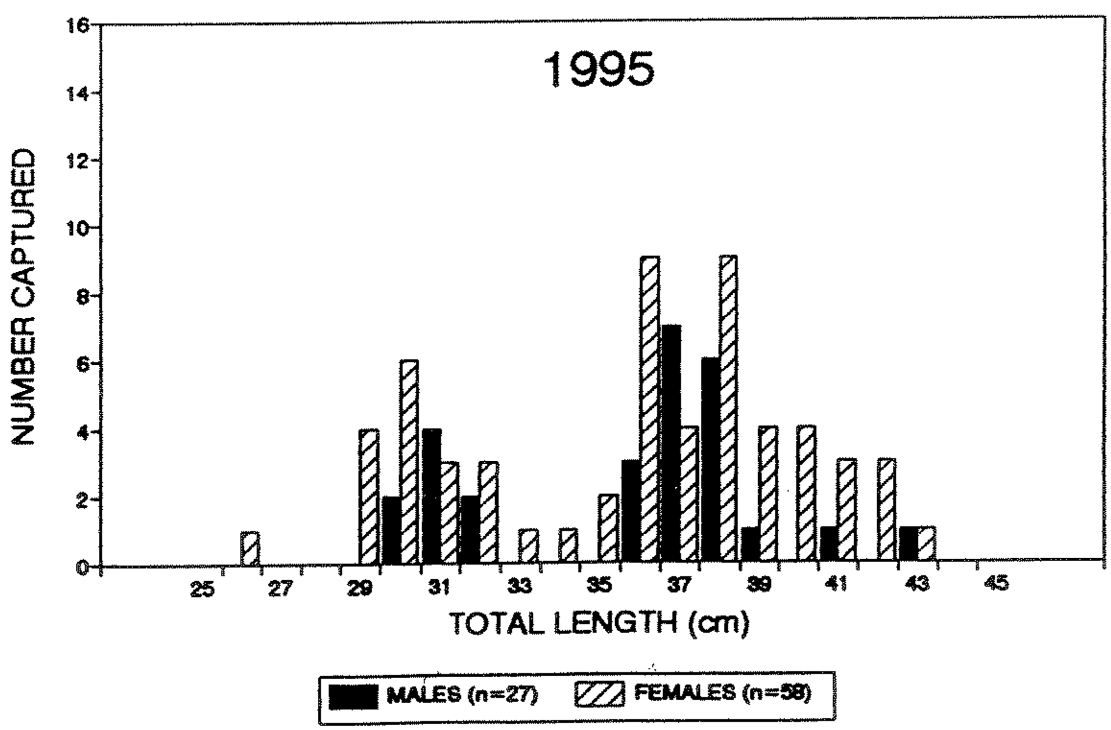


Figure 9. Length frequencies by sex of all Arctic grayling captured during spawning migrations in Red Rock Creek, 1994 and 1995.

Age and Growth

Age and growth data were obtained from analysis of 351 scale samples collected during the Red Rock Creek spawning runs. The mean lengths at capture for each sex and age class closely correspond with the distinct peaks in length frequencies (Table 4; Figure 9). Grayling trapped in 1994 were ages II-VII, while those trapped in 1995 were ages II-VI. A shift in age structure to younger fish in 1995 was apparent (Table 4; Figure 10). Ages II-III grayling only comprised 27% of the spawning run in 1994, as compared to 62% in 1995. Ages V+, however, made up 51% of the run in 1994, as opposed to only 18% in 1995.

Table 4. Numbers and mean total lengths (MTL) in millimeters of age-class by sex of adult Arctic grayling captured in Red Rock Creek, 1994 and 1995.

Age Class	Males		Females		Combined	
	Number(%)	MTL(sd)	Number(%)	MTL(sd)	Number(%)	MTL(sd)
			1994			
II	21 (24%)	322 (11)	12 (8%)	321 (11)	33 (14%)	322 (11)
III	9 (10%)	366 (7)	23 (15%)	366 (10)	32 (13%)	365 (10)
IV	23 (27%)	386 (4)	31 (20%)	386 (12)	54 (22%)	386 (6)
V	19 (22%)	407 (9)	49 (31%)	403 (7)	68 (28%)	404 (8)
VI	11 (13%)	420 (6)	34 (22%)	417 (8)	45 (19%)	418 (7)
VII	3 (4%)	427 (4)	6 (4%)	419 (14)	9 (4%)	422 (11)
Totals	86(100%)		155(100%)		241(100%)	
			1995			
II	8 (29%)	309 (8)	18 (31%)	301 (16)	26 (31%)	304 (14)
III	11 (41%)	368 (7)	16 (27%)	360 (9)	27 (32%)	363 (8)
IV	6 (22%)	381 (5)	11 (19%)	381 (4)	17 (20%)	381 (3)
V	1 (4%)	408 (0)	5 (9%)	400 (9)	6 (7%)	402 (8)
VI	1 (4%)	426 (0)	8 (14%)	413 (8)	9 (10%)	414 (9)
VII	0 (0%)	-	0 (0%)	-	0 (0%)	-
Totals	27(100%)		58(100%)		85(100%)	

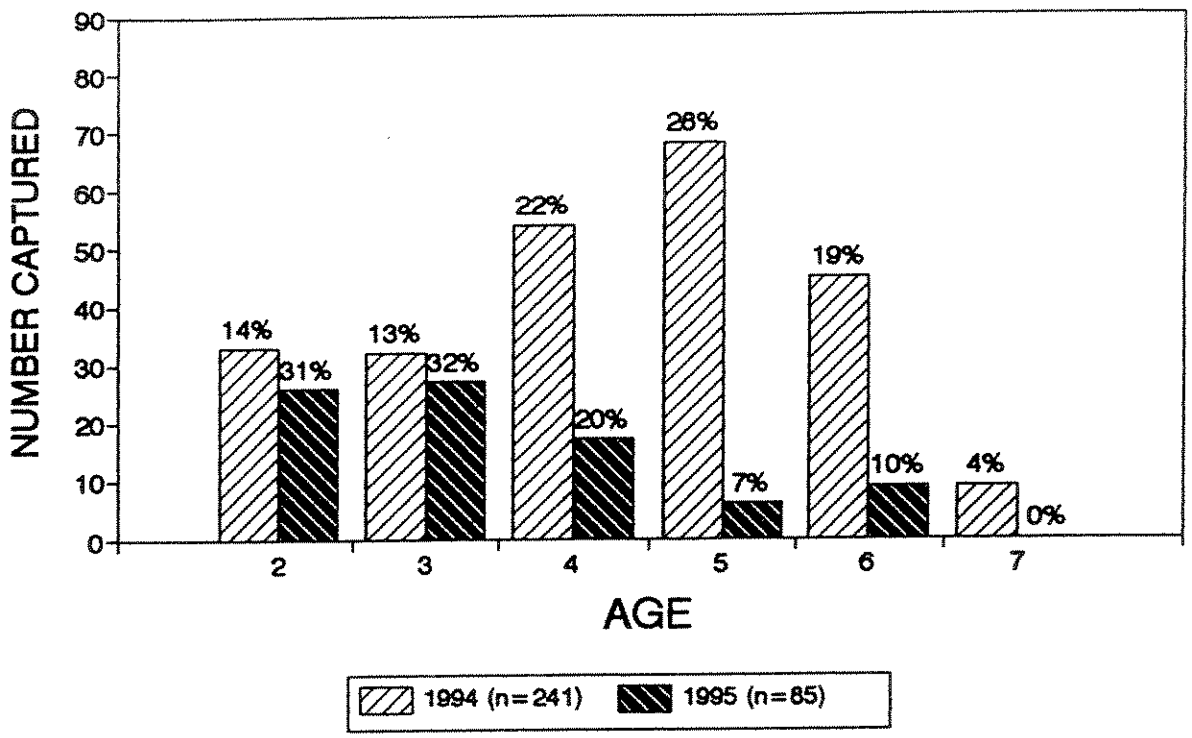


Figure 10. Age distribution of all adult Arctic grayling captured during spawning migrations in Red Rock Creek, 1994 and 1995.

Red Rock grayling mature at ages II and III. In both years, the total number of spawners in each of these ages-classes was similar (Table 4). Males generally averaged slightly longer than females at each age, with larger differences typically observed with older fish (Table 4). Differences were more pronounced in 1995 than in 1994, however sample sizes were much smaller. There also appears to be a difference in longevity and age at maturity between the sexes. In the 1994 spawning run the overall male : female sex ratio was 1.0 : 1.8, however, a ratio of 1.00 : 1.17 (30 : 35) was observed for ages II-III as compared to 1.00 : 2.70 (33 : 89) for ages V-VII. In the 1995 run the overall sex ratio was 1.0 : 2.1, but the sex ratio observed for ages II-III was 1.00 : 1.78 (19 : 34) as opposed to 1.00 : 6.50 (2 : 13) for ages V-VI. In both years, the younger age groups had a greater proportion of males relative to females versus the older age groups, suggesting that males in this population are generally shorter lived and mature earlier than females.

Average calculated length at succeeding annuli, and annual increments of growth for 351 grayling collected from Red Rock Creek are presented by sex in Appendix A Table 15. Although calculated lengths for males were generally greater than for females for most ages, differences were small, and therefore sexes were pooled (Table 5).

Growth rate is greatest during the first year of life, slowing slightly in the second year, and then declining sharply after maturity. Growth becomes fairly stable after 3 years, with annual increments of approximately 10 to 20 mm (Table 5). The oldest grayling sampled were age-VII.

Table 5. Average calculated total lengths (mm) at succeeding annuli and annual increments of growth for Arctic grayling collected from Red Rock Creek during the spawning runs of 1994 and 1995.

Age	Number (%)	Mean length at capture (sd)	range	Back-calculated length at each age 1	2	3	4	5	6	7
			1994							
I	5 (2)	192 (10.1)	178-203	191						
II	33 (13)	322 (10.6)	300-340	192	322					
III	32 (13)	365 (10.5)	330-379	191	322	365				
IV	54 (22)	386 (6.0)	372-396	192	322	366	386			
V	68 (28)	404 (7.9)	390-423	192	322	366	386	404		
VI	45 (18)	418 (6.9)	397-431	191	321	365	385	404	418	
VII	9 (4)	422 (11.2)	400-436	191	321	365	385	403	417	422
Total	246 (100)									
Average				192	322	365	385	404	418	422
Increment				192	130	43	20	19	14	4
Number				246	241	208	176	122	54	9
			1995							
I	20 (19)	185 (17.8)	153-211	182						
II	26 (25)	304 (14.2)	263-327	188	308					
III	27 (26)	363 (8.4)	340-375	185	311	360				
IV	17 (16)	381 (3.5)	375-390	185	308	364	379			
V	6 (6)	402 (7.8)	391-412	181	304	356	378	399		
VI	9 (8)	414 (8.5)	404-426	189	307	360	379	406	416	
VII	0 (0)									
Total	105 (100)									
Average				185	309	361	379	403	416	
Increment				185	124	52	18	24	13	
Number				105	85	59	32	15	9	
Grand Average				190	319	364	384	404	418	422
Increment				190	129	45	20	20	14	4
Number				351	326	267	196	137	68	9

Recaptures

Only 20 (8%) of the 241 adult grayling marked in 1994 were recaptured in 1995, accounting for 24% of the total catch (85) in 1995. Of these recaptures, 13 (65%) were ages V-VI and 18 (90%) were females (Table 6). Tags were retained in 16 (80%) of the recaptures which allowed individual growth from 1994 to 1995 to be calculated. Although the numbers of recaptures were small, mean increases in length for each age-class were very similar to annual increments of growth calculated from scale readings (Table 5).

Table 6. Individual increase and mean increase per age-class in total length (mm) from 1994 to 1995 of 16 recaptured Arctic grayling. Recaptures with missing tags (*) included but not used in calculations.

	Age		Total length		Individual	Mean increase
Sex	1994	1995	1994	1995	increase	per age-class
F	2	3	313	357	44	
F	2	3	302	356	54	49.0
F	3	4	*	376	*	
F	3	4	*	379	*	
M	3	4	368	381	13	
F	3	4	355	375	20	
F	3	4	359	385	26	19.7
F	4	5	*	390	*	
F	4	5	380	391	11	
F	4	5	385	402	17	
F	4	5	386	405	19	
F	4	5	389	412	23	17.5
F	5	6	*	407	*	
F	5	6	403	404	1	
F	5	6	417	419	2	
F	5	6	404	410	6	
F	5	6	412	418	6	
F	5	6	410	420	10	
M	5	6	414	426	12	
F	5	6	410	425	15	7.4

Age-1 Arctic Grayling

Adult fish traps were not designed to capture juvenile fish. Spacing between the pickets of the weir was sufficiently large (>2.0 cm) to allow passage of age-1 grayling. However, in both years a small number was captured. Five were captured in 1994 (all downstream migrants) and 21 in 1995. Except for the first one in 1995 (27 May), all were captured in the downstream trap (16 June - 31 July). Movement of age-1 grayling appeared to correspond with the timing of adult migration. In addition, 11 age-1 grayling were electroshocked in Red Rock Creek during this period. As with adults, all juvenile grayling appeared to be in excellent condition, but average size declined in 1995 (Table 7).

Table 7. Means and ranges of total length (mm), weight (g), and condition factor (K) of age-1 Arctic grayling captured in Red Rock Creek in June and July, 1994 and 1995.

Year	N	Mean length (s.d.) range	Mean weight (s.d.) range	Mean K (s.d.) range
1994	5	192.2 (10.2) 178 - 203	60.2 (10.5) 45 - 70	0.84 (0.05) 0.75 - 0.89
1995	32	182.5 (18.0) 145 - 211	54.2 (16.0) 29 - 76	0.83 (0.06) 0.71 - 0.97

Age-0 Arctic Grayling

Age-0 grayling were first captured from Red Rock Creek on 10 June, 1994, approximately 32 d after initial spawning activity (Table 8). Daily mean temperatures ranged from 5.0 to 11.0 °C during the incubation period. These grayling had a mean total length of 12.3 mm and were captured directly below the spawning area in a stationary drift net secured in the thalweg of the stream. Stream margins in the area were examined for the presence of grayling fry, but none were found.

Age-0 grayling first appeared in the fry sampling area downstream near the adult fish trap on 12 June. Abundance increased daily and seemed to peak about 18 June, approximately 33 d after the peak of spawning activity (Table 8). Grayling fry were consistently observed throughout the area along the stream margins and in backwater areas. Sampling of age-0 grayling from these areas continued from 12 June until they disappeared around 25 June, 13 d later. Yolk sacs were totally absorbed on all sampled fry. Mean total lengths during this period ranged from 14.7 mm on 12 June to 28.5 mm on 25 June.

Table 8. Number of days between the beginning and the peak of spawning activity and the beginning and peak of age-0 grayling emigration in Red Rock Creek, 1994.

Approximate date of event		Difference in days
Initial spawning 9 May	Initial fry emigration 10 June	32
Peak of Spawn 16 May	Peak fry emigration 18 June	33

Lengths of age-0 grayling captured in Red Rock Creek in 1994 ranged from 12-13 mm on 10 June, the first day they were sampled, to 27-30 mm on 25 June, the last day fry were observed (Figure 11; Table 9). The relationship between total Length (TL) and observation day (OD) during stream residence was:

$$TL = 1.05(OD) + 12.69; \qquad R = 0.932 \qquad df = 92$$

Observation day 0 is defined as the first day age-0 grayling were captured. This first sample was obtained directly downstream from the spawning area. Assuming that these fish had recently swam up, observation day 0 can also be defined as the first day of swim-up. Therefore, age-0 grayling at the time of swim-up have an estimated total length of about 12 mm which is consistent with the data.

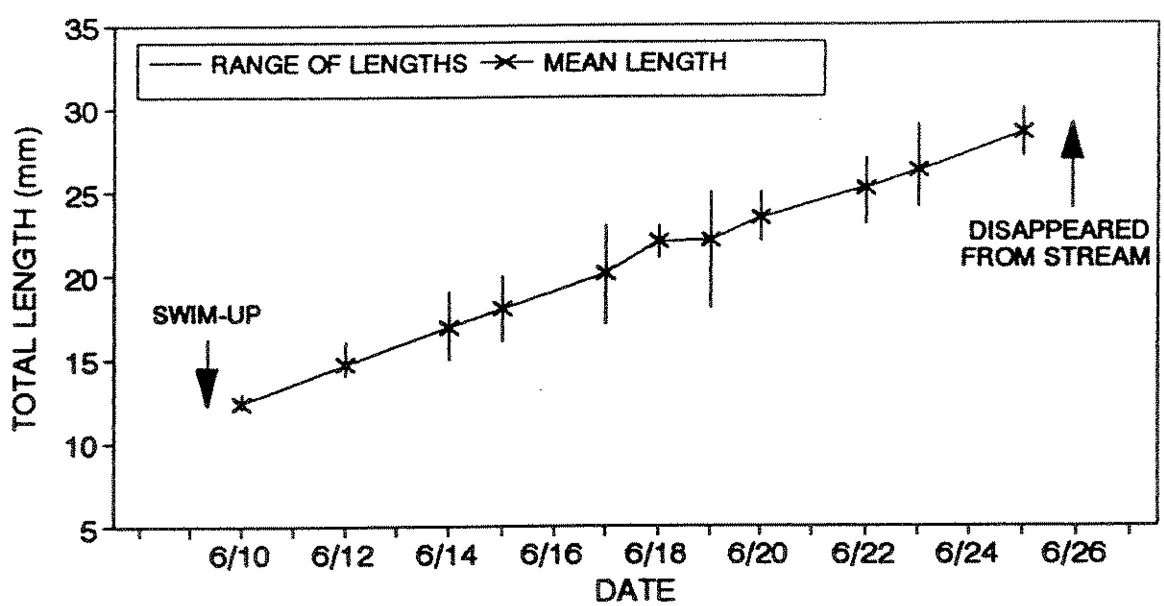


Figure 11. Means and ranges of total lengths (mm) of age-0 Arctic grayling sampled from Red Rock Creek during stream residency, June 1994

Table 9. Mean and range of total lengths (mm) of age-0 Arctic grayling sampled in Red Rock Creek, 10-25 June 1994.

Date	N	Mean (SD)	Range	Method/location
10 June	3	12.3 (0.6)	12-13	Upper drift net[1]
12 June	3	14.7 (1.2)	14-16	Seine[3]
13 June	2	14.0 (0.0)	14	Upper drift net[1]
14 June	11	16.9 (1.2)	15-19	Seine[3]
15 June	7	18.0 (1.3)	16-20	Seine[3]
15 June	1	15.0 -	15	Upper drift net[1]
17 June	15	20.1 (1.7)	17-23	Seine[3]
18 June	2	22.0 (1.4)	21-23	Lower drift net[2]
19 June	17	22.1 (1.9)	18-25	Seine[3]
20 June	13	23.4 (1.2)	22-25	Seine[3]
22 June	10	25.2 (1.3)	23-27	Seine[3]
23 June	11	26.2 (1.7)	24-29	Seine[3]
25 June	2	28.5 (2.1)	27-30	Seine[3]

[1] Drift net located in the thalweg directly downstream from the spawning area.

[2] Drift net located in the thalweg directly upstream from the adult fish trap.

[3] Samples collected with a seine along the stream margins and from backwater areas from a section of Red Rock Creek beginning at the Elk Lake Road bridge to a point approximately 0.7 km upstream.

During fry residency, mean daily temperatures in Red Rock Creek ranged from 9.5 to 15.5 °C. Rearing habitat consisted of slow water along the stream margins and backwater areas created by root wads, vegetation, and gravel bars. No apparent preference for depth or cover type was observed. Throughout their residency, age-0 grayling were frequently observed feeding on the surface of these areas. They were initially present in small groups of less than 20, consisting only of grayling. However, sucker fry appeared around 18 June, and within a few days they were abundant, making it difficult to locate grayling fry.

Fry abundance in rearing areas remained fairly constant during the day. Differences were observed between days, however, with emigration apparently occurring during the night. The thalweg and riffle areas were not thoroughly examined because the velocity and depth typically associated with these areas made visual observation and seining ineffective. Sampling of these areas was limited to the use of two stationary drift nets which only captured eight grayling fry in 34 d. During the stream residence period, examination of stomach contents from five cutthroat trout and three brook trout yielded no evidence of fry predation.

Age-0 grayling were observed in the lower 1.0 km of Red Rock Creek on 7 and 15 July, 12 and 20 d, respectively, after the disappearance of grayling fry from the sampling area upstream. Although none were measured on these dates, they appeared to be substantially larger. This section of the stream is typically deeper and much slower, with an abundance of aquatic vegetation, providing a lentic-like environment and possible summer juvenile rearing habitat. How long the age-0 grayling resided in this section is unknown.

No age-0 grayling were sampled in 1995. Although the stream margins were visually searched for the presence of fry, none were found. However, YOY grayling were observed in the stream near its mouth later in the summer and a small sample (n=5) was obtained by seining near the mouth of Red Rock Creek in the upper lake (Katzman, pers. comm.). This sample was obtained on 28 August, 1995, 94 d after the peak of spawning activity and approximately 60 d after swim-up. Assuming similar growth rates to the 1994 age-0 grayling, these fry should have obtained an estimated total length of 76.8 mm at observation day 60 (60 d after swim-up). Actual total lengths ranged from 69 to 86 mm and averaged 78.0 mm, which is consistent with the estimate.

Sympatric Species

In addition to Arctic grayling, several other species of fish were captured in the Red Rock Creek fish trap. As observed in Odell Creek, suckers (white and longnose) dominated the runs with captures in both years totaling more than 1,000 fish, including a single night's capture of 251 upstream migrants (21 May, 1995). Cutthroat trout were also captured in the trap, however their numbers were more comparable to those of grayling (Table 10).

Although a significant decline (65%) in the number of grayling trapped was observed in 1995, the number of spawning cutthroat trout trapped increased by 92%, from 207 in 1994 to 397 in 1995, with 54 (26%) of the 1994 trout recaptured in 1995. Average size and condition, however, declined in 1995, as was observed with grayling. Cutthroat

Table 10. Numbers, sex ratios, and means and ranges of total length (mm), pre-spawning weight (kg) and condition factor (K), and post-spawning weight and condition factor of all adult cutthroat trout captured in Red Rock Creek, 1994 and 1995.

	1994			1995		
	Male	Female	Combined	Male	Female	Combined
Total Number	71	136	207	135	262	397
Sex Ratio (M:F)			1:1.9			1:1.9
Mean Length	505	513	510	479	501	493
(s.d.)	(80.0)	(79.1)	(80.0)	(69.1)	(60.9)	(64.0)
range	320-680	322-750	320-750	326-683	334-780	326-780
Pre-spawn Conditions						
Number measured	12	17	29	31	85	116
Mean Weight	1.60	1.25	1.40	1.22	1.32	1.29
(s.d.)	(0.6)	(0.5)	(0.6)	(0.5)	(0.5)	(0.5)
range	0.4-2.5	0.4-2.2	0.4-2.5	0.4-2.3	0.4-2.4	0.4-2.4
Mean K	1.11	1.06	1.08	1.08	1.11	1.10
(s.d.)	(0.11)	(0.12)	(0.11)	(0.17)	(0.18)	(0.18)
Post-spawn Conditions						
Number measured	59	116	175	104	177	281
Mean Weight	1.48	1.48	1.48	1.19	1.41	1.32
(s.d.)	(0.6)	(0.6)	(0.6)	(0.6)	(0.7)	(0.6)
range	0.3-3.2	0.2-3.9	0.2-3.9	0.3-2.9	0.5-4.6	0.3-4.6
Mean K	1.08	1.02	0.96	1.00	1.01	0.94
(s.d.)	(0.14)	(0.19)	(0.18)	(0.18)	(0.19)	(0.18)

trout had identical sex ratios, 1.9 F : 1.0 M, between years (Table 10). Chronologies of the 1994 and 1995 Red Rock Creek cutthroat trout spawning runs and cutthroat trout length frequency distributions are presented in Appendix A Figures 14 and 15. Electrophoretic analysis of 25 cutthroat trout completed during my study indicated hybridization of rainbow trout with the Yellowstone cutthroat trout (Leary, unpublished data 1995). Therefore, the healthy population of cutthroat trout that exists in this system apparently offers no value as a genetically pure reserve stock for the threatened Yellowstone Cutthroat trout found east

Table 11. Numbers and means and ranges of total length (mm) and weight (g) of all brook trout, whitefish, and juvenile burbot captured in the Red Rock Creek fish trap, 1994 and 1995.

	Brook trout	Whitefish	Burbot
<u>1994</u>			
Total number	9	2	9
Mean length (range)	299 (201 - 420)	428 (400 - 456)	177 (146 - 213)
Mean weight (range)	306 (78 - 630)	869 (830 - 907)	38 (20 - 67)
<u>1995</u>			
Total number	11	2	7
Mean length (range)	300 (157 - 430)	354 (296 - 412)	174 (147 - 215)
Mean weight (range)	325 (31 - 760)	568 (300 - 825)	37 (22 - 65)

of the continental divide in Montana. Other less numerous species captured in the Red Rock Creek fish trap include brook trout, mountain whitefish, juvenile burbot (Table 11), longnose dace, and sculpin.

Spawning Habitat

The stream bottom in the Red Rock Creek spawning area was uniformly flat with a fairly homogeneous mixture of smaller diameter materials (Table 12). Pebble and gravel appeared most often in samples, but all materials ranging from fines to cobble were common. Overhanging streamside vegetation, mainly grass and willows (*Salix* sp.), occurred at irregular intervals throughout the spawning area. A few deep pools were also present in the area, which provide holding water and refuge.

Table 12. Percent composition of dominant and subdominant substrates at the Red Rock Creek Spawning area. Bottom materials were classified according to a modified Wentworth classification system (Cummins 1962). Percentages were based on 385 samples taken over a 250 m stretch of spawning habitat, September 1994.

Substrate Type	Boulder (>256mm)	Cobble (64-256mm)	Pebble (16-64mm)	Gravel (2-16mm)	Fines (<2mm)
Dominant	3.4%	17.6%	39.5%	14.0%	25.7%
Subdominant	0.5%	10.1%	27.0%	52.0%	10.4%

Historic Spawning Streams

During the study, no adult grayling were found in any of the other historic grayling spawning tributaries of the upper Centennial Valley (Table 1). On one occasion in 1994 (6/16), however, two age-1 grayling were observed in East Shambow Creek (Figure 1) less than 100 m from its mouth. It is assumed that these fish were utilizing this stream as summer habitat. The stream contained cooler water than the lake, possibly providing thermal refugia. Numerous small (<20cm) brook and cutthroat trout were also observed in this stream.

DISCUSSION

I captured 241 adult grayling in 1994 and only 85 in 1995. The decline in the number of captures was at least partly due to poor trap efficiency in 1995 resulting from high discharge during the spawning period. Only 24% of the grayling captured in 1995 were recaptures. However, since few older grayling (age V+) were captured in 1995 (15) compared to 1994 (122) and the number of younger fish (age II-III) remained fairly constant (53 and 65, respectively) a loss of older fish from the population is suggested (Table 4; Figure 12). This is also supported by the observation that all age II fish and many age III fish were first-time spawners and these made up the majority (63%) of migrants captured in 1995. Only 16% (7 of 44) of age III-IV grayling were recaptures, compared to 87% (13 of 15) of age V-VI fish.

High summer temperatures during 1994 followed by low oxygen levels in Upper Red Rock Lake during the winter may have resulted in high mortality, particularly of older grayling. Maximum daily stream temperatures in Red Rock Creek exceeded 20 °C on 18 occasions during June and July, 1994 (Figure 3). No temperatures were recorded after July, but stream temperatures likely increased as flows decreased. Kaya (1990) reported that grayling can survive short term exposure to temperatures greater than 20 °C but average maximum temperatures of 7 to 17 °C are optimal. Liknes and Gould (1987) concluded that warmer summer temperatures (mean 18 °C) may have been largely responsible for a lack of adult grayling in the lower section of their study area on the Big Hole River. The water level of the upper lake was also very low throughout the summer of 1994 and thermal conditions in the lake were

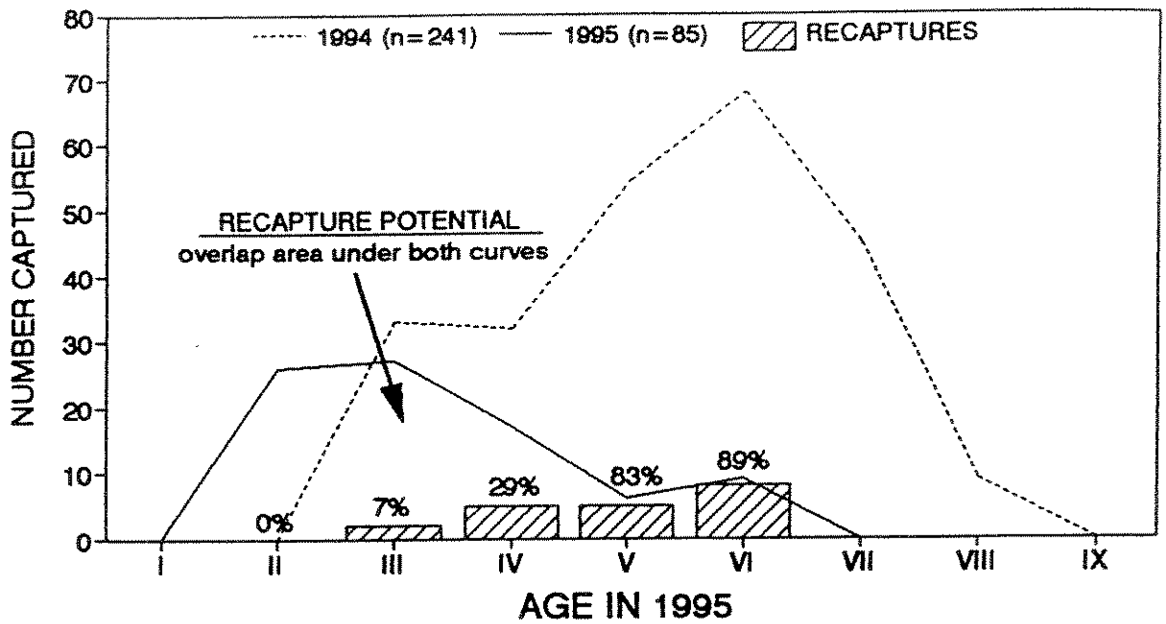


Figure 12. Age distribution of grayling captured in Red Rock Creek showing recapture potential, total recaptures, and percent recapture by age. Recapture potential is depicted as the area of overlap under the 1994 and 1995 curves assuming all 1994 fish returned. Both years are presented by 1995 ages.

probably more severe than in the stream. Although no significant summer mortality was observed, the added stress caused by the drought conditions may have decreased the graylings' ability to cope with the harsh winter conditions in the upper lake. Due to heavy snowpack, extreme anoxic conditions existed under the ice. Dissolved oxygen levels less than 1.0 ppm were common throughout the lake in late winter of 1994-1995 (Gangloff, unpublished data 1995).

Because trapping efficiency in Red Rock Creek was less than 100% in both years, no precise estimate of the number of spawning grayling could be made. However, data provided by MDFWP were used to calculate a rough estimate of population size. On 10 May, 1994, MDFWP personnel captured

35 grayling, of which 14 (40%) were marked. The 21 unmarked fish were tagged, bringing the total marked population to 137. The Peterson mark/recapture estimate was 290 (SE 56.4). Additional electrofishing on 16 May captured 64 grayling including 28 (44%) recaptures. Using these data, a spawning population of 313 (SE 39.7) was estimated. These estimates may be biased since the "closed population" assumption of the Peterson mark-recapture model was probably violated. Since the trap was breached 9-15 May, the number of grayling passing by the trap during this period is unknown. Immigration of unmarked fish to the sampling area would decrease the proportion of marked fish and emigration of marked fish from the sampling area would decrease the number of recaptures, therefore leading to an inflated estimate of population size. In 1994, 241 mature grayling were actually counted.

Only 12 grayling were trapped in Odell Creek in 1994 and a trap could not be maintained in 1995 due to high flows. The size, condition, and sex ratios were similar to those observed in Red Rock Creek, but the timing of migration was nearly 3 weeks later. I do not know if these grayling were part of the upper lake population.

Historically grayling were abundant in Odell Creek (USFWS 1978). In June, 1976, MDFG captured and marked 67 adult grayling here (MDFG 1977). In August of that year, no grayling were captured in gill-nets in the lower lake, but 23 were captured in the upper lake, including two recaptures from Odell Creek. This indicated that grayling could negotiate the river-marsh between the two lakes and suggested that they resided in the upper lake during non-spawning periods. With maximum depths less than 1 m and most of the lake freezing solid during winter, it is unlikely that grayling could over-winter in the lower lake today, but they could use the deep pools in lower Odell Creek. If grayling spawning in Odell Creek are upper lake residents, they must wait for the lower lake to thaw before beginning their ascent in this stream. This would help explain the delay in spawning migration relative to the Red Rock Creek spawning run.

Adult grayling were only observed in Red Rock and Odell creeks during the study. Spawning habitat does not appear to be the limiting factor. Besides Red Rock and Odell creeks, most of the smaller tributaries of the upper Centennial Valley offered suitable spawning habitat. Only Tom, Battle, and Antelope creeks, and the small spring creeks along the Upper Lake's south shore lacked potential spawning habitat or contained habitat that was not likely accessible to spawning fish.

A one-way fish weir and trap spanning Red Rock Creek during the spawning seasons of 1962-1966 captured on average 704 (range, 585-1,000) upstream migrating grayling and only 49 (range, 33-65) cutthroat trout per year (USFWS 1978). On 1 June, 1976, MDFG personnel captured 192 adult grayling and only 2 cutthroat trout while electrofishing a single stretch of Red Rock Creek (distance not reported). On 2 June, 1976, they captured 67 grayling and only 2 cutthroat trout from a single stretch of Odell Creek (MDFG 1977). From the 1994-1995 weir counts, it appears that numbers of Arctic grayling have substantially declined over the past few decades while cutthroat trout abundance appears to have increased (207 in 1994 & 397 in 1995) and currently more cutthroat trout than grayling use Red Rock Creek for reproduction. A number of factors appear to have contributed to this decline including excessive habitat degradation both on and off the refuge, siltation of critical habitats, water diversions, and competition with and predation by native and introduced fishes (Unthank 1989). An overview of these cumulative factors is presented in Appendix B.

Brown (1938) reported that grayling often began spawning runs before cutthroat and rainbow trout. During both years of my study, cutthroat trout began immigration into Red Rock Creek well before grayling and before ice-off of the upper lake. In 1995 several post-spawn cutthroat trout were captured moving back to the lake before ice-off. Cutthroat in Grebe Lake (Kruse 1959), Elk Lake (Lund 1973), and Hyalite Reservoir (Wells 1976; Zubic 1983) entered the spawning tributaries 1-5 weeks prior to grayling, but after ice had cleared from the lakes.

Grayling began entering Red Rock Creek in late April-early May, as ice began to break-up on the upper lake. Upstream movement occurred when mean daily temperatures ranged from 4.9 to 10.3 °C. This pattern is consistent with other Montana populations of lacustrine grayling which have been reported to spawn from about mid-May to mid-July, with migration into spawning tributaries typically triggered by water temperature associated with the time the lake becomes ice-free (Brown 1938; Kruse 1959; Peterman 1972; Lund 1973; Wells 1976; Deleray 1992). The close association of spawning migration and ice break-up has been reported for non-Montana populations as well (Fabricius and Gustafson 1955; Bishop 1971; Kratt and Smith 1980; Beauchamp 1990). Spawning migrations beginning before ice-off of the lake evidently are not typical of most lacustrine populations. The grayling and especially cutthroat trout, in this system, however, begin spawning migrations before the upper lake becomes ice-free, suggesting that extreme winter conditions may influence early migration.

Kaya (1990) reported that the time of spawning of a given grayling population may vary by as much as 4 to 6 weeks, but spawning usually occurs during high flows at stream temperatures of 4.4 to 10.0 °C. This appears to hold true for the Red Rock Lakes population as well (Table 13). Based on timing of up- and downstream migration, electrofishing, and visual observation, actual spawning activity occurred 8 to 25 May in 1994, peaking around 16 May, at mean daily temperatures ranging from 5.0 to 11.0 °C (maximum temperatures ranging from 6.0 to 15.5 °C). Actual spawning was not observed in 1995 due to poor visibility associated with high flow.

Table 13. Approximate dates and temperatures (°C) of Arctic grayling spawning activity observed in Red Rock Creek, 1942-95.

Year	Approximate Dates	Temperatures	Reference
1942	May 19	Not Reported	USFWS 1978
1950-51	May 21 - May 31	7.2 - 10.0	USFWS 1978
1952	May 19 - June 6	Not Reported	Nelson 1954
1962-66	Early May - Early June	7.2 - 12.8	USFWS 1978
1975	May 21 - May 31	10.6	Myers 1977
1976	Late May - Early June	Not Reported	MDFG 1977
1977	May 15 - 30	6.0 - 10.0	MDFG 1977
1984-86	Late May - Early June	Not Reported	Unthank 1989
1993	May 14 - May 29	7.0 - 11.0	Niethammer 1994[1]
1994	May 8 - May 25	5.0 - 11.0	this study
1995	Late May - Mid June	4.5 - 10.1	this study

[1] Personal Communication, 1994

Fabricius and Gustafson (1955) concluded that daily temperature fluctuations were the most influential stimulus affecting grayling spawning activity in small tributaries. Kaya (1990) noted that temperature, rather than increased stream flow, typically determines timing of spawning activity for lacustrine populations. During my study, movement was generally inhibited by cooler temperatures and accelerated by warmer temperatures, with most upstream migrants trapped during the late afternoon and evening when temperatures were elevated and flows were depressed, while most downstream movement occurred during the night and early morning. Other researchers have reported similar patterns for lacustrine populations of grayling (Peterman 1972; Lund 1974; Wells 1976) and cutthroat trout (Lund 1974; Jones et al. 1982; Zubic 1983).

Although stream temperatures were not optimal (often greater than 20 °C) during the summer of 1994, many grayling and trout remained in the creek throughout the summer as late as September, possibly utilizing the relatively cooler stream water as thermal refugia. Stream temperatures were much cooler in 1995 and never exceeded 15.0 °C during the months of June and July. With depths nearly 0.5 m greater, lake conditions were probably better as well. The number of grayling remaining in the stream throughout the summer of 1995 is not known, however, a few fishermen did report catching grayling in the late summer. One grayling, which had entered the stream to spawn on 14 May and was captured again during outmigration on 14 June, was caught by a fisherman near the trap site early in September.

Stream residence time of adult grayling differed between the sexes, with males remaining in the stream significantly longer than females ($P<.001$). Once females have spawned, reproductively there is nothing gained by remaining at the spawning area. For males, however, remaining in the area is of adaptive advantage resulting in an increase in spawning opportunities and ultimately increasing the number and genetic diversity of their progeny. Beauchamp (1990) reported that dominant male grayling remained on the spawning grounds significantly longer (8.1 d) than females and subdominant males ($P<.005$). He concluded that early arrival on the spawning grounds may be an adaptive advantage for males seeking vacant spawning territories.

The Red Rock Lakes grayling sex ratios of nearly two females per male were similar to those reported for other spawning populations of lacustrine grayling. Lund (1974) found spawning ratios of 2.1 F:1.0 M and 1.7 F:1.0 M for the Elk Lake population during the 2 years of his study. Peterman (1972) observed a ratio of 2.5 F:1.0 M from a sample of 9,364 grayling spawning in the primary tributary to Lake Agnes. However, Kruse (1959) and Bishop (1971) reported spawning ratios closer to an expected 1:1 ratio in their studies, while Wells (1976) and Beauchamp (1990) reported ratios in favor of males.

Several factors appear to influence sex ratios and ratios exhibited by spawning populations may not be indicative of the entire population. Peterman (1972) observed a ratio of 1.2 F:1.0 M in Lake Agnes which was significantly different than in the spawning tributary. He attributed the difference to antagonistic behavior between spawning males for limited space, which may have inhibited some males from entering the stream. Spawning habitat was also a limiting factor in Elk Lake and may have influenced sex ratios (Lund 1974). Red Rock Creek, however, is much larger than the tributaries investigated by Peterman and Lund and most spawning occurs several kilometers upstream. Antagonistic behavior near the mouth of Red Rock Creek appears unlikely. Further, spawning habitat does not appear to be a limiting factor for the Red Rock population.

Sex ratios also vary substantially as the spawning season progresses. During my study males generally began migration before females and remained in the stream longer. It is possible that the observed sex ratios may be exaggerated due to incomplete counts of males. Had the traps been installed sooner and maintained longer, a greater number of males may have been captured and a more representative sex ratio may have been attained. During the 1962-1966 Red Rock Creek trapping period, the number of female grayling captured each year was consistently greater than the number of male grayling (1.1-1.3 F : 1.0 M from sample sizes ranging from 585 to 1,000 individuals). It was noted however, that males were predominant in the early parts of the spawning runs while females dominated the latter parts and that a greater numbers of females would have probably been captured had the traps been operated longer (USFWS 1978). Peterman (1972) reported a marked change in sex ratios during the course of the Lake Agnes spawning run, from an initial ratio of 2.7 F:1.0 M to a ratio of 6.2 F:1.0 M in the latter part of the run. Beauchamp (1990), however, found that males composed approximately 50% of the stream population during the peak of spawning activity and nearly 100% at the beginning and end. These authors and others (Bishop 1971; Kratt and Smith 1980) also observed diurnal patterns with males generally moving onto the spawning grounds before females to establish and defend territories and remaining on the spawning grounds throughout much of the day while females "cruised" among territories and between spawning grounds and refuge areas. Thus, sampling of only the spawning grounds may result in biased sex ratios. Sex ratios obtained during spawning runs in Red Rock and Odell Creeks in 1976 were near 1.0 F: 1.5 M (MDFG 1977). These samples, however, were obtained through electrofishing a single section on a single date in early June in each stream. Further, many of the females were reportedly "spawned out," indicating that sampling was probably conducted in the latter stages of the spawn, potentially after emigration of many of the females from the area.

Information reviewed by Kaya (1990) indicates that fecundity of grayling varies greatly depending on size and nutritional status. Fecundity of Montana grayling has been reported to range from about 400 eggs from a 0.15 kg female to 13,000 eggs from a 0.91 kg female. During my study, eggs were collected from Red Rock grayling on 10 and 16 May 1994 (MDFWP, unpublished data). Females averaged over 8,000 eggs per individual, ranging from 1,400 for a 380 g fish to 15,400 for a 940 g fish. Fecundity of grayling from the nearby Elk Lake population was similar. Lund (1974) found an average of 8,170 eggs per female from a sample of 12 grayling. The largest number of eggs from a single individual was 13,365.

During my study spawning was only documented in the known spawning area of Red Rock Creek which is approximately 0.5 km long and located about 13.5 km above the Upper Lake between the confluences of Corral

Creek and Antelope Creek. Substrates in this stretch are composed of materials ranging from fines (<2 mm) to boulders (>256 mm), but dominated by gravels and pebbles (2-64 mm). Nelson (1954) reported that spawning grayling in Red Rock Creek chose substrates composed of 33% rubble, 31% course gravel, 29% fine gravel, and 7% sand. Other researchers have reported similar findings with grayling generally spawning over gravel substrates in shallow water of moderate velocity, typically in the transition areas between the lower end of a riffle and the head of a pool (Bishop 1971; Holton 1971; Hubert et al. 1985; Beauchamp 1990). Although gravels are preferred, grayling can use a greater variety of spawning substrate than other salmonids, ranging from fines to large rubble (Kaya 1990). Kaya (1990) reported depths used by spawning grayling ranging from a few centimeters to greater than 1.0 m and velocities from 30 to 120 cm/s. Spawning European grayling (Thymallus thymallus) also chose shallow water (0.1 to 0.4 m) of moderate velocity (26-92 cm/s) over substrates dominated by gravels (2-64 mm) in two French rivers (Sempeski and Gaudin 1995). Shepard and Oswald (1989) reported that spawning Big Hole River grayling were typically associated with areas of hydrologic instability where clean gravels existed. In Red Rock Creek, grayling were observed spawning over previously excavated cutthroat trout redds which were abundant in the area. The grayling appeared to be keying in on the clean fine gravels displaced by spawning trout. Clean gravels are important because they increase the likelihood that eggs will be deposited into these spaces, providing aeration and protection of the eggs and pre-emergent fry (Kaya 1990).

In 1994, fry first appeared in Red Rock Creek on 10 June, approximately 32 d after initial spawning activity (9 May). Fry abundance peaked around 18 June. Therefore, these fish had an estimated 22-23 d incubation period, assuming about 10 d to swimup. Temperatures during the incubation period ranged from 3.0 to 15.5 °C and averaged 8.7 °C. Hatching times of 8 to 27 d at temperatures of 2.0 to 16.1 °C followed by 3 to 10 d before swimup have been reported (Hubert et al. 1985; Kaya 1990). Wells (1976) found the interval between the peak of spawning activity and the peak of fry emigration for Hyalite Reservoir grayling was 34 d at mean daily temperatures ranging from 7 to 10.7 °C.

In 1994, age-0 grayling were first observed along the stream margin and in backwater areas of Red Rock Creek on 10 June and disappeared 26 June, but were most numerous 17-19 June in small groups of less than 20. The stream-residency period appears to have lasted about 12-15 d throughout most of the stream, however a few YOY were observed near the mouth later in the summer. Nelson (1954) also reported that fry were numerous in backwaters and other protected areas of Red Rock Creek for 2 to 3 weeks after emergence. Kaya (1990) noted that the length of time that age-0 lacustrine grayling remain in their natal streams before migrating into lakes differs among populations and even within a population, ranging from immediately after emergence (Kruse 1959; Lund 1974; Wells 1976) to within a few weeks (Nelson 1954) and possibly up to a year of age for an outlet-spawning population (Deleray 1991). Many fry remained in Red Rock Creek for at least 12-15 d in 1994, as evidenced by daily growth rates. However, this estimate may represent the maximum residence time, rather than the average, because many fry were probably emigrating from the stream throughout this period. On the other hand, age-0 grayling in Alaska and Europe have been reported to occupy surface waters until they reach lengths greater than 25-30 mm, when they begin to migrate to near-benthic habitats in the mainstream (Lee 1985; Scott 1985; Bardonnet et al. 1991; Sempeski and Gaudin 1995). Scott (1985) found that all larval grayling less than 25 mm were distributed within 1.5 m of the stream margin and in the upper third of the water column. They were typically in groups of less than 15 located downstream of littoral vegetation. This is consistent with what I observed in Red Rock Creek in 1994. All of the age-0 grayling sampled were less than 30 mm. If larger fry (>30 mm) moved into the mainstream, the estimated stream residency period of 12-15 d may be underestimated.

Fry abundance in the rearing areas remained fairly constant during the day. However, differences were observed between days, with the majority of emigration apparently occurring during the night, probably as a predator-avoidance adaptation. Similar nocturnal patterns have been reported for other populations (Kruse 1959; Wells 1976). Lund (1974) reported that 80% of grayling fry emigration occurred between 2000 and 0800 h, while Deleray (1991) recovered 68% moving downstream between 2200 and 0600 h.

Losses occurring during grayling egg deposition through the larval stage are naturally very high with mortality rates as great as 96% (Kruse 1959). Apparently, above-average stream flows can greatly contribute to these losses and have a profound effect on recruitment (Clark 1992). Clark (1992) tested the hypothesis that recruitment of Arctic grayling in the Chena River, Alaska was influenced by stream flow, using annual population data collected from 1976 to 1990. He found that stream flow during periods of egg deposition, hatching and emergence, and during the larval stage, was a significant (p=.005) descriptor of variability in grayling recruitment over the 15 year period. Because burial is limited, grayling eggs are vulnerable to high water velocities and streambed disturbances (Kaya 1990; Beauchamp 1990; Clark 1992). Grayling eggs are adhesive and stick to the substrate when first released, thus helping to prevent their downstream displacement. But within about an hour, water hardening occurs and the eggs become non-adhesive and vulnerable to downstream displacement (Kaya 1990). Nelson (1954) observed grayling eggs in pools of Red Rock Creek which he concluded had been washed down from spawning riffles upstream. Upon emergence, larval grayling have poorly developed fins and are unable to cope with high water velocities (Lee 1985). They typically prefer the slower water along stream margins and back water areas until they reach the juvenile stage (Nelson 1954; Scott 1985; Bardonnet et al. 1991; McClure and Gould 1991; Sempeski and Gaudin 1995). Fry also use interstitial spaces and shadows of boulders for cover (Kreuger 1981). These rearing habitats are considered critical to age 0 fish. High flow events occurring during the larval stage can flush fry downstream or leave them stranded in high-water pools or flooded meadows (Clark 1992).

By the time fry had began to emerge in 1994, flows had declined to less than their pre-runoff state and remained low throughout the summer. Runoff in 1995, however, was high with Red Rock Creek flowing at an out-of-bank stage throughout the high risk period, including egg-deposition, hatching, emergence, and the larval stage. Flooding continued through

June and into July. During this period grayling fry could not be found in the stream, suggesting that production in 1995 may have been limited. A few YOY grayling were observed in lower Red Rock Creek in late July and five were seined from the upper lake near the mouth of Red Rock Creek in late August, indicating that some recruitment did occur in 1995. Also, spawning activity apparently occurred over a much longer period of time in 1995 than 1994 as evidenced by timing of migrations. Therefore, emergence of fry would have also occurred over a longer time. With fewer fry in the stream at any one time, locating and observing fry would be more difficult. In addition, with so much water in the system, additional spawning habitat may have been available in 1995, further spreading out fry distribution and emigration time. Finally, due to the flooding, fry were not confined to the stream channel as they were in 1994 and could have been virtually anywhere in the floodplain.

Clark (1992) found that strong year-classes of Arctic grayling in the Chena River, Alaska, appeared coincident to low flow years and visa-versa during a 15-year period. Past grayling population and flow data were not available for Red Rock Creek. However, 1988 was the last drought before the study and fish produced in that year would have been age-IV in 1994. Age structure of the 1994 spawning run indicated a relatively strong year-class for age-VI grayling, suggesting good production and recruitment from the 1988 spawning run. The abundance of age-0 grayling in 1994 and Age-I grayling in 1995 suggests good recruitment from the 1994 run as well.

If flooding has a deleterious effect on grayling reproduction in this system, the chronology of reproduction does not seem advantageous for the Red Rock Lakes population. Other Montana lacustrine populations (Lund 1974; Wells 1976) begin migrations on declining stream flows which would appear to be an adaptive advantage. It is probable that a number of other factors are influencing early spawning migration for this population, including stream temperatures and severity of winter conditions in the upper lake. Since water temperature is depressed by high flows, Red Rock Lakes grayling may have adapted to spawn earlier to reduce stress associated with relatively high temperatures (>20°C) characteristic of Red Rock Creek during low flow periods. Also, grayling fry are less sensitive to high temperatures than adults (Feldmuth and Eriksen 1978; Hubert et al. 1985) and show improved growth rates at warmer temperatures (Walker 1983).

Grayling in Montana have highly variable growth rates and do not appear long-lived. Although a few 9 and 10-year-old grayling were documented from Lower Twin Lake of the Madison drainage (Nelson 1954), 6 years is more typical. The maximum age I estimated for Red Rock Lakes grayling was 7 years and Nelson (1954) reported a maximum age of 6. The maximum age reported for other Montana lacustrine populations include 6 years in Lake Agnes (Peterman 1972), 7 years in Elk Lake (Lund 1974) and 6 years in Hyalite Reservoir (Wells 1976). The oldest fish reported in the Big Hole River was 5 years (Liknes 1981; Shepard and Oswald 1989). Literature reviewed by Craig and Poulin (1975) and Armstrong (1986) indicated that longevities of populations in Alaska and northern Canada are greater (8 to 22 years). They concluded that northern populations of grayling tend to grow slower, live longer, and obtain smaller maximum sizes than southern populations.

Age-0 grayling sampled from Red Rock Creek in 1994 were about 12 mm at swimup (mid-June) and by the end of their 12-15 d stream residency period had reached 27-30 mm. This initial growth rate of approximately 1.05 mm per day appears to continue through the first summer with lengths of 80-90 mm obtained by late August. Nelson (1954) reported similar growth rates. Kaya (1991) found differences in size between Big Hole River and Red Rock Lakes grayling fry of the same age reared under identical hatchery conditions; on average, Big Hole grayling were consistently smaller at all ages. The initial growth rates exhibited by Red Rock grayling are among the largest reported for any Montana population, including the Big Hole River (Liknes 1981; Skaar 1989: McMichael 1990) and Deer Lake (Deleray 1991). Only the Madison River/Ennis Reservoir population, which exhibit fry growth rates of about 1.25 mm per day, are greater (Jeanes, unpublished data). Scott (1985) found that larval European grayling in an English River first emerged from the substrate at lengths of 15-19 mm and grew at slower rates than Montana grayling. Growth of age-0 grayling in Alaskan waters is reportedly substantially slower with mean fork lengths of only 60 mm achieved by the end of their first year (Craig and Poulin 1975).

The growth rate exhibited by the Red Rock Lakes grayling is one of the fastest reported for any grayling population in Montana (Table 14; Figure 13), as well as Alaska and Canada (Craig and Poulin 1975; Armstrong 1986). Although growth of Red Rock grayling is greatest during the first months of life, rapid growth is maintained throughout the first 2 years, dropping off sharply after maturity. Growth becomes fairly stable after 4 years with annual increments of 10-20 mm.

Although lengths at age calculated during my study were consistently greater than those found by Nelson (1954), actual growth rates appear almost identical to those reported by Nelson. This pattern of rapid growth during the first 2 years of life followed by a significant decline after maturity is similar to those exhibited by all of the populations reported in Table 14 except Hyalite Reservoir, which grew most rapidly in their second and third years. Wells (1976) noted, however, that the Hyalite grayling were late spawners with young-of-the-year not entering the reservoir until mid-August, therefore, the time before formation of the first annulus was substantially less than 1 year. Length at age-I observed during my study is the largest reported

Table 14. Calculated total lengths (mm) at succeeding annuli of various populations of Arctic grayling from Montana and Yellowstone National Park, WY. Populations arranged in descending order based on length at age-V.

Population	Length at age							Reference
	I	II	III	IV	V	VI	VII	
Hyalite Res.	86	246	350	395	418			Wells 1976
Elk Lake	137	310	368	396	414	432		Lund 1974
Red Rock L.	190	319	364	384	404	418	422	This Study
Red Rock L.	151	282	343	373	396	406		Nelson 1954
Big Hole R.	118	222	275	309	379			Liknes 1981
Big Hole R.	145	249	297	322	340			Shepard Oswald 1989
Grebe Lake	100	205	255	297	301	307		Brown 1943
Lake Agnes	103	206	247	265	280	300		Peterman 1972
Rogers Lake	137	247	285	304				Brown 1943

for any grayling population, and Red Rock grayling grew more rapidly during the first 3 years of life than any studied population in this region. By age-IV however, Elk Lake and Hyalite Reservoir grayling matched the growth exhibited by the Red Rock Lakes population (Figure 13). The largest fish measured during my study was an age-VII, 436 mm female, however, MDFG (1977) captured two Red Rock grayling greater than 455 mm in 1976 (age & sex not reported). Wells (1976) captured a 444 mm female that was only age-V while Lund (1974) found two age-VII males measuring 457 and 470 mm.

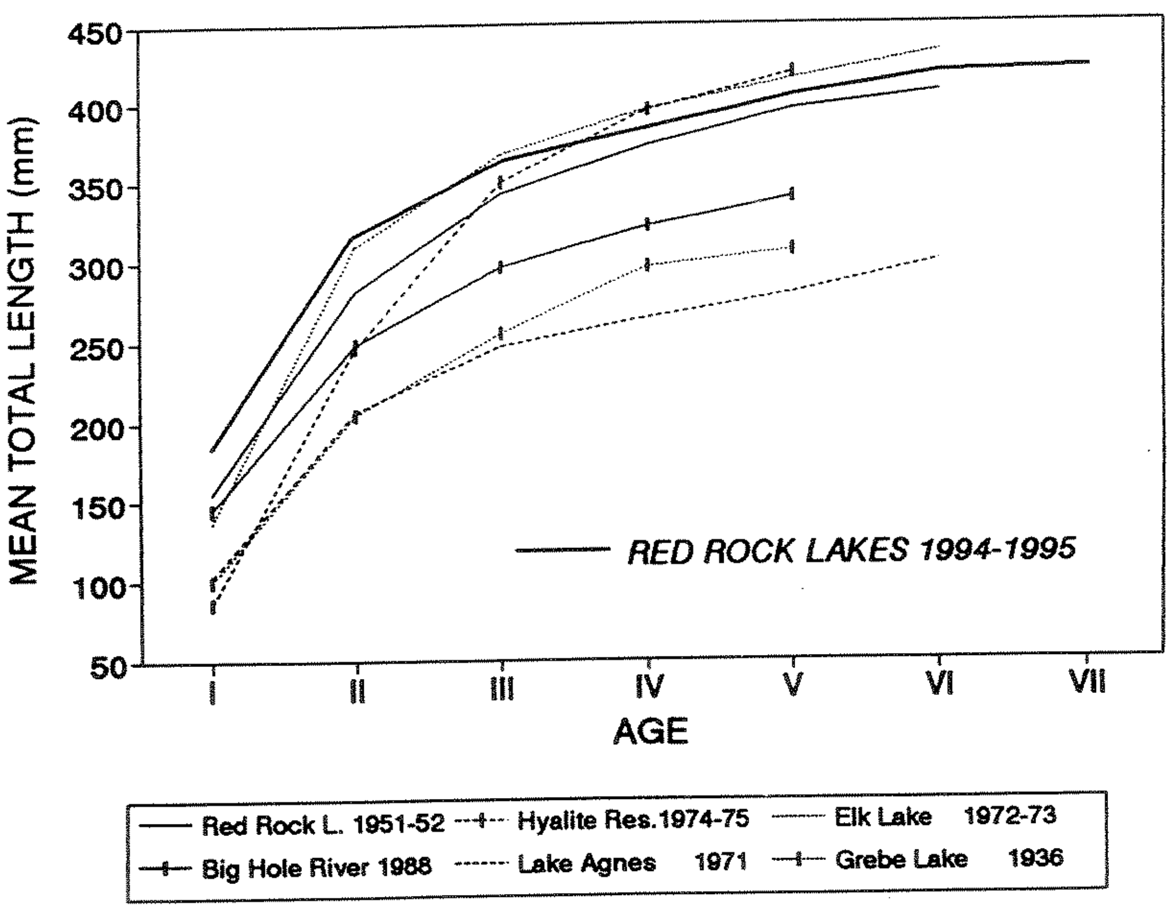


Figure 13. Comparison of growth of six Arctic grayling populations in southwestern Montana.

Age of sexual maturity of grayling in Montana is typically 2 to 3 years and appears to be related to growth rate (Kaya 1990). In the 1994 spawning run 14% and 13% of the spawners were age-II and age-III, respectively, while in 1995, 31% and 32% were age-II and age-III, respectively; indicating that a substantial proportion of Red Rock grayling become sexually mature at age-II (mean back-calculated length of 319 mm). Hubert et al. (1985) reported that maturity typically takes longer under slower growing conditions, in crowded situations, and at higher latitudes. Conditions in the Red Rock system appear suited for early maturity; growth is rapid, grayling are definitely not crowded, and this population is the most southern indigenous population in North America. Brown (1938), Nelson (1954), Peterman (1972), Lund (1974), and Shepard and Oswald (1989) reported finding sexually mature age-II grayling during their studies. However, all spawning grayling in Grebe Lake (Kruse 1959) and Hyalite Reservoir (Wells 1976) attained sexual maturity at age-III. In Alaska, age at sexual maturity ranges from 4 to 9 years (Armstrong 1986).

Nelson (1954) and MDFG (1977) found that age-III and older grayling were predominant in the Red Rock Creek spawning runs. Both of these investigations, however, were conducted by electrofishing potential spawning areas. Beauchamp (1990) and other researchers of grayling spawning strategies (Fabricius and Gustafsun 1955; Kruse 1959; Bishop 1971; Kratt and Smith 1980) reported that territorial behavior of older males relegates younger, less-dominant males, typically precocious age-2 males, to the fringe areas of the spawning grounds. Further, dominant males were the first to enter the spawning grounds in the mornings and the last to leave at night while females and less-dominant males spent a significantly greater amount of time in the refuge areas (pools). These findings suggest that sampling of only the spawning areas may result in the capture of a greater proportion of older fish than is actually present in the spawning population, especially in the case of males.

Once mature, Red Rock Grayling apparently spawn annually as reported for other populations (Lund 1974: Craig and Poulin 1975; Deleray 1990). In 1995, 87% of the age-V+ spawners captured at the trap were previously marked in 1994 (at age-IV+). However, only 16% of the 1995 age-III-IV spawners were marked in 1994 (at ages II-III). In both years, the younger age groups had a greater proportion of males relative to females compared to the older age groups, suggesting that males in this population are generally shorter lived and mature earlier than females. Males also appear to grow slightly faster than females however differences were not significant. Similar differences were reported for other populations (Ward 1951; Kruse 1959; Peterman 1972; Lund 1974).

Several studies warn of the possibility of inaccurate age estimation when ages are based solely on scale readings without some form of validation. Use of inaccurate age estimates has resulted in serious errors in the management and understanding of fisheries (Beamish and McFarlane 1983). Ages of Alaskan and Canadian grayling populations are often underestimated when based on scales due to missing first annuli and crowding of annuli on scales of older fish (Craig and Poulin 1975; Sikstrom 1983). Underestimating age can also result in exaggerated estimates of growth. Craig and Poulin (1975) compared ages of grayling obtained from both scale and otolith readings and found a maximum scale-based age of 11 years for their population, compared to 16 years from otoliths. Thus far, all estimates of age for Montana grayling have been scale-based, and therefore may have been underestimated. However, growth is typically greater while longevity is substantially less for Montana grayling than northern populations. Craig and Poulin (1975) found that scales and otoliths gave similar estimates through age 8 for a population which grew at a slower rate than any reported in Montana. Since Montana grayling rarely exceed 6-7 years of life, scale-based estimates are probably fairly accurate. Whenever possible however, ages should be validated by otolith and fin ray readings, mark-recapture, or by use of known-aged fish.

Sacrificing fish for the purpose of age validation using otoliths was not considered as important as preserving the few fish that remain in this declining population. However, length frequencies and recapture data suggest that my scale readings were accurate. Peaks exist in the length frequencies (Figure 9) which correspond well with actual mean lengths at age (Table 4) as well as mean back-calculated lengths at age (Table 5). Mean increments of growth for recaptured fish (Table 6) also correspond well with mean back-calculated annual incremental growth (Table 5).

The Red Rock Lakes Arctic grayling represent a native population which is distinct from the other indigenous population both behaviorally and genetically. They are the sole-surviving, native, lacustrine segment of this species in the continuous United States, and therefore represent a significant portion of the genetic diversity of the grayling resource in our country. Like our native, fluvial, Big Hole River grayling, the Red Rock Lakes grayling deserve our immediate attention. It appears that only a few hundred mature grayling remain in this system and depend almost entirely on Red Rock Creek for reproduction. While greatly reduced in numbers, these fish have maintained themselves without artificial propagation. The severity of the decline in numbers over the past few decades, however, is suggestive of imminent extinction. As the decline continues, other factors associated with small populations, including disease and debilitating double recessive genes common with inbreeding, may become detrimental (Beauchamp 1990). Knowing that other lacustrine populations have undergone boom and bust cycles (Kaya 1990), it is crucial that this population be monitored closely. The data obtained during my study will provide baseline information for future comparisons, management, and restoration efforts for this unique and valuable fishery.

APPENDICES

APPENDIX A

TABLES AND FIGURES

Table 15. Average calculated total lengths (mm) at succeeding annuli and annual increments of growth by sex for Arctic grayling collected from Red Rock Creek during the spawning runs of 1994-1995.

Age	Number		Mean Length at Capture		Back-Calculated Length (mm) at Each Age													
					1		2		3		4		5		6		7	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
									1994									
I	(5-juv)		192	192	192	192												
II	21	12	322	321	192	192	322	321										
III	9	23	366	366	192	192	322	321	365	365								
IV	23	31	386	386	192	192	322	321	365	365	385	386						
V	19	49	407	403	192	192	322	321	365	365	385	386	407	403				
VI	11	34	420	417	192	192	322	321	365	365	385	385	407	403	420	418		
VII	3	6	427	419	192	192	323	321	366	365	385	386	407	403	420	418	427	419
Total	86	155																
Average					192	192	322	321	365	365	385	386	407	403	420	418	427	419
Increments					192	192	130	129	43	44	20	21	22	17	13	15	7	1
Number					91	160	86	155	65	143	56	120	33	89	14	40	3	6
									1995									
I	(20-juv)		185	185	183	182												
II	8	18	309	301	194	188	319	308										
III	11	16	368	360	187	184	323	310	368	354								
IV	6	11	381	381	184	186	314	309	370	358	379	379						
V	1	5	408	400	184	180	311	304	360	350	380	377	416	393				
VI	1	8	426	413	189	190	316	308	362	355	375	379	423	402	421	416		
VII	0	0																
Total	27	58																
Average					186	185	319	308	368	355	379	379	419	399	421	416		
Increments					186	185	133	123	49	47	11	24	40	20	2	17		
Number					47	78	27	58	19	40	8	24	2	13	1	8		
Grand Average (by sex)	113	213			190	190	321	317	366	363	384	384	408	402	420	417	427	419
Grand Average (sexes combined)	351				190		318		364		384		404		418		420	

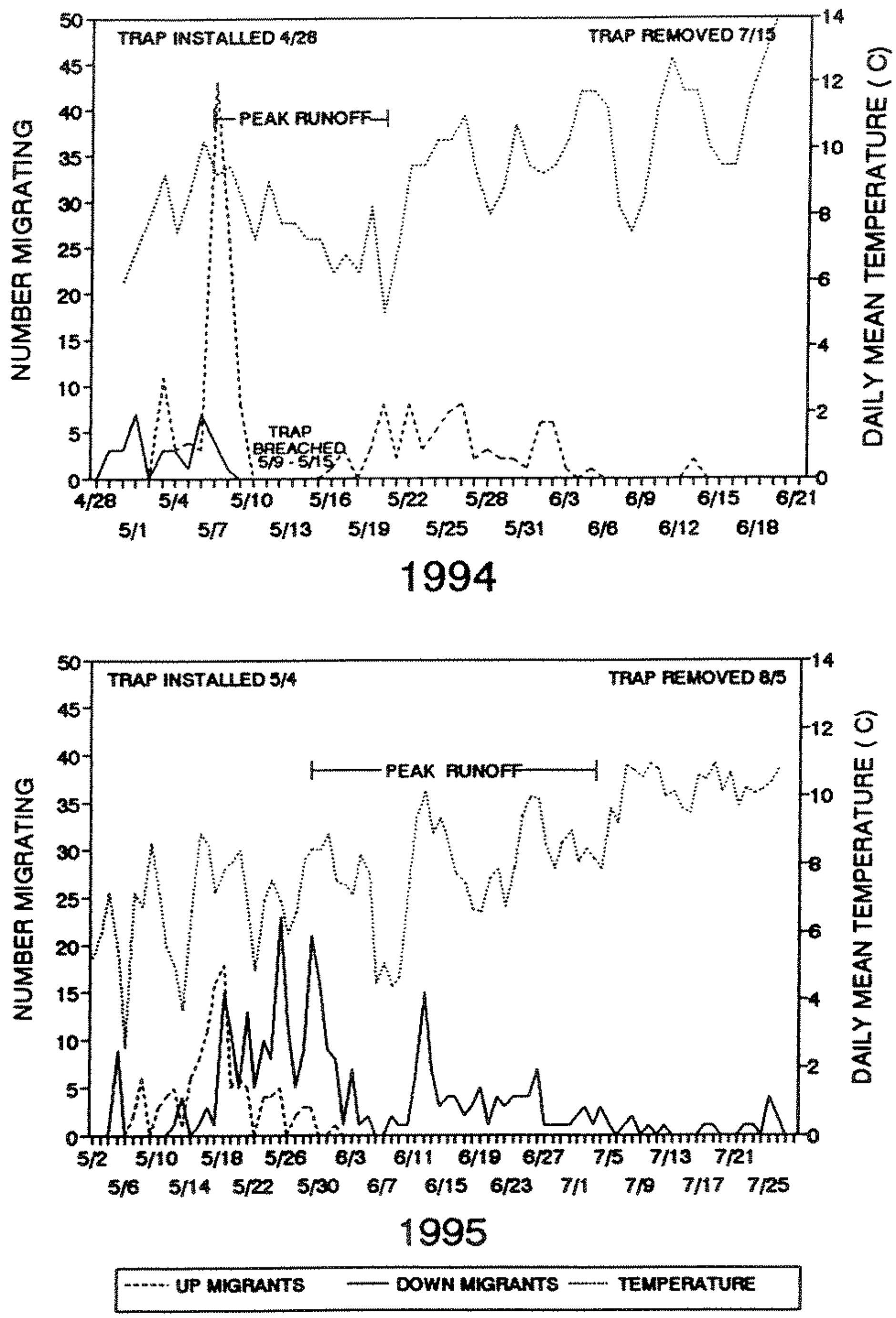


Figure 14. Chronologies of cutthroat trout spawning movements and corresponding mean daily temperatures (°C) in Red Rock Creek, 1994 and 1995.

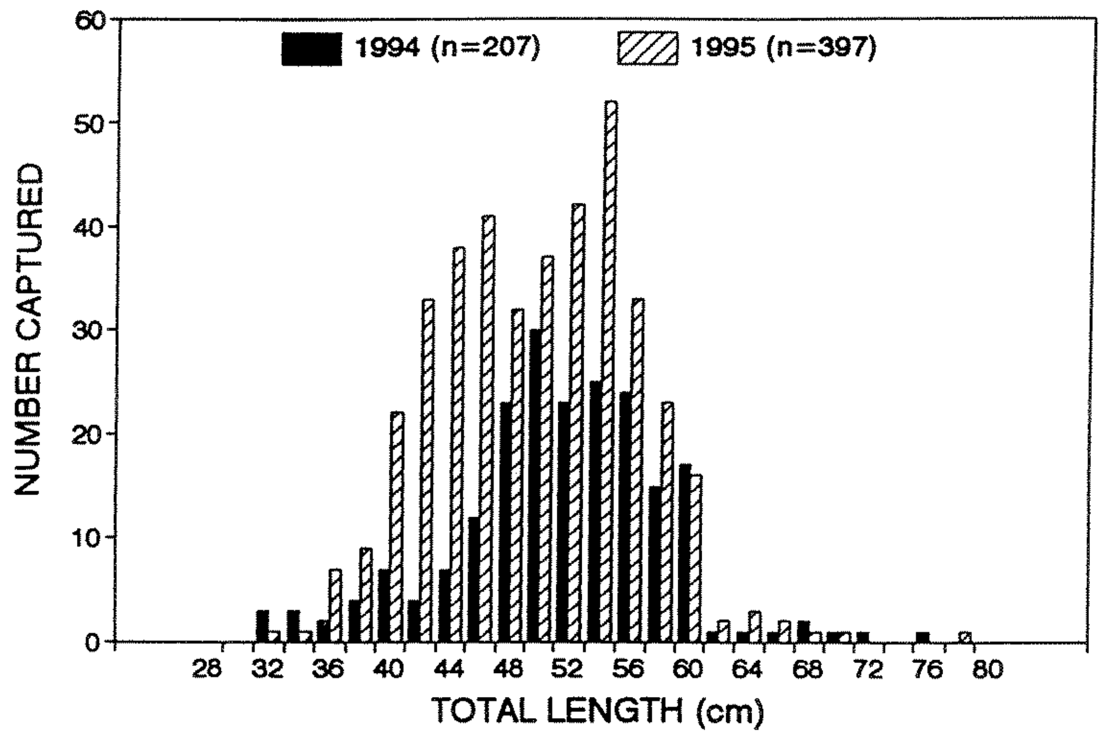


Figure 15. Length frequencies by year of all Cutthroat trout captured during spawning migrations in Red Rock Creek, 1994 and 1995.

Table 16. Aquatic habitat and stream bank stability indices for Red Rock and Odell Creeks, August 1988 (USFWS 1993). Eight 100-foot sections per stream.

	RED ROCK CREEK			ODELL CREEK		
	Mean	Variance	Range	Mean	Variance	Range
Total Reach Score	84.6	19.3	62 - 123	94.9	16.2	75 - 116
% Undercut Banks	21.3	23.1	0 - 70	1.8	3.5	0 - 7
% Overhanging Vegetation	23.1	23.6	0 - 70	9.0	7.0	0 - 15
% Bank Erosion	25.9	22.0	0 - 50	64.0	23.9	45 - 95
% Bottom covered with Fines		(not reported)		44.1	31.5	0 - 98
Stream Width (m)	6.66	1.95	4.8 - 10.1	5.58	1.65	3.6 - 8.4
Depth (m)	0.37	0.23	0.15 - 0.82	0.25	0.09	0.15 - 0.43
Size Composition of Bottom Materials (%)						
Exposed Bedrock	-	-	-	-	-	-
Large Boulders (>91.4 cm)	-	-	-	-	-	-
Small Boulders (30.5-91.4 cm)	0.6	1.8	0 - 5	1.3	0.5	0 - 10
Large Rubble (15.0-30.5 cm)	5.6	10.5	0 - 30	6.9	13.9	0 - 40
Small Rubble (7.6-15.0 cm)	20.6	15.9	0 - 50	13.1	20.2	0 - 50
Course Gravel (2.5-7.6 cm)	31.3	20.3	10 - 60	8.1	10.1	0 - 20
Fine Gravel (0.25-2.5 cm)	14.4	10.5	10 - 40	8.8	11.3	0 - 100
Sand, Silt, Clay, & Muck	27.5	17.5	10 - 50	61.8	31.5	0 - 100

Key to Reach Score
<38 = Excellent
39 - 76 = Good
77 - 114 = Fair
>114 = Poor

APPENDIX B

FACTORS CONTRIBUTING TO THE DECLINE OF THE RED ROCK LAKES ARCTIC GRAYLING

The decline of the Red Rock Lakes Arctic grayling population was the inevitable result of classic cumulative factors responsible for losses of fisheries elsewhere (USFWS 1993). Vincent (1962) suggested that major causes of the decline of grayling in Michigan and Montana were climate, exploitation, introduction of exotics and habitat change. He noted that overgrazing and dewatering of streams were important contributors to habitat deterioration in the Centennial Valley. Since Vincent's study, overgrazing continued and other land-use practices intensified resulting in further deterioration of grayling habitat (MDFG 1977; Unthank 1989).

Red Rock and Odell drainages are highly erosive and naturally contribute large quantities of sediment to Upper and Lower Red Rock lakes (Bengeyfield 1988). Poor conservation practices in these drainages have exacerbated the sediment problem. Cattle grazing both on and off the refuge, sheep grazing south of the refuge, timber harvest, phosphate mining, and a undersized road crossing have combined to severely impact Odell Creek (Fischer 1976; Bengeyfield 1988). The major source of fines in Red Rock Creek were reported to be from streambanks in the heavily grazed private lands east of the Refuge (Myers 1977). Myers found that these private lands contributed to a 338 percent increase in suspended sediment load, from 29.8 ppm at the mouth of Hell Roaring Canyon to 130.6 ppm at the Refuge's east boundary, only 10 km downstream. Much of the riparian areas in this stretch remains unfenced today with cattle grazing continuing from late spring to early fall. Overgrazing by cattle and sheep was also reported in the Tom Creek drainage by Myers (1977) who found 80 percent active bank erosion and an increase of 2,500 percent in sediment load in a distance of only 3.2 km during runoff in this stream. Combined, these factors diminished the habitat quality and overall productivity of the streams through erosion, increased silt deposition, and elevation of water temperatures.

Habitat surveys conducted in August 1988 indicated fair to poor aquatic and riparian habitat in the Red Rock and Odell drainages (USFWS 1993). Bank erosion, filling of pools, and covering of spawning gravels were common and widespread (Appendix A Table 16). This sedimentation problem is two-fold. First, silt adversely affects spawning habitat, egg and fry survival, and the habitat and survival of insects and other aquatic food organisms. Secondly, deterioration of the lake habitat due to sediment deposition may be occurring. Brower (1897) reported depths ranging from 3.0 to 7.6 m in the upper lake nearly 100 years ago. Depths greater than 5.0 m in the 1940's were reported by Young (1989). Paullin (1973) found a maximum depth of only 2.2 m in 1973. The deepest point located in September 1993 was 1.8 m and depths in the lower lake rarely exceeded 0.5 m (USFWS, unpublished data). As the lakes become shallower, eutrophication is accelerated, and grayling habitat is destroyed. Thermal stratification rarely occurs in the summer, providing little thermal refugia. Current research examining winter habitat and grayling distribution under the ice of the upper lake, has found that extremely anoxic conditions can occur. Dissolved oxygen levels of less than 1.0 ppm were very common throughout the lake in late winter 1995 (Gangloff, unpublished data 1995). It appears that the deterioration of lake habitat will continue unless either drastic land use practices are employed and/or the lakes are artificially deepened.

In recent years, the condition of Odell Creek has improved. The majority of riparian area has been protected through fencing and the removal of an undersized road culvert, which was believed to be a barrier to migration, has allowed increased flows to flush out much of the fine sediment which dominated the lower section of this stream. In 1994, habitat enhancement projects begun on private land bordering Odell Creek (Tim Tiplady, USFWL, pers. comm.). These include protecting degraded streambanks through diversion of flows and reestablishment of willows, creation of meanders where down-cutting and channelization had occurred, and returning small tributaries that had been routed to ditches to their original channels, which in turn will contribute to summer flows and habitat. Although grazing continues throughout the summer on much of the refuge, riparian grazing has been generally eliminated. Grazing's biggest impact remains on non-refuge lands, especially along Red Rock and Tom creeks where it continues to be a problem.

To create additional habitat for trumpeter swans, a permanent concrete sill was constructed in 1957 across the outlet of the Red Rock Lakes system raising the outlet elevation by 0.6 m (Young 1989). By keeping the lakes at full pool, natural flushing may have been reduced, possibly increasing siltation rates. The sill was also a barrier to the return of Red Rock Lakes grayling that historically migrated downstream to spawn in tributaries of the Red Rock River below the lakes (Nelson 1954; Young 1989). In 1988, the height of the sill was increased and the outlet structure was modified making it possible to flush water and sediment through the system during spring runoff, while maintaining greater lake depths during the winter.

Accessibility may also be a factor limiting the use of those streams flowing directly into the lakes. These tributaries, including Red Rock Creek, do not possess deep channels at their inlets. Red Rock Creek actually contains water as deep or deeper than much of the lake throughout its course, but at its inlet it becomes much shallower. Due to the broad and shallow deltas associated with these tributaries, finding the streams and then actually entering them may be a problem for early migrating fish. During the winter of 1994, several holes were drilled through the ice across the outlets of most tributaries, including Red Rock, Odell, Elk and Tom Creeks. In most cases the lake was frozen solid to the bottom. Adequate flows and temperatures are required to break-up ice, therefore the larger streams are likely to open first. Because grayling and especially cutthroat trout in this system spawn very early, they may ascend those streams with open outlets before other streams become readily available.

Irrigation diversions, which block spawning migrations, de-water streams, elevate water temperatures, and increase silt loads have further contributed to the decline of the Red Rock Lakes grayling (Nelson 1954; USFWS 1978; Unthank 1989; Young 1989). During low flow periods of summer, 50 to 100 percent of the water in most creeks, including Red Rock and Odell, was historically lost to irrigation. Many fish ventured down the ditches only to become stranded in irrigated fields. Jim Hanson, an early rancher of the Red Rock Creek drainage, reported his ditches being full of grayling throughout the spring and into the summer and that he used a team and wagon to haul tubs of stranded grayling from his fields back to the creek, while hundreds of others perished (USFWS 1978). Nelson (1954) had observed several cases during the course of his study where ranch diversions into fields went on all summer, depriving the creeks of water and resulting in the loss of large numbers of grayling, including a large percentage of the annual recruitment. Unthank (1989) reported finding large numbers of game fishes in diversion ditches on Red Rock and Odell Creeks in the fall of 1988. Through the purchasing of lands, water rights in the upper Centennial Valley have progressively been acquired by the refuge which has ultimately resulted in substantial reductions in water diversions (USFWS 1993).

Beaver dams were believed to be barriers to spawning migration, with many historical reports of grayling piled up below beaver dams unable to pass even during peak flows (USFWS 1978). Nelson (1954) recommended that beaver dams, as well as beaver, be removed from all tributaries to Upper Red Rock Lake. Since his study, the Refuge has experienced years of beaver dam removal, beginning with the removal of 100 beaver and 90 dams during Nelson's study alone. However, information reviewed by Unthank (1989) indicated that because of the higher flows associated with spawning migration most beaver dams can be passed by grayling and therefore do not create barriers to migration. A missing piece of the grayling puzzle may involve irrigation diversions (Young 1989). Apparently, when water diversions in the valley were much more extensive, ranchers would begin to irrigate as soon as the snow could be cleared from their ditches. With most of the spring run-off diverted into irrigated fields, many dams remained impassible to fish.

Recently, however, diversions have been greatly reduced and beaver have been recognized for the positive influence they provide to aquatic systems. They help retain flows and sediments in localized areas that would otherwise be lost to the system, leading to reestablishment of streambanks and riparian vegetation, raised water tables, and critical pool habitat for fish at all times of the year. With the apparent rapid sedimentation rates observed in the lakes, retention of sediment by beaver dams may be more of a benefit than a detriment, especially since spawning habitat does not appear to be a limiting factor in this system.

During my study, only a few dams were observed in Red Rock Creek and none were barriers to migration. Several large dams (>1.5 m high) existed in Odell Creek that may have impeded upstream movement under normal flow conditions. However, during high flows accessible channels around the dams were created by overflow in 1994 and all of the dams were blown out in 1995. The portion of Tom Creek below the county road was completely clogged with beaver dams, with 30+ structures observed in the lower kilometer alone. Due to the density and close proximity of the dams, spawning habitat was not available, however, only one dam appeared impassible to fish in 1994, and none in 1995. This section of Tom Creek was also investigated for the presence of grayling in 1976 (MDFG 1976). Conditions were apparently very much the same. The stretch contained numerous beaver dams and was described as "little more than a settling basin for sediments." The dams apparently were not so high as to negate migration because four adult grayling were captured upstream. Most of the other smaller tributaries examined during my study also contained beaver dams but none appeared impassible.

As with most native fisheries, introduced exotics create additional problems for grayling in the form of competition, and predation. Early management efforts in the valley focussed on the creation of recreational opportunities for fishermen and introductions of non-native species were extensive (USFWS 1978). Although records are sketchy, brook trout, rainbow trout, and Yellowstone cutthroat trout were first introduced into the valley around the turn of the century. Stocking continued almost on a yearly basis until the mid-1980's. Fish were released into all available waters with apparently little regard for the existing communities. Since the introduction of these exotics, there has been a substantial decline of indigenous species, including the Arctic grayling and westslope cutthroat trout. By 1941 the brook trout was the predominant fish species on the refuge (Unthank 1989). Competition with and predation by introduced fish, including brook and rainbow trout, has often been suggested as a major contributor to the reduction in the Arctic grayling's range in Montana and Michigan (Vincent 1962; Kaya 1990, 1992). Nelson (1954) examined the stomachs of numerous brook trout from the Red Rock Creek drainage. Grayling fry were recovered from most stomachs, with one stomach containing 42 grayling fry, indicating that predation may be another limiting factor for this population. Examination of stomach contents from three brook trout and five cutthroat-rainbow trout during the fry residency period of 1994 yielded no evidence of fry predation. However, due to the greatly reduced spawning population the abundance and availability of grayling fry was likely substantially less than during Nelson's study.

Competition with and/or predation by indigenous species are also potential problems for this population. Large burbot (>500 mm) are abundant in the Red Rock Lakes system (USFWS 1978; Unthank 1989; and Katzman, unpublished data 1995). They are very piscivorous, able to engulf relatively large prey, including many size-classes of grayling and trout. In order to survive the severe winter conditions that can exist under the ice in the lakes, fish likely concentrate in areas where dissolved oxygen is highest, namely spring seeps and creek inlets. Being forced to spend much of the winter in close proximity to burbot, which feed mainly at night and are most active during the winter (Brown 1971), makes the potential for predation even greater. Whether or not suckers adversely affect grayling is unknown. Nelson (1954) reported that native suckers were the most abundant fish in Red Rock Lakes. In 1979, the upper lake was reported to be heavily populated with suckers, with the ratio of suckers to game fish estimated at 15 to 1 (USFWS, unpublished data 1979). Suckers remain the predominant fish in the upper lake with total captures at the Red Rock Creek fish trap numbering well over 1,000 fish in 1994 and 1995.

Whether it occurs on eggs, fry, sub-adults or in all stages of life, predation likely plays a deleterious role on grayling numbers and recruitment in this system, especially with the abundance of very large predators. Eutrophication of the lakes may be enhancing the size and abundance of these predators which may preclude rebuilding of the grayling population. Research is currently underway at Red Rock Lakes in an effort to better understand the impact of predation on this dwindling grayling population (Katzman, unpublished data 1995).

Past fishery management efforts in the Centennial Valley have focussed on the creation and maintenance of quality fishing opportunities as a recreational output with fishing pressure believed to be light enough so that both the aesthetic values of the area and the fishery resource remained self sustaining (USFWS 1978). Historic over-harvest appears to have initiated declines of the Arctic grayling in other native populations (Vincent 1962; Armstrong 1985; Kaya 1990), however little is known of the effects of recreational fishing on this population. In 1947 angling in the valley was reported as becoming poorer due to heavy public fishing. In the 1950's, several of the Refuge's waters, including the upper and lower lake, were closed to angling and the grayling limit was reduced from 15 to 5 fish per day (USFWS 1978). These regulations remained in effect until 1994, when a state-wide, catch-and-release only regulation was adopted for all grayling captured from streams, including tributaries to Red Rock Lakes.

The latest concern associated with the Red Rock Lakes system is the recent discovery of whirling disease in its waters. This parasitic disease, which evidently has no cure, readily infects juveniles of most salmonid species (MDFWP 1995). Although the effects of this disease on Arctic grayling are not yet understood, it is responsible for a 90 percent decline from 1991 to 1994 in the wild rainbow trout population of the upper Madison River. In April 1995, the disease was discovered in fish from a tributary to the lower Red Rock River (Oswald, MDFWP, pers. comm.), and brook and rainbow-cutthroat trout collected during this study (May 1995) from the upper reaches of Red Rock Creek were also highly infected, indicating that whirling disease has probably worked its way through the entire Red Rock system.

In recent years steps have been taken to help restoration of this native population of Arctic grayling. The refuge has taken some positive action beginning with reductions in grazing and water diversions (Unthank 1989). The refuge is currently managing all waters within its boundaries to benefit the native fishery communities and is working on the following issues (USFWS 1993):

- historical water diversions (now 90% corrected)
- riparian livestock grazing within refuge boundaries
- siltation of streams and lakes (some natural, some induced by human land uses)
- competition with and/or predation by exotics such as rainbow and brook trout, and native suckers and burbot (impact unknown)
- beaver dam, wetland, and fishery dynamics (development of guidelines for managing beaver dams holistically; dams have significant wetland and riparian wildlife values too significant to dismiss)
- water levels in the lakes (partially regulated by water control structure below the lakes which was completed in 1988)
- historic over-harvest either by anglers or through stranding on irrigated pastures or ditches resulting from a lack of fish screens (catch and release only for all grayling and screens used where needed)
- several other less evident factors (Odell Creek culvert replaced with bridge in FY92).

In addition to this study, 2 graduate projects are currently underway in an effort to gather information on the status and ecology of this population. Further, Montana Department of Fish, Wildlife, and Parks has been conducting long-term investigations on several of the waters of the Upper Centennial Valley in an effort to assess fish population trends. The findings of these and other studies will help provide the necessary biological basis needed for future management and restoration of this unique grayling population.

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