The fluvial Arctic grayling (Thymallus arcticus) of the upper Big Hole River drainage, Montana
by George Alton Likneś

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Fish and Wildlife Management
Montana State University

Abstract:
The distribution and habitat requirements of the stream-dwelling Arctic grayling in the upper Big Hole River drainage were studied in 1978 and 1979. Study section's 1-4 were established on the upper Big Hole River and Section 5 on its principle tributary, the North Fork of the Big Hole. Arctic grayling were found in Sections 1 and 2 and in 11 tributary streams, including the North Fork, in the study area.

The number of Arctic grayling captured per electrofishing run per kilometer in Sections 1, 2 and 5 were 16.9, 5.3 and 4.9, respectively. Population and standing crop estimates of Arctic grayling were 35/km and 6.7kg/km for the size range 25.1-29.7 cm in Section 1. The number of hours water temperatures exceeded 17 C on Sections 1 and 2 in 1979 were significantly lower than Sections 3 and 5 during comparable periods of time. The mean depth of Section 1, where densities of Arctic grayling were greatest, was 28.4 cm (±22.6), mean width was 12.21 m (±4.92), mean velocity was 0.21 m/s (±0.15) and the gradient was 0.29%. Suitable spawning substrate was present and aquatic vegetation was abundant. The mean depth of Section 2 was 39.7 cm (±30.6), mean width was 15,95 m (±5.02), mean velocity was 0.33 m/s (±0.23) and the gradient was 0.23%. The mean depth of Section 3 was 37.3 cm (±23.1), mean width was 48.09 m (±14.75), mean velocity was 0.21 m/s (±0.15) and the gradient was 0.11%. The growth rate of Arctic grayling in the upper Big Hole River drainage was less than in six other populations. Arctic grayling in the Big Hole River reached sexual maturity at age III at which time they had a back-calculated length of 27.5 cm.

STATEMENT OF PERMISSION TO COPY

In presenting this thesis in partial fulfillment of the requirements for an advanced degree at Montana State University, I agree that the Library shall make it freely available for inspection. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by my major professor, or, in his absence, by the Director of Libraries. It is understood that any copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Signature George A. Liknes

Date 3/27/81

THE FLUVIAL ARCTIC GRAYLING (*THYMALLUS ARCTICUS*) OF THE

UPPER BIG HOLE RIVER DRAINAGE, MONTANA

by

George Alton Liknes

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Fish and Wildlife Management

Approved:

William R. Gould
Chairperson, Graduate Committee

J M Pickett
Head, Major Department

Henry L Parsons
Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

March, 1981

ACKNOWLEDGMENT

The author wishes to extend his sincere appreciation to the following, who among others, assisted him through the course of this study. Dr. William R. Gould directed the study and assisted in the preparation of the manuscript. Drs. Ira K. Mills and Harold D. Picton critically reviewed the manuscript. John Dolan, USFS District Ranger, graciously provided housing and access to U. S. Forest Service facilities. Special thanks to Herald Wetzsteon, Larry Tucker, Richard Lawson and all other cooperating residents and landowners of the upper Big Hole Basin. Thanks are due Mark Lere, Wade Fredenberg, and Steve Sando, fellow graduate students, who assisted in field work and offered ideas and suggestions. Dr. Dalton E. Burkhalter and Mr. Robert McFarland provided computer programs for data analyses. Finally, special thanks are extended to my family for their support throughout my academic career. This study was financed by the Montana Cooperative Fishery Research Unit (Cooperators: Mont. Dept. of Fish, Wildlife and Parks, U. S. Fish and Wildlife Service and Mont. State Univ.).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF FIGURES

ABSTRACT

The distribution and habitat requirements of the stream-dwelling Arctic grayling in the upper Big Hole River drainage were studied in 1978 and 1979. Study sections 1-4 were established on the upper Big Hole River and Section 5 on its principle tributary, the North Fork of the Big Hole. Arctic grayling were found in Sections 1 and 2 and in 11 tributary streams, including the North Fork, in the study area. The number of Arctic grayling captured per electrofishing run per kilometer in Sections 1, 2 and 5 were 16.9, 5.3 and 4.9, respectively. Population and standing crop estimates of Arctic grayling were 35/km and 6.7kg/km for the size range 25.1-29.7 cm in Section 1. The number of hours water temperatures exceeded 17 C on Sections 1 and 2 in 1979 were significantly lower than Sections 3 and 5 during comparable periods of time. The mean depth of Section 1, where densities of Arctic grayling were greatest, was 28.4 cm (±22.6), mean width was 12.21 m (±4.92), mean velocity was 0.21 m/s (±0.15) and the gradient was 0.29%. Suitable spawning substrate was present and aquatic vegetation was abundant. The mean depth of Section 2 was 39.7 cm (±30.6), mean width was 15.95 m (±5.02), mean velocity was 0.33 m/s (±0.23) and the gradient was 0.23%. The mean depth of Section 3 was 37.3 cm (±23.1), mean width was 48.09 m (±14.75), mean velocity was 0.21 m/s (±0.15) and the gradient was 0.11%. The growth rate of Arctic grayling in the upper Big Hole River drainage was less than in six other populations. Arctic grayling in the Big Hole River reached sexual maturity at age III at which time they had a back-calculated length of 27.5 cm.

INTRODUCTION

Arctic grayling (*Thymallus arcticus*) were once widely, but intermittently distributed in the Missouri River and its tributaries above the Great Falls in Montana (Vincent, 1962; Henshall, 1906). Today, the only substantial population of stream-dwelling Arctic grayling in Montana is found in the upper Big Hole River and its tributaries. This remnant population of Arctic grayling contains only fish native to Montana. However, Arctic grayling from stocks originating elsewhere in Montana were planted in the upper Big Hole River from 1937-1962 (Mont. Dept. of Fish, Wildlife and Parks files).

Concern for the continued well-being of this unique population of stream-dwelling Arctic grayling in the upper Big Hole River drainage has recently increased. Only small numbers of Arctic grayling have been found in previous sampling of the river and they may soon be subjected to additional biological and physical impacts. Brown trout (*Salmo trutta*) are believed to be pioneering the area and oil exploration is underway in the drainage.

The purpose of this study was to determine the distribution, relative abundance and habitat requirements of the stream-dwelling Arctic grayling in the upper Big Hole River. Field work was conducted from June to September in 1978 and from April to September in 1979.

DESCRIPTION OF STUDY AREA

The upper Big Hole River drainage is located in southwestern Montana in Beaverhead, Deer Lodge and Silver Bow counties. It extends from the Bitterroot Mountains south of Jackson to Divide. It receives tributaries from the Bitterroot Range on the west, the Anaconda Range on the north and the Pioneer Mountains on the east. The area of the Big Hole River drainage is approximately 7,175 km^2 (Heaton, 1960).

The study area extended over approximately 90 km from the headwaters of the upper Big Hole River to Sportsman Park (Figure 1). Upstream from Pintlar Creek (Figure 1), the Big Hole River lay in several braided, meandering channels. Below Pintlar Creek the river was confined to a single channel in a narrow canyon. A sagebrush-grassland vegetation type was present on the foothills surrounding the tributary streams but the land adjacent the river in the study area was extensively irrigated for the production of hay. The riparian vegetation in the study area was primarily grasses, sedges and willows. Some conifers were present on the river below Pintlar Creek.

The average annual discharge of the upper Big Hole River at a site 14.5 km southwest of Jackson was 1069 m^3 from 1940-1954 (MDNRC, 1979). The maximum recorded discharge was 26.56 m^3/s and the minimum flow was 0.142 m^3/s (Aagaard, 1969). The mean discharge at a site approximately 8 km north of Jackson, Montana was 4.4 m^3/s between July 26 and September 15, 1978 (Wells and Rehwinkel, 1980).

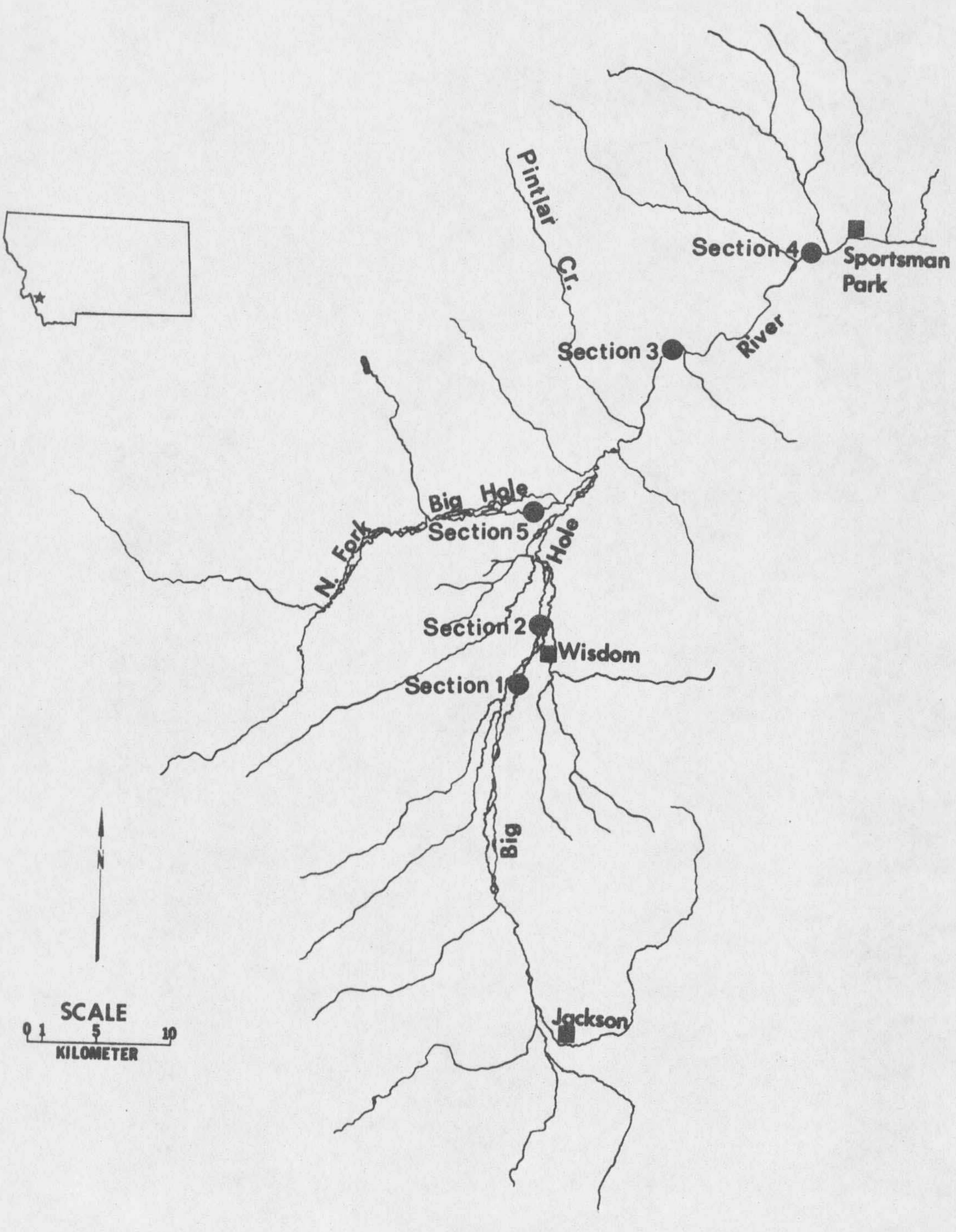

Figure 1. Map of study area showing locations of study sections.

Five sections were established for detailed study (Figure 1). The legal description and lengths of each section is given in Appendix Table 8.

METHODS

The distribution of Arctic grayling in the upper Big Hole River drainage was determined from collections made by angling, electrofishing, drift nets and seines. Five sections of the river were electrofished for estimates of fish populations. Population estimates were calculated using Chapman's modification of the Petersen formula (Ricker, 1975).

The physico-chemical parameters of the water at stations on Sections 1, 2, 3 and 5 were measured at least every 15 days from mid-June to early September in 1979. Concentrations of dissolved oxygen were determined using the azide modification of the Winkler method (APHA, 1976). Alkalinity and hardness were determined by titration. Conductivity was measured with a Beckman RB3-Solu Bridge. The pH was determined in the field with an Orion model 407 Specific Ion Meter. Temperatures were recorded with Ryan model D-15 thermographs. Water temperatures at Sections 1, 2 and 3 were continually recorded from April 21 to September 1, 1979 and on Section 5 from June 23 to August 25, 1979. Water temperature analysis was performed using TEMP, a computer program developed by Dr. D. E. Burkhalter.

Selected parameters of the physical habitat in Sections 1, 2 and 3 were measured for correlation with the populations of Arctic grayling in these sections. In areas containing braided channels, only the major channel was habitat-typed and electrofished. The length of each section was measured down the center of the channel. The length of each pool and riffle was recorded and a pool-riffle periodicity and ratio calculated. The pool-riffle periodicity is the mean distance between riffles in terms of mean stream widths for the section (Leopold and Langbein, 1966). Pools were defined as areas with reduced water velocities in which the surface was smooth and had maximum depths equal to or greater than 0.5 m. Riffles were defined as all areas not designated to be pools.

Thirty-seven transects or sample points were established perpendicular to the channel on each section. The distances between the transects on Sections 1, 2 and 3 were 45, 100 and 150 m, respectively. Transects were located only on the upper half of Section 1 because the lower half of the section was completely dewatered in 1979. However, the habitat in the upper portion of Section 1 appeared to be representative of the entire section. Velocities were measured at 0.6 of the depth below the surface with a Gurley AA current meter. Measurements were made at intervals of 1 m across each transect in Section 1 and 2 and at every 3 m in Section 3. Water depth was recorded to the nearest centimeter at intervals of 0.5 m on each transect. Thalweg depth and velocity was measured on each transect. Discharges were calculated from the point velocities and depths of selected transects. The length of each transect was divided into length in pool and length in riffle. The gradient for each section was obtained from USGS topographical maps.

Shoreline cover within 1.5 m of either side of the transect was measured. The area of overhanging brush within 1.0 m of the surface of the water was measured. Debris and undercut banks within 0.6 m of the water surface were measured. The area of aquatic plants and the area of instream cover provided by debris within 1.5 m of each side of the transect were measured also.

The composition of the bottom materials in each section was determined by estimating the length of each type of material along each transect. The bottom materials were classified after Wentworth (1922) as bedrock (unbroken, solid rock), boulders (>26 cm in diameter), rubble (6.4-26 cm in diameter), gravel (2 mm-6.3 cm in diameter) and fines (<2 mm in diameter).

The general condition of the banks at the end of each transect was qualitatively evaluated as stable or unstable. An unstable bank was defined as one exhibiting evidence of recent soil erosion or sloughing.

Mean values for water velocities, water depths, thalweg velocities and depths, pool widths, riffle widths and bottom materials were calculated for each section. A mean value also was calculated for each physico-chemical parameter on each section.

The variance of the standing crop estimates were calculated using the equation (Gerking, 1967):

$$V(B) = V(\bar{w}N) = \bar{w}^2 V(N) + N^2 V(\bar{w}) + 2\bar{w}N\mathrm{cov}(\bar{w},N)$$

where $V(B)$ = variance of standing crop,

$\bar{w}$ = mean weight of sample,

$V(\bar{w})$ = variance of the mean weight,

N = population estimate and

$V(N)$ = variance of the population estimate.

Fulton's condition factor was computed using the formula (Bagenal and Tesch, 1978):

$$K = \frac{100\ w}{1^3}$$

where K = condition factor,

w = total weight and (g)

1 = total length. (cm)

The total length-weight relationship was determined for Arctic grayling using the equation (Bagenal and Tesch, 1978):

$$\log W = \log a + b(\log L)$$

where W = total weight,

L = total length

and a and b are constants.

The Monastyrsky method modified by Hile (1941) was used to back-calculate lengths at age of fish with the equation which adjusted for allometry:

$$\log L_n = \log L + b(\log S_n - \log S)$$

where L_n = total length of fish at age n,

L = total length of fish,

b = regression coefficient of logarithmic scale radius-total body length regression,

S_n = anterior scale radius at annulus n and

S = total anterior scale radius.

The FIRE 1 computer program (Hesse, 1977) was used to analyze age and growth data.

Statistical tests were performed according to methods in Snedecor and Cochran (1967) using MSUSTAT (Lund, 1979) and SPSS (Nie et. al., 1975). Significant differences were those in which the probability of obtaining the same results by chance was less than 0.05.

RESULTS

Population Characteristics

Distribution of Arctic grayling

Arctic grayling were collected from seven locations on the upper Big Hole River and from 11 tributary streams including a collection from Francis Creek by J. Decker-Hess and that from LaMarche Creek by E. Vyse (Figure 2). Age 0 Arctic grayling were collected from all of these sites on the river and from seven tributary streams. Age I+ or older fish were found at two locations on the river and in ten tributaries. Both age 0 and age I+ or older Arctic grayling were collected at two locations on the river and in six tributary streams. The Arctic grayling found in tributaries were taken near the mouths of the streams except in Miner and Mussigbrod creeks, where they were captured upstream and downstream, respectively, from lakes containing populations.

Although Arctic grayling are most abundant near the headwaters in the upper Big Hole Basin, individuals have been found further downstream. Arctic grayling were captured by personnel of the Montana Department of Fish, Wildlife and Parks in an electrofishing section that included Section 4 of the present study (Peterson, 1974) and in a section near Bryant Creek (Wells and Rehwinkel, 1980). The farthest downsteam Arctic grayling are known to be found is Melrose, Montana (J. Wells and V. Kozakiewicz, personal communication).

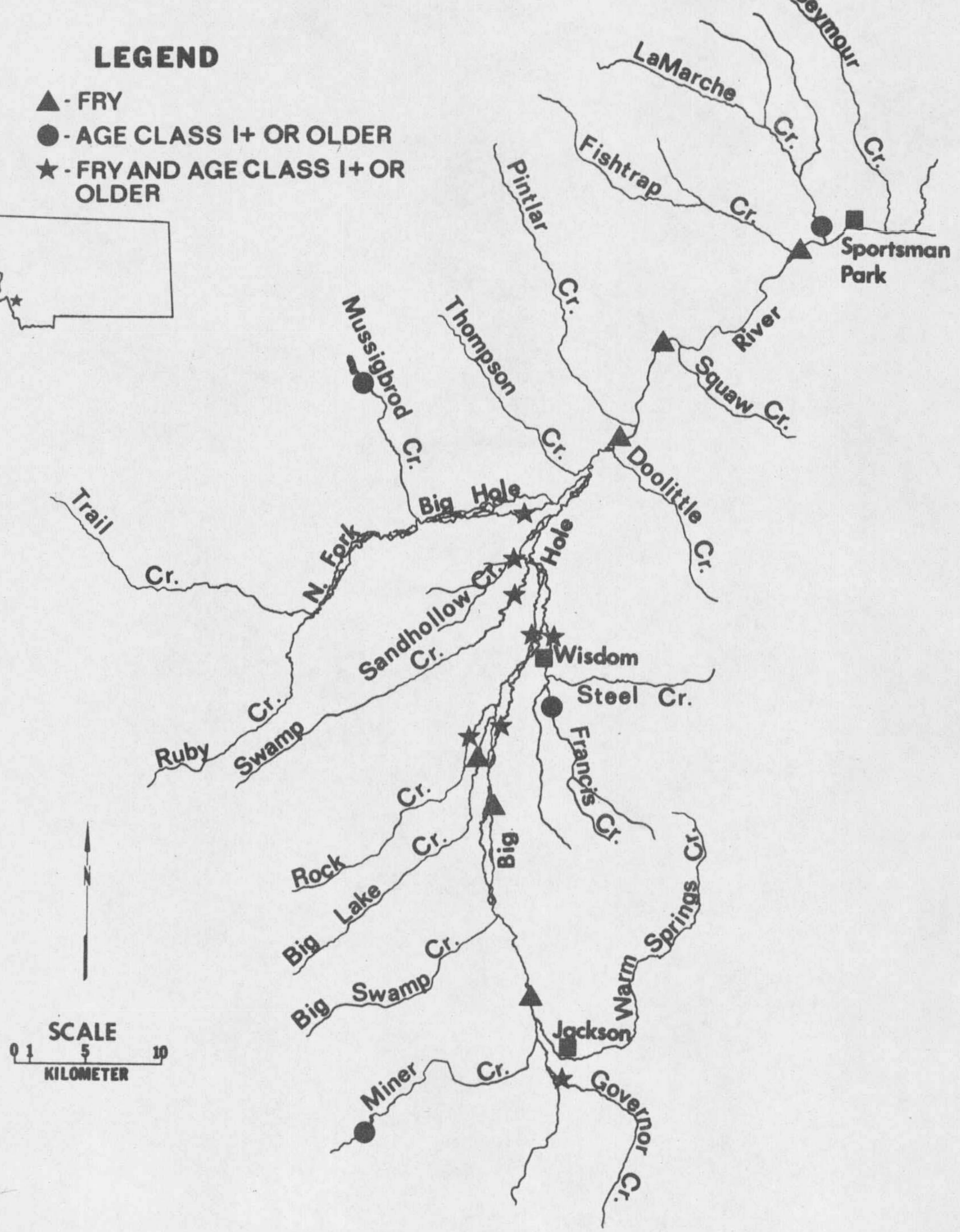

Figure 2. The location of collection sites of Arctic grayling in the upper Big Hole River drainage during 1978 and 1979.

Arctic grayling were not found in Deep, Warm Springs, Johnson and Fishtrap creeks, although these streams appear to contain suitable habitat. Wipperman (1965 and 1967) reported finding adults in Deep Creek. The presence and absence of Arctic grayling in nearby tributaries of the same stream may be due to their specific habitat requirements (Willard and Herman, 1977).

Relative Abundance and Standing Crop

The numbers and sizes of Arctic grayling captured by electrofishing in each study section are shown in Appendix Table 9. The numbers of Arctic grayling were largest in Section 1 and progressively declined in downstream study sections. The average number of Arctic grayling captured per electrofishing run per kilometer in Sections 1, 2 and 5 were 16.9, 5.3 and 4.9, respectively. All were taken in sections above the mouth of the North Fork of the Big Hole River. However, 11 underyearlings 2.7 cm or less in total length were collected by seining below the confluence of the North Fork of the Big Hole River with the main river (Figure 2). Below the North Fork of the Big Hole River, personnel of the Montana Department of Fish, Wildlife and Parks found 2.8 Arctic grayling per electrofishing run per kilometer in the main river near Fishtrap Creek (Peterson, 1974) and 0.6 Arctic grayling per run per kilometer near Bryant Creek (Wells and Rehwinkel, 1980). The estimates of the number and standing crop of Arctic grayling in Section 1 are shown in Table 1.

Table 1. Estimates of population number and standing crop of Arctic grayling on Section 1 of the upper Big Hole River during 1978 (80% confidence intervals are in parentheses).

Section	Size range (cm)	Per km N	Per km Standing crop (kg)	Per hectare N	Per hectare Standing crop (kg)
1	25.1-29.7	35 (24-46)	6.7 (4.2-9.2)	28 (19-37)	5.5 (3.5-7.5)

Sympatric Species

Eleven species of fish coexist with Arctic grayling in the study area. Mountain whitefish (*Prosopium williamsoni*) and brook trout (*Salvelinus fontinalis*) were the most abundant game fish present throughout the study area. Longnose suckers (*Catostomus catostomus*), burbot (*Lota lota*), mottled sculpin (*Cottus bairdi*) and longnose dace (*Rhinichthys cataractae*) were common over the entire study area. Rainbow trout (*Salmo gairdneri*), cutthroat trout (*Salmo clarki*) and rainbow-cutthroat trout hybrids (*S. gairdneri* X *S. clarki*) were limited in distribution in the study area. Only one brown trout (*Salmo trutta*) was observed during this study; it was electrofished on Section 4 near the mouth of LaMarche Creek. However, eight brown trout were captured approximately 10.4 km downstream from the study area by personnel of the Montana Department of Fish, Wildlife and Parks (Wells and Rehwinkel, 1980). Mountain suckers (*Catostomus* *platyrhynchus*) and white suckers (*Catostomus commersoni*) have been collected in the study area (Wells and Rehwinkel, 1980), but none were noted in this study. The estimated numbers and standing crop of brook trout on Sections 1 and 2 are presented in Appendix Table 10.

Age and Growth

A total of 471 scale samples were collected in the Big Hole River drainage of which 337 were obtained in Sections 1, 2 and 5. The mean total length and weight at time of capture and calculated mean total length and weight at each annulus for the 314 fish aged I year or older from Sections 1, 2 and 5 are presented in Appendix Table 11. The calculated lengths and weights for fish of the same age from all sections were similar; the maximum and minimum mean back-calculated lengths and weights never differed more than 0.9 cm and 28 gm, respectively. So, the data from the 431 fish age I or older collected in the upper Big Hole River drainage were pooled (Table 2).

The equations used in the calculations are given in Appendix Table 12. Although the correlation coefficients of the standard scale radius-body length relationship were 0.91 or greater, the logarithmic scale radius-body length relationship was used in the back-calculation of lengths because its predictive value was even greater.

Table 2. Mean total length and weight (standard deviation in parentheses) at time of capture and calculated mean total length and weight at each annulus for all Arctic grayling captured in the upper Big Hole River drainage in 1978 and 1979.

Age Group	N	Mean total length(cm)	Mean total weight(gm)	Calculated length (cm) at each age				
				1	2	3	4	5
I	61	19.8 (±2.0)	76 (±23)	11.6				
II	190	26.1 (±1.6)	168 (±34)	11.9	22.1			
III	167	29.2 (±1.9)	231 (±45)	11.7	22.3	27.5		
IV	12	31.6 (±2.2)	282 (±56)	11.9	23.0	27.8	30.5	
V	1	38.1	431	15.0	27.2	32.0	35.6	37.9
Mean back-calculated length (cm)				11.8	22.2	27.5	30.9	37.9
Mean increment of back-calculated length (cm)				11.8	10.4	5.2	2.8	2.3
Calculated weight (gm)				26.7	114.8	188.3	246.5	395.1

The Arctic grayling from the upper Big Hole River drainage grew most rapidly in the first year and showed a pronounced decline of the growth rate between the second and third years (Table 2). Arctic grayling from the Red Rock drainage (Nelson, 1954) displayed the same pattern of growth, however Arctic grayling in Hyalite Reservoir grew most rapidly in their second year of life (Wells, 1976). The growth curves of Arctic grayling in the upper Big Hole River drainage, two Montana streams not in the Big Hole River drainage where Arctic grayling were collected in the 1950's and three Alaskan rivers are compared in Figure 3. The growth rate of Arctic grayling from the upper Big Hole River drainage was less than in the other Montana streams but greater than in the Alaskan rivers. The growth rate of Arctic grayling in the upper Big Hole River was less than in Hyalite Reservoir (Wells, 1976), Elk Lake (Lund, 1974), Grebe Lake (Kruse, 1959), and the Red Rock drainage (Nelson, 1954) but greater than Peterman (1972) found in Lake Agnes. The growth rate of Arctic grayling in the upper Big Hole River closely resembled that of the species in Canadian lakes (Ward, 1951; Miller, 1946).

Arctic grayling in the upper Big Hole River attained sexual maturity at age III. However, Lund (1974), Peterman (1972), Nelson (1954) and Brown (1938) have reported that a few individuals in Montana matured at age II. In the northern portion of their range, Arctic grayling usually reach sexual maturity between age IV and VI

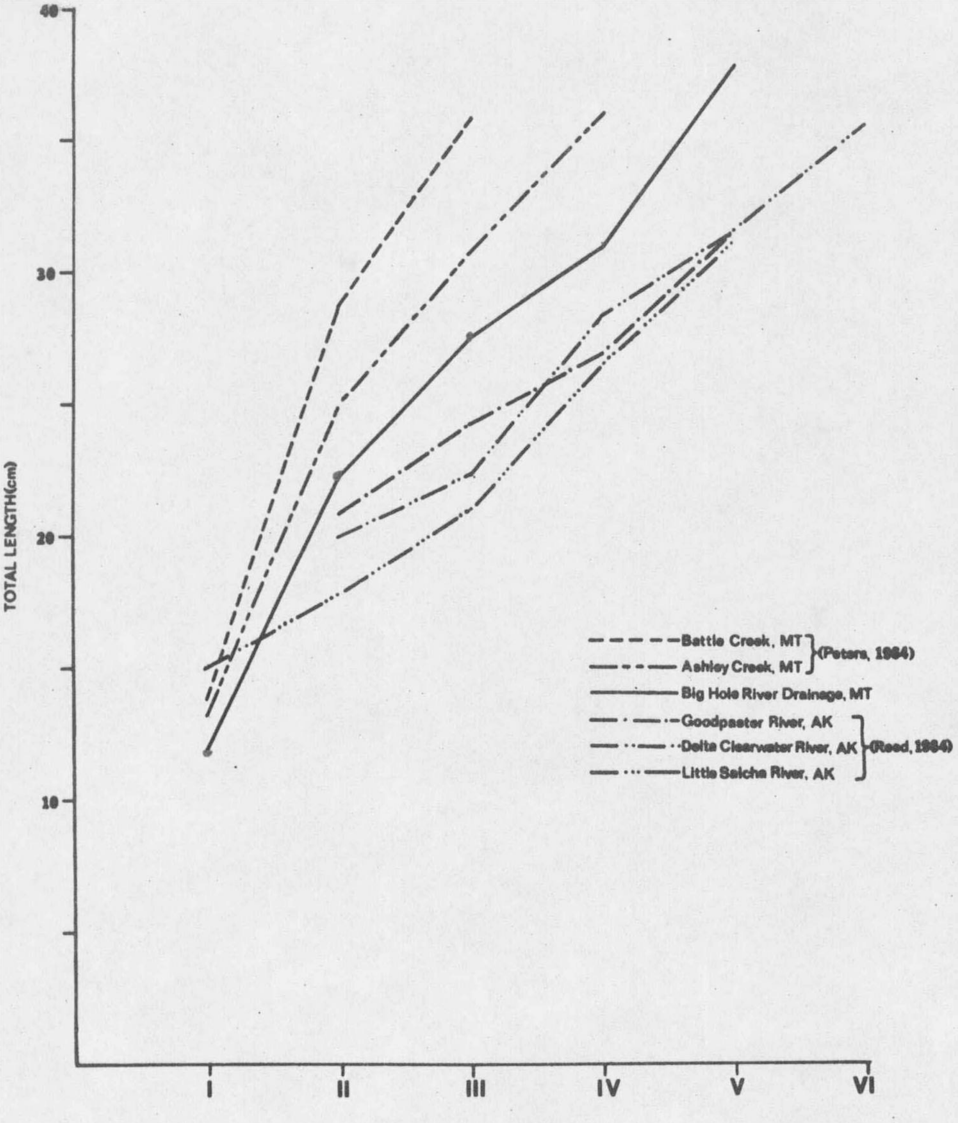

Figure 3. Growth curves of Arctic grayling in the Big Hole River drainage, two Montana streams, and three Alaskan rivers.

(Bishop, 1971; Wojcik, 1955). Wojcik (1955) believed that Arctic grayling could not become sexually mature at lengths of less than 27 cm. Fish in the Big Hole River population which reached sexual maturity at age III had a back-calculated length of 27.5 cm (Table 2).

The oldest fish collected from the Big Hole River was estimated to be 5 years of age. In Montana, Nelson (1954) found an individual 10 years old in Lower Twin Lakes, but Lund (1974), Peterman (1972), Nelson (1954) and Brown (1943) reported that the oldest Arctic grayling found in other populations were 6 or 7 years of age. The oldest Arctic grayling in North America are found in the northern portions of their range. Bishop (1971) reported 11-year-old fish from a tributary of the MacKenzie River and Reed (1964) collected 18 Arctic grayling 8 years old in Alaska.

A total of 146 age 0 Arctic grayling were collected throughout the upper Big Hole River drainage from May 27-July 27, 1979 (Appendix Table 13). The mean total lengths of fry from the Big Hole drainage collected during June 24-30 and July 22-28 were 94% and 28% greater, respectively, than for fry from Narrows Creek (Lund, 1974) during the same periods in 1972 and 1973. The smaller length of fry in Narrows Creek was probably due to the later spawning time there. The peak of spawning activity in Narrows Creek was between May 28 and June 7 in 1972 and 1973, while most spawning activity in the Big Hole River during 1979 occurred in late April and early May.

Some fry appeared to leave the spawning stream quickly and moved into the main river from May 27-29, 1979 while others remained in Sandhollow Creek much longer (Appendix Table 13). The fry that left Sandhollow Creek in May were about the same size as newly hatched fry (Watling and Brown, 1955). Most of the age 0 Arctic grayling captured moving from Sandhollow Creek were obtained from overnight sets of drift nets. Wells (1976) and Lund (1974) reported that most Arctic grayling fry movement occurred between evening and morning. Kruse (1959) determined that the greatest downstream movement occurred from 7:30 to 10:30 P.M.

The smallest Arctic grayling with scales found in this study was 39 mm in total length. It was taken on July 5, 1979. The smallest fingerlings that Brown (1943) and Nelson (1954) found with scales were 35.5 and 45 mm, respectively.

Condition Factors

The mean condition factors (K) of Arctic grayling 17.5-31.6 cm in total length from Sections 1, 2 and 5 are presented in Table 3. Analysis of variance indicated that the condition factor of fish collected from Section 1 during May was significantly less ($P \leq 0.05$) than from those collected there in later months of 1978. The lower condition factor of Arctic grayling taken in May was probably because the sample contained spawned-out individuals.

Table 3. Mean condition factors (K) and standard deviations (in parentheses) of Arctic grayling 17.5-31.6 cm in total length from study sections 1, 2 and 5 on the upper Big Hole River in 1978 and 1979.

Section	Date	N	K
1	5/79	39	0.90(±0.07)
1	6/78-8/78	155	0.96(±0.06)
2	7/78-8/78	65	0.95(±0.08)
5	8/79	10	0.97(±0.11)

Regressions of length and condition factor for collections of Arctic grayling 8.1-38.1 cm in total length from Sections 1 and 2 are shown in Figure 4. These regressions had little predictive value, but both were significantly different from each other and also from zero (F tests; $P<0.05$). The slope of the regression for fish in Section 2 indicates smaller fish were in relatively better condition than larger fish while the opposite was true for fish from Section 1. The slopes of the regressions for fish from Section 1 in May and Section 5 were not significantly different from zero (F test; $p<0.05$).

Characteristics of Habitat

Stream Morphology and Cover

Selected parameters of the physical habitat were measured between July 16 and August 20, 1979 when mean discharges were 0.68, 2.07 and

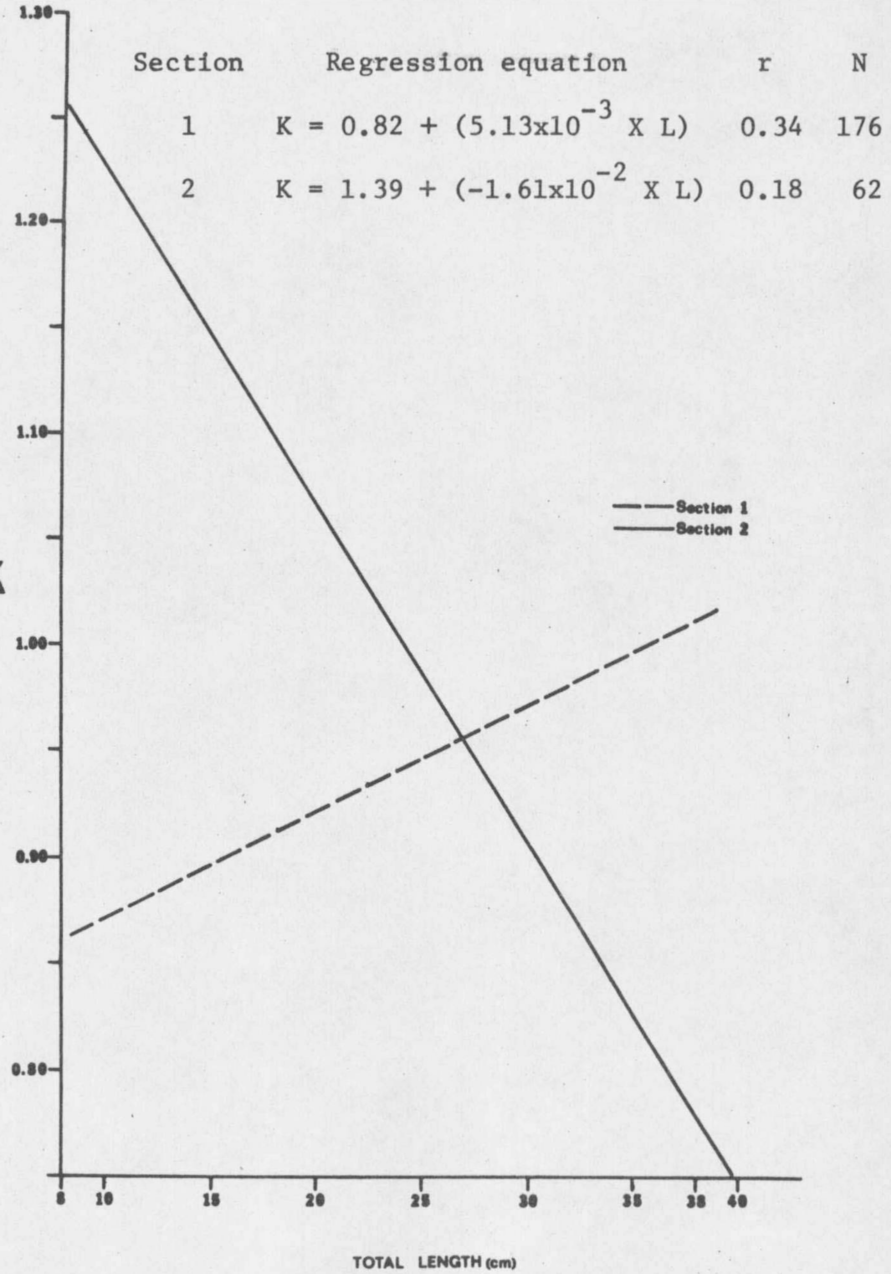

Figure 4. Length-condition regressions of Arctic grayling 8.1-38.1 cm in total length in Sections 1 and 2 in the upper Big Hole River during 1978 and 1979.

3.50 m^3/s at Sections 1, 2 and 3, respectively. The measurements of morphological parameters are shown in Table 4 and the sample size of each parameter is shown in Appendix Table 14. The mean width, pool width and riffle width increased in a downstream direction. Analysis of variance showed significant differences in some parameters between the sections. Comparison of sample means (Q-test; $P<0.05$) showed the mean width and the mean riffle width of Section 3 were significantly greater than in Sections 1 and 2. The mean pool width was significantly greater in each downstream section. The mean depth in each section was significantly different. The mean depth was least in Section 1 and greatest in Section 2. The mean thalweg depth and the mean velocity of Section 2 were significantly greater than in other sections. The mean thalweg velocity of Section 2 was significantly greater than that of Section 1. The percentage of stable banks and the pool-riffle periodicity increased in each downstream section. The pool-riffle periodicity of Section 3 was significantly greater than that of Section 1. The pool-riffle ratio was greatest in Section 1 and decreased in a downstream direction through the study sections, as did the gradient. The proportion of rubble substrate in Section 3 was significantly greater than in Sections 1 and 2. The amount of gravel in Section 1 was significantly greater than in Section 3.

The area of shoreline cover in the study sections is shown in Table 5. The total shoreline cover per 500 m measured in Section 2

Table 4. Mean values and standard deviations (in parentheses) of physical habitat parameters measured in study sections on the upper Big Hole River between July 16 and August 20, 1979.

Parameter	Section 1	Section 2	Section 3
Width (m)	12.21(±4.92)	15.95(±5.02)	48.09(±14.75)
Riffle width (m)	10.83(±4.77)	12.62(±4.46)	51.50(±15.81)
Pool width (m)	8.95(±5.23)	13.40(±5.30)	40.00(±7.60)
Thalweg depth (cm)	54.7(±24.0)	77.3(±33.5)	61.8(±22.0)
Depth (cm)	28.4(±22.6)	39.7(±30.6)	37.3(±23.1)
Thalweg velocity (m/s)	0.27(±0.18)	0.42(±0.28)	0.32(±0.15)
Velocity (m/s)	0.21(±0.15)	0.33(±0.23)	0.21(±0.15)
Stable banks (%)	70.3(±5.0)	78.4(±4.8)	93.2(±2.9)
Pool-riffle periodicity	6.3(±4.2)	7.2(±4.5)	11.6(±7.6)
Pool-riffle ratio	1.51	1.29	0.27
Gradient (%)	0.29	0.23	0.11
Bottom materials			
Boulders	0.9(±5.5)	0.0	0.1(±0.8)
Rubble	41.5(±19.8)	38.8(±14.2)	51.4(±15.6)
Gravel	42.8(±16.2)	39.3(±12.9)	33.0(±11.3)
Fines	14.8(±17.7)	21.9(±20.3)	15.5(±15.5)

was 75 and 5330% greater than that in Sections 1 and 3, respectively. Section 2 displayed greater amounts of shoreline cover in all three cover types. The amount of instream debris considered potential cover was greater in Section 2 than in Sections 1 and 3. The area of instream cover provided by debris was 25.5, 46.4 and 0.0 m^2/500 m in Sections 1, 2 and 3, respectively. Aquatic plants (primarily *Ranunculus aquatilis*) were much more abundant in Section 3 than in Sections 1 and 2. The surface area occupied by aquatic plants was 151.1, 32.0 and 7410.4 m^2/500 m in Sections 1, 2 and 3, respectively.

Table 5. Area (m^2/500m) of shoreline cover in the study sections of the upper Big Hole River measured between July 16 and August 20, 1979.

	Cover type			
Section	Brush	Undercut	Debris	Total
1	56.5	57.5	16.7	130.7
2	78.4	83.4	66.3	228.1
3	0.0	4.2	0.0	4.2

Temperature and Water Chemistry

The values of the physico-chemical parameters of each study section are presented in Appendix Tables 15-22. The mean values and ranges of these parameters are shown in Table 6.

Table 6. Mean and range (in parentheses) of values for physicochemical parameters measured on study sections in the upper Big Hole River drainage from April 21, 1979 through September 1, 1979.

Parameter	Section 1	Section 2	Section 3	Section 5
Temperature (C)	13.7 (0-24)	13.6 (1-25)	15.2 (2-25)	18.0* (12.5-23)
Total alkalinity (mg/l $CaCO_3$)	50.7 (35-60)	51.4 (40-60)	56.4 (35-70)	37.5 (30-40)
Total hardness (mg/l $CaCO_3$)	42.8 (40-50)	41.4 (40-50)	35.7 (30-45)	25.8 (15-30)
Calcium hardness (mg/l $CaCO_3$)	32.1 (25-40)	34.3 (30-40)	30.0 (20-40)	22.5 (15-30)
Magnesium hardness (mg/l $CaCO_3$)	10.7 (0-20)	7.1 (0-10)	5.7 (0-10)	3.3 (0-10)
pH	7.44 (7.22-7.64)	7.38 (6.78-7.80)	7.56 (7.26-7.72)	7.24 (7.04-7.38)
Conductivity (μmhos/cm)	94.1 (50-120)	100.3 (52.5-120)	105.8 (52.5-140)	71.7 (55-90)
Dissolved oxygen (mg/l)	8.7 (7.7-10.2)	8.7 (7.6-10.3)	8.8 (6.5-11.6)	8.8 (7.9-10.0)

* Based on data collected from June 23-August 25, 1979.

Analysis of variance showed significant differences in the water temperatures in Sections 1, 2, 3 and 5. The mean temperatures of Sections 1 and 2 were significantly lower than those of Sections 3 and 5 during periods of comparable data (Q test; $P<0.05$). Water temperatures of 17 C and above exceed the physiological optimum for growth and food conversion efficiency of salmonids (Brett et al., 1969; Wurtsbaugh and Davis, 1977). The recorded number of hours water temperatures exceeded 17 C on Sections 1, 2, 3 and 5 showed that those on Sections 1 and 2 were significantly lower than Sections 3 and 5 during comparable periods of time (Chi-square; $P<0.05$). There were more hours of water temperatures above 17 C in July than in any other month. Water temperatures were above 17 C for 60, 83, and 76% of the time of that month on Sections 1, 3 and 5, respectively. On Section 2, the water in July was above 17 C for 60% of the time during which data were collected. The number of hours the water temperature was greater than 17 C was significantly lower on Sections 1 and 2 than on Sections 3 and 5 during comparable periods in July (Chi-square; $P<0.05$).

Analysis of variance showed no significant differences between chemical parameters measured in Sections 1, 2 and 3. However, analysis of variance and comparison of sample means (Q-test; $P<0.05$) showed differences in the water quality between sections 1-3 on the main river and in Section 5 on a tributary. The alkalinity and total hardness on all sections on the main river were significantly greater than at Section 5. The calcium hardness of Section 2, the magnesium hardness of Section 1 and the conductivity in Section 3 were significantly greater than those parameters in Section 5. The average values of dissolved oxygen from sections on the main river were not statistically different from the section on the tributary. Each individual value was above 85% saturation and mean values were all above 100% saturation.

DISCUSSION

The fluvial Arctic grayling of Montana appear to be largely confined to 44 km of the upper Big Hole River between Jackson and the North Fork of the Big Hole River and approximately 11 tributary streams in the immediate and adjacent area (Figure 2). The greatest number of Arctic grayling in the upper Big Hole River was found in a section lying between Mark Clemow Lane and Wisdom where mean depth, width and velocity were 28.4 cm (±22.6), 12.21 m (±4.92) and 0.21 m/s (±0.15), respectively, and the gradient was 0.29%. This section had a substrate composed primarily of gravel and fines and abundant aquatic vegetation. A comparison of the habitats in the study sections indicated Arctic grayling may have a closer relationship to current velocities than overhead cover.

Vincent (1962) defined Arctic grayling habitat as water with a (1) velocity between 0.31 and 0.61 m/s, (2) gradient between 0.09% and 0.28% with a maximum of 0.38%, (3) depth between 31 and 91 cm and (4) spawning substrate of primarily gravel and coarse sand with frequent beds of aquatic vegetation. The mean velocity, thalweg velocity and depth of Section 1 in the upper Big Hole River was less than in Vincent's criteria, but the mean thalweg depth was within his cited limits. The gradient of Section 1 was greater than the normal range Vincent (1962) cited, but well below the maximum listed.

The Arctic grayling was originally found throughout the upper Missouri River drainage. Several reasons have been proposed to explain the reduction of its range in Montana streams. The alteration of temperatures and dewatering from irrigation may have had an important impact on Arctic grayling.

The thermal tolerance of Arctic grayling is not precisely known. Wojcik (1955) found that Arctic grayling were stressed at 17.2 C and actively avoided water temperatures of 20 C. Vincent (1962) reported that the range of temperature tolerance for Arctic grayling was usually between 10 and 18.3 C. Lord (1932) reported adult Arctic grayling have been held in ponds with water temperatures as high as 23.3 C without any apparent mortality. Feldmeth and Eriksen (1978) found that adult Arctic grayling from Montana acclimated to 13 C had a critical thermal maximum (CTM) of 26.9 C. However, Arctic grayling in the upper Big Hole River were most numerous in Sections 1 and 2 which had significantly fewer hours of water temperatures above 17 C than Sections 3 and 5. Section 3 is probably influenced more by irrigation return water than the other sections. Vincent (1962) felt that man's alteration of habitat appears to have accelerated the natural trend of increasing water temperatures which could cause a reduction in the Arctic grayling's distribution. He also suggested that Arctic grayling may have been able to inhabit some streams with high summer water temperatures by moving to spring-fed tributaries during periods of high water temperatures. Wojcik (1955) has reported this type of movement for Arctic grayling in Alaska. There are no spring-fed tributaries to Section 3, but the presence of Arctic grayling in Section 5 indicates that spring-fed areas may be present.

Dewatering for irrigation had reduced the flows in some tributary streams and in the main river and may have reduced the distribution of Arctic grayling in the upper Big Hole River drainage. The portions of streams most severely affected by dewatering are the areas lying on the valley floor which are the preferred habitats of the Arctic grayling. A dewatered section of Big Swamp Creek, approximately 4.8 km upstream from its confluence with the Big Hole River, was dewatered on June 26, 1979, and on July 16, 1979 the two major channels in Section 1 were dewatered when the entire discharge of the river was diverted through a headgate. Heaton (1960) concluded that reduced flows and dewatered streams appeared to be the primary limiting factors in trout production in the Big Hole River drainage. Vincent (1962) correlated the abrupt decline of Arctic grayling in the Gallatin River drainage, Montana with increases in diversion of water and alteration of the natural drainage pattern.

Barriers may be excluding Arctic grayling from some tributaries of the upper Big Hole River containing suitable habitat. No Arctic grayling were collected from Deep, Warm Springs and Doolittle creeks, which contained numerous beaver dams. Beaver dams appeared to have a deleterious effect upon the adfluvial population in the Red Rocks drainage by blocking spawning migrations (Nelson, 1954). Vincent

(1962) reported that from available evidence, beaver and Arctic grayling populations have an inverse relationship.

Fishing may also be responsible in part for the apparent decline of the Arctic grayling in the upper Big Hole River drainage because this species appears to be very vulnerable to angling. Arctic grayling may be twice as easy to catch as brook trout and five or six times as easy as brown trout (Vincent, 1962) and consequently may be subject to overharvesting. A limited creel census by fish and game wardens from 1954 through 1963 extending from Pintlar Creek to the headwaters near Jackson showed that Arctic grayling composed 13.3% of the catch (Wipperman, 1965). Fisherman logs for the same place and time showed they comprised 25.5% (Wipperman, 1965). However, the populations of fishermen and Arctic grayling in this area during those years is unknown, so the effects of fishing cannot be accurately assessed.

The mean size of Arctic grayling and brook trout creeled from the warden census and fisherman logs was 24.6 cm. If the growth rates have not changed since those years, this could indicate that most Arctic grayling being harvested were prespawners of age II since Arctic grayling in this study reached sexual maturity at age III with a mean back-calculated length of 27.5 cm. If fishing pressure was great, it could have resulted in the substantial harvest of prespawners and interfered with reproduction. Wojcik (1955) concluded that overexploitation resulted in the reduction of Arctic grayling populations in rivers near Fairbanks, Alaska. Vincent (1962) attributed the decline of Arctic grayling populations in part to overexploitation in the Au Sable River, Michigan and the Madison River, Montana. However, other simultaneous events occurring in these rivers, such as logging, introduction of exotic trout, construction of dams and agriculture, prevented actual documentation of declines due to overexploitation.

The reduction of the Arctic grayling's range in Montana and Michigan also has been suggested to be due, either partially or entirely, to competition with exotic species. Vincent (1962) stated Arctic grayling were highly intolerant of introduced trout. Holton (1971) felt exotic species were a major factor contributing to the decline of Arctic grayling. Domrose (1963) reported that the introduction of brook trout and rainbow trout was responsible for the demise of the Arctic grayling in the Centennial Valley. Brown (1943) said that the absence of competitive exotic species is essential to the continued survival of Arctic grayling. However, this species does appear to be able to live together with exotic trout in some situations. Larsen (1947, cited by Nillson, 1967) reported that in Denmark, 16 European grayling (*Thymallus thymallus*) were introduced into a brown trout population. After 10 years there was a large population of grayling and a small population of brown trout. Although Arctic grayling may not dominate exotic trout, they have coexisted with them and cutthroat trout in several lakes in Montana and Wyoming (Table 7).

Table 7. Lakes in Montana and Wyoming containing Arctic grayling and other salmonids.

Lake	Sympatric trout species	Yrs. of coexistence	Source
Miner Lakes	brook trout	50[1]	Peterson, 1974
Mussigbrod Reservoir	brook trout	50[1]	Elser & Marcoux, 1972
Grebe Lake	rainbow-cutthroat trout hybrids	60	Kruse, 1959
Elizabeth Lake	rainbow trout	42	Vincent, 1962
Hyalite Reservoir	cutthroat, brook trout	*	Wells, 1976
Elk Lake	cutthroat, rainbow, hybrids & lake trout	24	Lund, 1974
Hamby Lake	cutthroat, hybrids, brook trout	*	Peterson, 1974
Broadwater Lake	brook trout	26	Marcuson, 1974
Lone Elk Lake	brook trout	*	Marcuson, 1974
Rough Lake	brook trout	*	Marcuson, 1974
Widewater Lake	brook, rainbow trout	*	Marcuson, 1974
Fox Lake	brook, rainbow trout	*	Marcuson, 1974

1 = assumes introductions occurred at the same time as in the Big Hole River.
* = unknown.

Vincent (1962) stated that interspecific competition needed 40 years to manifest itself. During the first 20 years, exotic trout increased, after which there was a sorting period in some areas and then a 20 year period in which the Arctic grayling population declined. In addition to cohabitation of lakes for as long as 60 years, Vincent reported that Arctic grayling coexisted with exotic species in the Otter River, Michigan, the upper Gibbon River above Virginia Cascades (Benson et al., 1959), the upper and central Madison River and the Centennial Valley. Sympatry of Arctic grayling and brook trout occurred in the Otter River for at least 50 years and probably much longer and Arctic grayling fared better than brook trout for a portion of this time (Vincent, 1962).

Brook trout were introduced into the upper Big Hole River around 1929 (Fred Else, personal communication) so the Arctic grayling has lived sympatrically with them in that area for 52 years or approximately 17 generations. Numerous lakes containing both trout and Arctic grayling and the Big Hole River suggests that Arctic grayling apparently can coexist with brook trout if exploitation and habitat changes are not pronounced. Tryon (1947) found that adult Arctic grayling planted into the West Gallatin River, Montana containing rainbow and cutthroat trout lived and grew well although they did not spawn there. Kruse (1959) observed that there was not any obvious antagonism between

Arctic grayling and rainbow-cutthroat hybrids during feeding in Grebe Lake.

Introduced and native fishes apparently can coexist by segregation into different habitats and/or feeding niches when they become sympatric. Nelson (1954) found an inverse relationship in the distribution of brook trout and Arctic grayling in Red Rock Creek, suggesting spatial segregation into different habitats. However, segregation of Arctic grayling and brook trout into different macrohabitats was not apparent in the Big Hole River, since brook trout populations were similar in Sections 1 and 2, but the density of Arctic grayling was quite different. Interspecific social contact of Arctic grayling and brook trout fry in nature should be minimal because they have different emergence dates, which is what Griffith (1972) found for cutthroat and brook trout. Detailed studies of the social behavior and microhabitat utilization of brook trout and Arctic grayling would be needed to determine the amount of niche overlap between Arctic grayling and other species. Brown trout appear to be invading the upper Big Hole River and may become another factor influencing the population of Arctic grayling there.

The decline of the Arctic grayling in the upper Big Hole River drainage and also in its historic range is probably not due to any single reason, but rather to a combination of overexploitation, habitat change and possibly interspecific competition operating simultaneously.

Vincent (1962) felt that the Arctic grayling was vulnerable to changes because it had a high degree of genetic homogeneity. The average heterozygosity of Arctic grayling is 0.034, which is in the normal range of salmonids and is similar to that of other fish that have strigent habitat requirements (Lynch and Vyse, 1979).

Management Recommendations

The fluvial Arctic grayling of the upper Big Hole River drainage is a species of special concern to Montana (Deacon, et al., 1979). It is the only fluvial Arctic grayling stock in the contiguous United States. Several measures should be taken to insure the continued existence of this unique morph. Water reservations for instream flows should be secured. The populations and water quality particularly in Section 1 should be frequently estimated or monitored. Barriers on tributary streams in the upper Big Hole River drainage should be removed to enable the Arctic grayling to potentially increase its range. A minimum size limit of 27.5 cm should be instituted to allow most Arctic grayling to spawn before being removed by angling and a thorough creel census should be conducted to determine the fishing pressure and harvest. As the ultimate safeguard for this unique population, other secure areas with suitable habitat similar to Section 1 should be sought for receiving plants of Arctic grayling to further protect this unique gene pool.

REFERENCES CITED

REFERENCES CITED

Aagaard, F. C. 1969. Temperature of surface waters in Montana. U.S. Dept. of the Interior, Geological Survey and Montana Fish and Game Comm. 613 pp.

APHA. 1976. Standard methods for the examination of water and wastewater, 14 ed. Amer. Public Health Association, Washington, D.C. 1193 pp.

Bagenal, T. B. and F. W. Tesch. 1978. Age and growth. Pages 101-136 in T. B. Bagenal, editor. Methods of assessment of fish production in fresh waters, 3 ed. Blackwell Scientific Publications, Oxford and Edinburgh, Great Britain.

Benson, N. G., O. B. Cope, and R. V. Bulkley. 1959. Fishery management studies on the Madison River system in Yellowstone National Park. U.S. Dept. of the Interior, Fish and Wildlife Service. Spec. Sci. Rep.: Fish. no. 307. 29 pp.

Bishop, F. G. 1971. Observations on spawning habits of the Arctic grayling. Prog. Fish-Cult. 33(1):12-19.

Brett, J. R., J. E. Shelbourn, and C. T. Shoop. 1969. Growth rate and body composition of fingerling sockeye salmon, *Oncorhynchus nerka*, in relation to temperature and ration size. J. Fish. Res. Bd. Canada 26(9):2363-2394.

Brown, C. J. D. 1938. Observations on the life history and breeding habits of the Montana grayling. Copeia 1938(3):123-126.

____________. 1943. Age and growth of Montana grayling. J. Wild. Mgmt. 7(4):353-364.

Deacon, J. E., G. Kobetich, J. D. Williams, S. Contreras and other members of the Endangered Species Committee of the American Fisheries Society. 1979. Fishes of North America endangered, threatened or of special concern: 1979. Fisheries 4(2):29-44.

Domrose, R. J. 1963. Age and growth of brook trout in Montana. Proc. Mont. Acad. Sci. 23:47-62.

Elser, A. A. and R. G. Marcoux. 1972. Inventory of the waters of the project area. Fed. Aid Proj. F-9-R-19, Job. no. I-a. Montana Dept. of Fish and Game, Helena. 39 pp.

Feldmuth, C. R. and C. H. Eriksen. 1978. A hypothesis to explain the distribution of native trout in a drainage of Montana's Big Hole River. Verh. Internat. Verein. Limnol. 20:2040-2044.

Gerking, S. H. 1967. The biological basis of freshwater fish production. Blackwell Scientific Publications, Oxford and Edinburgh, Great Britain. 495 pp.

Griffith, J. S., Jr. 1972. Comparative behavior and habitat utilization of brook trout (*Salvelinus fontinalis*) and cutthroat trout (*Salmo clarki*) in small streams in northern Idaho. J. Fish. Res. Bd. Canada 29(3):265-273.

Heaton, J. R. 1960. Inventory of waters of the project area-Big Hole River drainage survey. Fed. Aid Proj. F-9-R-8, Job. no. I. Montana Dept. of Fish and Game, Helena. 14 pp.

Henshall, J. A. 1906. A list of the fishes of Montana. Bull. Univ. of Mont., Missoula 34(11):1-12.

Hesse, L. 1977. Fire 1, a computer program for the computation of fishery statistics with aged and nonaged subsamples. IBM360/65, Fortran IV G level. E. Huff, editor. Nebraska Game and Parks Commission, Lincoln. Neb. Tech. Ser., No. 1. 60 pp.

Hile, R. 1941. Age and growth of the rock bass, *Ambloplites rupestris* (Rafinesque), in Nebish Lake, Wisconsin. Trans. Wis. Acad. Sci. Arts. Lett. 33:189-337.

Holton, G. D. 1971. Montana grayling: the lady of the streams. Mont. Outdoors 2(5):18-23.

Kruse, T. E. 1959. The grayling of Grebe Lake, Yellowstone National Park, Wyoming. U. S. Fish and Wildlife Service. Fish. Bull. 149(59):307-351.

Larsen, K. 1947. Stallingens Udbredelse og Forekomst i Danmark (English summary: The occurrence of the grayling in Denmark and its distribution in individual rivers). Undersøgelser over Stallingen (*Thymallus thymallus* L.) i Danmark. Danmarks Sportfiskerforbund. Skive. (not seen, cited by Nilsson, 1967).

Leopold, L. B. and W. B. Langbein. 1966. River meanders. Sci. Amer. 214(6):60-70.

Lord, R. F. 1932. Notes on Montana graylings at the Pittsford, Vt., experimental trout hatchery. Tran. Amer. Fish. Soc. 62:171-178.

Lund, J. A. 1974. The reproduction of salmonids in the inlets of Elk Lake, Montana. M.S. Thesis, Montana St. Univ., Bozeman. 43 pp.

Lund, R. E. 1979. A user's guide to MSUSTAT--an interactive statistical analysis package. Dept. of Math. Sci., Montana St. Univ., Bozeman. 74 pp.

Lynch, J. C. and E. R. Vyse. 1979. Genetic variability and divergence in grayling, *Thymallus arcticus*. Genetics 92:263-278.

Marcuson, P. 1974. Beartooth grayling study. Fed. Aid Proj. F-20-R-18, Job. no. I-a (supplement). Montana Dept. of Fish and Game, Helena. 18 pp.

Miller, R. B. 1946. Notes on the Arctic grayling, *Thymallus signifer* Richardson, from Great Bear Lake. Copeia 1946(4):227-236.

MDNRC. 1979. Potential off-stream reservoir sites in the Big Hole River Basin. Montana Dept. of Nat. Res. and Cons., Helena. 49 pp.

Nelson, P. H. 1954. Life history and management of the American grayling (*Thymallus signifer tricolor*) in Montana. J. Wild. Mgmt. 18(3):324-342.

Nie, N. H., C. H. Hull, J. G. Jenkins, K. Steinbrenner and D. H. Bent. 1975. Statistical package for the social sciences, 2 ed. McGraw-Hill, Inc., New York. 675 pp.

Nilsson, Nils-Arvid. 1967. Interactive segregation between fish species. Pages 295-313 in S. D. Gerking, editor. The biological basis of freshwater fish production. Blackwell Scientific Publications, Oxford and Edinburgh, Great Britain.

Peterman, L. G. 1972. The biology and population characteristics of the Arctic grayling in Lake Agnes, Montana. M. S. Thesis, Montana St. Univ., Bozeman. 29 pp.

Peters, J. C. 1964. Age and growth studies and analysis of bottom samples in connection with pollution studies. Fed. Aid Proj. F-23-R-6, Job. no. I and II. Montana Dept. of Fish and Game, Helena. 76 pp.

Peterson, N. 1974. Southwestern Montana Fisheries Study. Fed. Aid Proj. F-9-R-22, Job. no. I-b. Montana Dept. of Fish and Game, Helena. 13 pp.

Reed, R. J. 1964. Life history and migration patterns of Arctic grayling, *Thymallus arcticus* (Pallas), in the Tanana River. Alaska Dept. of Fish and Game, Juneau. Res. Rep. No. 2. 30 pp.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin 191, Department of the Environment, Fisheries and Marine Service. Ottawa, Canada. 382 pp.

Snedecor, G. W. and W. G. Cochran. 1967. Statistical methods, 6 ed. Iowa St. Univ. Press, Ames. 593 pp.

Tryon, C. A., Jr. 1947. The Montana grayling. Prog. Fish-Cult. 9(3):136-142.

Vincent, R. E. 1962. Biogeographical and ecological factors contributing to the decline of Arctic grayling, *Thymallus arcticus* (Pallas), in Michigan and Montana. Ph. D. Thesis, Univ. of Mich. 169 pp.

Ward, J. C. 1951. The biology of the Arctic grayling in the southern Athabaska drainage. M. S. Thesis, Univ. of Alberta. 71 pp.

Watling, H., and C. J. D. Brown. 1955. The embryological development of the American grayling from fertilization to hatching. Trans. Amer. Micro. Soc. 74(1):85-93.

Wells, J. D. 1976. The fishery of Hyalite Reservoir during 1974 and 1975. M. S. Thesis, Montana St. Univ., Bozeman. 47 pp.

Wells, J. D., and B. J. Rehwinkel. 1980. Southwest Montana fisheries study. Fed. Aid Proj. F-9-R-27, Job. no. I-b. Montana Dept. of Fish, Wild. and Parks, Helena. 32 pp.

Wentworth, C. K. 1922. Grade and class terms for clastic sediments. J. Geol. 30:377-392.

Willard, E. E. and M. Herman. 1977. Montana grayling and its habitat. Montana Forest and Cons. Expt. Sta., Univ. of Mont., Missoula. 15 pp.

Wipperman, A. H. 1965. Big Hole River sport fishery. Fed. Aid Proj. F-9-R-13, Job no. I-a. Montana Dept. of Fish and Game, Helena. 10 pp.

___________. 1967. Southwest Montana Fishery Study. Fed. Aid Proj. F-9-R-15, Job no. I. Montana Dept. of Fish and Game, Helena. 14 pp.

Wojcik, F. J. 1955. Life history and management of the grayling in interior Alaska. M. S. Thesis, Univ. of Alaska, Fairbanks. 54 pp.

Wurtsbaugh, W. A. and G. E. Davis. 1977. Effects of temperature and ration level on the growth and food conversion efficiency of *Salmo gairdneri*, Richardson. J. Fish. Biol. 11:87-98.

APPENDIX

Appendix Table 8. Locations of study sites on the upper Big Hole River.

Section electrofished	Legal description	Location	Length (meters)
Section 1	T3S, R15W, Sections 17,8 and 4	McDowell Ranch	4450
Section 2	T2S, R15W, Sections 28,21,16 and 15	Barker Ranch	4900
Section 3	T1N, R14W, Sections 33,28 and 27	Christiansen Ranch	4600
Section 4	T2N, R13W, Sections 33 and 34	Roberts Ranch	3500
Section 5	T1S, R15W, Sections 32 and 33	Rutledge Ranch	2050

Appendix Table 9. Catch statistics of Arctic grayling on study sections of the upper Big Hole River during 1978 and 1979.

Section	Size range(cm)	Date	Number Marked	Captured	Recaptured
1	8.1- 9.9	8/15-8/25/78	5	3	0
	10.0-10.9		1	10	0
	17.0-18.5		3	0	0
	19.0-19.9		3	4	0
	20.0-20.9		3	4	0
	21.0-21.8		5	5	0
	22.1-22.6		0	3	0
	23.5-23.9		0	2	0
	24.0-24.9		8	6	0
	25.0-25.9		11	9	5
	26.0-26.9		6	14	1
	27.0-27.9		13	10	2
	28.0-28.7		4	9	1
	29.0-29.7		4	6	2
	30.0-30.7		4	2	0
	31.0-31.5		1	0	0
	32.0-33.0		1	2	0
	Total		72	89	11
2	8.1- 9.1	8/2-8/8/78	0	3	0
	19.3-20.1		1	2	0
	23.9-24.9		1	5	0
	25.7-25.9		2	2	0
	26.2-26.9		5	7	0
	27.2-27.9		4	3	0
	28.2-28.7		2	3	0
	29.0-29.5		2	3	0
	30.2-30.7		0	2	0
	31.5-32.0		0	2	0
	33.0-33.5		2	1	0
	Total		19	33	0
3	ND	8/1/78	0		
4	ND	8/30/79	0		

Appendix Table 9. (Continued)

Section	Size range(cm)	Date	Number Marked	Number Captured	Number Recaptured
5	17.5-19.2	8/31/79	4		
	20.0-20.5		3		
	21.4-21.7		2		
	31.5-31.9		1		
	Total		10		

Appendix Table 10. Catch statistics, estimates of numbers and standing crop of brook trout on study sections of the upper Big Hole River during 1978 (80% confidence intervals are in parentheses).

Section	Size Range(cm)	Number Marked	Number Captured	Number Recaptured	Per km N	Per km Standing Crop(kg)	Per Hectare N	Per Hectare Standing Crop(kg)
1	19.8-21.8	13	13	5	7 (4-10)	0.7 (0.4-1.0)	6 (4-8)	0.6 (0.4-0.8)
1	21.9-23.2	6	2	0				
1	23.3-31.0	69	78	21	56 (43-69)	12.2 (7.4-17.0)	46 (36-56)	10.0 (8.0-12.0)
1	31.1-32.2	2	5	0				
1	32.3-40.5	9	10	4	5 (3-7)	2.0 (1.0-3.0)	4 (3-5)	1.6 (0.8-2.4)
2	8.6-23.2	9	8	0				
2	23.3-31.0	46	66	8	71 (44-98)	16.8 (8.3-25.3)	45 (28-62)	10.6 (5.3-15.9)
2	35.0-42.1	2	0	0				
3	27.2-39.6	8						
4	8.5-32.5	79						
5	6.7-38.4	212						