Yellowstone River (Nelson Spring Creek) R-3

POTENTIAL INFLUENCE OF RECREATIONAL USE ON NELSON SPRING CREEK, MONTANA

by

Bruce Charles Roberts

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

of

Master of Science

in

Fish and Wildlife Management

MONTANA STATE UNIVERSITY
Bozeman, Montana

March 1988

APPROVAL

of a thesis submitted by

Bruce Charles Roberts

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

March 1, 1988 — Robert G. White
Date — Chairperson, Graduate Committee

Approved for the Major Department

March 1, 1988 — Peter F. Brussard
Date — Head, Major Department

Approved for the College of Graduate Studies

3-2-88 — [signature]
Date — Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his absence, by the Dean of Libraries when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature Bruce C. Roberts

Date March 1, 1988

VITA

Bruce Charles Roberts was born to Maxine and Hadley Roberts on March 6, 1961 in Great Falls, Montana. He attended and graduated from Salmon High School, Salmon, Idaho in January 1979 and University of Idaho, Moscow, Idaho in May 1985 with a Bachelor of Science degree in Fisheries Resources. He was accepted to graduate school at Montana State University in October 1985 and since then has been working on a Master of Science degree in Fish and Wildlife Management.

ACKNOWLEDGMENTS

I wish to express my appreciation to Dr. Robert G. White for his superior guidance and assistance throughout this study and to Drs. Lynn Irby, Calvin Kaya and Ray White for the review of this thesis.

I also wish to thank friends and personnel of the Montana Department of Fish, Wildlife and Parks, Montana State University and U.S. Fish and Wildlife Service for their assistance throughout this study: Jim Brammer, Sue Brammer, Jody Brostrom, Pat Bigelow, Annie Connor, Bill Connor, Chris Clancy, Thurston Dotson, Doug Dwyer, Pat Dwyer, Pat Graham, Bob Gresswell, Mike Hensler, Sam Lohr, George Liknes, Beth MacConnell, Bob McFarland, Mark Novak, Wes Orr, Jerry Perez, Jim Petersen, Jim Peterson, Bill Schrader, Ed Seth, Dee Topp, Dick Vincent, Art Viola, Tom Weaver, Jerry Wells, Tommy Williams, Denise Wilson and Bob Wiltshire. Thanks are extended to Charlie Smith for the use of facilities and equipment at the Bozeman Fish Technology Center.

Thanks go to the William Dana, Jr. and Edwin Nelson families. Without their cooperation, this study would have not been possible. Finally, my most sincere thanks are extended to Maxine and Hadley Roberts for the love, encouragement and support they gave throughout this study.

TABLE OF CONTENTS

	Page
APPROVAL	ii
STATEMENT OF PERMISSION	iii
VITA	iv
ACKNOWLEGMENTS	v
TABLE OF CONTENTS	vi
LIST OF TABLES	viii
LIST OF FIGURES	xi
ABSTRACT	xiv
INTRODUCTION	1
DESCRIPTION OF STUDY AREA	4
METHODS	10
Laboratory	10
Multiple Human Wading	10
Single Wading Event	20
Field	22
Spawning Use	22
Embryonic Development Specific to Nelson Spring Creek	23
Recreational Use in Sections 3 and 4	24
RESULTS AND DISCUSSIONS	27
Laboratory	27
Multiple Human Wading	27
Single Wading Event	36
Field	45
Spawning Use	45
Embryonic Development Specific to Nelson Spring Creek	52
Recreational Use in Sections 3 and 4	56

TABLE OF CONTENTS--*Continued*

	Page
POTENTIAL INFLUENCE OF RECREATIONAL USE ON NELSON SPRING CREEK	61
SUMMARY	65
REFERENCES CITED	68
APPENDIX	73

LIST OF TABLES

Table Page

1. Mean particle size distribution determined from five McNeil substrate samples taken from known spawning areas in section 4 of Nelson Spring Creek, Montana, October 1985 12

2. Wading frequency, depth of eggs and egg source of the five wading experiments 14

3. Embryonic development rates (centigrade temperature units[a] and days) of brown, rainbow and cutthroat trout in the laboratory . 30

4. Percent mortality[a] from wading treatments 1-6 during experiments 3, 4 and 5 31

5. Survival coefficients used to adjust percent survival of treatment eggs and pre-emergent fry. Coefficients based upon nonwading-related mortality in the optimium incubation environment of a Heath stack incubator 31

6. Mean adjusted percent embryo and pre-emergent fry survival in control egg baskets located near chamber inflows and outflows. Control egg baskets retrieved at the end of the same developmental period, but from different treatments were combined to increase sample size 33

7. Range of water temperatures and dissolved oxygen during wading experiments 35

8. Dimensions and surface area (m^2) of spawning areas within the 13 sections in Nelson Spring Creek, Montana in July 1986 46

9. Number of cutthroat trout redds and percent of total in each of 13 sections in Nelson Spring Creek, Montana in 1986 and 1987. Spawning sections 11-13 were unavailable for cutthroat trout spawning 48

LIST OF TABLES--Continued

Table Page

10. Streamside and underwater observations of tagged trout during their respective spawning period in Nelson Spring Creek, Montana from 18 November 1985 to 4 August 1986 50

11. Timing and abundance of trout migrating from the Yellowstone River into Nelson Spring Creek, Montana as determined by trapping and electrofishing, fall 1984 to summer 1986 (Clancy 1984, Clancy 1985 and C. Clancy, pers. comm.) 51

12. Embryonic development rates (centigrade temperature units[a] and days) of brown, rainbow and cutthroat trout specific to section 4 of Nelson Spring Creek, Montana . . . 53

13. Mean percent brown, rainbow and cutthroat trout survival (standard error) in test egg baskets (n = 8) exposed to wading treatments 1-6 and corresponding controls (n = 8) for all five experiments. Sample sizes for brown trout (experiment 1) ranged between 2-5 73

14. Mean percent brown, rainbow and cutthroat trout mortality (standard error) in test egg baskets (n = 4) exposed to one wading event in 1.0 m and 0.3 m wide chambers at various stages of development (CTU) and corresponding controls (n = 4). Egg baskets were arranged in the chambers according to experimental design "A" (Figure 6). Sign test ($\alpha = 0.05$) was used to statistically analyze comparison data 74

15. Mean percent brown and rainbow trout mortality (standard error) in test egg baskets (n = 4) exposed to one wading event in 1.0 m and 0.3 m wide chambers at various stages of development (CTU) and corresponding controls (n = 4). Egg baskets were arranged in the chambers according to experimental design "B" (Figure 6). Sign test ($\alpha = 0.05$) was used to statistically analyze comparison data 75

LIST OF TABLES--Continued

Table Page

16. Weekly trout redd counts made on Nelson Spring Creek, Montana from 1 November 1985 to 11 August 1986 77

17. Weekly cutthroat trout redd counts made on Nelson Spring Creek, Montana from 3 June to 24 July 1987 78

18. Number of registered anglers on the Dana ranch and estimated angler use (min) in sections 3 and 4 of Nelson Spring Creek, Montana between 28 February and 30 August 1986 79

LIST OF FIGURES

Figure		Page
1.	Location of Nelson Spring Creek relative to Livingston, Montana, Yellowstone River, Armstrong Spring Creek, McDonald Creek and nearest access areas	5
2.	Nelson Spring Creek, Montana study area showing spawning sections (1-13), property lines and high-water side-channels of the Yellowstone River	6
3.	Weekly staff gage readings (cm) taken at the bridge (Dana ranch) on Nelson Spring Creek, Montana between 18 November 1985 and 20 October 1986	8
4.	Diagram of incubation chambers and the process used to plant eggs in the substrate: 1) egg baskets placed in the substrate within wood retaining frames; 2) 2 cm layer of substrate placed in each basket; 3) 200 eggs evenly distributed; 4) egg baskets carefully filled with substrate mixture before wood retaining frames were removed	11
5.	Diagram of wading treatments and egg basket retrieval relative to periods of development . .	15
6.	Diagram of the wide (1.0 m) and narrow (0.3 m) incubation chambers used in chamber width comparison experiments and the location of the control and test egg baskets. Experimental design "A" was used for experiments 1, 2 and 3 (brown, rainbow and cutthroat trout) and experimental design "B" was used for experiments 4 and 5 (brown and rainbow trout)	18
7.	Location of spawning areas in sections 3, 4 and 5 and of the Minolta 8 mm movie camera with coverage view	25

LIST OF FIGURES--Continued

Figure Page

8. Mean adjusted survival (%) and standard error bars for Harrison Lake brown trout (experiment 1) and McConaughy rainbow trout (experiment 2) eggs and pre-emergent fry in the control (n = 8) and test (n = 8) egg baskets exposed to wading treatments 1-6 in the laboratory. Brown trout sample size ranged between 2 and 5. Brown trout test egg baskets were waded on once every third day; rainbow trout were waded on twice-daily 28

9. Mean adjusted survival (%) and standard error bars for Yellowstone Lake cutthroat trout (experiment 3), Bighorn River brown trout (experiment 4) and Desmet rainbow trout-Harrison Lake (experiment 5) eggs and pre-emergent fry in the control (n = 8) and test (n = 8) egg baskets exposed to wading treatments 1-6 in the laboratory. Test egg baskets were waded on twice-daily 29

10. Mean percent mortality and standard error bars for control (n = 4) and test (n = 8) egg baskets exposed to one wading event in relation to centigrade temperature units, developmental stage and days after fertilization: Harrison Lake brown trout (experiment 1), McConaughy rainbow trout (experiment 2), Yellowstone Lake cutthroat trout (experiment 3), Bighorn River brown trout (experiment 4) and Desmet rainbow trout-Harrison Lake (experiment 5) 37

11. Percent survival to hatching of Bighorn River brown trout, McConaughy rainbow trout and Yellowstone Lake cutthroat trout pre-eyed eggs incubated at two water temperature regimes and handled daily between fertilization and eye-up. Each point represents percent survival from one handling test 40

12. Weekly counts of new brown, rainbow and cutthroat trout redds on Nelson Spring Creek, Montana made from 1 November 1985 to 11 August 1986 47

LIST OF FIGURES--Continued

Figure Page

13. Number of centigrade temperature units per week during trout egg incubation and pre-emergent fry development in section 4 of Nelson Spring Creek, Montana 54

14. Number of trout redds with developing eggs and/or pre-emergent fry in sections 3 and 4 of Nelson Spring Creek, Montana between 1 November 1985 and early September 1986 55

15. Angler use on lower Nelson Spring Creek, Montana (sections 3 and 4) between 28 February and 30 August 1986 57

16. Number of invited anglers per week registering to fish on the Dana ranch, and the number of boats landing per week near the mouth of Nelson Spring Creek, Montana between 9 March and 30 August 1986 (Graham et al. 1986) 59

ABSTRACT

Potential effects of angler wading on trout embryo and pre-emergent fry survival were investigated in laboratory channels. Impact varied with wading frequency and stage of embryonic development. Mortality was highest between the initiation of chorion softening and hatching and for pre-emergent fry. A slight increase in susceptability to wading occurred at the time of blastopore closure. Twice-daily wading throughout development resulted in embryo and pre-emergent fry mortality of up to 96%, while single wading treatments applied just prior to hatching resulted in mortality as high as 43%. The severity and pattern of wading-related mortality was similar between brown, rainbow and cutthroat trout. Spawning sections of Nelson Spring Creek with the greatest potential impact from angler use were used extensively by Yellowstone River migrant spawners. Sixty-two percent (13.1 h) of the angler use in these sections between 28 February and 30 August 1986 occurred when cutthroat trout embryos and pre-emergent fry were incubating (15 June to 30 August). Potential detrimental impact of anglers accessing Nelson Spring Creek by wading was greatest for Yellowstone River cutthroat trout.

INTRODUCTION

A 1983 Montana Supreme Court decision granted public access to all flowing waters in Montana. The ruling allows sportsmen to wade and fish all streams between the high-water marks if access is gained legally. In 1985, the Montana Department of Fish, Wildlife and Parks (MDFWP) was directed by the state legislature under House Bill 265 (Chapter 556, Laws of 1985) to adopt rules pertaining to the management of recreational use of rivers and streams. A process was established by which persons may petition the Fish and Game Commission to restrict public recreational use of certain waterways: 1) to protect against impacts of recreational use; and, 2) to limit recreational use of streams to their actual capacity. This process became effective July 12, 1985.

On July 22, 1985, William Dana, Jr. filed the first petition under this law requesting that Nelson Spring Creek be closed to recreational use without permission of the owners. Specific allegations included:

> "The creek is incapable of supporting unlimited wading in its bed because this would inevitably cause severe damage to its fragile ecosystem including its irreplaceable role as a spawning ground for Yellowstone River trout."

> "Unlimited wading in Nelson Spring Creek would create a strong, though with current data unquantifiable, risk of severely degrading the creek as a spawning area and if that degradation occurs there will be degradation of the Yellowstone fishery for miles up and downstream from the mouth of the creek."

On August 5, 1985, Edwin S. Nelson filed a second petition to limit access to Nelson Spring Creek. A report on these petitions with potential alternatives for action was presented to the Montana Fish and Game Commission on September 4, 1985 (Wells et al. 1985). Following a public hearing the alternative course of action chosen by the commission was to conditionally extend the petition for 14 months and conduct necessary research:

1) To ascertain the amount and types of use on Nelson Spring Creek as it flows through the Nelson and Dana ranches.

2) To determine the distribution and timing of spawning and quantify the effect of wading on survival of brown, rainbow and cutthroat trout eggs.

3) To evaluate the sensitivity of spring creeks to damage by evaluating spring creeks under a variety of use patterns.

4) To conduct studies on the "social" carrying capacity of spring creeks. If restrictions are needed, efficient and equitable methods of restricting use would be evaluated.

Minimal water level fluctuations of Nelson Spring Creek and the creek's rectangular channel form, force unauthorized anglers to wade portions of the creek to legally access fishing areas upstream. The major focus of this study was to examine the potential impact of wading through spawning areas on survival of trout eggs and pre-emergent fry. Specific objectives were:

1) Evaluate effects of wading on brown, rainbow and cutthroat trout eggs and pre-emergent fry.
2) Document the amount, distribution and timing of brown, rainbow and cutthroat trout spawning in Nelson Spring Creek.
3) Document the amount of recreational use on lower Nelson Spring Creek.

DESCRIPTION OF STUDY AREA

Nelson Spring Creek originates from a series of coldwater springs and parallels the Yellowstone River in a northerly direction for 2.6 km before entering the Yellowstone River at river kilometer 813 south of Livingston, Montana (Figure 1) (Decker-Hess 1986). The creek lies entirely within Township 03 South, Range 09 East, Sections 23 and 26 of Park County. Public access to the creek is limited to floaters and waders staying within the ordinary high-water mark of the Yellowstone River and Nelson Spring Creek or by landowner permission. Nearest public access is approximately 3.2 river kilometers downstream and 5.0 river kilometers upstream from the confluence of the creek with the Yellowstone River (Figure 1).

Land adjacent to the creek is owned by the Edwin Nelson and William Dana, Jr. families. The upper 1.30 km and the lower 0.55 km of the creek flows through the Dana ranch; the middle 0.75 km of stream flows through the Nelson ranch (Figure 2). The lower 0.25 km lies within a high-water side-channel of the Yellowstone River and is inundated during spring flows of high water years. Land and water uses consist of a commercial trout hatchery, a

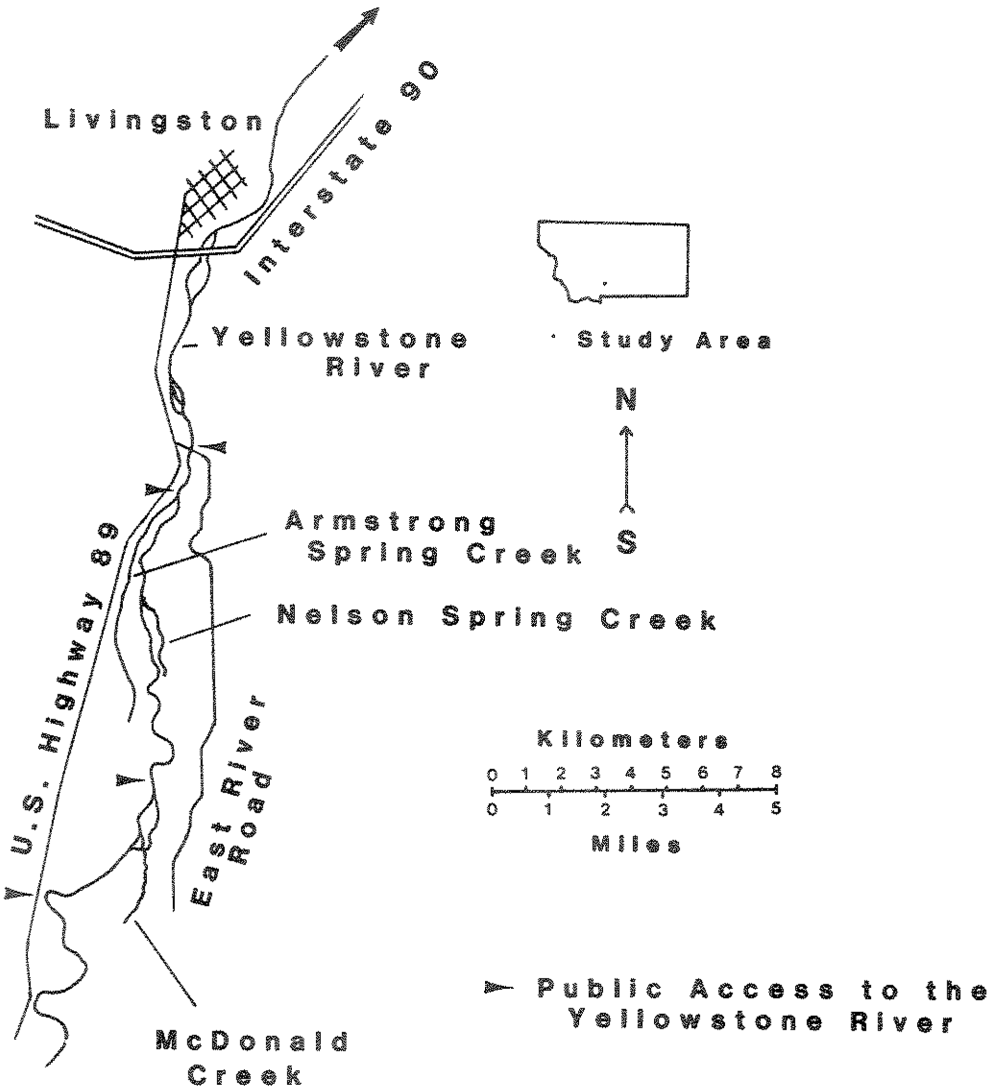

Figure 1. Location of Nelson Spring Creek relative to Livingston, Montana, Yellowstone River, Armstrong Spring Creek, McDonald Creek and nearest access areas.

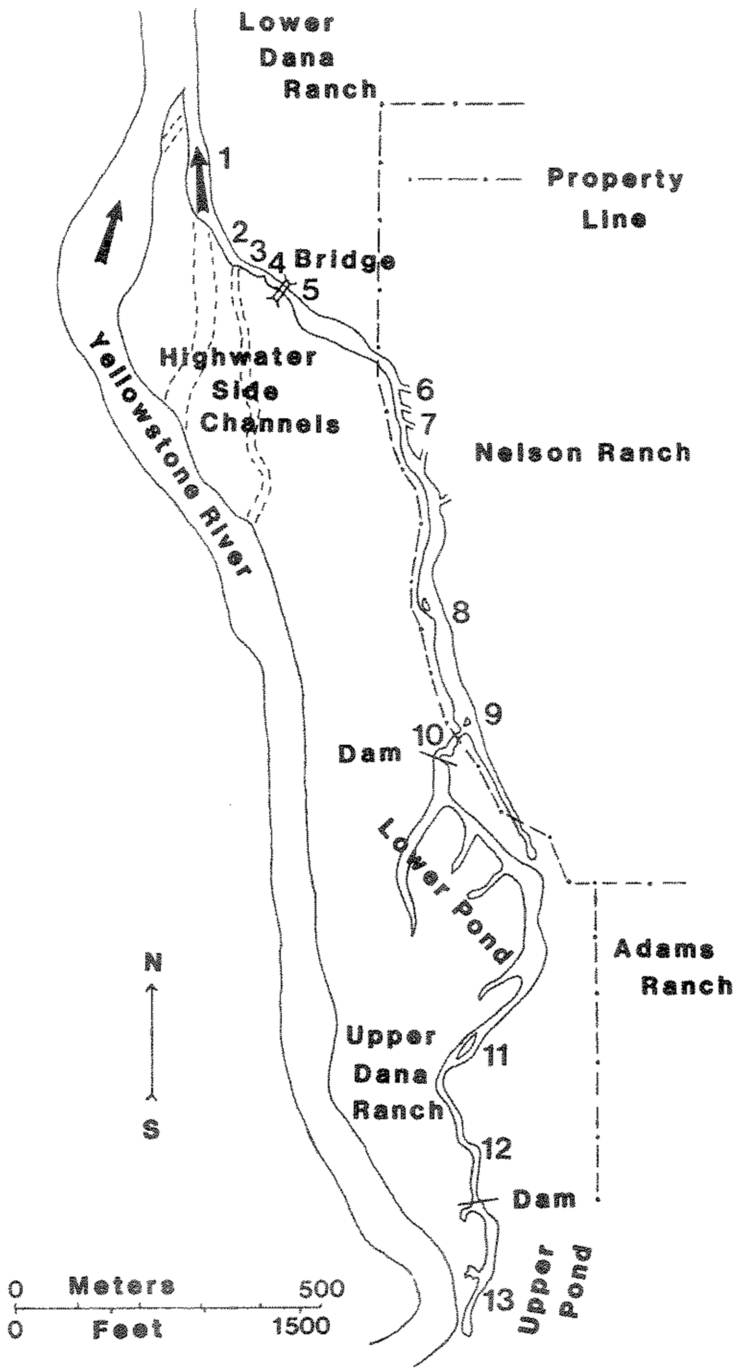

Figure 2. Nelson Spring Creek, Montana study area showing spawning sections (1-13), property lines and high-water side-channels of the Yellowstone River.

limited entry fee fishery, cattle grazing and hay production. Fishing on the Dana Ranch is free and by invitation only. Livestock grazing occurs on the Dana ranch during the summer months while pastures on the Nelson ranch are used by livestock during the winter and the early spring calving season.

Nelson Spring Creek is fed by spring water, most of which surfaces around two headwater ponds (Figure 2). Water temperatures at the creek origin, measured by a hand held thermometer, ranged from 9-10^{o}C, while the water temperatures near the mouth varied from 5.5-16.5^{o}C. Mean stream width during the summer, excluding the two headwater ponds, is 18 m and ranges from 5 to 39 m; mean depth is appproximately 35.5 cm. Aquatic plants cover over 50% of the bottom during summer months (Decker-Hess 1986). Minimal water level fluctuations were observed at the bridge (Dana ranch) between 18 November 1985 and 20 October 1986 (Figure 3), excluding a 3-week period in late May and early June when flood waters from the Yellowstone River inundated the creek to a point upstream of the bridge. The high-water mark near the bridge is not considered the "ordinary high-water mark" as defined in House Bill 265 because of the lack of permanent physical characteristics (Campbell and Waltermire 1985). Discharge near the stream mouth ranges between 1.13 and 1.78 m^3/s (A. Dana, pers. comm., based on measurements from

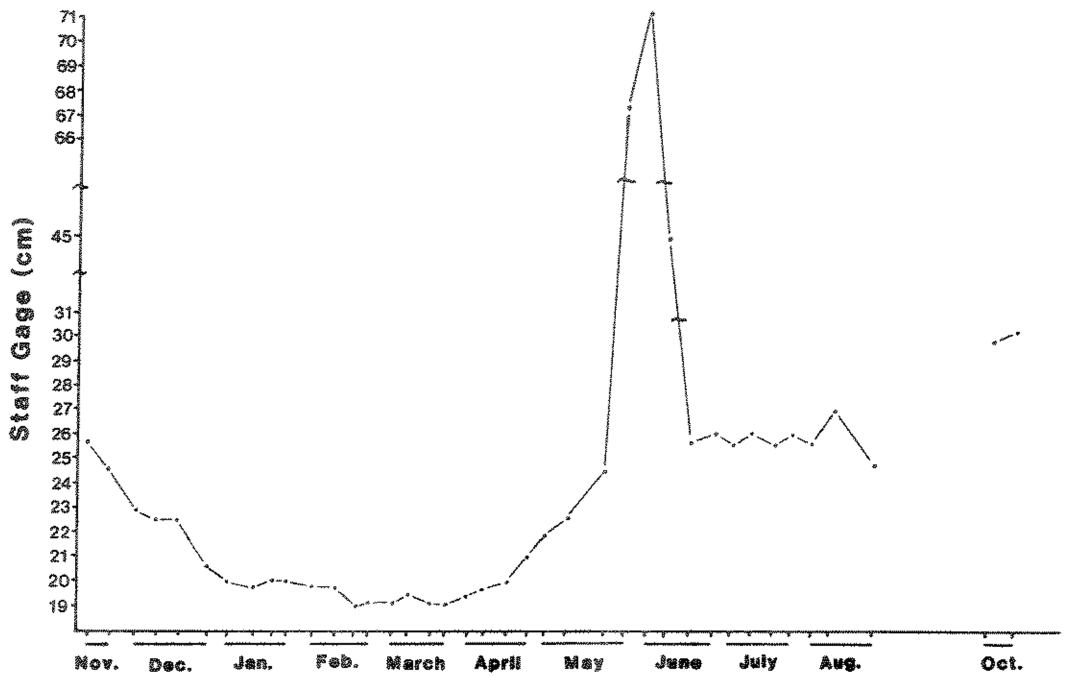

Figure 3. Weekly staff gage readings (cm) taken at the bridge (Dana ranch) on Nelson Spring Creek, Montana between 18 November 1985 and 20 October 1986.

T. Hallin, surveyor). Two ditches divert water during the summer irrigation period. Most of the flow coming from the upper springs is diverted at the lower end of the upper pond. Adequate flow is allowed between the ponds to insure that redds from late spawning rainbow trout in sections 11 and 12 are not dewatered. Few fish reside above the lower pond. Supersaturation of dissolved gases in the spring water result in high incidence of gas bubble trauma in trout residing near the spring source.

The creek's resident fish include brown trout (*Salmo trutta*), rainbow trout (*S. gairdneri*), mountain whitefish (*Prosopium williamsoni*), longnose sucker (*Catostomus catostomus*), white sucker (*C. commersoni*) and sculpin (*Cottus* sp.). Nelson Spring Creek is also used for spawning by migratory populations of all species with the possible exception of the sculpin. Yellowstone cutthroat trout (*S. clarki bouvieri*) also use the creek for spawning and juvenile rearing, but a resident adult population has not been documented. Hatchery origin rainbow trout were documented in all sections with the highest densities observed just above the hatchery ponds in early summer. Hatchery fish were readily identified by their eroded fins during snorkeling surveys. Brook trout (*Salvelinus fontinalis*) are rare, but have been observed in the lower headwater pond. A few carp (*Cyprinus carpio*) were observed near the stream mouth during late spring months.

METHODS

Laboratory

Multiple Human Wading

To evaluate effects of wading on survival of brown, rainbow and cutthroat trout eggs and pre-emergent fry, five laboratory experiments were conducted at the Bozeman Fish Technology Center of the U. S. Fish and Wildlife Service. These experiments were designed to reduce variability inherent in natural stream channels. Experiments were conducted in three 1.2 m wide x 2.4 m long channels, each subdivided into eight 1.2 m long x 0.3 m wide x 0.33 m deep chambers and filled with natural stream gravel (Figure 4). Substrate composition in each chamber simulated that found in spawning section 4 of Nelson Spring Creek as determined from the mean particle size distribution of five McNeil substrate samples (Table 1) (McNeil and Ahnell 1964). Washed stream gravel (i.e., rounded) was acquired from local gravel quarries and mixed in a portable cement mixer according to the size distribution in Table 1. Water flow through each chamber was adjusted to 0.14 +/- 0.005 L/s. Gradient of each chamber was maintained near 2%. Dissolved oxygen measurements (mg/L) were taken periodically at both the

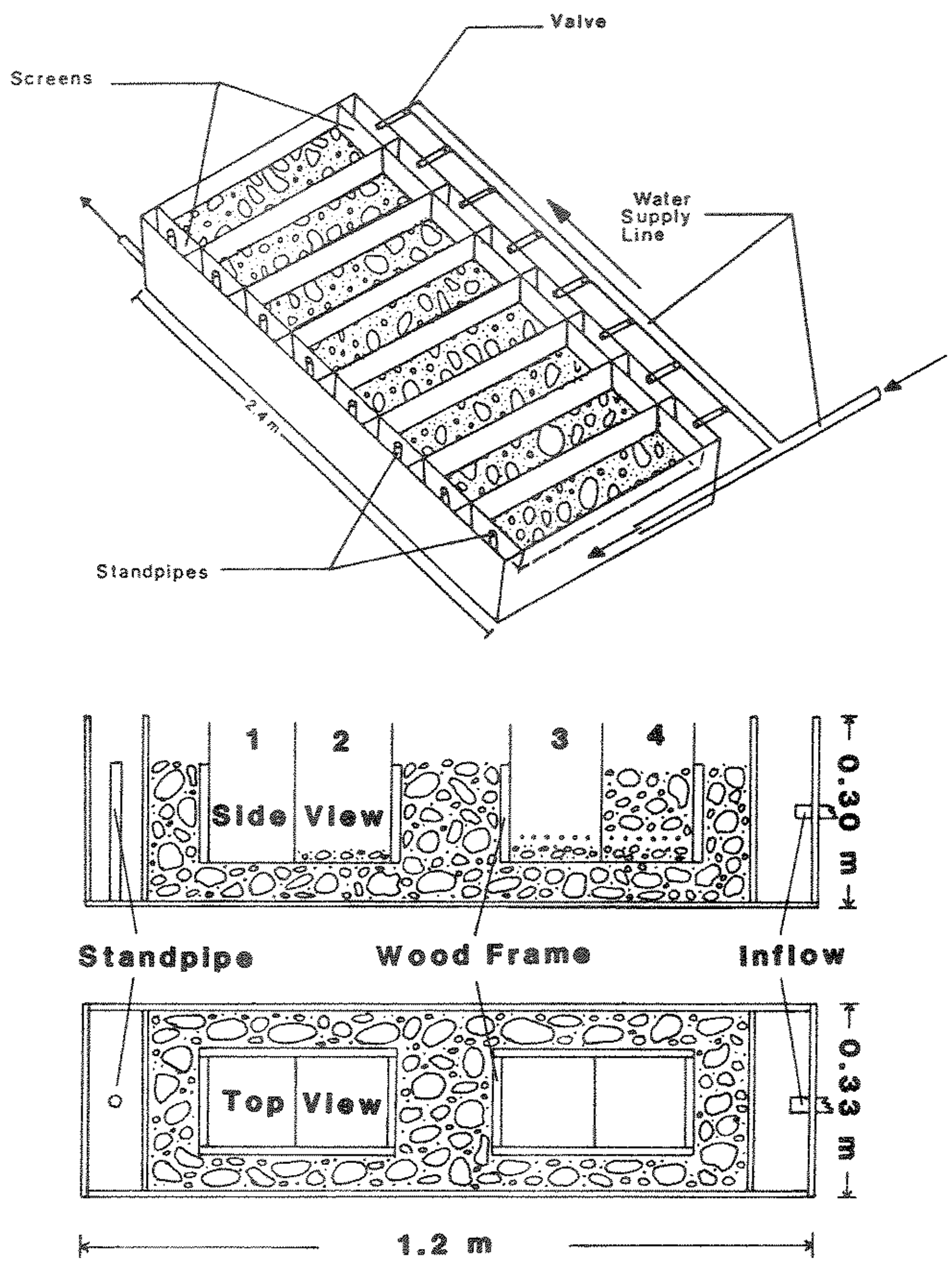

Figure 4. Diagram of incubation chambers and the process used to plant eggs in the substrate: 1) egg baskets placed in the substrate within wood retaining frames; 2) 2 cm layer of substrate placed in each basket; 3) 200 eggs evenly distributed; 4) egg baskets carefully filled with substrate mixture before wood retaining frames were removed.

inflow and outflow.

Table 1. Mean particle size distribution determined from five McNeil substrate samples taken from known spawning areas in section 4 of Nelson Spring Creek, Montana, October 1985.

Particle size class(mm)	Percent
>38.10	30.8
19.05-38.10	32.4
12.70-19.05	9.6
6.35-12.70	10.4
4.76-6.35	2.4
2.00-4.76	5.0
0.76-2.00	3.0
0.42-0.76	3.0
<0.42	3.4

Water temperature was monitored continuously using a Taylor recording thermograph. Centigrade temperature units (CTU) were calculated (sum of mean daily temperatures above $0^{o}C$) to monitor development rates and predict stages of development.

To prepare for planting eggs, a 10 cm layer of gravel was placed in the bottom of each chamber (Figure 4). Two wood retaining frames (15.5 cm x 31 cm inside dimensions) were positioned within each chamber and the area around the frames filled with the substrate mix (Table 1). Two open-topped plastic-screen egg baskets (15.5 cm long x 15.5 cm wide x 15.5 or 23.0 cm deep) were placed within each wood retaining frame to facilitate egg or pre-emergent fry recovery; tall baskets extending above the water surface were used for treatments that included fry emergence. Substrate mix was placed in the bottom of each egg basket to a depth of approximately 2 cm to insure eggs were not resting on exposed plastic-screen. Fertilized eggs from all spawners were thoroughly mixed before planting to eliminate possible differential survival due to egg quality. Water hardened eggs were disinfected in a Betadine solution (20 ml/L water) for 15 min. Two hundred fertilized and water hardened eggs were counted with a 100-hole plexiglass egg counter (Piper et al. 1983) and evenly distributed over the substrate mix in each egg basket. Egg baskets were then carefully filled with substrate and the wood frames removed. Eggs were buried 15.5 cm (Ottaway et al. 1981, Greeley 1932 and Smith 1941), with the exception of brown trout eggs (experiment 1) which were buried 8 cm (Table 2). Eggs were obtained from wild brood stock, with the exception of rainbow trout eggs used in experiment 2 which were acquired from Ennis National Fish Hatchery (Table 2).

Four replicates of the following six wading treatments were evaluated for each trout species to determine the effect of human wading on survival during different periods of development (Figure 5):

Treatment 1: Wading between fertilization and eye-up.

Treatment 2: Wading between eye-up and hatching.

Treatment 3: Wading between fertilization and hatching.

Treatment 4: Wading between hatching and emergence.

Treatment 5: Wading between eye-up and emergence.

Treatment 6: Wading between fertilization and emergence.

Table 2. Wading frequency, depth of eggs and egg source of the five wading experiments.

Experiment	Trout species	Wading frequency	Depth eggs planted(cm)	Egg source
1	brown	Once every 3 days	8.0	Harrison Lake
2	rainbow (McConaughy)	Twice-daily	15.5	Ennis Nat'l Fish Hatchery
3	cutthroat	Twice-daily	15.5	Yellowstone Lake (Stream 229 and Little Thumb Creek)
4	brown	Twice-daily	15.5	Bighorn River
5	rainbow (Desmet)	Twice-daily	15.5	Harrison Lake

Treatments were randomly assigned to one of the 24 chambers to reduce the effect of chamber variability observed in previous experiments (Weaver and White 1985). The only constraint was that every treatment would have at

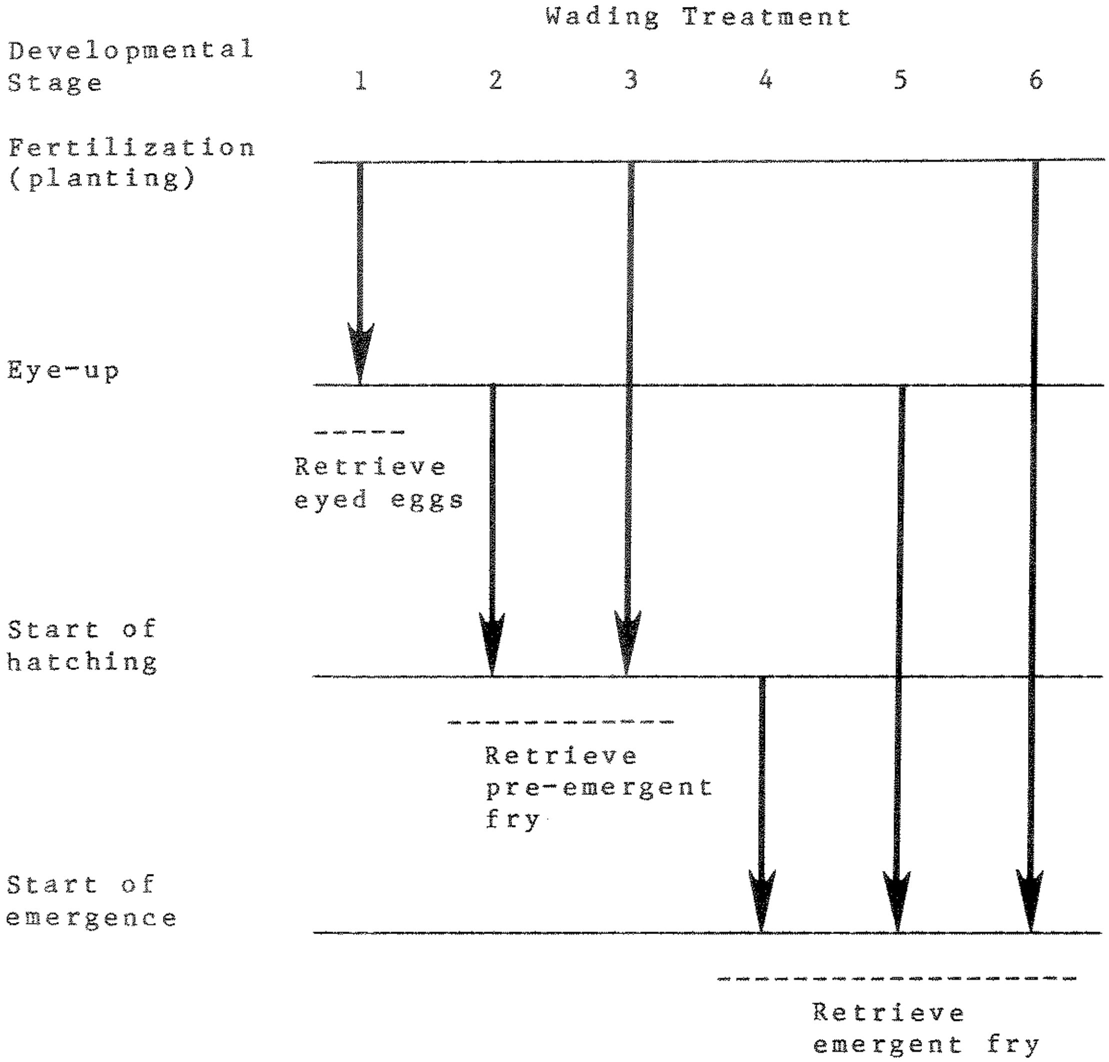

Figure 5. Diagram of wading treatments and egg basket retrieval relative to periods of development.

least one of its four replicates in each set of eight chambers. Each replicate (or chamber) consisted of two test and two control egg baskets. To eliminate possible differential survival as a result of egg location, control egg baskets were located near the inflow in two replicates and near the outlet in the remaining two replicates. A

Mann-Whitney test (Zar 1984) was used to determine if adjusted survival in control egg baskets differed statistically (α = 0.05) from survival in test egg baskets.

Wading treatments were administered by one person weighing 75 kg. During experiment 1, eggs and pre-emergent fry were waded on once every third day, while eggs and pre-emergent fry were waded on twice-daily during experiments 2-5 (Table 2). Wading events were applied in alternating direction to eliminate effects of uneven pressure distribution between the heel and toe portion of a boot. To allow for delayed mortality, egg baskets were left in the substrate 7 days after completion of each treatment (Figure 5). Egg baskets were then removed from the chambers to determine percent survival. Contents of each egg basket were placed in a white enamel pan, and live and dead eggs and/or fry were enumerated. Unaccounted for eggs, pre-emergent fry and emergent fry ($<$ 200) were assumed to have decomposed after being crushed during the experiments. Egg baskets in experiment 1 (brown trout) were removed and survival determined following completion of the last wading treatment.

As a check for percent fertilization and as a second control for determining nonwading-related mortality, eggs handled the same way as those planted in experimental chambers were incubated in a Heath stack. Percent survival in the Heath stack at 7 days after the start of eye-up, hatch, and emergence was used to adjust survival from both control and test egg baskets (i.e., survival in the egg baskets was calculated based on the number of live eggs out of 200 in the Heath stack, rather than 200 that were planted in each egg basket). A Mann-Whitney test (Zar 1984) was used to determine if adjusted survival of controls located near the inflow of each chamber differed statistically ($\alpha = 0.05$) from controls located near the outflow. Observations of development in the Heath stack were used to determine when wading treatments were initiated and/or terminated.

In addition, experiments were conducted to test the assumption that the narrow width (0.3 m) of the incubation chambers did not influence the outcome of the multiple wading treatments. Percent mortality due to one wading event was compared between the narrow chamber (0.3 m) and wide chamber (1.0 m) (Figure 6). The wide chamber was assumed to closely replicate a natural spawning bed. Brown, rainbow and cutthroat trout eggs and pre-emergent fry (experiments 1, 2 and 3) were tested using experimental design "A", while brown and rainbow trout (experiments 4 and 5) were also tested using experimental design "B" (Figure 6).

Substrate mix (Table 1), planting procedure (Figure 4) and depth of eggs (Table 2) was the same in chamber

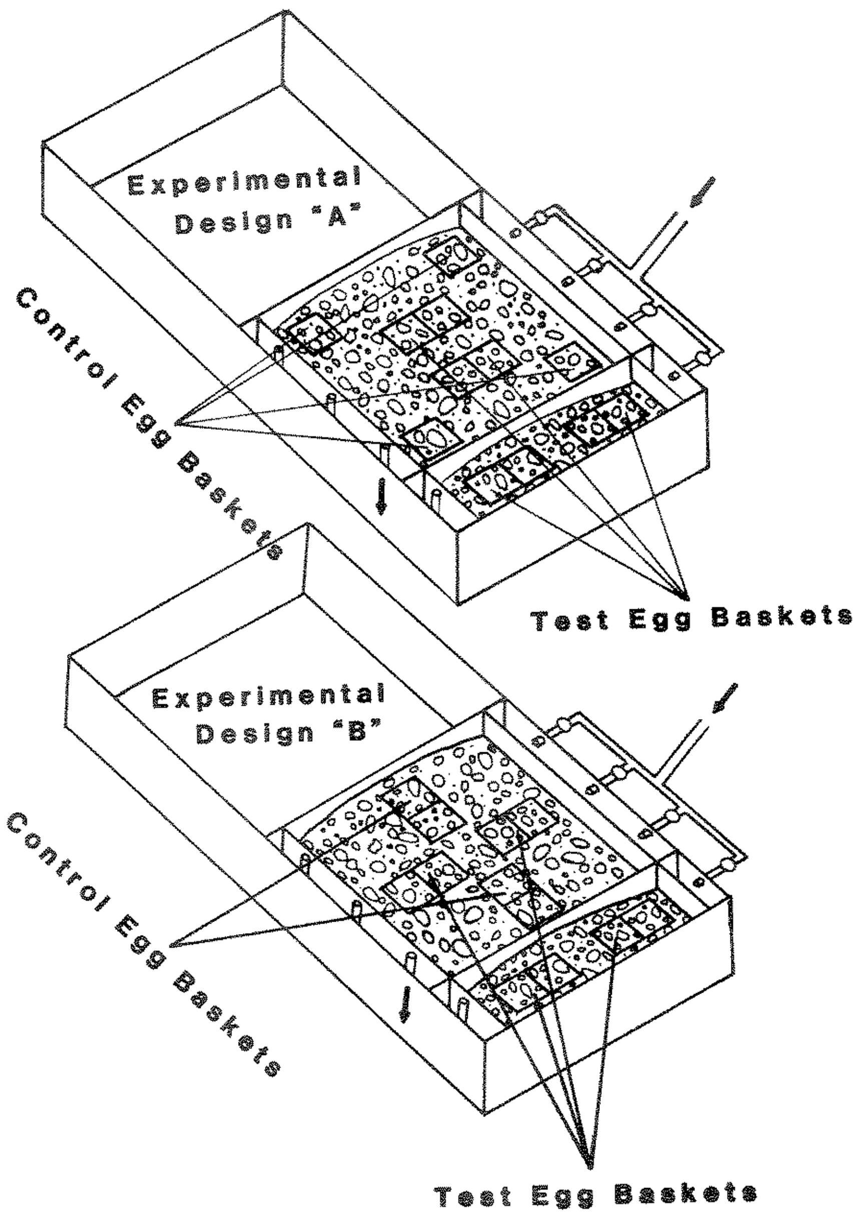

Figure 6. Diagram of the wide (1.0 m) and narrow (0.3 m) incubation chambers used in chamber width comparison experiments and the location of the control and test egg baskets. Experimental design "A" was used for experiments 1, 2 and 3 (brown, rainbow and cutthroat trout) and experimental design "B" was used for experiments 4 and 5 (brown and rainbow trout).

width experiments as in the multiple wading experiments. Eggs and pre-emergent fry were planted in the substrate one day (water temperature 10.5-13.5^{o}C), waded on once the same day and retrieved the following day. Prior to planting and following retrieval, eggs and pre-emergent fry were held in a Heath stack incubator (water temperature 7.3-8.6^{o}C). Temperature differences between the Heath Stack incubator and experimental chambers were assumed to not influence mortality (Peterson et al. 1977). Pre-eyed eggs scheduled to be waded on between day 7 and 15 after fertilization were planted in the gravel prior to day 7 and retrieved after day 15 due to the extreme sensitivity to handling at this stage of development. Surviving eggs and pre-emergent fry were placed in a Heath stack incubator for 7 days following treatment to document delayed mortality. Two comparison tests were run on pre-eyed eggs, two on eyed eggs and two on pre-emergent fry for each species.

A sign test (Zar 1984) was used to test the assumption that percent egg and pre-emergent fry mortality does not differ statistically (α = 0.05) between wide (1.0 m) and narrow (0.3 m) chambers following one wading event. For experimental design "A", comparisons were made between mean percent mortality in egg baskets (n = 4) waded on in the wide chamber (1.0 m) vs. those (n = 4) waded on in the narrow chamber (0.3 m). Results were combined from the first three experiments to increase sample size (n = 3 x 6 = 18). It was assumed that differences between means resulted from chamber width and were not species specific. For experimental design "B", comparisons were made between percent mortality in corresponding egg baskets in the wide and narrow chambers (e.g., front-wide vs. front-narrow) (Figure 6). Samples (n = 4) from each test (i.e., two pre-eyed egg tests, two eyed egg tests and two pre-emergent fry tests) were combined to increase sample size (n = 4 x 6 = 24). Samples were not combined between species.

Single Wading Event

Data from the chamber width comparison experiments were also used to test the effect of one wading event on embryo and pre-emergent fry survival. Percent mortality values from one wading event in the narrow chamber (n = 4) were combined with percent mortality values from the wide chamber (n = 4), and Mann-Whitney tests (Zar 1984) were run to determine if there was a statistical difference (α = 0.05) in mortality between test (n = 4 + 4) and control (n = 4) egg baskets at various developmental stages. Four control egg baskets were placed in the 1.0 m wide chamber during each test to quantify percent mortality due to planting and retrievel procedures (Figure 6). These four control egg baskets were surrounded by hardware cloth to protect against possible horizontal substrate movement caused by a single wading event. Control and test eggs and pre-emergent fry were counted, planted and retrieved in the same manner.

Several of the single wading treatments were conducted near the time of blastopore closure (i.e., period of increased sensitivity). To precisely define when this period occurred, tests were conducted on pre-eyed eggs of each species. A sample of 200 or 300 eggs from a randomly selected Heath tray compartment was gently netted and placed in a 100 ml graduated cylinder of water. The cylinder was covered, inverted and returned to the upright position three times; time was allowed for eggs to settle after each inversion. Handled eggs were then returned to the same compartment and allowed to develop through hatching. Dead eggs were periodically counted and removed. A new sample of 300 live eggs was handled each day from fertilization until eye-up, except for cutthroat trout eggs where only 200 eggs were handled each day. Brown and rainbow trout eggs exposed to handling treatments were incubated in two water temperature regimes, while cutthroat trout eggs were incubated at one: brown trout - 7.5^{o}C and 10.5^{o}C; rainbow trout - 8.1-8.4^{o}C and 10.5^{o}C; and cutthroat trout - 7.3-7.5^{o}C.

Field

Spawning Use

Weekly redd counts were made by walking the entire length of Nelson Spring Creek (Figure 2) from 1 November 1985 to 11 August 1986 with a few exceptions: Section 13 was not discovered until 19 December 1986; Sections 1 and 2 were flooded by the Yellowstone River from 30 May to 6 July 1986. Flow in sections 11 and 12 was inadequate for spawning from 6 June 1986 until early September, the end of the irrigation season. Spawning sections varied in length and were irregularly spaced along the creek in known spawning areas. Spawning sections were numbered from the mouth upstream (Figure 2). Outflow and inflow ditches to the hatchery ponds and raceways on the Nelson ranch were not censused. Accurate redd counts were difficult in section 10 (spillway pools) due to deep water.

In 1987, only cutthroat trout spawning was monitored. In an attempt to document the relative importance of Nelson Spring Creek for cutthroat trout spawning, redd counts were expanded to include the other two known spawning tributaries in the Livingston-lower Paradise Valley area: McDonald Creek and Depuy's section of Armstrong Spring Creek. Redd counts began 3 June 1987 and ended 24 July 1987.

To determine area of spawning riffles and to estimate the proportion of Nelson Spring Creek used for spawning, each redd location was recorded on a map. An orange-painted rock was placed on each redd to prevent multiple counting. In times of spawning overlap between species, an attempt was made to determine when the last fish of one species and the first of the second species spawned.

During weekly redd counts, locations of Floy-tagged trout were recorded to document the distribution of Yellowstone River trout in Nelson Spring Creek. Trout migrating out of the Yellowstone River into Nelson Spring Creek to spawn were tagged during MDFWP electrofishing and trapping surveys near the mouth of the creek. It was assumed that observed fish spawned in sections near where they were observed. In addition, four snorkeling surveys were conducted to locate tagged fish. The observer snorkeled in a downstream direction (except in sections 11 and 12) from the top of the lower pond to the mouth of the creek (Figure 2).

Embryonic Development Specific to Nelson Spring Creek

Brown, rainbow and cutthroat trout eggs were stripped, fertilized, water-hardened and planted in the substrate in section 4 during peak spawning of each species. Brown trout gametes were obtained from Armstrong

Spring Creek, while rainbow and cutthroat trout gametes were obtained from Nelson Spring Creek. A simulated trout redd was excavated in a known spawning area. One-hundred water-hardened eggs were placed in each of six gravel filled plastic-screen baskets and buried 10 to 20 cm in the artificial redd. An egg basket was removed periodically to observe development. A Peabody Ryan model "J" thermograph was used to monitor water temperature and centigrade temperature units were calculated. Days and CTU to eye-up, hatch and emergence were estimated based on the physical appearance of the embryos and/or pre-emergent fry.

Recreational Use in Section 3 and 4

A Minolta 8 mm movie camera was mounted in a streamside tree and programmed to take a single picture of sections 3 and 4 every 5 min during daylight hours to record angler use (Figure 7). Four other cameras were operated by the MDFWP to estimate angling pressure on other lower Nelson Spring Creek sections and the Yellowstone River. Sections 3 and 4 contained the spawning riffles that one landowner feared would be adversely impacted by unauthorized use. Anglers having permission from the Dana family (invited anglers) were asked to register prior to fishing and to not wade in sections 3 and 4.

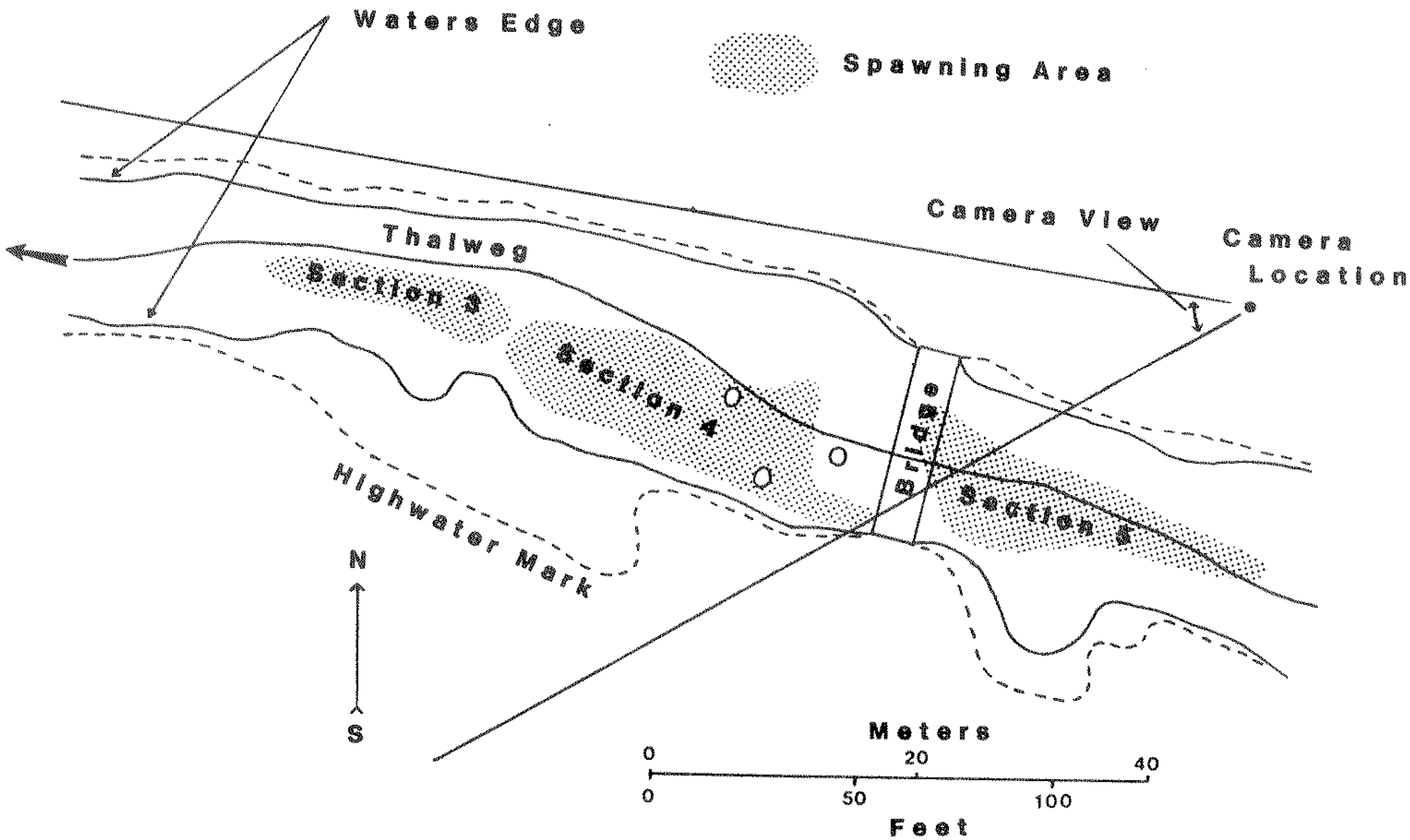

Figure 7. Location of spawning areas in sections 3, 4 and 5 and of the Minolta 8 mm movie camera with coverage view.

Film footage from the camera taking pictures of sections 3 and 4 was analysed by the MDFWP, and angler locations were placed on a map similar to Figure 7. Time spent fishing by exclusively bank anglers, exclusively wading anglers and those fishing from both the bank and stream was estimated by multiplying the number of film observations by 5 min. Photographs were also used to determine if anglers were wading through known spawning areas in sections 3 and 4 (Figure 7), and if so, to determine how long they fished these areas and if the wading path was random or followed a distinct pattern.

RESULTS AND DISCUSSION

Laboratory

Multiple Human Wading

All multiple wading treatments resulted in significantly lower ($P < 0.05$) trout embryo and/or pre-emergent fry survival compared to controls, with exception of brown trout in experiment 1 which had too few samples for statistical evaluation (Figures 8 and 9 and Appendix, Table 13). Several samples were lost in experiment 1 (brown trout) due to deteriation of thread used in making the egg baskets. Results of experiment 2 (rainbow trout) were also inconclusive because of low adjusted survival in both control and test egg baskets. Low percent survival resulted from reduced egg viability and from allowing too much water to flow over the surface of the substrate, thus reducing intragravel flow and consequently reducing the amount of oxygen supplied to developing embryos and pre-emergent fry. The delay in rainbow trout fry emergence in experiment 2 relative to experiment 5 (Table 3) probably resulted from these low intragravel flows and oxygen concentrations.

In experiments 3, 4 and 5, twice-daily wading from egg fertilization to fry emergence (treatment 6) resulted

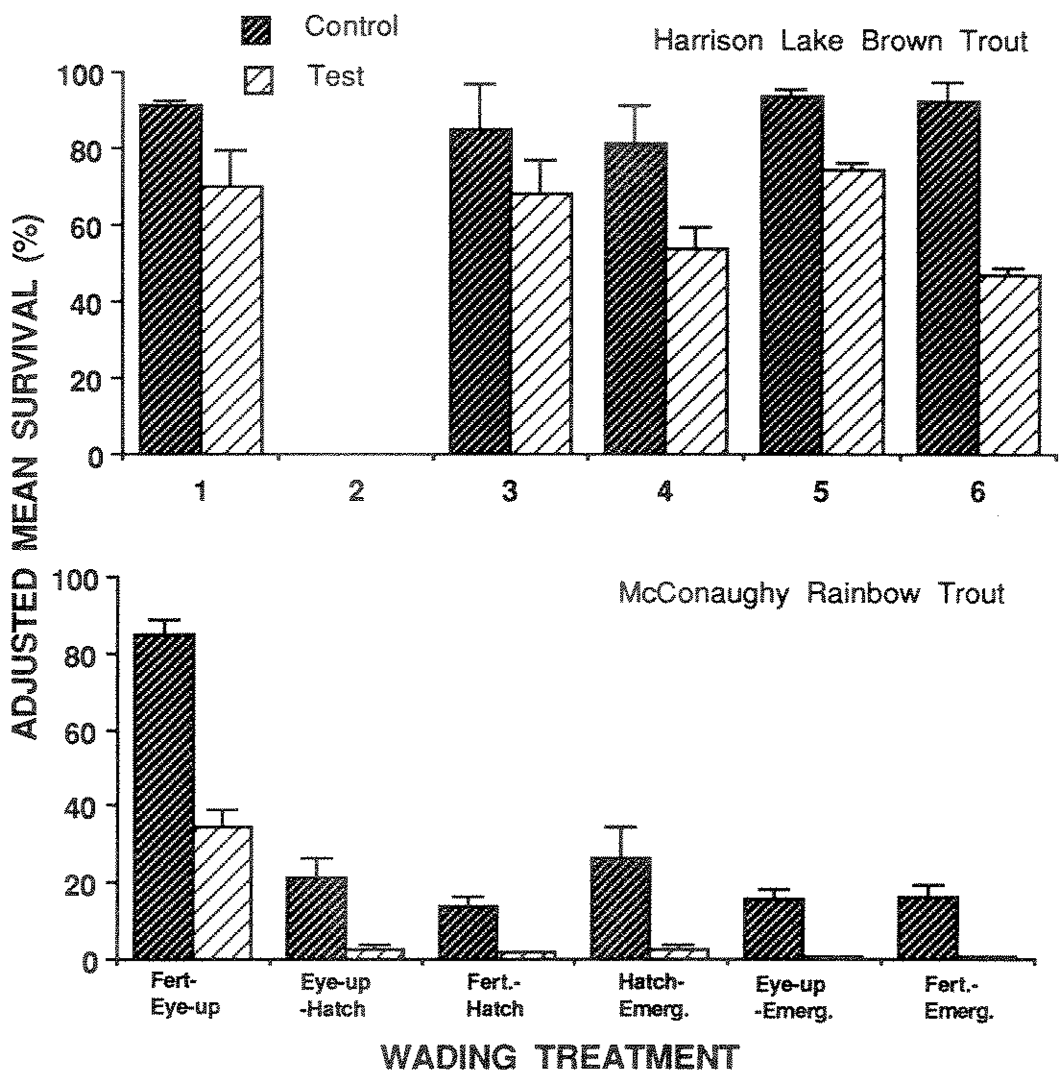

Figure 8. Adjusted mean survival (%) and standard error bars for Harrison Lake brown trout (experiment 1) and McConaughy rainbow trout (experiment 2) eggs and pre-emergent fry in the control (n = 8) and test (n = 8) egg baskets exposed to wading treatments 1-6 in the laboratory. Brown trout sample size ranged between 2 and 5. Brown trout test egg baskets were waded on once every third day; rainbow trout egg baskets were waded on twice-daily.

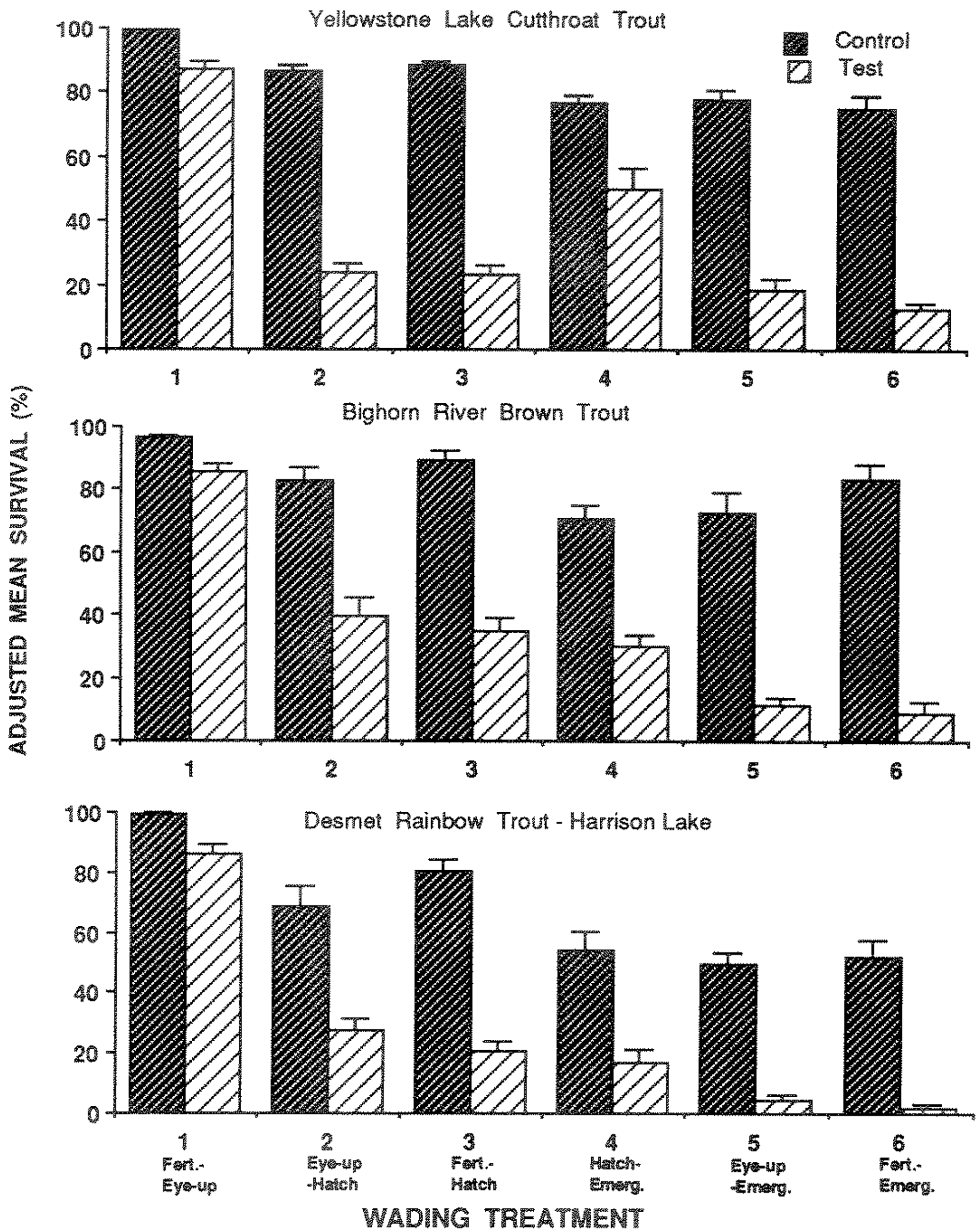

Figure 9. Adjusted mean survival (%) and standard error bars for Yellowstone Lake cutthroat trout (experiment 3), Bighorn River brown trout (experiment 4) and Desmet rainbow trout-Harrison Lake (experiment 5) eggs and pre-emergent fry in the control (n = 8) and test (n = 8) egg baskets exposed to wading treatments 1-6 in the laboratory. Test egg baskets were waded on twice-daily.

Table 3. Embryonic development rates (centigrade temperature units[a] and days) of brown, rainbow and cutthroat trout in the laboratory.

Trout species	Faint eye-up	Hatching 1%	Hatching 50%	Hatching 100%	Start of emergence
Harrison Lake brown (experiment 1)	217.5[b] 28 days	382.5[b] 51 days	412.5[b] 55 days	- -	564.4[b] 75 days
McConaughy rainbow (experiment 2)	165.7 21 days	328.5 41 days	343.9 43 days	359.5 45 days	632.4 84 days
Yellowstone Lake cutthroat (experiment 3)	175.8 24 days	301.6 41 days	- -	331.5 45 days	496.5 67 days
Bighorn River brown (experiment 4)	239.6 30 days	432.9 54 days	448.9 56 days	465.1 58 days	709.7 88 days
Desmet rainbow - Harrison Lake (experiment 5)	184.9 24 days	337.1 44 days	- -	374.1 49 days	606.1 80 days

[a] centigrade temperature units = sum of mean daily temperatures above 0°C.

[b] CTU are low because of calibration problems with the thermograph.

in 82.8% mortality (adjusted test survival relative to adjusted control survival) for cutthroat trout, 89.2% for brown trout and 96.0% for rainbow trout, respectively (Table 4). Survival was adjusted using survival coefficients in Table 5. The lower mortality in cutthroat trout experiments was probably related to faster embryo development (i.e., fewer wading applications) (Table 3).

Table 4. Percent mortality[a] from wading treatments 1-6 during experiment 3, 4 and 5.

Experiment	Trout species	Treatment 1	2	3	4	5	6
3	cutthroat	12.3	72.5	73.6	35.0	76.2	82.8
4	brown	11.3	52.4	61.3	57.1	84.1	89.2
5	rainbow	13.3	59.2	74.5	68.9	91.2	96.0

[a] Percent mortality = (100% - (adjusted test survival ÷ adjusted control survival))

Table 5. Survival coefficients used to adjust percent survival of treatment eggs and pre-emergent fry. Coefficients based upon nonwading-related mortality in the optimium incubation environment of a Heath stack incubator.

Experiment	Trout species	Eye-up	Hatching	Emergence
1	Harrison Lake brown	0.990	0.964	0.955
2	McConaughy rainbow	0.909	0.769	0.753
3	Yellowstone Lake cutthroat	0.985	0.956	0.941
4	Bighorn River brown	0.989	0.889	0.875
5	Desmet rainbow - Harrison Lake	0.978	0.953	0.942

Mortality resulting from treatments 1 (pre-eyed egg period), 2 (eyed egg period) and 4 (pre-emergent fry period) ranged from 11.3-13.3%, 52.4-72.5% and 35.0-68.9%, respectively (Table 4). Mortality from treatment 3 (fertilization to hatching) was 1.1-15.9% higher than mortality from treatment 2 (eye-up to hatching). Although wading from fertilization to emergence (treatment 6) always resulted in the highest mortality, mortality was only 4.8-6.4% higher than observed from treatment 5 (eye-up to emergence). These results indicate that wading-related mortality is lowest during the pre-eyed period of development and most detrimental after eye-up.

Of the two wading treatments that encompassed two periods of development (Figure 5), treatment 5 (eye-up to emergence) consistently resulted in higher mortality compared to treatment 3 (fertilization to hatching) (Table 4). Results were similar between trout species, except for cutthroat trout where eyed egg mortality (treatment 2) was higher and pre-emergent fry mortality (treatment 4) lower than in corresponding brown and rainbow trout treatments. The large wading-related mortality of brown and rainbow trout fry between hatching and emergence (treatment 4) indicates that of the three developmental periods tested, this period is most impacted by wading (Table 4).

Factors evaluated to determine if they influenced interpretation of wading experiments include location of egg baskets within experimental chambers, chamber width, water temperature and dissolved oxygen concentrations. No significant difference ($P > 0.05$) was observed in mean adjusted percent survival (Table 6) between control egg baskets located near chamber inflows and those located near chamber outflows for any period of development or for any trout species tested. Based upon these results, mortality in test egg baskets was also assumed to have not been affected by location within experimental chambers.

Table 6. Mean adjusted percent embryo and pre-emergent fry survival in control egg baskets located near chamber inflows and outflows. Control egg baskets retrieved at the end of the same developmental period, but from different treatments were combined to increase sample size.

			Percent Survival		
Experiment	Trout species	Control location	Eye-up[a] (n = 4)	Hatch[b] (n = 8)	Emergence[c] (n = 12)
3	cutthroat	inflow	99.4	88.3	76.8
		outflow	99.5	86.8	70.6
4	brown	inflow	85.2	82.6	80.5
		outflow	86.4	85.5	70.1
5	rainbow	inflow	99.4	72.2	56.8
		outflow	99.4	80.4	49.9

[a] treatment 1
[b] treatments 2 and 3
[c] treatments 3, 4 and 5

No significant difference in mortality from one wading event was observed between narrow (0.3 m) and wide (1.0 m) incubation chambers (Appendix, Tables 14 and 15). Data acquired from experiments using both experimental design "A" and "B" (Figure 6) yielded the same conclusions. These results support predictions of two Montana State University physicists (D. Robiscoe and G. Caughlan, pers. comm.) that width of channel should not influence results since force applied to the substrate surface would continue in a vertical plane rather than dispersing horizontally. During the last week of incubation, differences in mortality were larger between narrow and wide chambers, but no consistent pattern was observed. Based upon these findings, experimental results should be applicable to interpreting effects of wading on trout redds in natural streams.

During all experiments, water temperatures remained within the suitable range for incubation of trout eggs (1.5-15°C) (Timoshina 1972 and Kwain 1975) and, therefore, are not thought to have influenced results. Water temperatures ranged from 7.1-8.4°C during experiments (Table 7). Incubation temperatures were consistently higher during late winter and early spring months when the brown and rainbow trout experiments were being conducted than during the rest of the year.

Dissolved oxygen concentrations during tests ranged from 8.55-10.05 mg/L. These oxygen levels are within the optimum for incubation of trout eggs (Phillips and Campbell 1961). Inflow oxygen concentrations were consistently higher than outflow concentrations, but the differences never exceeded 0.10 mg/L. Intragravel oxygen concentrations were not measured.

Table 7. Range of water temperatures and dissolved oxygen during wading experiments.

Experiment	Trout species	O_2 (mg/L)	Water temperature(°C)
1	brown	8.55-9.40	7.5[a]
2	rainbow	8.90-9.60	7.6-8.4
3	cutthroat	9.65-10.05	7.3-7.5
4	brown	8.90-9.60	7.9-8.3
5	rainbow	9.60-9.90	7.1-8.1

[a] thermograph was inaccurately calibrated.

The main source of mortality from multiple wading experiments was direct vertical pressure and/or physical disturbance. Pressure placed on the substrate directly above the eggs and pre-emergent fry by the 75 kg wader was equivalent to 460 g/cm^2, 644 g/cm^2 and 1,613 g/cm^2 if all the body weight was evenly distributed over an entire boot, distributed evenly over the toe portion or distributed evenly over the heel portion, respectively. Substrate compaction of 1 to 2 cm was observed around each test egg basket as compared to control egg baskets. It took approximately seven to eight wading events to reach maximum observable compaction.

Direct mortality from crushing and/or physical disturbance may result in indirect mortality due to *Saprolegnia* fungi hyphae or zoospores from dead eggs spreading to live eggs (Smith et al. 1985). Compaction of substrate may also result in indirect mortality due to reduced intragravel flow. Coble (1961) showed a close relationship between apparent velocity and dissolved oxygen concentrations in intragravel water. Alderdice et al. (1958) demonstrated that dissolved oxygen requirements of trout embryos increase as development progresses. Mortality from reduced dissolved oxygen concentrations should start to increase near hatching when oxygen requirements of embryos start to increase.

Single Wading Event

Mortality from one wading event ranged from 0-43.4% (test survival relative to control survival) depending on stage of development (Figure 10 and Appendix, Tables 14 and 15). Pre-eyed eggs, and eyed eggs between eye-up and the start of chorion softening exhibited the lowest mortality (0.0-9.6%), while pre-emergent fry and eyed eggs

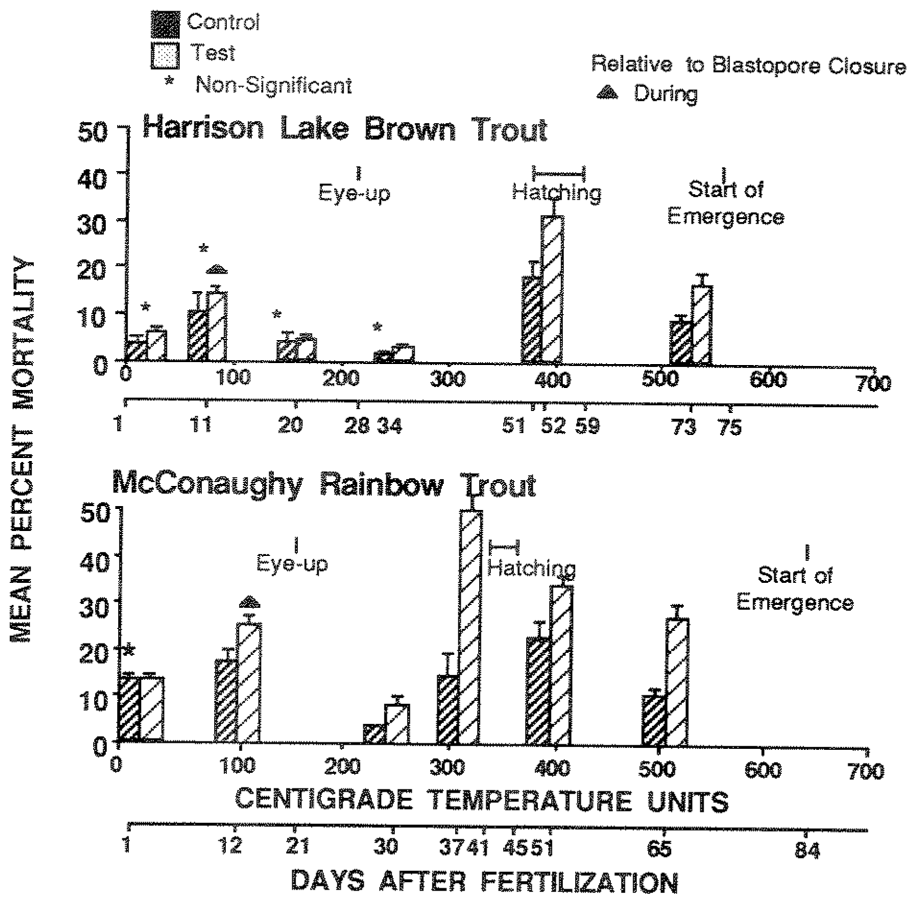

Figure 10. Mean percent mortality and standard error bars for control (n = 4) and test (n = 8) egg baskets exposed to one wading event in relation to centigrade temperature units, developmental stage and days after fertilization: Harrison Lake brown trout (experiment 1), McConaughy rainbow trout (experiment 2), Yellowstone Lake cutthroat trout (experiment 3), Bighorn River brown trout (experiment 4) and Desmet rainbow trout-Harrison Lake (experiment 5).

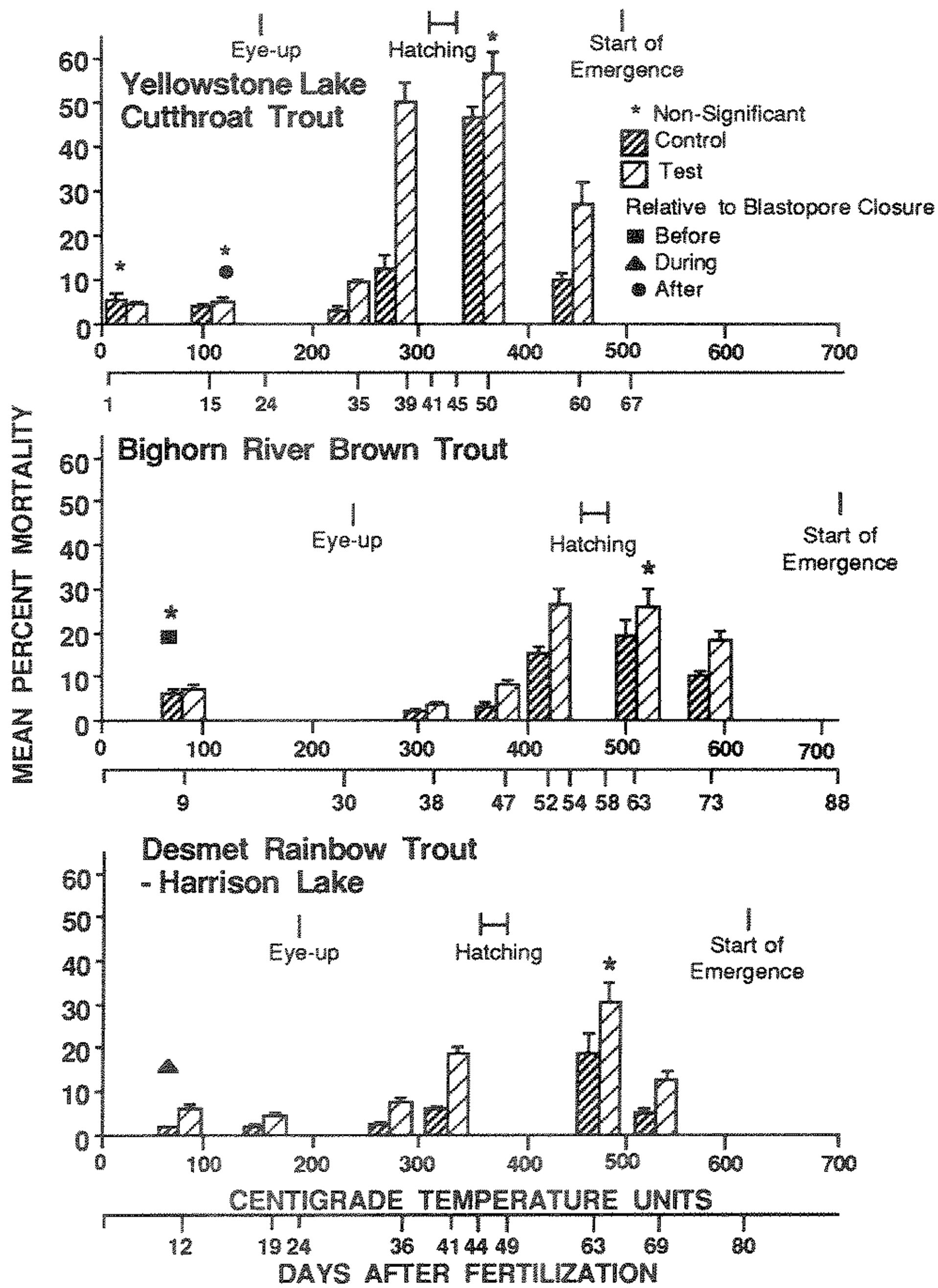

Figure 10. Continued.

between the start of chorion softening and hatching exhibited the highest mortality (5.1-43.4%).

Mortality of pre-eyed eggs receiving one wading event did not differ significantly ($P > 0.05$) from the controls, except when wading occurred during a brief period of increased sensitivity (i.e., blastopore closure). Pre-eyed eggs waded on during this period exhibited 3.8-9.6% mortality. Blastopore closure occurred between 80 and 100 centigrade temperature units for brown and rainbow trout, and between 80 and 95 CTU for cutthroat trout as defined by handling tests (Figure 11). For brown and rainbow trout eggs incubated under different water temperature regimes, highest sensitivity to handling in the warmer regimes occurred 2 to 3 days earlier. Centigrade temperature units associated with highest mortality, however, were similar. These data closely support the findings that steelhead and rainbow trout pre-eyed eggs handled in the same manner exhibited a sensitive period between 90 and 110 CTU (Johnson et al. 1983 and Johnson et al. 1986, unpublished).

Mortality ranged from 2.3 to 43.4% for eyed eggs exposed to one wading event. Highest mortality occurred between the start of chorion softening (approximately mid-way between eye-up and hatching) and hatching. All eyed eggs waded on during this period showed significantly higher ($P < 0.05$) mortality than controls.

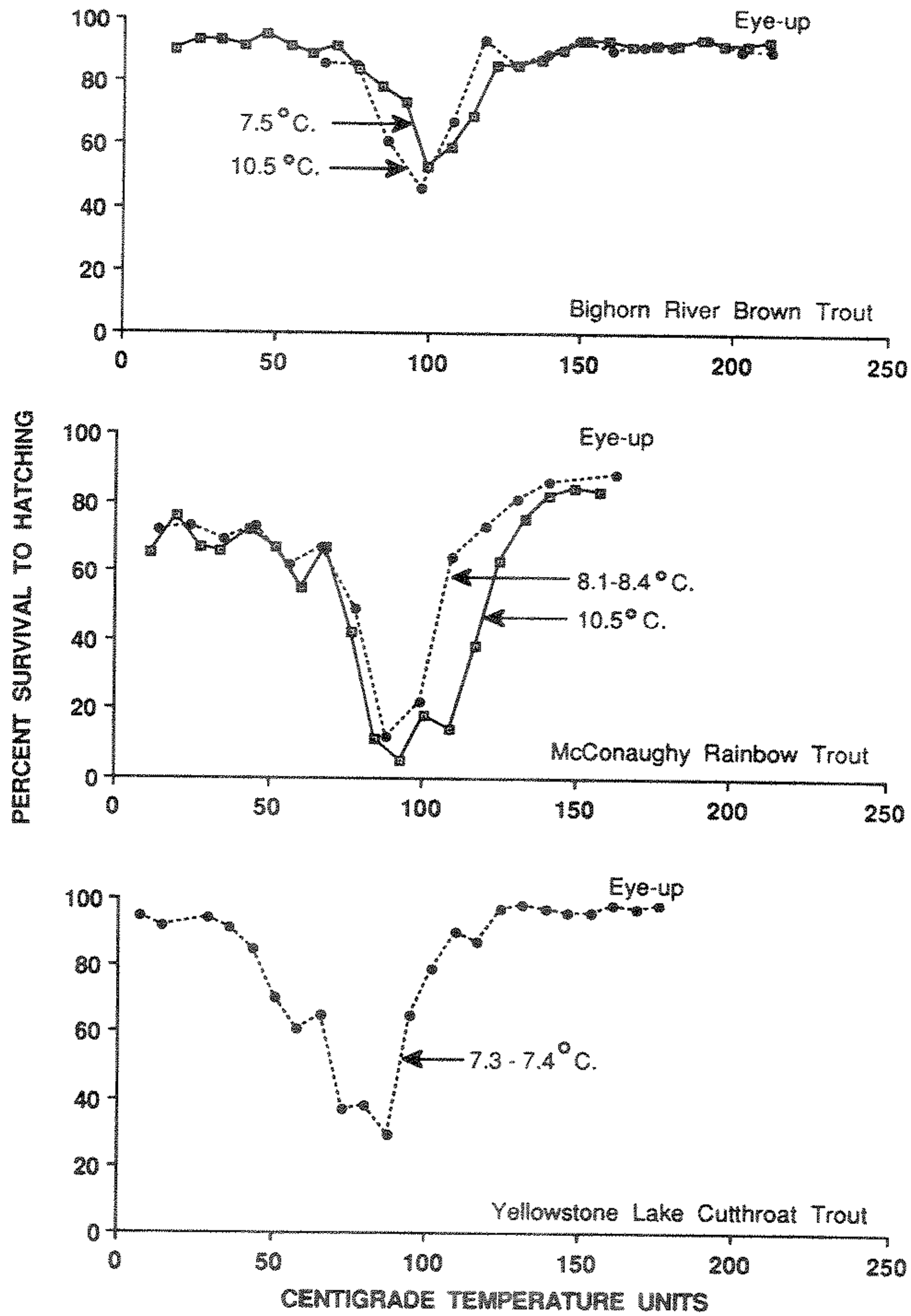

Figure 11. Percent survival to hatching of Bighorn River brown trout, McConaughy rainbow trout and Yellowstone Lake cutthroat trout pre-eyed eggs incubated at two water temperature regimes and handled daily between fertilization and eye-up. Each point represents percent survival from one handling test.

Mortality as high as 19.1% was observed for pre-emergent fry exposed to one wading event. Variability in mortality was relatively high for tests conducted on pre-emergent fry with large yolk sacs (i.e., just following hatching), resulting in no significant differences ($P > 0.05$) in mortality between control and test fry. Tests conducted on pre-emergent fry with small yolk sacs (i.e., nearing emergence) resulted in significantly greater mortality ($P < 0.05$) of test fry compared to controls.

Differences in observed mortality between wading treatments can be related to trout embryonic development. Following fertilization, the permeable chorion allows the perivitelline space to fill with fluids (water hardening). The chorion then hardens, increasing protection to the embryo from being crushed (Blaxter 1969). Inside the hardened chorion, the embryo is bouyed in a dorsal position by lipid droplets and is free to rotate, minimizing environmental disturbances (Knight 1963). Approximately mid-way between fertilization and eye-up, during the period of blastopore closure, trout embryos become more sensitive to physical disturbance (Jensen and Alderdice 1983, Johnson et al. 1983 and Smirnov 1955). Post et al. (1974) attributed increased mortality from physical shock during this short developmental period to detachment of the newly formed blastoderm from the perivitelline membrane, which results in yolk contents spilling into the perivitelline space and death of the embryo.

Inherent characteristics of pre-eyed embryos effectively protect them from the impacts of wading, except during the period of blastopore closure. Pre-eyed embryos during this period of development exhibited 3.8-9.6% mortality from wading compared to 76-94% mortality from handling (Figure 11). Low mortality from wading during blastopore closure is probably due to relatively little physical disturbance within the substrate.

Following eye-up, embryos remain protected until the start of chorion softening. Approximately mid-way between eye-up and hatching, softening enzymes are secreted into the perivitelline fluid from the ectodermal gland located near the gills of the developing embryo to soften the chorion for hatching (Blaxter 1969). Eyed embryos hatch prematurely if chorions are ruptured. High mortality of prematurely hatched fry probably results from the lack of physical development necessary to survive and from crushing of fragile body parts (especially the large yolk sac and less than fully developed circulatory, muscular and skeletal systems). Fragile body parts also make pre-emergent fry vulnerable to human wading. Results from single wading tests showed that wading-related mortality started to increase approximately mid-way between eye-up and hatching, which coincides with the time of release of softening enzymes from the ectodermal glands, and remained high until emergence.

Hayes (1949) and Hein (1907, cited by Hayes 1949) showed that the susceptibility of eggs to crushing follows a distinct pattern between fertilization and hatching; less than 0.25 kg is required to crush salmon and trout eggs prior to water hardening, 3-5 kg between water hardening and the start of chorion softening and less than 1 kg between the start of chorion softening and hatching. These data lend support to the pattern of wading-related mortality demonstrated in the study. Prior to water hardening trout eggs should be extremely vulnerable to mortality if subjected to wading. Few trout eggs during this stage of development would be affected by human wading since water hardening is fully completed within 20 min (Leitritz and Lewis 1976). Few eggs were crushed from wading treatments applied between water hardening and the start of chorion softening, while eggs at later stages of development were often crushed. Mortality during blastopore closure probably resulted from wading-related physical disturbance.

To my knowledge, no one has previously evaluated the effect of wading on egg and/or pre-emergent fry survival, but some related research has been reported. In addition to information on crushing susceptibility reported by

Hayes (1949) and Hein (1907), cited by Hayes (1949), Gangmark and Broad (1956) concluded that salmon embryos planted in egg canisters suffer high mortality from bedload movement caused by floods. Other researchers have examined various human-related disturbances that might effect embryo survival. Jensen and Alderdice (1983) reported that pre-eyed coho salmon embryos exposed to mechanical shock treatments exhibited four levels of sensitivity; the least sensitive period occurred prior to first cell division, while the most sensitive period occurred during a period of cell rearrangement (gastrulation), which includes blastopore closure. Thereafter, sensitivity declined through eye-up. Sheng (1985) concluded that sensitivity of pre-eyed chum salmon embryos (in the substrate) to electrical output of electroshockers was similar to the mechanical shock sensitivity curve described by Jensen and Alderdice (1983).

Embryos in artificial redds subjected to four levels of physical shock simulating underground nuclear detonations (Post et al. 1974) and test detonations near a natural stream simulating seismic detonations used in oil and gas exploration (Lloyd and Marshall 1986) showed no significant decrease in embryo survival. Rosenberg (1985) found no significant reduction in survival of eyed embryos when dropped 60 cm into water.

Field

Spawning Use

Trout used 13 spawning areas, encompassing 4.6% of the surface area of Nelson Spring Creek (Figure 2; Table 8). A total of 506 trout redds were indentified in the creek between 1 November 1985 and 11 August 1986. Seventy-five percent of the spawning took place in sections 4, 9, 11 and 12 (Appendix, Table 16). Section 4 (one of the sections with the greatest potential impact by wading anglers) contained 20.5% (104) of the total redds; sections 9, 11 and 12 contributed 12.5% (64), 10.9% (55) and 29.1% (147), respectively. Sections 3, the other section of potential impact, contained 2.5% (13) of the total redds.

Brown and rainbow trout spawning time in sections 6-13 overlapped considerably, while little overlap was observed in sections 1-5 (Figure 12). Rainbow trout spawning in sections 6-13 began earlier and lasted longer (19 December 1985 to 2 May 1986) than in sections 1-5 (16 January to 18 April 1986), excluding two rainbow trout redds observed 23 May 1986. Brown trout spawning in sections 6-13 was last observed 16 January 1986 while no spawning occurred after 30 December 1985 in sections 1-5.

Morrison and Smith (1980) reported that hatchery trout held in constant 10°C water spawned earlier and over a longer time period than fish held in water temperatures

Table 8. Dimensions and surface area (m^2) of spawning areas within the 13 sections in Nelson Spring Creek, Montana in July 1986.

Spawning section	Length(m)	Mean width(m)	Area(m^2)	Percent of total area(m^2)[a]
1	12.2	8.4	102.5	0.3
2	39.0	3.8	148.2	0.4
3	15.0	3.1	46.5	0.1
4	29.0	6.3	182.7	0.5
5	23.3	3.8	88.5	0.3
6	12.8	3.6	46.1	0.1
7	23.4	7.5	103.5	0.3
8	11.6	1.8		
	6.4	1.7	30.6	0.1
9	12.8	14.4		
	8.8	5.2	230.1	0.7
10	14.6	1.9	27.7	0.1
11	74.9	3.4	254.7	0.8
12	90.5	3.1	280.6	0.8
13	22.0	1.9	41.8	0.1
Total			1,583.5 m^2	4.6%

[a] total area excluding the area of the two headwater ponds.

which fluctuated from 1-17°C. If wild brown and rainbow trout respond similarly, most spawners using sections 6-13 are probably residents (i.e., constant water temperature), while most spawners using sections 1-5 are probably migrants from the Yellowstone River (i.e., fluctuating water temperature). Spawning overlap prevented an exact redd count in sections 6-13 for brown and rainbow trout. In sections 3 and 4, 42 brown trout redds were observed compared to 52 rainbow trout redds.

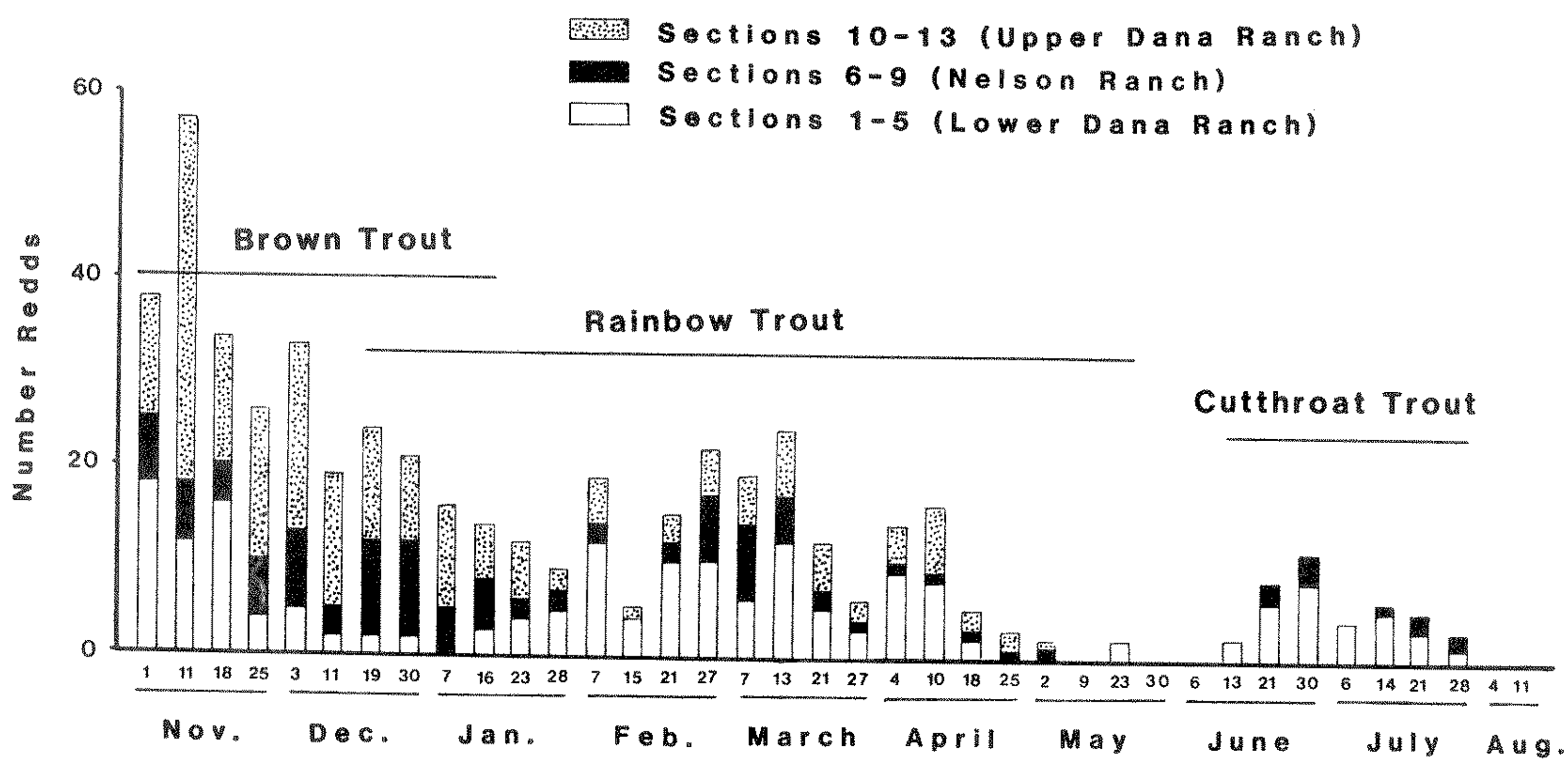

Figure 12. Weekly counts of new brown, rainbow and cutthroat trout redds in Nelson Spring Creek, Montana made from 1 November 1985 to 11 August 1986.

Cutthroat trout spawning did not appear to overlap with rainbow trout spawning in either 1986 or 1987. Thirty-nine cutthroat trout redds were identified in 1986 compared to 31 in 1987. Since a resident cutthroat trout population has not been documented in the creek, I assumed that all spawning cutthroat trout were Yellowstone River migrants. Most cutthroat trout spawning took place in sections 3, 4 and 9 (Table 9). Sections most likely to be impacted by wading (3 and 4) contained 58% of the cutthroat trout redds in 1986 and 81% in 1987 (Table 9). Timing and length of spawning periods were similar between years: 13 June to 28 July 1986 and 10 June to 14 July 1987 (Appendix, Tables 16 and 17).

Table 9. Number of cutthroat trout redds and percent of total in each of 13 sections in Nelson Spring Creek, Montana in 1986 and 1987. Spawning sections 11-13 were unavailable for cutthroat trout spawning.

	Section													
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
1986	1	1	6	17	4	0	1	0	9	0	-	-	-	39
	3%	3%	15%	43%	10%	0%	3%	0%	23%	0%	0%	0%	0%	100%
1987	0	1	5	20	0	0	0	0	5	0	-	-	-	31
	0%	3%	16%	65%	0%	0%	0%	0%	16%	0%	0%	0%	0%	100%

(-) = not checked.

Floy-tag observations in Nelson Spring Creek indicate that sections 1-5 are the most important spawning areas for Yellowstone River rainbow and cutthroat trout. Only 12 Yellowstone River brown trout were trapped and tagged at the mouth of the creek in fall 1985 and only one of these fish was subsequently observed during the spawning period. Tagged rainbow trout were observed as far upstream as section 12. Seventy-six percent (26 of 34) of the tagged rainbow trout were observed in sections 1-5 (Table 10). Five of six observations (83%) of tagged cutthroat trout were also made in sections 1-5; the sixth fish was observed just upstream of section 6. Several tagged trout were observed in the creek several months following their respective spawning periods.

Peak spawning activity for each trout species in sections 1-5 during 1985-1986 (Figure 12) coincided with the peak migration of Yellowstone River trout into NSC as determined by MDFWP trapping and electrofishing surveys (Table 11). Survey data from fall 1984 to summer 1986, indicate that most Yellowstone River brown trout move into Nelson Spring Creek during early to mid-November, rainbow trout from early February to late March and cutthroat trout from mid-June to mid-July.

Of the three streams surveyed, Nelson Spring Creek is the principal cutthroat trout spawning tributary in the Livingston-lower Paradise Valley area. During the summer

Table 10. Streamside and underwater observations of tagged trout during their respective spawning period in Nelson Spring Creek, Montana, from 18 November 1985 to 4 August 1986.

Date	Stream-side obs.	Under-water obs.	Sections 1-5	6-9	10-lower pond	11-12
11/18/85	X		BT(1)			
1/6/86	X					?(1)
2/15/86	X					RB(1)
2/27/86	X					?(1)
2/27/86		X	RB(12)			
3/7/86	X		?(2)			
3/21/86	X		?(2)			
4/4/86		X	RB(11)	RB(1)	RB(3)	(0)
4/10/86		X	RB(3)	(0)	RB(3)	(0)
6/13/86	X		CT(1)	CT(1)[a]		
7/6/86		X	CT(2)	(0)	(0)	(0)
7/14/86	X		CT(1)			
8/4/86	X		CT(1)	?(1)		

BT = brown trout.
RB = rainbow trout.
CT = cutthroat trout.
? = unidentified trout.
( ) = number tagged fish sighted.
a = observed in ditch below hatchery raceways (R. Nelson, pers. comm.)

of 1987, 19 cutthroat trout redds were identified in lower Armstrong Spring Creek (Depuy's section) and 13 in McDonald Creek compared to 31 in Nelson Spring Creek. More rainbow and brown trout spawning occurs in the lower section of Armstrong Spring Creek (Depuy's) then in the upper section (O'Hair's) (B. Auger, pers. comm.). It is assumed that most of the cutthroat trout spawning also takes place in the lower section, and the redd counts accurately depict the spawning run of Yellowstone River

Table 11. Timing and abundance of trout migrating from the Yellowstone River into Nelson Spring Creek, Montana as determined by trapping and electrofishing, fall 1984 to summer 1986 (Clancy 1984, Clancy 1985 and C. Clancy, pers. comm.).

Trout species	Year	Method[a]	Dates	Males	Females	Spawning condition of females
brown	1984	ELFH	10/16	-	-	green
			10/29	-	-	green
			11/7	17	12	some ripe
			11/13	18	11	some ripe
	1985	TRAP	10/11-22	0	0	-
			10/23-30	1	1	green
			11/1-10	7	3	green
rain-bow	1984	TRAP	3/20-30	19	10	50% ripe
	1986	TRAP	1/29-31	18	4	most green
			2/1-10	13	4	most green
			2/11-20	0	4	green
			2/21-28	17	14	33% ripe
			3/1-10	26	11	33% ripe
			3/11-20	12	14	50% ripe
			3/21-30	1	6	ripe-spent
			4/1-	-	-	-
cut-throat	1984	ELFH	6/25	2	3	ripe
			7/2	3	0	-
			7/9	5	6	ripe
			7/16	3	7	spent
			7/23	3	2	spent
	1985	ELFH	6/3	1	0	-
			6/12	2	2	green
			6/19	0	1	ripe
			6/27	9	6	ripe
			7/5	9	5	ripe
			7/9	5	3	spent
			7/17	3	3	spent
	1986	ELFH	6/17	1	0	-
			6/25	1	4	most green
			6/30	4	2	spent
			7/7	1	4	ripe
			7/14	1	1	spent
	1986	TRAP	6/11-20	2	1	-
			6/21-30	15	6	green
			7/1-4	8	7	ripe

[a] ELFH = electrofishing and TRAP = trapping.

cutthroat trout into Armstrong Spring Creek.

Nelson Spring Creek and other area spring creeks are important spawning tributaries for both cutthroat and rainbow trout (C. Clancy, pers. comm.). Yellowstone River cutthroat trout in the Livingston-lower Paradise Valley area are exclusively tributary spawners, while rainbow trout are primarily tributary spawners. Because irrigation dewatering of numerous spawning tributaries in the Livingston-lower Paradise Valley area has affected recruitment of cutthroat trout into the Yellowstone River (Berg 1975), the importance of Nelson Spring Creek is greatest for cutthroat trout relative to brown and rainbow trout.

Embryonic Development Specific to Nelson Spring Creek

Embryonic development rates specific to Nelson Spring Creek differed considerably between trout species (Table 12). Differences in development rates are thought to be a result of inherent species differences as well as variations in centigrade temperature units. Cutthroat and rainbow trout development rates in the laboratory and stream were similar (Tables 4 and 12). Centigrade temperature units were not measured for brown trout in the stream.

Brown trout eggs planted in the substrate in section 4 on 1 November 1985 took 33 days to eye-up and 66 days

Table 12. Embryonic development rates (centigrade temperature units[a] and days) of brown, rainbow and cutthroat trout specific to section 4 of Nelson Spring Creek, Montana.

Trout species	Date planted	Predicted Eye-up	Predicted Hatching	Predicted Emergence	Egg source
brown	11/2/85	12/5/85 (33 days)	1/7/86 (66 days)	---[b]	Armstrong Spring Creek
rainbow	3/13/86	4/1/86 (19 days) (168 CTU)	4/21/86 (39 days) (352 CTU)	5/20/86 (68 days) (641 CTU)	Nelson Spring Creek
cut-throat	7/2/86	7/16/86 (14 days) (158 CTU)	7/28/86 (26 days) (294 CTU)	8/14/86 (47 days) (478 CTU)	Nelson Spring Creek

[a] centirade temperature unit (CTU) = sum of mean daily temperatures above 0°C.
[b] no fry surviving to emergence.

to hatch. Estimating the number of days to emergence for brown trout was not possible. Based on 33 days to eye-up and 66 days to hatch, it was assumed that emergence occurred around 100 days. High mortality in brown trout egg baskets before hatching and complete mortality prior to emergence was thought to be related to trampling by white-tailed deer. Deer and deer tracks were observed in the vicinty of the buried egg baskets.

Rainbow and cutthroat trout eggs were planted in the substrate 13 March and 2 July 1986, respectively. Eye-up, hatch and emergence occurred at approximately 19, 39, and 68 days for rainbow trout, respectively, and 14, 26 and 47 days for cutthroat trout, respectively (Table 12). Based on embryonic development rates (Table 12), centigrade temperature units per week (Figure 13), and temporal distribution of spawning of all three species in sections 3 and 4 (Appendix, Table 16), it appears there were eggs and/or pre-emergent fry in the gravel from 1 November 1985 to early September 1986 (Figure 14).

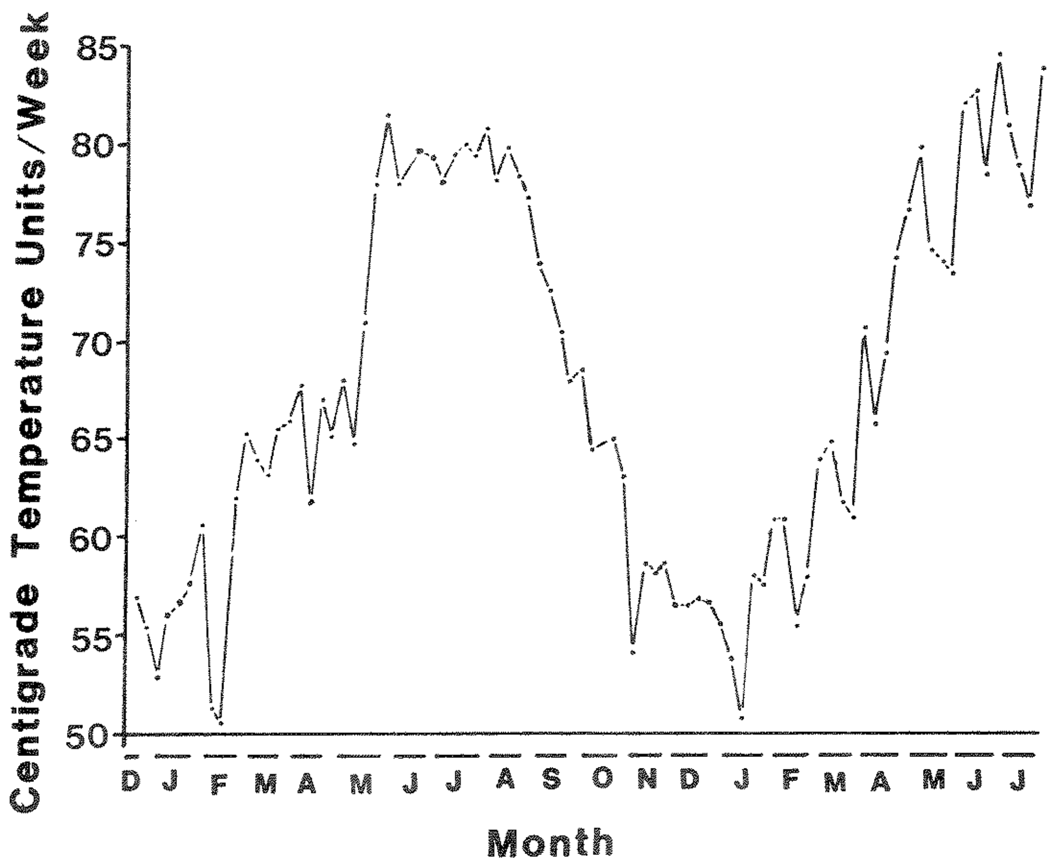

Figure 13. Number of centigrade temperature units per week during trout egg incubation and pre-emergent fry development in section 4 of Nelson Spring Creek, Montana.

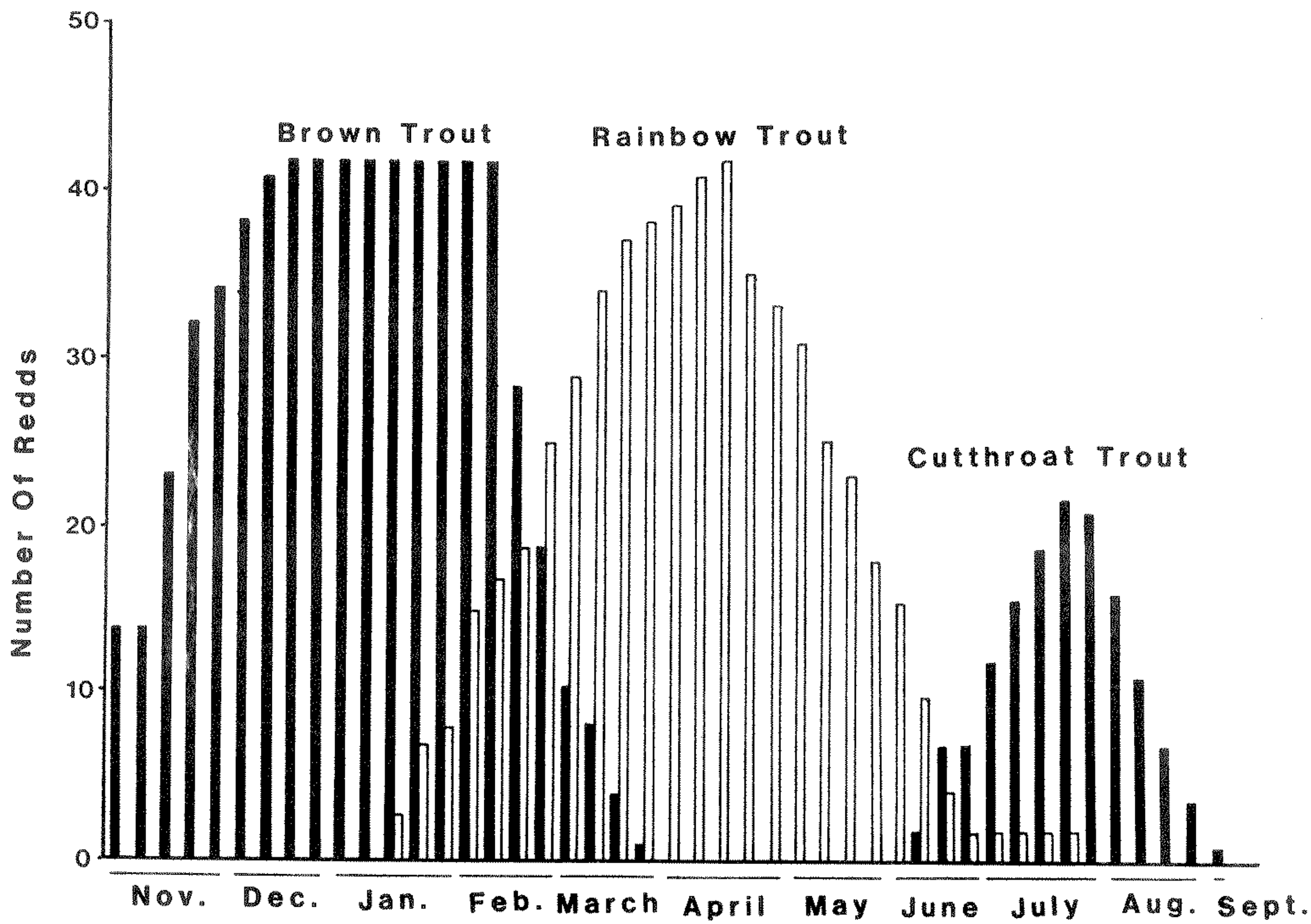

Figure 14. Number of trout redds with developing eggs and/or pre-emergent fry in sections 3 and 4 of Nelson Spring Creek, Montana between 1 November 1985 and early September 1986.

Recreational Use in Sections 3 and 4

Seventy-one anglers were photographed fishing sections 3 and 4 between 28 February and 30 August 1986 (Appendix, Table 18); they fished a total of 21.1 h. Sixteen anglers spent an estimated 3.7 h fishing from the bank; 35 anglers spent an estimated 10.4 h fishing from within the stream (wading), and 20 anglers spent an estimated 7.0 h fishing from both the bank and within the stream (Figure 15). Sixty-two percent (13.1 h) of the angler use in sections 3 and 4 between 28 February and 30 August 1986 occurred when cutthroat trout eggs and pre-emergent fry were incubating (15 June to 30 August). Most of the 35 wading anglers were presumed to have accessed Nelson Spring Creek by wading upstream from the Yellowstone River since invited guests were requested not to wade in sections 3 and 4. Thirty-six percent (5.5 h) of the time wading anglers spent fishing in sections 3 and 4 was within known spawning areas.

Approximately 85% of those fishing from within the stream waded up the left half (looking downstream) of sections 3 and 4 which contained approximately 95% of the spawning area. By identifying the heavily used areas, it was possible to identify those redds that were potentially impacted by wading. I estimated that 29 of 42 brown trout redds, 33 of 52 rainbow trout redds and 13 of 23 cutthroat

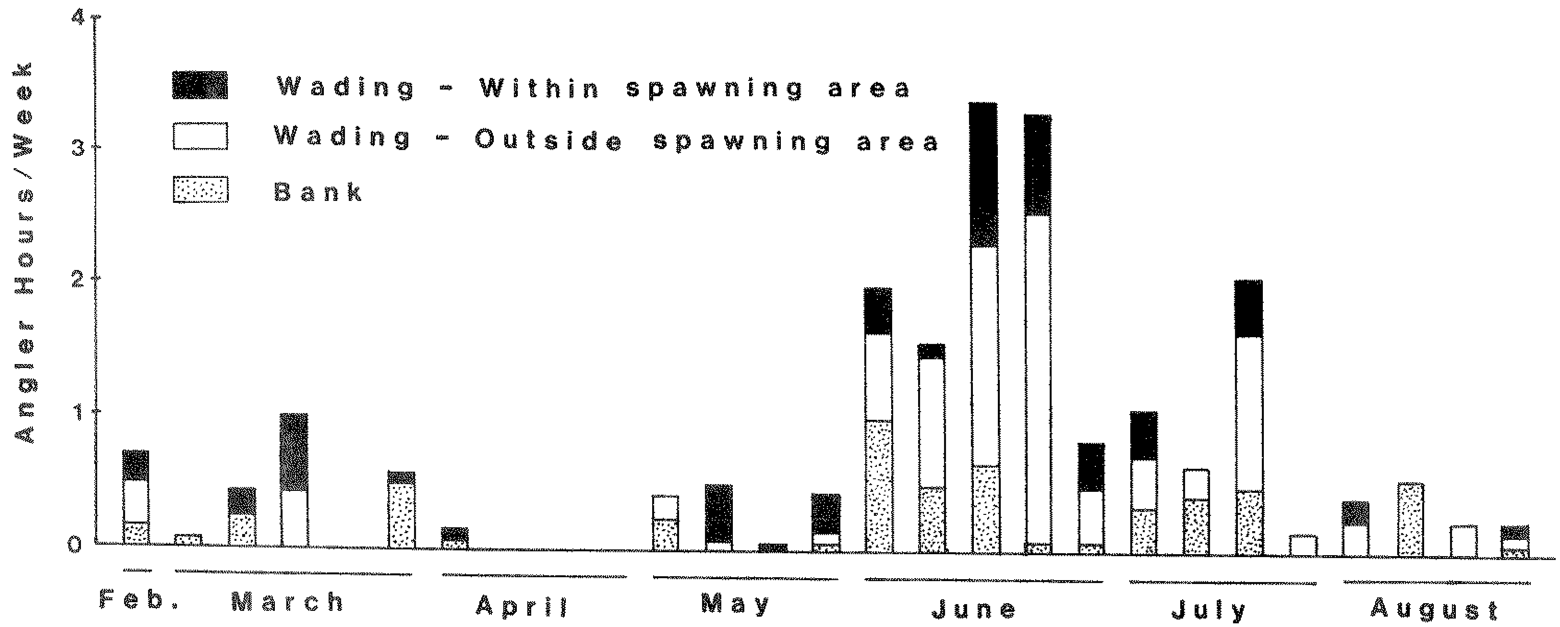

Figure 15. Angler use on lower Nelson Spring Creek, Montana (sections 3 and 4) between 28 February and 30 August 1986.

trout redds in sections 3 and 4 were located in areas of heavy angler use. Brown trout redds were probably least impacted because of light angler use in winter (pers. observation).

It was not possible to distinguish between invited and uninvited anglers accessing Nelson Spring Creek. Seventy-eight percent (232) of the 299 invited anglers registering on the Dana Ranch between 28 February to 30 August 1986 gained access during the period when incubating cutthroat trout eggs and/or pre-emergent fry were in the substrate (15 June to 30 August) (Figure 16 and Appendix, Table 18). From the photographic census, MDFWP identified 72 boats that landed near the mouth of the creek between 9 March and 30 August 1986 (Graham et al. 1986). Eighty-one percent of these boat landings occurred between 15 June and 30 August 1986 (Figure 16). As a result of extremely high and muddy conditions on the Yellowstone River between late May and early July 1986, few boats landed near the mouth of the creek. Therefore, most of the fishing pressure in sections 3 and 4 during this highwater period in 1986 likely came from anglers accessing the creek with landowner permission. In low water years, it would be expected that more boats would land near the mouth of Nelson Spring Creek in June when cutthroat trout are spawning.

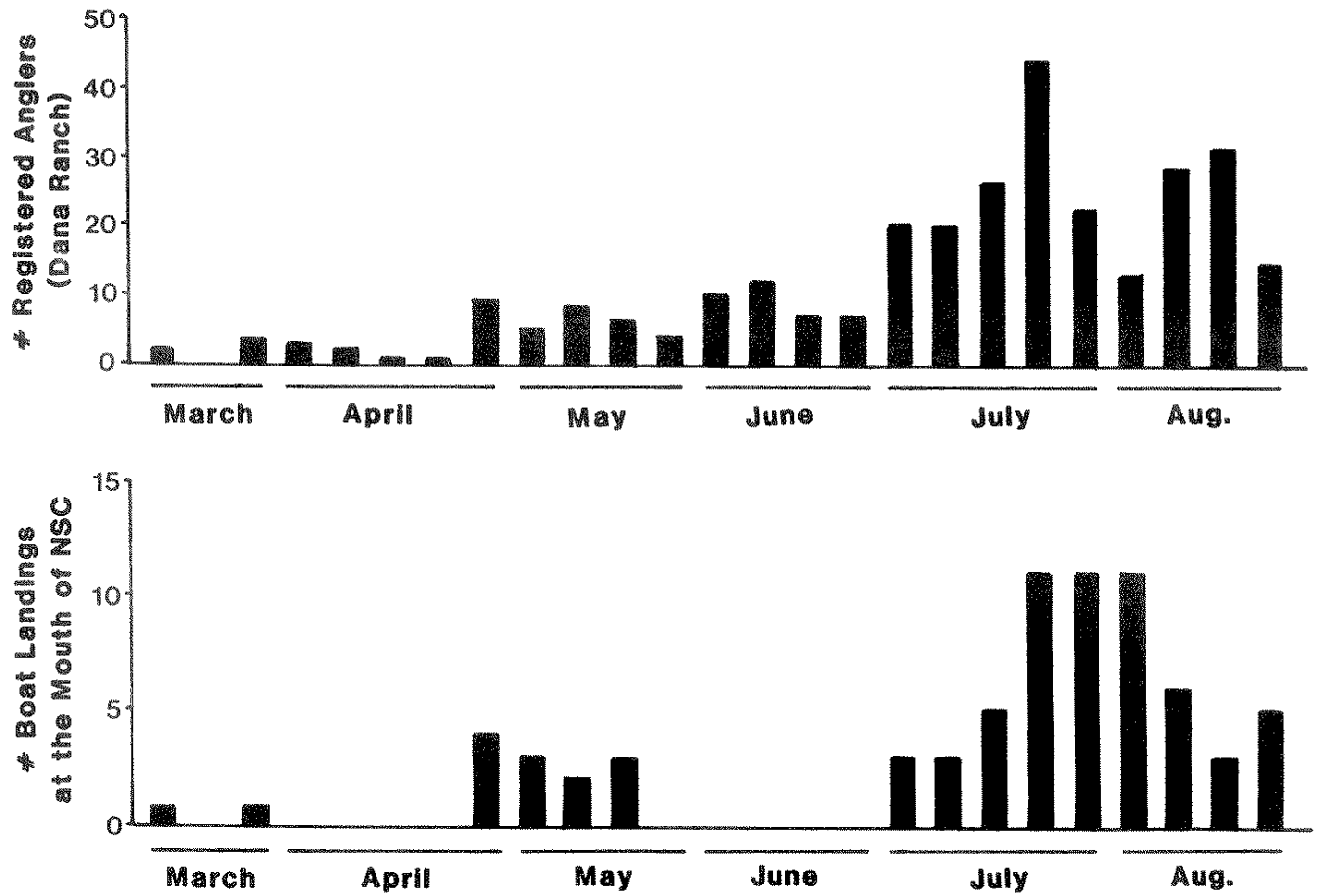

Figure 16. Number of invited anglers per week registering to fish on the Dana ranch, and the number of boats landing per week near the mouth of Nelson Spring Creek, Montana between 9 March and 30 August 1986 (Graham et al. 1986).

Wading by livestock (horses and cows) and white-tailed deer in spawning areas of sections 3 and 4 was also documented. Livestock were photographed 16 times wading in the stream; only one of those times was in known spawning areas. White-tailed deer were photographed two times wading in known spawning areas. Heaviest deer use in the stream channel appeared to be during late fall and early winter months when brown and rainbow trout were spawning and cameras were not operational.

POTENTIAL INFLUENCE OF RECREATIONAL USE ON NELSON SPRING CREEK

Several factors were considered in estimating potential damage to the Yellowstone River fishery from anglers wading in Nelson Spring Creek: 1) the effects of human wading on egg and pre-emergent fry survival; 2) importance of lower Nelson Spring Creek for recruitment to the Yellowstone River; 3) amount of recreational use occurring in lower Nelson Spring Creek when incubating eggs and/or pre-emergent fry are in the substrate; and 4) status of the trout population of concern.

Eggs and/or pre-emergent fry survival decreases significantly from multiple wading events as well as single wading events at sensitive developmental stages. Results of wading experiments indicate that the large potential impact to eggs and pre-emergent fry of each trout species exposed to human wading is nearly equal.

Importance of lower Nelson Spring Creek for spawning and recruitment to the Yellowstone River is greatest for cutthroat trout. Yellowstone River cutthroat trout populations in the Livingston-lower Paradise Valley area are exclusively tributary spawners, and this creek is the principal spawning tributary in this area. It is extremely important for cutthroat trout recruitment to the

Yellowstone River because of its stable summer flows (Clancy, in press). Most Yellowstone River brown trout are main-stem and side-channel spawners, while rainbow trout use other area spring creeks as well as Yellowstone River side-channels for spawning (C. Clancy, pers. comm.).

Sixty-two percent (13.1 h) of the angler use in sections 3 and 4 of Nelson Spring Creek between 28 February and 30 August 1986 occurred when cutthroat trout eggs and pre-emergent fry were incubating (15 June to 30 August). Considerably lower angler use was observed when brown and rainbow trout eggs and pre-emergent fry were incubating.

Cutthroat trout populations in the vicinity of Nelson Spring Creek (28 fish/mile > 30.5 cm) are low compared to cutthroat trout populations (39-89 fish/mile > 30.5 cm) in other sections of the Yellowstone River in the Livingston-Paradise Valley area and to brown and rainbow trout populations (80 fish/mile > 40.5 cm) in the same section (Clancy 1985). Low cutthroat trout populations in the Yellowstone River are a result of dewatering of spawning tributaries (Berg 1975) and possibly overfishing.

Elimination of wading on cutthroat trout redds will increase the number of emergent fry. Density-dependent survival of these fry is expected to be high due to the small abundance of cutthroat trout in rearing areas of the Yellowstone River. Increased survival should result in increased numbers of adult cutthroat trout returning to Nelson Spring Creek to spawn. However, due to the present five-fish daily creel limit and to the vulnerability of cutthroat trout to angling (Vincent and Clancy 1980), population increase will be slow. Angling probably has a much larger effect on the present cutthroat trout population structure in this portion of the Yellowstone River than does trampling of redds by anglers in Nelson Spring Creek. Johnson and Bjornn (1978) estimated annual cutthroat trout mortality in the St. Joe River, Idaho at 0.62 in 1969 and 0.71 in 1970 prior to initiating trophy-fish regulations (33 cm (13") minimum size-3 fish limit), as compared to 0.47 in 1974 and 0.56 in 1975 after regulations were instituted. Overall, the impact of receational use in Nelson Spring Creek is greatest for Yellowstone River cutthroat trout.

Wading restrictions should not be limited to humans to insure high survival of trout embryos and pre-emergent fry. Spawning areas should be fenced to prevent cattle wading. It is safe to assume that wading by cattle would result in embryo and pre-emergent fry mortality at least as large as was demonstrated for human wading. Minimal foot loading values of large ungulates (i.e., standing evenly an all hooves) are much greater than human foot loading values. Foot loading values of moose, elk and bison, assumed to be close to cattle, range between 650

g/cm^2 and 720 g/cm^2 (Telfer and Kelsal 1984). Uneven weight distribution of large ungulates would result in much higher foot loading values than those reported.

SUMMARY

1) The severity and pattern of mortality was similar between tested trout species. Twice-daily wading throughout development resulted in embryo and pre-emergent fry mortality of up to 96%, while single wading events just prior to hatching resulted in mortality as high as 43.4%. Impact of wading varied with wading frequency and embryonic stage of development. Mortality was highest for pre-emergent fry and eyed eggs between the start of chorion softening and hatching. Lowest mortality occurred between fertilization and the start of chorion softening. A slight increase in susceptibility occurs at the time of blastopore closure.

2) Width of experimental chambers had no significant effect on egg and/or pre-emergent fry mortality in wading experiments.

3) Of the 506 trout redds identified in Nelson Spring Creek between 1 November 1985 and 11 August 1986, 117 were in sections 3 and 4 (sections with greatest potential impact), Forty-two of those redds were made by brown trout, 52 by rainbow trout and 23 by cutthroat trout.

4) Thirty-nine cutthroat trout redds were identified in Nelson Spring Creek in 1986 and 31 in 1987. Most cutthroat trout spawning took place in sections 3, 4 and 9.

5) Brown trout spawned in sections 1-5 from 1 November to 30 December 1985; rainbow trout from 16 January to 23 May 1986 and cutthroat trout from 13 June to 28 July 1986 and 10 June to 14 July 1987.

6) Days to eye-up, hatch and emergence in section 4 in 1986 were 19, 39 and 68 for rainbow trout and 14, 26 and 47 for cutthroat trout, respectively. Brown trout embryos took 33 days to eye-up and 66 days to hatch.

7) Based on the temporal distribution of spawning for all three trout species and embryonic development rates specific to section 4, eggs and/or pre-emergent fry were in the gravel from 1 November 1985 to early September 1986 in sections 3 and 4.

8) From observations on tagged trout, it appears that most rainbow and cutthroat trout migrants from the Yellowstone River spawn in the lower part of the creek.

9) Seventy-one anglers were observed fishing sections 3 and 4 between 28 February and 30 August 1986; they fished a total of 21.1 h. Sixty-two percent (13.1 h) of the

angler use in sections 3 and 4 between 28 February and 30 August 1986 occurred when cutthroat trout eggs and pre-emergent fry were incubating (15 June to 30 August). Thirty-six percent (5.5 h) of the time anglers spent fishing while wading in sections 3 and 4 was within known spawning areas.

10) Wading-related mortality in Nelson Spring Creek will have a greater impact on the Yellowstone River cutthroat trout population than on brown and rainbow trout populations because: 1) it is the principal spawning tributary in the Livingston-lower Paradise Valley area; 2) most cutthroat trout spawn in the lower reaches which are frequently waded through by anglers, and their eggs and/or pre-emergent fry are incubating when the greatest angler use occurs; and, 3) cutthroat trout populations are low in this part of the Yellowstone River.

REFERENCES CITED

Alderdice, D. F., W. P. Wickett and J. R. Brett. 1958. Some effects of temporary exposure to low dissolved oxygen levels on Pacific salmon eggs. Journal of the Fisheries Resrach Board of Canada. 15:229-250.

Berg, R. 1975. Fish and game planning, upper Yellowstone and Shields River drainages. Montana Department Fish and Game, Federal Aid Fish and Wildlife Restoration Project FW-3-R, Helena.

Blaxter, J. H. S. 1969. Development: eggs and larvae. Pages 177-243 in W.S Hoar and D.J. Randall, editors. Fish Physiology Volume III. Academic Press, Inc, London.

Campbell, M. F. and J. Waltermire. 1985. House Bill No. 265, Chapter 556, Laws of 1985, Helena, Montana.

Clancy, C. 1984. Inventory and survey of waters of the project area. Yellowstone River drainage. Montana Department Fish, Wildlife and Parks. Project No. F-9-R-32, Job No. I-C, Helena, Montana.

__________. 1985. Inventory and survey of waters of the project area. Yellowstone River drainage. Montana Department Fish, Wildlife and Parks. Project No. F-9-R-33, Job No. I-C, Helena, Montana.

__________. In Press. Effects of dewatered spawning tributaries on Yellowstone cutthroat trout in the Yellowstone River, Montana. American Fisheries Society Symposium No. 4. Bethesda, Maryland.

Coble, D. W. 1961. Influence of water exchange and dissolved oxygen in redds on survival of steelhead trout embryos. Transactions of the American Fisheries Society. 90:469-474.

Decker-Hess, J. 1986. An inventory of the spring creeks in Montana. American Fisheries Society and Montana Deparment Fish, Wildlife and Parks, Bethesda, Maryland.

Gangmark, H. A. and R. D. Broad. 1956. Further observations on stream survival of king salmon spawn. California Deparment Fish and Game. 42:37-49.

Graham, P., J. Wells and C. Clancy. 1986. Report two and recommendations on a request to restrict public recreational use on Nelson's Spring Creek filed by William Dana. Montana Department Fish, Wildlife and Parks, Helena, Montana.

Greeley, J. R. 1932. The spawning habits of brook, brown and rainbow trout, and the problem of egg predators. Transactions of the American Fisheries Society. 62:239-248.

Hayes, F. R. 1949. The growth, general chemistry and temperature relations of salmonid eggs. The Quarterly Review of Biology. 24:281-308.

Hein, E. 1907. Zur Biologie der Forellenbrut. III. Ueber die Wirkungen von Druck, Stoss und Fall auf die Entwicklung der Bachforelleneier. Allgemeine Fischerei-Zeitung Munchen, 32:383-387; 398-402. (This reference was unavailable and was not read. The information cited from it was obtained in Hayes 1949.)

Jensen, J. O. T. and D. F. Alderdice. 1983. Changes in mechanical shock sensitivity of coho salmon (Oncorhynchus kisutch) eggs during incubation. Aquaculture. 32:303-312.

Johnson, T. H. and T. C. Bjornn. 1978. Evaluation of angling regulations in management of cutthroat trout. Job Completion Report, Project F-59-R-7 and F-59-R-8. Idaho Department Fish and Game and Idaho Cooperative Fishery Research Unit, Moscow.

Johnson, S. C., G. A. Chapman and D. G. Stevens. 1983. Sensitivity of steelhead trout embryos to handling. The Progressive Fish-Culturist. 45:103-104.

________________, G. A. Chapman and D. G. Stevens. 1986 (unpublished). Effects of developmental stage on the sensitivity to handling of coho salmon and rainbow trout embryos. U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, Oregon.

Knight, A. E. 1963. The embryonic and larval development of the rainbow trout. Transactions of the American Fisheries Society. 92:344-355.

Kwain, W. 1975. Embryonic development, early growth, and meristic variation in rainbow trout (Salmo gairdneri) exposed to combinations of light intensity and temperature. Journal of the Fisheries Research Board of Canada. 32:397-402.

Leitritz, E. and R. C. Lewis. 1976. Trout and salmon culture. Fisheries Bulletin No. 164. California Department Fish and Game and University of California, Berkeley.

Lloyd, J. W. and S. Marshall. 1986. Effects of surface charge seismic exploration on incubating eggs. U. S. Forest Service. Kootenai National Forest, Libby, Montana.

McNeil, W. J. and W. H. Ahnell. 1964. Success of pink salmon spawning relative to size of spawning bed materials. U. S. Fish and Wildlife Service. Special Scientific Report Fisheries 469.

Morrison, J. K. and C. E. Smith. 1980. The effect of water temperature on the sexual development and egg quality of rainbow trout broodstock. Bozeman Informantion Leaflet Number 14. Fish Cultural Developmental Center. U.S. Fish and Wildlife Service, Bozeman, Montana.

Ottaway, E. M., P. A. Carling, A. Clarke and N. A. Reader. 1981. Observations on the structure of brown trout, Salmo trutta Linnaeus, redds. Journal of Fish Biology 19:593-607.

Peterson, R. H., H. C. E. Spinney and A. Sreedharen. 1977. Development of Altantic salmon (Salmo salar) eggs and alevins under varied temperature regimes. Journal of the Fisheries Research Board of Canada. 34:31-43.

Piper, R. G., I. B. McElwain, L. E. Orme, J. P. McCraren, L. P. Fowler and J. R. Leonard. 1983. Fish hatchery management. U. S. Fish and Wildlife Service. Washington, D.C.

Phillips, R. W. and H. J. Campbell. 1961. The embryonic survival of coho salmon and steelhead trout as influenced by some environmental conditions in gravel beds. 14th Annual Report Pacific Marine Fisheries Commission, Portland, Oregon.

Post, G., D. V. Power and T. M. Kloppel. 1974. Survival of rainbow trout eggs after receiving physical shocks of known magnitude. Transactions of the American Fisheries Society. 103:711-716.

Rosenberg, D. L. 1985. The effects of physical shock on the survival of coho salmon embryos during advanced development. The Progressive Fish-Culturist. 47:166-168.

Sheng, M. 1985. The effects of back pack electroshockers on incubating chum eggs. Canada Department Fisheries and Oceans, Vancouver, B.C.

Smirnov, A. I. 1955. The effect of mechanical agitation at different periods of the development on the eggs of autumn chum salmon (Oncorhynchus keta infras. autumnalis Berg, Salmonidae). Doklady Akademii Nauk SSSR. 105:873-876. (Translation from Russian by Fisheries Research Board of Canada Translation series No. 230, 1959).

Smith, O. R. 1941. The spawning habits of cutthroat and eastern brook trout. Journal of Wildlife Managment. 5:461-471.

Smith, S. N., R. A. Armstrong, J. Springate and G. Barker. 1985. Infection and colonization of trout eggs by Saprolegniaceae. Transactions of the British Mycological Society. 85:719-764.

Telfer, E. S. and J. P. Kelsall. 1984. Adaptation of some large North American mammals for survival in snow. Ecology. 65:1828-1834.

Timoshina, L. A. 1972. Embryonic development of the rainbow trout (Salmo gairdneri irideus(Gibb.)) at different temperatures. Journal of Ichthyology. 12:425-432.

Vincent, E. R. and C. Clancy. 1980. Fishing regulation evaluation on major trout waters. Job Progress Report, Federal Aid Project No. F-9-R-28, Job No. II-c. Montana Department Fish, Wildlife and Parks, Helena, Montana.

Weaver, T. M. and R. G. White. 1985. Coal Creek fisheries monitoring study No. III. Montana Cooperative Fishery Research Unit and U. S. Forest Service, Bozeman, Montana.

Wells, J., C. Clancy and P. Graham. 1985. Report and recommendations on a request to restrict public recreational use on Nelson's Spring Creek filed by William Dana, Jr. and Edwin S. Nelson. Montana Department Fish, Wildlife and Parks, Helena, Montana.

Zar, J. H. 1984. Biostatistical Analysis. Second Edition. Prentice-Hall, Inc. Englewood Cliffs, New Jersey.

APPENDIX

Table 13. Mean percent brown, rainbow and cutthroat trout survival (standard error) in test egg baskets (n = 8) exposed to wading treatments 1-6 and corresponding controls (n = 8) for all five experiments. Sample sizes for brown trout (experiment 1) ranged between 2-5.

Experiment	Egg baskets	Wading Treatments 1	2	3	4	5	6
1 (brown trout)	Control	91.5 (0.9) n=5	- - -	84.9 (11.7) n=4	81.5 (9.5) n=2	93.8 (1.9) n=4	92.2 (5.4) n=3
	Test	70.3 (9.3) n=5	- - -	68.4 (8.2) n=4	53.8 (5.7) n=2	74.4 (2.0) n=4	46.8 (1.7) n=3
2 (rainbow trout)	Control	85.1 (3.7)	21.4 (5.1)	13.6 (2.5)	26.4 (8.4)	16.0 (2.4)	16.3 (3.3)
	Test	34.5 (4.6)	2.8 (1.1)	1.6 (0.5)	2.6 (1.2)	0.6 (0.3)	0.6 (0.2)
3 (cutthroat trout)	Control	99.4 (0.3)	86.9 (1.6)	88.3 (1.4)	76.8 (2.2)	78.1 (3.0)	75.1 (4.1)
	Test	87.2 (2.4)	23.9 (2.7)	23.3 (3.1)	49.9 (6.7)	18.6 (3.6)	12.9 (1.8)
4 (brown trout	Control	96.3 (0.5)	82.8 (4.2)	89.1 (3.1)	70.4 (4.6)	72.3 (7.0)	83.2 (5.1)
	Test	85.8 (2.0)	39.4 (6.1)	34.5 (4.6)	30.2 (3.5)	11.5 (2.5)	9.0 (3.3)
5 (rainbow trout)	Control	99.3 (0.6)	68.3 (7.1)	80.5 (3.8)	54.3 (6.1)	49.8 (3.5)	52.2 (5.4)
	Test	86.1 (3.4)	27.9 (3.5)	20.5 (3.2)	16.9 (4.5)	4.4 (1.7)	2.1 (0.8)

Table 14. Mean percent brown, rainbow and cutthroat trout mortality (standard error) in test egg baskets (n = 4) exposed to one wading event in 1.0 m and 0.3 m wide chambers at various stages of development (CTU) and corresponding controls (n = 4). Egg baskets were arranged in the chambers according to experimental design "A" (Figure 6). Sign test (α = 0.05) was used to statistically analyze comparison data.

Experiment	CTU at wading	Percent Mortality			Sign test
		Control	1.0 m	0.3 m	(1.0 m > 0.3 m = +)
1 (brown trout)	7.5	3.8 (1.2)	6.3 (1.6)	6.1 (1.1)	+
	86.7	10.8 (3.3)	14.6 (2.9)	13.8 (1.5)	+
	154.5	4.0 (2.0)	4.6 (0.6)	4.5 (1.4)	+
	255.0	1.4 (0.5)	3.3 (0.8)	2.8 (0.3)	+
	390.0	18.3 (2.8)	37.4 (4.5)	24.9 (3.5)	+
	525.3	8.6 (1.9)	13.5 (2.8)	19.4 (3.4)	-
2 (rainbow trout)	3.5	13.1 (1.4)	11.9 (0.7)	14.1 (2.4)	-
	94.1	17.5 (2.4)	24.3 (2.5)	26.5 (2.9)	-
	247.6	3.6 (0.4)	7.1 (1.5)	10.1 (2.6)	-
	303.6	12.4 (3.6)	47.9 (5.2)	52.9 (3.0)	-
	396.8	23.6 (2.3)	34.6 (1.9)	33.5 (1.5)	+
	501.4	10.4 (1.5)	26.2 (3.7)	28.9 (5.1)	-
3 (cutthroat trout)	4.4	4.6 (1.4)	4.1 (1.4)	4.3 (1.1)	-
	109.3	3.9 (0.7)	6.6 (0.8)	4.5 (1.3)	+
	257.2	3.0 (0.6)	9.3 (0.5)	9.0 (1.5)	+
	286.8	12.5 (3.1)	38.3 (3.2)	61.3 (0.8)	-
	369.0	46.3 (2.8)	62.5 (8.1)	50.5 (3.8)	+
	444.0	10.3 (1.3)	36.2 (6.4)	18.2 (4.4)	+
					(+) = 10 (-) = 8

Table 15. Mean percent brown and rainbow trout mortality (standard error) in test egg baskets (n = 4) exposed to one wading event in 1.0 m and 0.3 m wide chambers at various stages of development (CTU) and corresponding controls (n = 4). Egg baskets were arranged in the chambers according to experimental design "B" (Figure 6). Sign test (α = 0.05) was used to statistically analyze comparison data.

CTU at wading	Experiment 4 - Brown Trout Percent Mortality Control	1.0m	0.3m	Sign Test (1.0m > 0.3m = +)
76.2	9.0	14.0	3.5	+
	6.0	5.0	6.0	-
	6.0	9.5	6.0	+
	4.0	5.0	6.0	-
Mean(SE)	6.3(1.0)	8.4(2.2)	5.8(0.8)	
303.8	2.5	4.5	3.5	+
	2.0	6.5	4.0	+
	2.5	4.0	3.0	+
	1.0	2.5	4.0	-
Mean(SE)	2.0(0.4)	4.4(0.8)	3.6(0.2)	
376.6	1.5	3.0	9.5	-
	1.0	8.5	8.0	+
	7.0	4.5	14.0	-
	2.5	4.5	12.0	-
Mean(SE)	3.0(1.4)	5.1(1.2)	10.9(1.3)	
416.7	12.5	28.5	25.5	+
	17.5	10.5	20.0	-
	13.5	25.0	39.5	-
	18.0	24.5	38.0	-
Mean(SE)	15.4(1.4)	22.1(4.0)	30.8(4.8)	
505.5	10.5	26.4	36.5	-
	26.1	7.8	31.1	-
	23.5	23.6	39.3	-
	18.2	14.5	29.4	-
Mean(SE)	19.6(3.5)	18.1(4.3)	34.1(2.3)	
586.7	8.0	15.1	6.4	+
	13.7	24.4	23.1	+
	9.0	19.1	18.0	+
	10.0	14.9	24.4	-
Mean(SE)	10.2(1.2)	18.4(2.2)	18.0(4.1)	
				(+) = 10 (-) = 14

Table 15. Continued.

CTU wading	Experiment 5 - Rainbow Trout Percent Mortality Control	1.0 m	0.3 m	Sign Test (1.0m > 0.3m = +)
91.9	1.0	3.0	5.5	-
	1.5	3.5	9.5	-
	2.5	9.5	6.5	+
	1.0	5.0	5.5	-
Mean(SE)	1.5(0.4)	5.3(1.5)	6.8(0.9)	
136.5	2.5	3.5	3.0	+
	1.5	6.0	4.5	+
	1.0	3.5	2.0	+
	2.5	4.5	5.5	-
Mean(SE)	1.9(0.4)	4.4(0.6)	3.8(0.8)	
279.8	2.0	10.0	6.5	+
	3.5	4.5	9.5	-
	3.0	10.0	10.5	-
	1.0	6.5	5.0	-
Mean(SE)	2.4(0.4)	7.8(0.6)	7.9(0.8)	
310.9	5.5	22.0	18.5	+
	6.5	19.5	28.5	-
	6.5	12.5	11.5	+
	6.0	17.0	19.0	-
Mean(SE)	6.1(0.2)	17.8(2.0)	19.4(3.5)	
481.9	8.1	21.1	31.1	-
	30.6	28.8	41.0	-
	20.0	13.1	21.0	-
	15.9	45.0	44.2	+
Mean(SE)	18.7(4.7)	27.0(6.8)	34.5(5.1)	
527.4	7.0	9.6	6.5	+
	3.5	11.9	10.1	+
	4.4	24.4	14.6	+
	5.5	6.4	16.7	-
Mean(SE)	5.1(0.8)	13.1(3.9)	12.0(2.3)	
				(+) = 12 (-) = 12

Table 16. Weekly trout redd counts made on Nelson Spring Creek, Montana from 1 November 1985 to 11 August 1986.

Month	Day	Section 1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Nov.	1	0	3	2	12	1	1	3	1	2	0	4	9	-	38
	11	0	3	0	9	0	1	4	1	0	1	10	28	-	57
	18	1	3	3	6	3	0	3	0	1	0	4	10	-	34
	25	0	1	0	2	1	1	0	1	4	0	7	9	-	26
Dec.	3	0	1	1	3	0	2	0	0	6	0	6	14	-	33
	11	0	0	0	3	0	1	0	1	1	0	6	8	-	20
	19	0	1	0	1	0	1	1	2	6	1	2	7[a]	2	24
	30	0	1	0	0	1	2	0	2	6	0	2	6	1	21
Jan.	7	0	0	0	0	0	1	2	0	2	0	5	5	1	16
	16	0	0	0	3	0	1	0	0	4	0	1[a]	5[b]	0	14
	23	0	0	0	4	0	0	0	0	2	0	1[a]	4[a]	1	12
	28	4[a]	0	0	1	0	0	0	0	2	0	0	2	0	9
Feb.	7	5	0	1	6	0	0	0	1	1	0	0	5	0	19
	15	2	0	0	2	0	0	0	0	0	0	0	0	1	5
	21	8	0	0	2	0	1	0	0	1	0	0	3	0	15
	27	4	0	0	6	0	0	2	0	5	1	0	4	0	22
March	7	2	0	0	4	0	1	1	0	6	0	0	5	0	19
	13	3	1	0	5	3	2	1	0	2	0	1	6	0	24
	21	2	1	0	2	0	0	0	0	2	0	1	4	0	12
	27	1	0	0	2	0	0	0	0	1	0	0	2	0	6
April	4	1	4	0	4	0	1	0	0	0	0	1	3	0	14
	10	1	1	0	6	0	1	0	0	0	0	3	4	0	16
	18	0	0	0	2	0	0	0	0	1	0	1	1	0	5
	25	0	0	0	0	0	1	0	0	0	0	0	2	0	3
May	2	0	0	0	0	0	0	0	0	0	0	0	1	0	1
	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	23	0	0	0	2	0	0	0	0	0	0	0	0	0	2
	30	-	-	0	0	0	0	0	0	0	0	0	0	0	0
June	6	-	-	0	0	0	0	0	0	0	0	-	-	-	0
	13	-	-	1	1	0	0	0	0	0	0	-	-	-	2
	21	-	-	2	3	1	0	0	0	2	0	-	-	-	8
	30	-	-	2	3	3	0	1	0	2	0	-	-	-	11
July	6	-	0	0	4	0	0	0	0	0	0	-	-	-	4
	14	1	1	0	3	0	0	0	0	1	0	-	-	-	6
	21	0	0	1	2	0	0	0	0	2	0	-	-	-	5
	28	0	0	0	1	0	0	0	0	2	0	0	0	0	3
Aug.	4	0	0	0	0	0	0	0	0	0	0	-	-	-	0
	11	0	0	0	0	0	0	0	0	0	0	-	-	-	0
Total		35	21	13	104	13	18	18	9	64	3	55	147	6	506

[a] rainbow trout redd and [b] brown trout redd
(-) = not checked.

Table 17. Weekly cutthroat trout redd counts made on Nelson Spring Creek, Montana from 3 June to 24 July 1987.

Month	Day	Section 1	2	3	4	5	6	7	8	9	10	11	12	13	Total
June	3	0	0	0	0	0	0	0	0	0	0	-	-	-	0
	10	0	0	0	3	0	0	0	0	1	0	-	-	-	4
	17	0	0	1	7	0	0	0	0	0	0	-	-	-	8
	22	0	1	2	2	0	0	0	0	1	0	-	-	-	6
	30	0	0	2	3	0	0	0	0	3	0	-	-	-	8
July	7	0	0	0	3	0	0	0	0	0	0	-	-	-	3
	14	0	0	0	2	0	0	0	0	0	0	-	-	-	2
	24	0	0	0	0	0	0	0	0	0	0	-	-	-	0
Total		0	1	5	20	0	0	0	0	5	0	0	0	0	31

(-) = not checked.

Table 18. Number of registered anglers on the Dana ranch and estimated angler use (min) in sections 3 and 4 of Nelson Spring Creek, Montana between 28 February and 30 August 1986.

	Dana register	Camera coverage		
Week	# Registered anglers	# Bank anglers (a)	# Bank & wading anglers (a,b,c)	# Wading anglers (b,c)
2/28-3/1	0	0	3(10,35,15)	0
3/2-3/8	4	1(5)	0	0
3/9-3/15	2	0	2(15,10,10)	0
13/16-3/22	0	0	0	4(60,35)
3/23-3/29	4	0	0	0
3/30-4/5	3	1(30)	0	1(5,5)
4/6-4/12	2	0	1(5,5,5)	0
4/13-4/19	0	0	0	0
4/20-4/26	1	0	0	0
4/27-5/3	9	0	0	0
5/4-5/10	5	1(15)	0	1(10,0)
5/11-5/17	8	0	0	1(30,25)
5/18-5/24	6	0	0	1(5,5)
5/25-5/31	4	0	1(5,20,15)	0
6/1-6/7	10	1(15)	5(45,60,20)	0
6/8-6/14	12	2(25)	1(5,5,5)	1(60,0)
6/15-6/21	7	1(25)	2(15,35,10)	3(130,55)
6/22-6/28	7	0	1(5,30,5)	7(165,40)
6/29-7/5	20	0	1(5,30,5)	2(15,15)
7/6-7/12	20	1(5)	1(15,45,20)	0
7/13-7/19	26	2(25)	0	3(15,0)
7/20-7/26	44	3(25)	1(5,5,0)	6(90,25)
7/27-8/2	22	0	0	2(10,0)
8/3-8/9	13	0	0	2(25,10)
8/10-8/16	28	2(35)	0	0
8/17-8/23	31	1(15)	0	0
8/24-8/30	14	0	1(5,5,5)	1(5,0)
Total	299	16(220)	20(135,285,115)	35(625,215)

(a) = estimated # of minutes fishing from the bank.
(b) = estimated # of minutes fishing from within the stream (wading).
(c) = estimated # of minutes fishing from within known spawning areas (wading).