Winter Migration and Survival of Telemeterized Juvenile Rainbow trout in the Henrys Fork of the Snake River, Idaho

project final report

by

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Abstract.- Concealment habitat, such as macrophytes beds and cobble and boulder complexes, is crucial for juvenile trout to survive the winter in the Henrys Fork of the snake river. This habitat is limited to the area between Island Park Dam and Riverside campground, where most of the juvenile trout are spawned and spend their first summer. During any given winter most (>85%) of the juvenile trout produced in this area are unaccounted for at the end of winter. Therefore, radio transmitters were surgically implanted into Juvenile trout at Last Chance in early December and those fish were located bi-monthly through the winter to assess movement and areas of the river selected by juvenile trout during winter. Additionally, trout were implanted with dummy transmitters and held in cages at Last Chance to assess mortality caused by transmitters and surgeries.

Transmittered trout moved both upstream to Box Canyon and downstream to Riverside Campground but most of them died either in Last Chance or Harriman State Park. Transmitters were recovered from the surface of the substrate and buried in the substrate as far as 20 cm below the surface of the substrate. One unknown wintering area was discovered in Thurmon Creek immediately downstream from Silver Lake Dam. An estimated 2000 juvenile trout and 2000 juvenile whitefish were observed in this area (visual estimate).

Dummy transmittered fish survival was low (25 - 33%). This was not attributed to the use of transmitters as fish that experienced surgery but received no transmitter also experienced high mortality rate. All of the control fish survived the experiment.

Because of the high mortality rate of the caged fish it was not possible to extrapolate the mortality rates of the transmittered fish to the population as a whole. However, movement of one fish into Thurmon Creek led to the discovery of that population and the eventual possibility of enhancing the habitat in that area or the extension of the range of fish in this area by the construction of a fish ladder on Silver Lake Dam. Further research on this population will be necessary before such construction should be attempted.

Introduction

Over the past 15 years, numerous studies have focused on loss of juvenile rainbow trout (Onchorynchus mykiss) in the Henrys Fork of the Snake River during winter (Gregory 2000). These studies have shown that during the day, juvenile trout conceal themselves in cobble and boulder substrate along the river margin (Contor and Griffith 1995) and in mid-river macrophytes (Griffith and Smith 1995). However, macrophytes provide habitat for only the early part of the winter (Griffith and Smith 1995) prior to their scenescing or being removed by waterfowl, which generally occurs by January or February. Studies have shown that winter survival is affected by availability of suitable habitat and the size of the fish as they enter the winter (Smith and Griffith 1994, Meyer and Griffith 1997a). However, relatively high winter survival of caged fish (Meyer and Griffith 1997a), even without adequate habitat (Smith and Griffith 1994), compared to low retention rates of in-river fish (Meyer 1995, Mitro 1999) suggested that winter loss of juvenile trout may be attributed more to emigration than mortality. Cage studies confirm that this could be the case, as when adequate habitat was not present, juvenile trout attempt to emigrate (Bjornn 1971; Meyer and Griffith 1997b). An intensive mark-recapture migration study, which included sample sites from Box Canyon to Riverside Campground (Figure 1), showed that some juvenile trout successfully emigrate from the Last Chance area to both Box Canyon and Riverside Campground (Mitro 1999). But the majority of the fish present in Last Chance during autumn were never found (Mitro 1999).

Numerous habitat improvement efforts, to increase the wintering success of juvenile rainbow trout have been attempted (Gregory 2000). However, the only measure that has met with much success has been to increase late winter flows from Island Park Dam (Mitro 1999). Unfortunately, conditions under which this strategy is possible have historically been rare (Benjamin and Van Kirk 1999).

Survival or retention rates of 18 - 23% for juvenile trout from the Box Canyon area approach survival rates reported in the literature for juvenile salmonids (3.3 - 90%) in other rivers (Needham, Moffett, and Slater 1945; Hunt 1969; Ward and Stanley 1993; Seelbach 1993; Quinn and Peterson 1996. However, survival or retention rates of juvenile trout in the Last Chance area (<1%; Mitro 1999) are much lower than those rates. But fishing success in those sections continues to be good (Van Kirk and Gamblin 2000). This either means that the number of juvenile trout that survive their first winter are sufficient to stock the Henrys Fork with an adequate fish population, or some of the juvenile trout are in fact surviving the winter in some unknown location, and then returning to become part of the adult population. One hypothesis proposed is that macrophytes in the Last Chance area provide important early winter habitat. As these macrophytes slough off, fish move upstream where, if late winter flows are high, the additional habitat wetted by the high flows provides late winter habitat (Mitro 1999).

The primary objective of this study were to track juvenile trout movement from the Last Chance area to assess the possibility of an unknown wintering area for juvenile trout. Other objectives included assessing the extent of upstream movement and the extent and corollaries of downstream movement.

Since biotelemetry was the most direct method of evaluating these objectives and since transmitters that would last through most of the winter required a large battery, it was necessary to use radio transmitters that would exceed 2% of the fish's body weight. Studies have shown that exceeding as much as 12% of the fish's body weight did not significantly affect swimming performance of juvenile rainbow trout at summer water temperatures (Brown et al. 1999). However, tests were not conducted at low water temperatures and only swimming speed was evaluated. Therefore, control groups and in-stream cages were used in this study to assess the effect of oversized transmitters on juvenile trout survival during winter.

Study Area

The Henrys Fork of the Snake River is a 75% spring fed (at Island Park; Benjamin 2000) river whose source is Big Springs and is located primarily in eastern Idaho near Yellowstone National Park (Figure 1). The upstream most portion of the study area was Island Park Dam, a hypolymnetic release dam constructed in 1938 with a capacity of $1.67*10^8$ m^3. Box Canyon, that section of the Henrys Fork from Island Park Dam to the community of Last Chance is typified by basalt cobble and boulder substrate with basalt cliffs near each bank. Lodgepole pine (Pinus contorta) along the river provides woody debris input into the canyon. Gradient in this section of river is approximately 0.5%. The Last Chance section begins at the mouth of Box Canyon and is typified by a silt, sand, and gravel substrate with abundant macrophytes in summer and autumn. The banks contain a few basalt cobble and boulders with their concentration being greater on the upstream end near the mouth of Box Canyon. The Harriman and Harriman East sections have been grouped for this study as, during winter, the habitat in each of them is similar (although Harriman East is slightly lower gradient and therefore had slower water velocities and deeper water). Cobble and boulder substrate are absent from these areas and, although macrophytes are abundant during the summer, they are grazed off by waterfowl early in the winter (Whitman, 2001). This area provides little winter habitat for juvenile trout (Gregory, personal observation). At the community of Pinehaven (just downstream from the lower boundary of Harriman State Park) the river again enters a basalt canyon through which it proceeds for the remainder of the study area. This canyon is similar to Box Canyon in substrate and woody debris input. The upper end of this canyon (from Pinehaven to Riverside Campground) has been included in past studies. However, as the portion of this canyon between Riverside Campground and the mouth of Warm River is inaccessible during winter, and Mesa Falls, a waterfall 17 km downstream from Riverside Campground, precludes upstream migration of fish. No previous winter studies have addressed this portion of the river. The above described portion of the Henrys Fork has only two major tributaries, the Buffalo River, which enters the Henrys Fork approximately 600 m downstream from the Island Park Dam, and Thurmon Creek which enters the river in the Harriman section. Small dams near the mouths of both streams, constructed in the early 1900's, have almost completely blocked Henrys Fork fish use of those tributaries until 1996 when a fish ladder was installed on the Buffalo River Dam. The Silver Lake Dam, on Thurmon Creek, remains impassible to fish. The lower end of the study area was Ashton Reservoir, which is located 70 km downstream from Island Park Dam (Figure 1).

Methods

Movement Studies

Previous studies have shown that mass movement from the Last Chance area by juvenile rainbow trout typically begins in December (Mitro 1999) and few fish remain by February (Mitro 1999; Griffith and Smith 1995). Therefore, juvenile rainbow trout were collected from the Last Chance reach of the Henrys Fork on 30 November via electrofishing. Fish were collected from both mid-channel macrophyte habitat and near-bank cobble and boulder substrate. As transmitters with an expected battery life of at least 60 days were needed and were relatively large, only the largest fish (fish 122 - 170 mm) were retained. This represented the largest 10% of the population. Previous studies have shown that this size range of fish are still age-0's

(Angradi and Contor 1989). Fish were held in cages in the Henrys Fork until surgeries were performed.

Fish were divided into two groups based on size (small fish 21 - 31 g and large fish 32 - 51 g) and 21 fish from each group were randomly selected to receive live transmitters. Two sizes of transmitters (both 150 - 151 Mhz; Advanced Telemetry Systems) were used for this experiment. Small transmitters, weighed 2.1 g (with an expected battery life of 60 days) and large transmitters, weighed 3.1 g (with a life expectancy of 100 days). Large fish received the large transmitters and small fish received small transmitters. Transmitters received by the fish comprised 6 - 10% of their body weight.

Transmitters were surgically implanted into the fish on 2 Dec 2000 following the methods of Winter (1996) and Swanberg et al. (1999). Surgical instruments and radio transmitters were sanitized prior to each surgery in a 70% alcohol solution. Prior to surgery, fish were anesthetized with tricaine methanesulfonate (MS-222), weighed and measured. Fish were placed upside down on a wooden v-shaped operating table that was covered with thin ruber fabric and was partially submerged in a dilute solution of anesthesia. Throughout surgery the fish's gills were bathed with the same solution. An incision point was cleaned with betadine and then alcohol swabs. For each fish, an incision (15 mm long) was made anterior to the pelvic girdle and slightly removed from the fish's mid-ventral line. An 18 gauge needle was pushed through the body wall slightly posteriorly and laterally from the incision. The transmitter antenna was pushed through the needle and the needle was removed. The transmitter was then placed inside the body cavity with the antenna extending through the hole made by the needle. The incision was then closed with a running suture of 4-0 Vicryl, using an atraumatic needle. Although staples have been shown to cause less infection than sutures (Swanberg et al. 1999), sutures were used because we could not find staples small enough for these fish, we thought that staples would be more likely to hook on the substrate while the fish were in concealment and therefore would pull out, and we did not anticipate infection being a problem due to the low water temperatures. Additionally, staples have been used because they are easier and faster to use for those not accustomed to suturing (Swanberg et al. 1999). We secured the services of professional surgeons for this task and no surgeries lasted longer than 5 minutes with average surgery time under 3 minutes.

Following surgery, the fish were placed in a recovery bucket until the effects of sedation were no longer visible. They were then placed in cages in the river for 4 hours, after which they were released in two locations in the Last Chance reach. One location was in mid-river macrophytes and the other was near cobble and boulder substrate.

Tracking of fish took place five days after surgery and again seven days later and then at approximately two week intervals thereafter. Each time fish were tracked their approximate location was recorded with a GPS (global positioning system) unit. When fish remained stationary for two to three tracking periods their exact location was assessed to see if they had expelled their transmitter or had died. In many cases, fish were concealed in cobble or boulder substrate which precluded locating either the fish or the expelled transmitter.

In addition to mobile tracking, a fixed tracking station was located in the Harriman reach near the upstream boundary (approximately 3.3 km downstream from the release site). This station scanned the transmitter frequencies continuously and recorded date and time when signals were detected. Water temperature was recorded in Last Chance (on a Onset Stowaway temperature logger) and discharge records (for Island Park Dam) were obtained from the United States Geological Survey. Fish detection at the fixed tracking station was plotted against these parameters to assess whether one of them served as a cue to fish movement.

Cage Study

The small fish which remained, after removal of those assigned to receive live transmitters, were randomly assigned to the following control groups: control (weigh and measure only), surgery (weigh, measure, and experience surgery) and small dummy treatment (weigh, measure, implant small dummy transmitter). Additionally, the remaining large fish were assigned as large dummy treatments (weigh, measure, implant large dummy transmitters). We were unable to collect enough large fish at Last Chance to provide the number needed for the large dummy transmitters. Therefore, eight fish that received the large dummy transmitters were collected from Box Canyon. There was no significant difference (%=0.05) in length or weight of fish between those that received live vs. dummy transmitters of the same weight. Also, there was no significant difference in length or weight of fish between controls, surgeries, and small dummy treatments and there was no significant difference (P=0.68) in percent of body weight carried by fish implanted with live or dummy large or small transmitters (mean 8.5% of fish's body weight).

Six triangular cages (those used by Smith and Griffith 1994) constructed of wood, hardware cloth, and angle iron (1.5 m long on each side, 1 m tall with 5-mm-wire mesh sides and bottom) were anchored in the Henrys Fork near the bank. To provide protection from floating ice and debris a wire mesh deflector was installed upstream from the cages as was done by Smith and Griffith (1994). Eight to ten angular cobble sized (10 - 40 cm diameter) rocks were placed in the cages to provide concealment habitat. Two fish from each control group were placed in each cage. As eight fish were placed in the cage and the cage inclosed an area of 1.125 m^2, fish density in each cage was 7 fish/m^2. This was slightly over half the density used by Smith and Griffith (1994).

On 16 March surviving fish were removed from the cages. Fish that experienced surgery were taken to the lab for necropsy.

Results

Movement Study

Within 5 days of transmitter implantation fish had dispersed both upstream to Box Canyon (maximum movement 0.4 m) and downstream to Harriman (maximum movement >10.6 km) but the majority of the telemeterized fish remained near the release sites. By the next tracking period (12 days after implantation) maximum movement from the release site was 1.9 km upstream to Box Canyon and 20.1 km downstream to Riverside Campground. This represented the maximum downstream movement observed. The maximum upstream movement of 4.4 km from the release site occurred by the end of December (28 days after surgery). Three fish migrated to Box Canyon, one of which returned to Last Chance by 19 February. Two fish migrated to the canyon between Pinehaven and Riverside Campground. One fish moved to the mouth of Thurmon Creek and was still located there on 7 March, when presumably the transmitter battery died. Most of the fish (13) remained near the release site in the cobble and boulder habitat where it was not possible to recover transmitters or ascertain whether or not the fish were still alive. Many of the fish migrated to Harriman where they died or expelled their transmitters. Transmitters were recovered under shelf ice (2), on the surface of the substrate (3), and buried in the substrate (8). Transmitters were found buried under silt, sand, and gravel with one recovered transmitter being buried under 15 cm of silt and 5 cm of gravel. However, most often (6 times), transmitters were found buried in 5 - 10 cm of sand and gravel. One of these buried transmitters was still inside the dead fish.

Most of the fish recorded by the stationary tracking unit passed that station in December. However, we were unable to detect a correlation between downstream movement and water temperature or flow changes. Fish did not move in groups but trickled by the station singly.

Cage Studies

All of the control fish survived the 104 day experiment. Half (6) of the fish that only experienced surgery survived and 33 and 25% (4 and 3) of the fish that were implanted with small and large dummy transmitters respectively survived to the end of the experiment. Two fish, along with their dummy transmitters, were missing from the cages (one in each of two cages) at the end of the experiment. All the other fish were either accounted for as live fish or recovered carcasses.

Dissection of the caged fish that experienced surgery showed that the incisions had healed. No areas of inflamation were observed including around the antenna exit wound. In nearly all cases some of the pyloric caeca had adhered to the incision but it did not appear to be inflamed or damaged. Transmitters were partially encapsulated with tissue, particularly where the transmitter was in contact with the viscera but not necessarily between the transmitter and the body wall. The tissue was always adhered to the viscera.

Discussion

Movement study

Movement of the magnitude observed in this study was not more extensive than that observed by Mitro (1999), who marked juvenile trout in the fall and subsequently recaptured them in the spring. Mitro (1999) observed over-winter movement of marked fish from Last Chance upstream to Box Canyon and downstream to Riverside Campground. Although he did not search for fish downstream from Riverside Campground, our study suggests that fish may not migrate beyond that point. This is not too surprising as this section contains the first cobble and boulder substrate encountered by the fish in their downstream migration. Studies have shown that winter emigration was correlated to presence and complexity of cobble and boulder habitat (Bjornn 1971; McMahon and Hartman 1989; Meyer and Griffith 1997b). Bjornn (1971) also hypothesized that when subyearling trout encountered suitable habitat they would stop migrating.

Upstream movement of juvenile trout was much less extreme and rapid than was downstream movement. And, two of three fish stopped migrating when they first encountered large amounts of cobble and boulder substrate. The fish that moved the farthest upstream carried a large transmitter which comprised 6% of its body weight while the two that moved furthest downstream carried a small and large transmitter that comprised 9 and 10% of their body weights respectively.

Lack of movement by the fish that remained near the release site suggests they died (mortality sensors were not available on the size of transmitters used in this study). However, the fish that moved furthest upstream into Box Canyon remained stationary for over 6 weeks prior to returning to Last Chance, where it was verified to be alive. Because we could not verify mortality for most of the test fish, we do not know if the survival results of the cage studies represent mortality rates of the test fish.

Based on previous work by Mitro (1999) we know that some fish from Last Chance move to Box Canyon or Pinehaven and Riverside Campground during winter. But, populations of wintering fish in Thurmon Creek were undiscovered. The discovery of fish wintering in this area was surprising as no cobble or boulder habitat was present. In fact, with the exception of undercut banks, this stream contained little structure of any kind which was suitable for winter concealment. Many fish wintering in Thurmon Creek did not exhibit typical winter concealment behavior (as described by Chapman and Bjornn 1969; Cunjak 1988; Contor and Griffith 1995) but instead were easily visible in the area of the stream closest to Silver Lake Dam. We estimated (visual estimate) that a few thousand fish were present in this area with approximately half of them being subyearling rainbow trout, another large portion being subyearling mountain whitefish (Prosopium williamsoni), and a few being Utah chubs (Gila atraria).

Although temperature was not recorded in Thurmon Creek, or in the Henrys Fork adjacent to Thurmon Creek, water temperature at Last Chance averaged 3.0 °C for the period of the study (1 Dec - 18 March). Water temperature in Harriman would presumably be colder than this as it has been observed to cool, on the average, in a downstream direction during winter (Smith and Griffith 1994). Water temperature, collected once with a hand-held thermometer, showed that water coming over the Silver Lake Dam spillway was 0.5 °C while water leaking through the bottom release pipe was 4.0 °C. Most of the fish were located downstream from the bottom release pipe upstream from the confluence of that channel and the one from the spillway. Fraser et al. (1993) showed that warmer winter water temperatures caused juvenile Atlantic salmon to be progressively less nocturnal. However, no studies have addressed whether juvenile trout select a thermal advantage over concealment habitat when the choices are mutually exclusive and the temperature of each is well below the winter concealment threshold.

Although juvenile trout concealment in the spaces between cobbles or boulders (Chapman and Bjornn 1969; Griffith and Smith 1993), woody debris and undercut banks (Bustard and Narver 1975; Cunjak 1996), aquatic macrophytes (Cunjak 1996, Griffith and Smith 1995), and shelf ice (Cunjak 1996; Gregory and Griffith 1996; Meyer and Griffith 1997a) have been described, little information is available on concealment habitat selected by salmonids when these habitat types are not present. In the Harriman section of the Henrys Fork these habitats are virtually absent, except aquatic macrophytes which are present in summer, fall, and early winter. In these areas transmitters were often recovered buried in the substrate or under shelf ice. As this was a period of low flows it is unlikely that enough substrate was moving to cover transmitters after they had been expelled by the fish or the fish had died. To verify this assumption, I placed 10 recovered transmitters in the Henrys Fork and recovered them after six weeks. None of the transmitters were found to be buried in the substrate. Meyer and Griffith (1997b) observed that in cages, which did not contain cobble or boulder habitat, juvenile rainbow trout would occasionally burrow into loose gravel such that only a portion of their dorsal or caudal fin was visible above the substrate. It is unclear whether these habitats are insufficient to the extent that they seriously decrease odds of survival for fish inhabiting them, or if high mortality of fish in this section was related to surgery and transmitter implantation.

Our failure to detect mass movement of juvenile trout from Last Chance based on changes in flow or water temperature does not mean such movement does not occur. Mitro (1999) observed the highest drop in juvenile trout generally occurred in December but in one year it did occur in November. Larger than normal numbers of waterfowl in the area prior to our study (Whitman 2001) caused macrophytes to be grazed off sooner than usual. This reduced the macrophyte density which reduced the habitat available to juvenile trout (Griffith and Smith 1995). It also caused water levels to drop at Last Chance (Vinson, Vinson, and Angradi 1992) which, in combination with low flows, dewatered some of the bank habitat. Therefore, when trout were collected at the end of November, fewer trout were present than were expected, meaning mass movement from Last Chance may have already occurred. It is also possible that, as the reduction in habitat in Last Chance is gradual, due to scenesing and grazing removal of macrophytes, emigration from Last Chance may be gradual and based more on habitat availability than conditions such as water temperature and discharge.

Cage Study

Survival of telemeterized fish varries greatly between studies. Bunnell and Isely (1999) observed 7 - 25% mortality after a 50 days with adult rainbow trout. All of the adult rainbow trout studied by Martin et al. (1995) remained alive after 47 days. Chisholm and Hubert (1985) lost 8 of 30 adult rainbow trout (27% mortality) implanted with dummy transmitters in a 175 day experiment. Mortality of our test fish was much higher than those reported in these studies. Possible explanations for this include holding fish in-river, cumulative affects of winter including low water temperatures, stresses of surgery, and overweight transmitters. If holding fish in-river caused the additional mortality, then much of the research directed at assessing the effects of surgical implantation of transmitters on fish needs to be re-evaluated. Many of the studies on the mortality associated with surgical implantation of radio transmitters have been conducted at summer water temperatures. These results may not be directly applicable to winter situations. Physiologically, winter is a critical period for salmonids (Gardiner and Geddes 1980; Cunjak 1988) and the additional stresses of surgery and transmitter implantation could contribute to high mortality. The overweight transmitters were not the main problem as they caused only an additional 17 - 25% mortality over surgeries alone. Although transmitters that were 2% of the fish’s body weight were not tested, presumably mortality for fish containing these would fallen somewhere between mortality caused by surgery and mortality caused by the transmitters used in this study. I do not believe our surgical procedures were at fault as surgeries were performed consistent with those methods reported in the above literature, surgery times were shorter than many reported in the above literature, and experienced surgeons performed the operations.

Conditions during our experiment seemed to reflect those experienced during other years as 100% survival of our control fish concurs with the results of Smith and Griffith (1994), who observed no mortality between 8 December and 16 March for juvenile rainbow trout held in the Henrys Fork in cages containing cover. The evaluation time periods of Meyer and Griffith (1997a) coincided less well with our experiment, but they also observed little mortality in caged juvenile rainbow trout for the time period of our cage experiment.

The cage study showed that surgery and transmitter implantation in juvenile rainbow trout during winter can substantially reduce their survival rate and could therefore affect the results of telemetry studies in this time period. More controlled research is needed in the basic methods of telemetry studies, especially focusing on effect of surgery, transmitters, and transmitter size on subject survival during winter.

As the surgery and to a lesser but additive degree the transmitters reduced the fishes likelihood of survival, it is impossible to apply the results of our movement study to the population in general. However, as the primary objective of the study was to find an unknown concentration of wintering juvenile trout, the objective of the study was accomplished without extrapolating specific results to the population.

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Literature Cited

Angradi, T., and C. R. Contor. 1989. Henry's Fork fisheries investigations. Idaho Department of Fish and Game. Federal Aid in Sport Fish Restoration. Project F-17-R-12. Subproject III. Job 7 a and b. Job Completion Report for 1996 - 1997, Boixe.

Benjamin, L. 2000. Groundwater hydrology of the Henry's Fork springs. Intermountain Journal of Science. 6: 119-142.

Benjamin, L. and R. W. Van Kirk. 1999. Assessing instream flows and reservoir operations on an eastern Idaho river. Journal of the American Water Resources Association. 35: 899-909.

Bjornn, T. C. 1971. Trout and salmon movements in two Idaho streams are related to temperature, food, stream flow, cover, and population density. Trans. Am. Fish. Soc. 100: 423-438.

Brown, R. S., S. J. Cooke, W. G. Anderson, and R. S. McKinley. 1999. Evidence to challenge the "2% rule" for biotelemetry. N. Am. J. Fish. Manage. 19:867-871.

Bunnell, D. B. and J. J. Isely. 1999. Influence of temperature on mortality and retention of simulated transmitters in rainbow trout. N. Am. J. Fish. Manage. 19: 152-154.

Bustard, D. R. and D. W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri). Journal of the Fisheries Research Board of Canada 32: 667-680.

Chapman, D. W. and T. C. Bjornn. 1969. Distribution of salmonids in streams, with special reference to food and feeding. Pages 153-176 in T. G. Northcote, editor. Symposium on salmon and trout in streams. H. R. MacMillan Lectures in Fisheries University of British Columbia, Vancouver.

Chisholm, I. M. and W. A. Hubert. 1985. Expulsion of dummy transmitters by rainbow trout. Trans. Am. Fish. Soc. 114: 766-767.

Contor, C. R. and J. S. Griffith. 1995. Nocturnal emergence of juvenile rainbow trout from winter concealment relative to light intensity. Hydrobiologia 299: 179-183.

Cunjak, R. A. 1988. Physiological consequences of overwintering in stream: the cost of acclimitization? Can. J. Fish. Aquat. Sci. 45: 443-452.

Gardiner, W. R. and P. Geddes. 1980. The influence of body composition on the survival of juvenile salmon. Hydrobiologia 69:67-72.

Cunjak, R. A. 1996. Winter habitat of selected stream fishes and potential impacts from landuse activity. Canadian Journal of Fisheries and Aquatic Sciences 53(supplement 1): 267-282.

Fraser, N. H., N. B. Metcalfe, and J. E. Thorpe. 1993. Temperature-dependent switch between diurnal and mocturnal foraging in salmon. Proceedings of the Royal Society of London B. 252: 135-139.

Gardiner, W. R. and P Geddes. 1980. The influence of body composition on the survival of juvenile salmon. Hydrobiologia 69: 67-72.

Griffith, J. S. and R. W. Smith 1993. Use of winter concealment cover by juvenile cutthroat and brown trout in the South Fork of the Snake River, Idaho. N. Am. J. Fish. Manage. 13:823-830.

Griffith, J. S. and R. W. Smith 1995. Failure of submersed macrophytes to provide cover for rainbow trout throughout their first winter in the Henrys Fork of the Snake River, Idaho. N. Am. J. Fish. Manage. 15:42-48.

Gregory, J. S. 2000. Winter fisheries research and habitat improvement on the Henry's Fork of the Snake River. Intermountain Journal of Science. 6: 232-248.

Gregory, J. S. and J. S. Griffith 1996. Winter concealment by subyearling rainbow trout: space size selection and reduced concealment under surface ice and turbid water conditions. Canadian Journal of Zoology 74: 451-455.

Hunt, R. L. 1969. Overwinter survival of wild fingerling brook trout in Lawerence Creek, Wisconsin. Journal of the Fisheries Research Board of Canada. 26: 1473-1483.

Martin, S. W., J. A. Long, and T. N. Pearsons. 1995. Comparison of survival, gonad development, and growth between riinbow trout with and without surgically implanted dummy radio transmitters. North American Journal of Fisheries Management 15: 494-498.

McMahon, T. E. and G. F. Hartman. 1989. Influence of cover complexity and current velocity on winter habitat used by juvenile coho salmon (Oncorhynchus kisutch). Canadian Journal of Fisheries and Aquatic Sciences 46: 1551-1557.

Meyer, K. A. 1995. Experimental evaluation of habitat use and survival of rainbow trout during their first winter in the Henrys Fork of the Snake River, Idaho. Master's thesis, Idaho State University, Pocatello, ID.

Meyer, K. A. and J. S. Griffith. 1997a. First-winter survival of rainbow trout and brook trout in the Henrys Fork of the Snake River, Idaho. Can. J. Zool. 75:59-63.

Meyer, K. A. and J. S. Griffith. 1997b. Effects of cobble-boulder substrate configuration on winter residency of juvenile rainbow trout. N. Am. J. Fish. Manage. 17:77-84.

Mitro, M. 1999. Sampling and analysis techniques and their application for estimating recruitment of juvenile rainbow trout in the Henrys Fork of the Snake River, Idaho. Doctoral Dissertation. Montana State University, Bozeman Montana, August 1999.

Needham, P. R., J. W. Moffett, and D. W. Slater. 1945, Fluctuations in wild brown trout populations in Convict Creek, California. Journal of Wildlife Management 9:9-25.

Quinn, T. P. and N. P. Peterson. 1996. The influence of habitat complexity and fish size on over-winter survival and growth of individually marked juvenile coho salmon (Oncorhynchus kisutch)in Big Beef Creek, Washington. Canadian Journal of Fisheries and Aquatic Sciences 53: 1555-1564.

Seelbach, P. W. 1993. Population biology of steelhead in a stable-flow, low-gradient tributary of Lake Michigan. Transactions of the American Fisheries Society. 122: 179-198.

Smith, R. W. and J. S. Griffith 1994. Survival of rainbow trout during their first winter in the Henrys Fork of the Snake River, Idaho. Trans. Am. Fish. Soc. 123:747-756.

Swanberg, T. R., D. A. Schmetterling, and D. H. McEvoy. 1999. Comparison of surgical stables and silk sutures for closing incisions in rainbow trout. North American Journal of Fisheries Management. 19: 215-218.

Van Kirk, R. W. and M. Gamblin. 2000. History of fisheries management in the upper Henry's Fork watershed. Intermountain Journal of Science. 6: 263-284.

Vinson, M. R., D. K. Vinson, and T. R. Angradi. 1993. Aquatic macrophytes and instream flow characteristics of a Rocky Mountain river. Rivers. 3: 260-265.

Ward, B. R. and P. A. Stanley. 1993. Egg-to-smolt survival and fry-to-smolt density dependence of Keogh River steelhead trout. Pages 209-217 in R. J. Gibson and R. E. Cutting, editors. Production of juvenile Atlantic Salmon, Salmo salar, in natural waters. Canadian Special Publications in Fisheries and Aquatic Sciences 118.

Whitman, C. 2001. Effects of instream flows and waterfowl herbivory on aquatic macrophytes and Harriman State Park. USFWS report, Chubbuck, ID.

Winter, J. D. 1996. Advances in underwater biotelemetry. Pages 555-590 in B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.