Submitted August 1995
Accepted July 1998
Published September 1998

The Relationship of Cattle and Salmon Redds at Catherine Creek: A Scientific Assessment

H.W. Li, J.B. Kauffman, R.L. Beschta, and B.A. McIntosh
Departments of Fisheries and Wildlife, Forest Engineering, Forest Science
Oregon State University
Corvallis, Oregon 97331-3802, 97331-5706, 97331-5705

Abstract

A recent paper by Johnson et al. (1995) reported higher densities of salmon redds in livestock-grazed riparian reaches than in ungrazed reaches of Catherine Creek, a tributary of the Grande Ronde River Basin in northeastern Oregon. By logical extension, one might infer that cattle have a positive influence on salmon spawning areas. After reviewing Johnson et al. (1998 [formerly 1995]), we concluded that their analysis was unsupportable because of an inappropriate study design and flawed statistical analysis. Repeated annual measures cannot overcome the inadequate study design, leaving any interpretations regarding the effects of livestock grazing on the density of salmon redds invalid. In addition, there were omissions of pertinent data concerning the study area, its biological features, and current land use. For instance, livestock use on the Catherine Creek study area was moderate in meadow communities and light in the streamside tree/shrub communities. Livestock utilization in the streamside tree/shrub communities is at the lowest levels of detectability, and these levels are not representative of most grazed streams in eastern Oregon. We present additional information needed to interpret the effects of grazing on Catherine Creek, suggest appropriate methods to test for grazing effects on spawning salmonids, and propose that interdisciplinary research be conducted on this issue.

Introduction

The paper, "Mapping and Analysis of Catherine Creek Using Remote Sensing and Geographic Information Systems (GIS)," presented information on the presence of spring chinook salmon redds in a stretch of Catherine Creek in the Grande Ronde River Basin of eastern Oregon (Johnson et al., 1998 [formerly Johnson 1995]). The stated objectives of this study "were to quantify the surface hydrology of Catherine Creek on the Hall Ranch of northeastern Oregon as it relates to livestock grazing and salmon spawning" (p. 1 [12]). The authors conclude that theirs was "a preliminary study of livestock grazing *effects* (our italics) on stream morphology and resultant salmonid habitat" (p. 11 [23]). This conclusion went beyond the stated objectives and capabilities of the study design described by Johnson et al. (1998 [1995]). The study design was appropriate for the study of riparian vegetation (Kauffman et al., 1983a; Green and Kauffman, 1995) but inadequate for studying the effects of livestock grazing on salmon spawning. Subsequently, the interpretations of Johnson et al. (1998 [1995]) may have confused the public and led the media to misinterpret or extend the implications beyond the limits of the study (Anderson, 1995; Oregon Farm Bureau News, 1995). While Johnson et al. (1998 [1995]) did not provide specific conclusions regarding grazing impacts on salmon spawning habitats, misinterpretations by readers of the Johnson et al. (1998 [1995]) paper were the consequence of a study design inappropriate to the conclusions made, flawed data analysis, and unclear interpretations of the results. The objectives of our paper are to present a scientific review of the Johnson et al. (1998 [1995]) study, to provide additional information relevant to the interpretation of livestock influences, and to suggest scientifically sound strategies to assess the influence of grazing on salmonid habitats.

Since 1978, scientists have been conducting riparian ecology research along Catherine Creek in northeastern Oregon. The study site is located on lands managed by Oregon State University's Eastern

Oregon Agricultural Research Center (EOARC) in the Wallowa Mountains of northeastern Oregon. Catherine Creek is a third-order tributary to the Grande Ronde River. Elevation of the site is approximately 1030 m. Mean annual discharge is 3.4 m^3/sec with peak flows occurring from April to early June (Green, 1991). Kauffman's initial study (1982) established five livestock exclosures, and the objectives were to examine the influences of late-season livestock grazing on plant community composition, wildlife communities, and streambank erosion. Ongoing, long term studies of Catherine Creek have focused on the composition and structure of the riparian ecosystem (Kauffman, 1982; Kauffman et al., 1985; Green, 1991; Case, 1995), wildlife communities (Kauffman et al., 1982), livestock influences on streambanks (Kauffman et al., 1983b), livestock influences on plant communities (Kauffman et al., 1983a; Green, 1991; Korpela, 1992; Green and Kauffman, 1995) and the biogeochemistry of riparian zones (Green and Kauffman, 1989; Green, 1991).

Adequacy of Study Design

Johnson et al. (1998 [1995]) took advantage of the existing study design of exclosures and grazed plots used previously to examine the effects of livestock grazing on the riparian zone (Kauffman et al., 1983a; Green and Kauffman, 1995). While the study design was appropriate for the study of riparian vegetation, it was entirely inadequate for studying the spawning preferences of salmon for five reasons:

1. The study design of Johnson et al. (1998 [1995]) was statistically flawed because none of the treatment replicates (i.e., grazed and exclosure) were independent. In other words, the results were not influenced by the treatments alone. Experimental upstream plots can affect downstream plots through influences on the movements of water, sediments, and organic matter. In addition, downstream factors such as dams, land use activities, and other physical or chemical blocks to fish passage or survival can influence upstream plots and fish movements. No amount of randomization or interspersion of experimental stream units can correct for this problem. Repeated measures annually would not overcome the inadequacies of the study design. The lack of independence associated with the small exclosures and grazed plots precluded any attempts at a valid or meaningful statistical analysis. While the downstream/upstream interactions were not likely as strong of an influence on vegetation responses to grazing, it is of utmost importance for studies of livestock influences on salmon spawning.

2. Because of the lack of independence among replicates, the study lacked true replication; it was pseudoreplicated *sensu* Hurlbert (1984). The Johnson et al. (1998 [1995]) study was conducted at the wrong spatial scale; the unit of replication should have been the stream basin (e.g., Catherine Creek), with each stream basin being a replicate. Designing a study such as this at the basin-scale would eliminate the upstream-downstream problem of confounding influences by examining the full range of spawning habitats in each stream.

3. The original study design of Kauffman (1982) did not consider differences in channel morphology, stream gradient, substrate, or spawning gravels in the placement of exclosures because these factors did not bias that study of plants. By adopting Kauffman's design uncritically, Johnson et al. (1998 [1995]) introduced biases at the stream-reach scale because the plots were not adequately stratified to address the effects of cattle upon salmon redds.

4. Returning salmon show high fidelity to parental sites of spawning (Groot and Margolis, 1991). This behavior can confound differences in site selection for redds in damaged streams. Because of traditional behavior, an adequate site close to the natal origin of a fish may be chosen over an optimal site further away. Again, this points out the need to conduct an experiment using entire watersheds as the unit of replication.

5. The upper Grande Ronde watershed was an inappropriate place to conduct the study because spring chinook salmon populations (a Federally listed endangered species) were so

low that it was impossible to get an adequate statistical "signal" from any stream within the basin. We do not imply that this was due entirely to the ecological condition of the riparian zone and upland ranges; other factors such as negotiating passage through eight mainstem dams in the Columbia and Snake rivers were also confounding influences.

Analytical Rigor

Statistical Analysis

Johnson et al. (1998 [1995]) recognized several statistical shortcomings of their study. They noted that "it is difficult to separate livestock effects on the stream because excluded areas are relatively small and closely associated with grazed parcels" (p. 8 [20]). However, after providing this cautionary statement, they conducted an analysis that appeared to show a greater number of redds in the grazed areas than in the excluded areas and that these differences were statistically significant. The generally held scientific standard is to place a level of statistical significance at $P < 0.05$ (although a level of $P < 0.10$ is often presented in the literature as significant). Johnson et al. (1998 [1995]) chose less rigorous levels of statistical significance ($P = 0.29$ in 1993, $P = 0.12$ in 1994) when testing for differences of redd density/ha of water between grazed and ungrazed areas. This analysis is irrelevant because an inappropriate study design and a low sample size made statistical tests meaningless.

Data Presentation

We found the presentation of data in Table 4 of Johnson et al. (1998 [1995]) was misleading. The five cattle exclosures and four grazed areas of Catherine Creek are very different in size (Kauffman et al., 1985). However, redd counts were presented as raw counts for each grazed or exclosed plot and were not standardized by water area. We standardized the data by water area to remove the bias of areal differences, and the resulting rankings of the experimental plots by redd densities changed (Table 1). When raw counts are used, the ranking of experimental plots in descending order of redd numbers is as follows: grazed plot 4, exclosure 5, grazed plot 2, grazed plot 1, a tie between grazed plot 3 and exclosure 3, and tied rankings among exclosures 1, 2 and 4 (Table 1). However, when standardized by water area, the ranking shifts to the following in descending order of redd density: exclosure 5, grazed plot 1, grazed plot 2, grazed plot 4, exclosure 3, grazed plot 3 and tied rankings among exclosures 1, 2 and 4 (Table 1). Based on redd density there was no significant statistical difference ($P = 0.29$) between grazed and exclosed areas; again, flaws in the statistical design and small sample size make any analysis irrelevant.

Livestock Utilization at Catherine Creek

Johnson et al. (1998 [1995]) did not report the levels of livestock utilization, providing little context for interpreting potential influences of livestock on the ecosystem. It is a standard practice in range management research to report the timing and degree of utilization in order to ascertain the influences of livestock on the ecosystem (J. Boone Kauffman, 1995, personal communication). Such information facilitates comparisons with grazing approaches used in other areas. The livestock grazing strategy of the EOARC reach of Catherine Creek has normally been late-season grazing for 13 to 28 days (mid-August to mid-September, file data, Eastern Oregon Agricultural Research Center). Only large wild ungulates and trespass cattle grazed within the exclosures. Kauffman (1982) reported that 85 to 104 spring-calving, cow-calf pairs annually grazed the 41.3 ha experimental riparian zone during 1978 to 1981. This is equivalent to 64 to 78 AUM (or 0.53 to 0.64 ha/AUM). An AUM is the amount of forage or feed required for one mature cow or equivalent for one month based on a daily consumption rate of 11.4 kg/day for 28 days. From 1987 until 1994, stocking rates ranged from 17 to 65 AUMs. Stocking rates during the 1993 and 1994 sampling period reported by Johnson et al. (1995) were 48 and 22 AUMs respectively or 28 to 75 percent of the grazing level reported by Kauffman (1982) and Kauffman et al. (1983a). These levels of livestock utilization were not representative of the much higher rates of utilization that normally occurs throughout riparian zones on western rangelands (Kauffman et al., 1983b; Green and Kauffman, 1995).

Within any given year, livestock utilization was not uniform among the various riparian plant communities. In the Catherine Creek study area, cattle showed a high initial preference for meadow-dominated communities and very little preference for ponderosa pine, black cottonwood, thin-leaf alder, or snowberry-Wood's rose-dominated communities (Kauffman et al., 1983a; Green, 1991; Korpela, 1992; Green and Kauffman, 1995). Utilization under the higher stocking rates reported by Kauffman et al. (1983a) and Green (1991) was 48 to 73 percent in meadow-dominated communities. In contrast, utilization was 10 to 27 percent in ponderosa pine, 14 to 16 percent in thin-leaf alder, 15 percent in snowberry-Wood's rose, and 1 to 11 percent in black cottonwood-dominated communities. These livestock utilization levels were at the lowest limits of detectability.

Johnson et al. (1998 [1995]) presented a map of a grazed plot showing locations of the salmon redds (reproduced in this paper as Figure 1A). Data gathered from Kauffman et al. (1985) were used to construct a map of community vegetation of the same area (Figure 1B): this map further elucidates potential livestock effects on the stream reach. Along this reach, the streamside plant communities are dominated by Ponderosa pine, black cottonwood, thin-leaf alder, and snowberry-Wood's rose. These communities were among the least utilized by livestock (utilization was 1 to 27 percent, Table 2). Given that utilization was at the lower limits of detectability, it was highly likely that the influence of livestock on these stream reaches was minimal. Areas with the highest densities of salmon redds (i.e., exclosure 5 and grazed areas 1 and 2) also coincided with streamside vegetation communities of similar composition (Kauffman et al., 1985). This suggests that salmon redds are associated more with site influences such as spawning gravels than the minimal livestock effects that occurred under this grazing strategy.

Channel System

The results presented in Johnson et al. (1998 [1995]) provided observations and interpretation of stream channels from aerial photography with no on-the-ground assessment of stream bed morphology or channel-shaping processes. Our ground-truthing indicated that there were major differences between grazed areas and exclosures in channel characteristics (widths, depths, sinuosity, gradient, channel diversity, and connectivity with riparian vegetation) independent of the grazing treatments. For example, the two most upstream treatments, (grazed area 4 and exclosure 5) occupy a reach that is currently locally aggrading and storing gravels in the channel. These two adjacent experimental units are typified as low gradient, shifting, braided, and unconstrained reaches with an abundance of gravel bars and, in all likelihood, an abundance of interstitial (hyporheic) flow. These characteristics are typically associated with high abundances of redds (e.g., Collings, 1972; Thompson, 1972; Healy, 1991). These two areas accounted for nearly 60 percent of all spawning redds in 1993 (total redds = 24) and 50 percent in 1994 (total redds = 2), but comprised only 25 percent of the stream length.

Although Johnson et al. (1998 [1995]) provide limited information on human modification of the stream channel, additional human modification of the channel could further account for the lack of salmon redds in exclosed reaches of stream. Further downstream of Grazed Area 4 (see Figure 2, Johnson et al., 1998 [1995]) the channel of Catherine Creek becomes more simplified (i.e., less sinuous, less channel braiding, and deeply incised in its historical floodplain). The simplicity of the channel in exclosure 1 was largely due to mechanical channelization by the Oregon Department of Transportation in 1989 in an attempt to protect State Highway 203 immediately downstream (J. Boone Kauffman, 1995, personal communication). Given this severe impact to this exclosure we were not surprised that no salmon redds occurred here in 1993 and 1994. Thus, while the reported treatments by Johnson et al. (1998 [1995]) were "grazed and excluded," there are other unreported channel features, channel alterations, and major differences in channel processes that confound any attempt at attributing the in-channel distribution of salmon redds to grazing practices on Catherine Creek. The study design and interpretability of the data are compromised when more than simple grazing differences exist between the study plots. Lack of information pertaining to stream gradient, geomorphology, vegetation, and management history represent severe shortcomings of the study because of their relevance to channel-forming processes and the creation and maintenance of spawning habitats.

Table 1. Salmon redd data from Catherine Creek, standardized by water area. Data are from Johnson et al. (1998 [1995]).

Experimental unit	1993 redd count	1994 wetted area (m^2)	Redds per ha of wetted area
Exclosure 1	0	2,060	0
Exclosure 2	0	2,693	0
Exclosure 3	1	3,823	3
Exclosure 4	0	3,523	0
Exclosure 5	6	2,858	21
Grazed Plot 1	3	1,762	17
Grazed Plot 2	5	3,623	14
Grazed Plot 3	1	4,820	2
Grazed Plot 4	8	7,413	11

Table 2. Community dominance and level of utilization for streamside plant communities along grazed area 4, Catherine Creek, OR. Plant community numbers correspond to those in Fig. 1B. Utilization data are from Kauffman (1982), Kauffman et al. (1983a), and Green (1991).

Community number	Dominant species	Utilization range (%)
66	alder (*Alnus rubra)*	14–16
67	cheatgrass (*Bromus tectorum)*	1–2
72	cottonwood (*Populus tricocarpa)*	1–11
78	Wood's rose (*Rosa* spp.)	15
81	Wood's rose (*Rosa* spp.)	15
82	cottonwood (*Populus tricocarpa)*	1–11
86	bluegrass (*Poa* spp.)	48–70
88	Wood's rose (*Rosa* spp.)	15
89	annual brome (*Bromus* spp.)	1–2
93	bluegrass (*Poa* spp.)	48–70
92	annual brome (*Bromus* spp.)	1–2
94	ponderosa pine (*Pinus ponderosa)*	10–27
102	snowberry (*Symphoricarpus* spp.)	15
103	sedge (*Carex* spp.)	59–73
104	cottonwood (*Populus tricocarpa)*	1–11

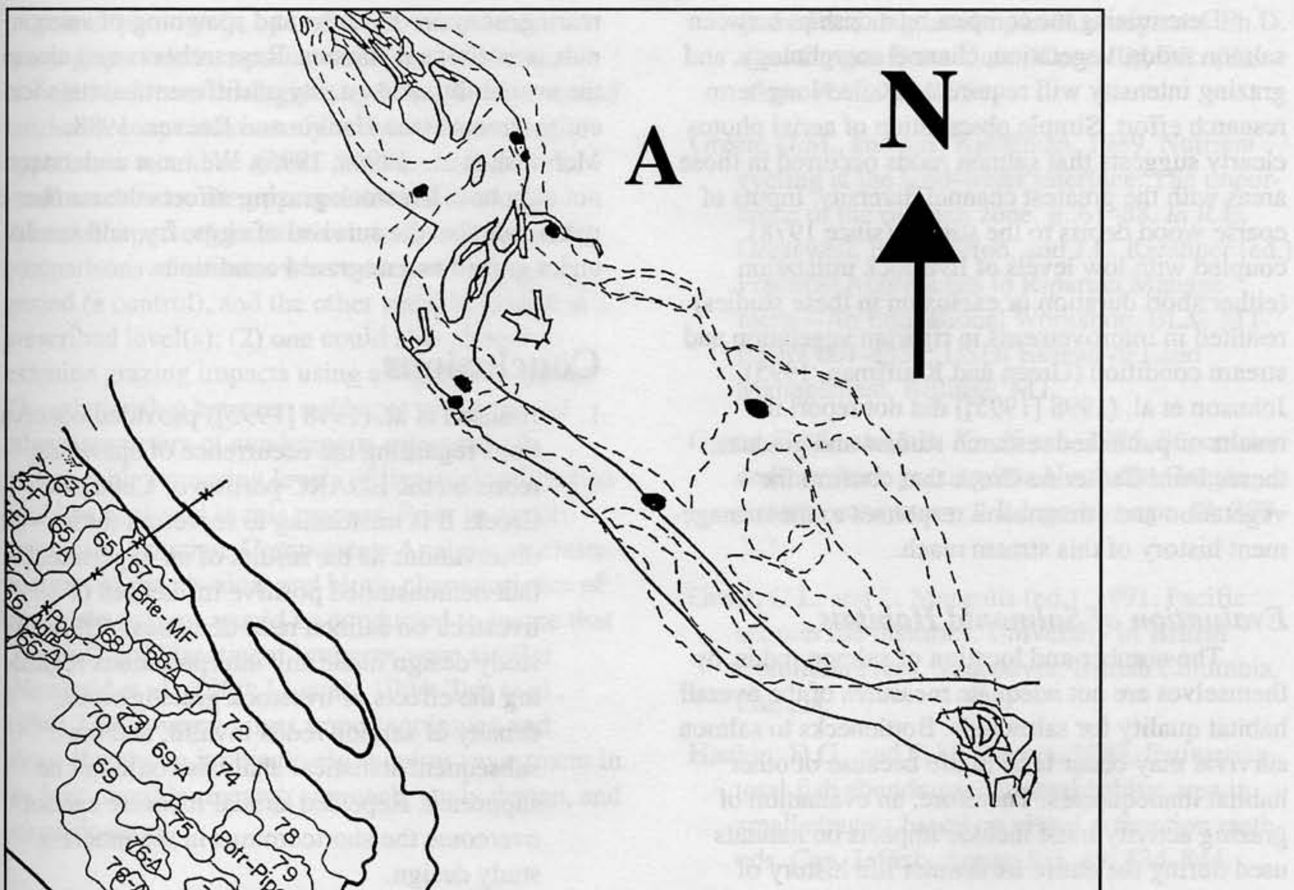

Figure 1. The top figure (A) is the location of salmon redds (large black dots), the 1979 channel (solid line), and the 1994 channel (dashed lines) of grazed area 4 from Johnson et al. (1998 [1995]). The lower figure (B) includes the associated plant communities along the south side of Catherine Creek (from Kauffman 1982, Kauffman et al. 1985). This entire reach is predominantly shrub- or tree-dominated; livestock utilization of these communities was 1 to 27 percent annually over the last 15 years. Plant community and range of utilization can be found in Table 2.

Determining the complex relationships between salmon redds, vegetation, channel morphology, and grazing intensity will require a detailed long-term research effort. Simple observation of aerial photos clearly suggests that salmon redds occurred in those areas with the greatest channel diversity. Inputs of coarse wood debris to the stream (since 1978) coupled with low levels of livestock utilization (either short duration or exclusion in these studies) resulted in improvements in riparian vegetation and stream condition (Green and Kauffman, 1995). Johnson et al. (1998 [1995]) did not report the results of published research studies and graduate theses from Catherine Creek that confirm the vegetation and streambank responses to the management history of this stream reach.

Evaluation of Salmonid Habitats

The number and location of salmon redds, by themselves are not adequate measures of the overall habitat quality for salmonids. Bottlenecks to salmon survival may occur later in life because of other habitat inadequacies. Therefore, an evaluation of grazing activity must include impacts on habitats used during the entire freshwater life history of salmon (i.e., emergence from the gravels to their spawning activities). For example, large pools provide rearing habitat for juvenile fish, resting habitat for adjust fish (Bjornn and Reiser, 1991), and refugia for adults and juveniles from natural disturbances, such as drought, fire, and winter-icing (Sedell et al., 1990). Recent research (McIntosh, 1992; McIntosh et al., 1994b) found that the frequency of large pools (> 0.8-m deep) in the Grande Ronde Basin decreased by 66 percent from the 1940s to the present. In Catherine Creek, the large pool frequency decreased by 61 percent, and on the EOARC, large pools decreased by 47 percent (9.0 to 4.8 pools/km). The rearing and holding capacity of the EOARC has been greatly diminished since first measured in the 1940s.

When viewed from the scale of the entire stream basin, spring chinook salmon use more than the EOARC reach for spawning in Catherine Creek. Redd densities have been higher both upstream and downstream of the EOARC (file data, Oregon Department of Fish and Wildlife, La Grande, OR). Thus, choosing the appropriate spatial scale is important to understand the carrying capacity for rearing, summer-holding, and spawning of salmonids in individual streams. Researchers must assess the availability and quality of different habitats for entire streams (see Hankin and Reeves, 1988; McIntosh et al., 1994a; 1995). We must understand not only how livestock grazing affects the number of redds, but also the survival of eggs, fry, and smolts under grazed and ungrazed conditions.

Conclusions

1. Johnson et al. (1998 [1995]) provided observations regarding the occurrence of spawning redds on the EOARC portion of Catherine Creek. It is misleading to represent these observations as the results of an experiment that demonstrated positive influences of livestock on salmon redd densities. A flawed study design made any interpretations regarding the effects of livestock grazing on the density of salmon redds invalid, and the subsequent statistical analysis could not be supported. Repeated annual measure cannot overcome the shortcomings in the inherent study design.

2. The "grazing treatment" was not described by Johnson et al. (1998 [1995]); it was late season, of short-duration, and with low levels of annual utilization (not greater than 27 percent) over the past 15 years. During this period, riparian plant communities changed measurably in both grazed and ungrazed areas. Especially notable was an increase in woody species. Long-term grazing practices consistent with those applied during the past 15 years at the Hall Ranch would likely assist in improving salmon spawning habitat throughout much of the upper Columbia River Basin. Unfortunately, the ecological condition and livestock grazing approaches on Catherine Creek are not representative of most other Columbia Basin riparian zones.

Johnson et al. (1998 [1995]) apparently recognized some of the shortcomings in their study and accurately concluded that many questions remain to be answered regarding the direct and indirect effects of grazing on spawning success, rearing, and emergent survival. We suggest an interdisciplinary team of geomorphologists, hydrologists, rangeland grazing specialists, riparian ecologists, fisheries biologists, stream ecologists, and statisticians should conduct a cooperative study wherein competing hypotheses would be tested. Streams, rather than small reaches are the appropriate unit of study. Potentially powerful statistical designs include: (1) comparisons of streams where one set(s) is not grazed (a control), and the other set(s) is grazed at a prescribed level(s); (2) one could also choose to examine grazing impacts using a regression design. The relationship between redds per unit area and other parameters of anadromous salmonid life history with increasing levels of livestock utilization could be analyzed in this manner. Prior to experimentation, Principle Components Analysis or cluster analysis of the physical and biotic characteristics of candidate streams would be conducted to insure that "control" and "treatment" streams were similar (Newbold et al., 1980; Li et al., 1994; Tait et al., 1994). Controversy raises important issues and ideas. Resolving it objectively requires investment in the best possible research approach, study design, and scientific team.

Literature Cited

Anderson, E.W. 1995. Despite over-popularized extremism, constructive collaboration does occur. Capital Press. 30 June.

Bjornn, T.C., and D.W. Reiser. 1991. Habitat requirements of salmonids in streams. p. 83–138. *In* Influences of forests and rangeland management on salmonid fishes and their habitats. Am. Fisheries. Soc. Sp. Publ. 19. Am. Fisheries Soc., Bethesda, MD.

Case, R.L. 1995. Structure, biomass and successional dynamics of forested riparian ecosystems of the Upper Grande Ronde Basin. M.S. thesis. Oregon State Univ., Corvallis, OR.

Collings, M.R. 1972. A methodology for determining instream flow requirements for fish. p. 72–86. *In* Proceedings Instream Flow Methodology Workshop. Washington State Water Program, Olympia, WA.

Green, D.M. 1991. Soil conditions along a hydrologic gradient and successional dynamics in a grazed and ungrazed riparian ecosystem. Ph.D. diss. Oregon State Univ., Corvallis, OR. (Dis. Abstr. AAG9214775).

Green, D.M., and J.B. Kauffman. 1989. Nutrient cycling at the land-water interface: The importance of the riparian zone. p. 61–88. *In* R.E. Gresswell, B.A. Barton, and J.L. Kershner (ed.) Practical Approaches to Riparian Management—An Educational Workshop. BLM-MT-PT-89-001-4351. USDI Bureau of Land Management, Billings, MT.

Green, D.M., and J.B. Kauffman. 1995. Succession and livestock grazing in a Northeast Oregon riparian ecosystem. J. Range Manage. 48: 307–313.

Groot, C.L, and L. Margolis (ed.). 1991. Pacific salmon life histories. University of British Columbia Press, Vancouver, British Columbia, Canada.

Hankin, D.G., and G.H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Can. J. Fish. Aquat. Sci. 45: 834–844.

Healy, M.C. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*). p. 313–393. *In* C. L. Groot and L. Margolis (ed.). Pacific salmon life histories. University of British Columbia Press, Vancouver, British Columbia, Canada.

Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs 54: 187–211.

Johnson, D.E., N.R. Harris, S. du Plessis, and T.M. Tibbs. 1998. Mapping and analysis of Catherine Creek using remote sensing and geographic information systems (GIS). p. 1-13. *In* A Catherine Creek Study—Perspectives, 1995–1998. Special Report 994. [formerly p. 10–26. *In* Eastern Oregon Agricultural Research Center Field Day Annual Report, 1995. Special Report 951. Agric. Exp. Stn., Oregon State Univ., and U.S. Dep. Agric., Agric. Res. Serv., Burns, OR.] Agric. Exp. Stn., Oregon State Univ., Corvallis, OR.

Kauffman, J.B. 1982. Synecological effects of cattle grazing riparian ecosystems. M.S. thesis. Oregon State Univ., Corvallis, OR.

Kauffman, J.B., W.C. Krueger, and M. Vavra. 1982. Impacts of a late season grazing scheme on nongame wildlife habitat in a Wallowa Mountain riparian ecosystem. p. 208–221. *In* L. Nelson and J.M. Peek (ed.) Wildlife-Livestock Relationships Symposium: Proceedings 10. Univ. of Idaho Forest, Wildlife, and Range Exp. Stn., Moscow, ID.

Kauffman, J.B., W.C. Krueger, and M. Vavra. 1983a. Effects of late season cattle grazing on riparian plant communities. J. Range Manage. 36: 685–691.

Kauffman, J.B., W.C. Krueger, and M. Vavra. 1983b. Impacts of cattle on streambanks in northeastern Oregon. J. Range Manage. 36: 683–685.

Kauffman, J.B., W.C. Krueger, and M. Vavra. 1985. Ecology and plant communities of the riparian area associated with Catherine Creek in northeastern Oregon. Oregon State Univ. Agric. Exp. Stn. Tech. Bull. 147. Oregon State Univ., Corvallis, OR. 35 p.

Korpela, E.J. 1992. Modeling riparian ecosystem processes: Biomass production and grazing. Ph.D. diss. Oregon State Univ., Corvallis, OR. (Dis. Abstr. AAG9229747).

Li, H.W., G.A. Lamberti, T.N. Pearsons, C.K. Tait, and J.L. Li. 1994. Cumulative effects of riparian disturbance in small streams of the John Day Basin, Oregon. Transactions of the Am. Fisheries Soc. 123: 627–640.

McIntosh, B.A. 1992. Historical changes in anadromous fish habitat in the upper Grande Ronde River, Oregon, 1941–1990. M.S. thesis. Oregon State Univ., Corvallis, OR.

McIntosh, B.A., D.M. Price, C.E. Torgerson, and H.W. Li. 1994a. Distribution, habitat utilization, movement patterns, and the use of thermal refugia by spring chinook in the Grande Ronde, Imnaha, and John Day basins. Progress Report, Bonneville Power Administration, Project No. 93-7000. Oregon State Univ., Corvallis, OR.

McIntosh, B.A., D.M. Price, C.E. Torgerson, and H.W. Li. 1995. Distribution, habitat utilization, movement patterns, and the use of thermal refugia by spring chinook in the Grande Ronde, Imnaha, and John Day basins. Progress Report, Bonneville Power Administration, Project No. 93-7000. Oregon State Univ., Corvallis, OR.

McIntosh, B.A., J.R. Sedell, J.E. Smith, R.C. Wissmar, S.E. Clarke, G.H. Reeves, and L.A. Brown. 1994b. Historical changes in fish habitat for selected river basins of eastern Oregon and Washington. Northwest Science, 68 (Special Issues): 36–53.

Newbold, J.D., D.C. Erman, and K.B. Roby. 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. Can. J. Fish. Aq. Sci. 37: 1076–1085.

Oregon Farm Bureau News. 1995. Salmon-killing cows a myth? 12 September, 53(17): 3.

Sedell, J.R., G.H. Reeves, F.R. Hauer, J.A. Stanford, and C.P. Hawkins. 1990. Role of refugia in recovery from disturbances: Modern fragmented and disconnected river systems. Environ. Manage. 14:711–724.

Tait, C.K., J.L. Li, G.A. Lamberti, T.N. Pearsons, and H.W. Li. 1994. Influences of riparian cover on benthic community structure in high desert streams. J. North Am. Ben. Soc. 13(1): 45–56.

Thompson, K. 1972. Determining stream flows for fish life. p. 31–50. *In* Proceedings, Instream Flow Requirement Workshop. Pacific Northwest River Basin Commission, Vancouver, WA.