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NATIONAL COUNCIL FOR AIR AND STREAM IMPROVEMENT

INFLUENCE OF CULVERT CROSSINGS ON MOVEMENT OF STREAM DWELLING SALMONIDS

TECHNICAL BULLETIN NO. 862

MAY 2003

by
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PRESIDENT'S NOTE

Through various agreements, such as the Forest and Fish Agreement in Washington and the Governor's Plan for Salmon and Watersheds in Oregon, the forest products industry has committed itself to improving watersheds for fish. A key component of those efforts will be improving forest industry roads by using mitigation measures that reduce rates of runoff and amounts of sediment delivered to streams, and that remove barriers to fish passage. These road improvements represent an expensive and daunting task, with other environmental issues and priorities competing for scarce resources.

Fish passage guidelines have been designed to essentially pass all species of fish of all sizes at all flows. These provide conservative protection for fish passage, but the expense of replacing all "technical" barriers is probably prohibitive and could lead to long delays in correcting real fish passage barriers where gains in access to suitable habitat could be substantial.

A special subset of the fish passage question is the role of culverts that pose potential passage barriers for streams that do not support anadromous (migrate to and from ocean) fish populations, but rather resident fish. In these cases, successful fish populations are often found above what are considered fish passage barriers but the culverts are criticized because of potential loss of genetic exchange between the upstream and downstream reaches. While these culverts tend to occur in the smallest headwater reaches, they can be numerous and are often difficult to replace because of natural stream gradients. Replacement activities incur their own collection of environmental risks. Therefore, it is important to understand just what types of culverts pose significantly greater barriers to fish passage. This project, which was co-funded by the National Fish and Wildlife Foundation, begins to explore this question. We hope that it will lead to additional research that can answer questions about what types of restrictions different culverts impose on fish passage and the significance of those passage restrictions.

Ronald A. Yeske

May 2003

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Mot du président

Par l'intermédiaire de plusieurs ententes telles que l'entente sur la forêt et les poissons de Washington (*Forest and Fish Agreement in Washington*) et le plan du gouverneur pour le saumon et les bassins versants dans l'Orégon (*Governor's Plan for Salmon and Watersheds in Oregon*), l'industrie des produits du bois s'est engagée à améliorer les bassins versants afin de protéger les poissons. Une des principales composantes de ces efforts consiste en l'amélioration des chemins forestiers en utilisant des mesures de mitigation qui réduisent les taux de ruissellement et les quantités de sédiments transportés vers les cours d'eau et qui permettent de retirer les obstacles au passage des poissons. Ces améliorations des chemins forestiers représentent une tâche coûteuse et décourageante qui entre en compétition avec les autres priorités et enjeux environnementaux, compte tenu des ressources plutôt rares.

Les lignes directrices relatives au passage des poissons ont été essentiellement conçues pour le passage de toutes les espèces de poissons, de toutes tailles et pour tous les débits. Elles assurent une protection conservatrice du passage des poissons mais les dépenses associées au remplacement de tous les obstacles "techniques" demeurent toutefois prohibitives et elles peuvent entraîner de longs délais dans la correction des vrais obstacles au passage des poissons. En corrigeant ces vrais obstacles, les gains d'accès aux habitats adéquats pourraient être substantiels.

Un des éléments importants reliés à la question du passage des poissons demeure le rôle des ponceaux qui sont susceptibles de créer des obstacles au passage dans les cours d'eau qui ne comportent pas de populations de poissons anadromes (migration de et vers l'océan) mais plutôt des poissons résidants. Dans ces cas, les populations de poissons performantes se trouvent souvent plus en amont des soit disant obstacles au passage des poissons mais les ponceaux sont critiqués étant donné la perte potentielle des échanges génétiques entre les individus en amont et en aval. Comme les ponceaux ont tendance à se trouver dans les petits cours d'eau supérieurs, ils peuvent être nombreux et leur remplacement peut s'avérer difficile étant donné les gradients hydriques naturels. Les activités de remplacement induisent leurs propres lots de risques environnementaux. Par conséquent, il est important de comprendre quels types de ponceaux constituent des obstacles significatifs pour le passage des poissons. Co-financé par la *National Fish and Wildlife Foundation*, ce projet débute l'exploration de cette question. Nous espérons qu'il permettra d'obtenir des données additionnelles qui pourront répondre aux questions relatives aux types de restrictions que les différents ponceaux produisent sur le passage des poissons et à l'importance de ces restrictions.

Ronald A. Yeske

mai 2003

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ABSTRACT

Mark-recapture techniques were used to examine the effects of culvert crossings on fish movement over the course of a year on eight small streams in forested lands of the Cascade Mountains of Washington. Assessments were made of movements of resident and juvenile anadromous salmonids and cottids through culverts and control reaches situated upstream and downstream of road crossings. A total of 5273 fish (4409 salmonids and 864 cottids) were captured and marked during the study. Throughout the course of the study, 43% of all marked salmonids were recaptured. The majority of the recaptured salmonids (68%) were collected in the same reach in which they had been marked; the remaining 32% moved at least into the adjacent sample reach. Over 16% of the recaptured salmonids moved farther than 100 feet in either an upstream or downstream direction. The number of fish detected moving downstream through a control reach (207 fish) was more than double that of upstream detections (102 fish). A total of 52 recaptured fish (51 salmonids, 1 cottid) had moved upstream through a culvert. Thirty cutthroat trout were recaptured over 500 feet upstream of their point of initial capture and marking. Upstream fish movement through culverts was comparable to that of the natural control reaches. Immigration of unmarked fish into study reaches was similar both upstream and downstream of study culverts. The culverts investigated are technically considered barriers under the State of Washington's culvert installation guidelines. Results indicate that reconsideration of the criteria used to determine the barrier status of culvert crossings during preparation of road maintenance and abandonment plans may be warranted.

KEYWORDS

barrier, culverts, fish, forest roads

RELATED NCASI PUBLICATIONS

Technical Bulletin No. 820 (January 2001). *Forestry operations and water quality in the northeastern states: Overview of impacts and assessment of state implementation of nonpoint source programs under the federal Clean Water Act.*

Technical Bulletin No. 468 (August 1985). *Industry and state programs developing or promoting silvicultural best management practices in the South*.

Technical Bulletin No. 337 (October 1980). *Research and field investigation on the impact of southern forestry management practices on receiving water quality and utility*.

Influence des traversées de ponceaux sur le mouvement des salmonides qui remontent les cours d'eau

Bulletin technique no. 862
mai 2003

RÉSUMÉ

Les techniques de marquage et de recapture ont été utilisées pour examiner les effets des traversées de ponceaux sur les mouvements de poissons pendant une année dans huit petits cours d'eau situés sur des terrains forestiers des *Cascade Mountains* de Washington. Des évaluations ont été réalisées sur le mouvement à travers les ponceaux des salmonidés anadromes résidants et juvéniles ainsi que celui des cottidés. Des sections de cours d'eau de contrôle ont été définies en amont et en aval des traversées du chemin. Un total de 5273 poissons (4409 salmonidés et 864 cottidés) ont été capturés et marqués lors de l'étude. Pendant le déroulement de l'étude, 43% de tous les salmonidés marqués ont été recapturés. La majorité des salmonidés recapturés (68%) ont été recueillis dans la section de cours d'eau de contrôle dans laquelle ils avaient été marqués. Les 32% restant se sont déplacés au moins dans la section de contrôle adjacente. Plus de 16% des salmonidés recapturés se sont déplacés plus loin que 100 pieds en direction amont ou aval. Le nombre de poissons qui ont été détectés en aval dans une section de contrôle (207 poissons) était plus du double des détections en amont (102 poissons). Un total de 52 poissons recapturés (51 salmonidés, 1 cottidé) avaient remonté un ponceau. Trente truites fardées ont été recapturées à plus de 500 pieds en amont de leur point initial de capture et marquage. Les mouvements des poissons remontant les ponceaux étaient comparables à ceux des sections de contrôle sans obstacles (cours d'eau « naturels »). L'immigration des poissons non marqués dans les cours d'eau à l'étude était similaire en amont et en aval des ponceaux analysés. Les ponceaux à l'étude sont techniquement considérés comme des barrières selon les lignes directrices de l'état de Washington portant sur l'installation de ponceau. Les résultats ont montré qu'il serait adéquat de reconsidérer les critères utilisés pour déterminer si les traversées de ponceaux sont des obstacles lors de la préparation des plans de maintenance et d'abandon des chemins.

MOTS CLES

obstacle, ponceaux, poissons, chemins forestiers

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INFLUENCE OF CULVERT CROSSINGS ON MOVEMENT OF STREAM DWELLING SALMONIDS

1.0 INTRODUCTION

The ability to move upstream is often critical to salmonids for access to spawning habitat (Fausch and Young 1995), for maintenance of populations in areas unsuitable for reproduction (Scrivener, Brown, and Anderson 1994), and for access to seasonally favorable habitat (Cederholm and Scarlett 1982). Culverts associated with forest road crossings of streams are potential barriers to upstream movement of stream dwelling salmonids. Culvert installations used for stream crossings may create temporary, partial, or seasonal barriers to fish movement, while others may preclude movement of fishes year-round. Culverts might also delay or deny access to seasonally critical habitats, fragment populations, and suppress the recovery of populations following disturbance (Detenbeck et al. 1992).

Restoration of fish passage through culverts is becoming a key component of road maintenance plans required of forest landowners in Washington State. Repair or maintenance work to improve fish passage for all life stages of fish is listed as a priority action for implementation of the road maintenance plans under revised Washington State forest practice rules. Washington Administrative Code 220-110-770 (Water Crossing Structures) provides specific guidelines for water crossing structures to ensure free and unimpeded passage for adult and juvenile fishes in order to preserve access to spawning and rearing habitat. It includes fish passage design criteria consisting of maximum water velocity, maximum hydraulic drop, and minimum flow depths for all crossing structures. These criteria are used as the technical definition of a fish passage barrier in the forest practice regulatory arena in Washington and they form the basis for fish passage design. Some type of barrier is assumed to be present when these criteria are not achieved.

The Forests and Fish Report (WDNR 1999) is the basis for changes in the state forest practice rules to address salmonid Endangered Species Act issues. The report states that one policy objective for the management of forest roads will be "… to maintain or provide passage for fish in all life stages…" To achieve the policy objectives, "..the rules and Forest Practice Board Manual will be amended to provide for….removing artificial barriers to passage of fish at all life stages." Landowners are now required to develop and implement road maintenance and abandonment plans for all state and private forest roads. Repair or maintenance work to improve fish passage is listed as a priority action for implementation of the plans.

Inventories of culverts in forested watersheds in Washington conducted by state and federal agencies, the tribes, and private organizations have determined that a majority of culverts situated along forest roads are technically considered barriers. Almost all culverts on streams with a moderate to steep gradient will fail WAC passage criteria (WDFW 1998; Sylte 2002). Any culvert with a slope of 1% or higher and water depth of 1 to 2 ft or more during "high flow" will have an average water velocity greater than 4 ft per second and exceed the WAC criteria (although fish can still sometimes swim upstream). This includes many culverts that present only a temporary, or "flow-dependent," barrier to fish passage or are barriers to juvenile and resident fish only. These temporary and partial barriers are omnipresent because of the preponderance of culverts that exceed maximum velocity criteria at the high flow design discharge. However, some studies indicate that under certain conditions, fish are capable of swimming through higher velocities and jumping greater heights than those indicated by culvert design guidelines (summarized by Kahler and Quinn 1998). Moreover, the significance of these temporary barriers as defined by state guidelines to upstream movement on population viability is poorly understood.

Considering the high costs of culvert retrofits and the preponderance of culverts that are technically defined as barriers based on WAC criteria, forest managers and landowners need to know how effective various culvert designs are in maintaining and restoring fish movement. The adaptive management section of the Forests and Fish Report identifies monitoring to determine the effectiveness of culverts in passing fish as a high priority project. Understanding the relative impact that any particular culvert has on fish movement, habitat connectivity, and population fragmentation is crucial in order to effectively incorporate monitoring findings towards adaptive management. Accordingly, the effects of 11 culverts on fish movement in eight streams flowing through forested lands in the Cascade Mountains of Washington State were investigated. Three questions were addressed: (1) Do the culvert types studied affect overall, directional, or seasonal fish movement? (2) Do these culverts affect the upstream movement of smaller fish more than larger fish? (3) Is there a relationship between culvert structural features, regulatory barrier status, and fish movement? This project represents an initial investigation that helps define additional questions that can only be addressed through a broader study of culverts.

2.0 METHODS

2.1 Study Sites

Eleven culvert crossings on eight streams in the Cascade Mountains of Washington were selected for this study of fish movement during the period of August 2001 through July 2002. Channel gradients of the study reaches averaged 4.6% (1.6 to 9.2%). Small cobbles to small boulders dominated stream substrates.

Culverts were characterized by pipe diameter, length, slope, size of corrugations, and vertical height of the outfall. Physical measurements were made for each culvert to determine whether individual culverts were consider barriers to upstream fish movement under state guidelines using the methods described by the Washington Department of Fish and Wildlife (WDFW) Barrier Assessment Protocol (WDFW 1998). Fish passage design flows were calculated for the study sites following the method of Powers and Saunders (1998) to determine if maximum velocity criteria were exceed at the high flow design discharge prescribed by the WDFW protocol.

Culvert crossings consisted of 2 to 7.5 ft (mean = 4.75 ft) diameter corrugated galvanized metal culvert pipes positioned within earth and gravel filled road prisms (Table 1). Culverts were installed at an average gradient of 3.4% (0.9 to 12.9%). Outflow drops ranged from 0 to 1.3 feet. Nine of the eleven sites contained culverts installed at a slope of 1% or greater; over 50% had outflow drops greater than 0.8 feet. All eleven culvert installations violated WAC water velocity criteria under fish passage design flows and were considered barriers to upstream migration under state standards.

All of the study streams were inhabited by non-anadromous cutthroat trout (*Oncorhynchus clarki*). Although stream resident strategies (spawn, rear, and mature within study streams) are suspected to be the prevalent life history forms in the study sites, fluvial or adfluvial life history forms may also have been present Eastern brook trout (*Salvelinus fontinalis*) also inhabited Peaches Creek, whereas coho salmon (*Oncorhynchus kisutch)* occurred in Camp Creek. Sculpins (*Cottus sp.*) inhabited six of the eleven study sites.

Table 1. Channel and Culvert Characteristics of Eleven Study Sites Investigated

	Channel slope (%)			Culvert Characteristics (feet)			
Study Site	Below Culvert	Above Culvert	Channel width (ft)	Diameter	Length	Slope (%)	Outfall Drop
West Cascades							
Camp	2.9	5.9	18	7.5	70	1.4	0
Hobie 1	3.2	4.4	16	6.0	40	0.9	0
Hobie 2	2.5	2.7	13	5.0	40	1.0	0.2
Stump 1	7.9	1.2	12	4.0	60	1.7	1.2
Stump 2	2.5	0.7	8	4.5	52	2.2	1.1
Mitchell	5.3	4.4	10	5.0	62	1.2	1.3
East Cascades							
SF Manastash	7.7	5.9	6	3.0	42	12.9	0.2
NF Manastash 1	2.7	3.3	8	3.0	30	2.6	0
NF Manastash 2	3.2	2.7	6	2.5	30	3.0	1.2
NF Taneum Tributary	8.9	9.3	8	4.0	62	6.4	0.4
Peaches	4.9	7.9	11	4.0	41	3.9	0.2

2.2 Study Design

Following the general approach for evaluating fish passage through culverts described by Cupp et al. (1999), this study was designed to compare the movement of fish through a reach "treated" with a culvert structure to the movement of fish through natural "control" reaches situated both upstream and downstream of the culvert. Each study site was divided into at least nine sample reaches of 100 ft in length. Five sample reaches were located downstream of each stream crossing structure and four sample reaches were situated upstream (Figure 1).

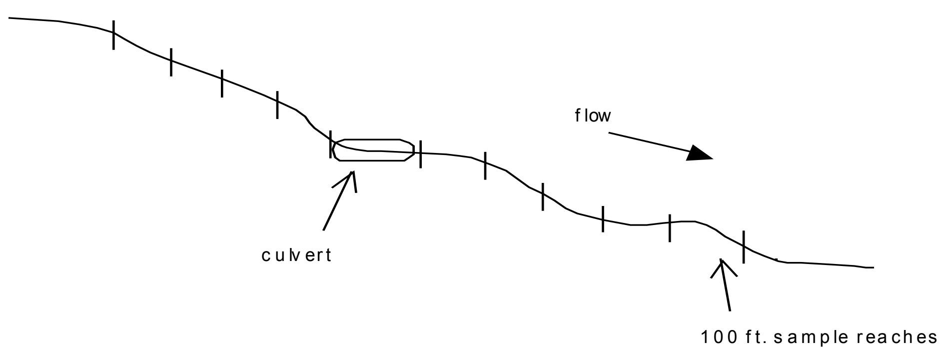

Figure 1. Schematic Diagram of a Typical Study Site Showing Consecutive Subdivisions of 100 ft Sampling Reaches

2.3 Fish Sampling

Fish were captured using a backpack electrofisher accompanied by one or two netters conducting a two to four pass removal in each separate 100 feet sample reach. Electrofishing efforts typically continued in each reach until five or less salmonids were captured in the final pass. All sample reaches within a study site were electrofished on the same day. All fish captured were identified to species, measured (total length to nearest mm), marked with a color unique to that sample reach, and released near the point of capture after processing. Fish were marked with injections of visible implant fluorescent elastomer tags (VIEs) from Northwest Marine Technology, Inc. (NMT 2002). Unique marks (red, orange, yellow, or green marks injected in or near the adipose eyelids, dorsal, caudal, or anal fins) identified the sample reach where a fish was captured. Before being released, fish were held in perforated holding buckets in the stream until all electrofishing passes were completed.

After the initial marking, each site was resampled once during each of the four seasons with the following exceptions. Fish movement was not monitored in three study sites in the east Cascades (Peaches, NF Taneum Tributary, and SF Manastash) during the winter interval as snow depth and cold water precluded effective sampling. One west Cascades site (Mitchell) was not sampled during the fall and winter intervals, as it was added to the study during the spring of 2002. Captured fish were examined for marks to determine if movement of the sample populations had occurred. As with the initial captures, all new captures and recaptured fish were measured for total length. During each subsequent resampling, unmarked fish were marked and fish that had moved were re-marked with colors unique to the sample reaches in which recaptures occurred. In an effort to capture marked fish that emigrated beyond the study reach boundaries, one pass elelctrofishing was also conducted approximately 500 feet upstream and downstream of the study site during each resample period. Sampling efforts beyond the study site focused largely on areas most likely to be used by fish (pools, undercut banks, boulder clusters, debris concentrations).

2.4 Data Analysis

Fish movement through stream crossing structures and across all natural reaches (each individual sample reach) was assessed. Fish were tallied as having moved through a natural control reach only if they were captured at least 100 ft upstream or downstream from their original capture location. That is, a fish had to be recaptured in a sample reach that was situated at least 100 ft upstream or downstream for it to be considered to have moved through a natural control reach. A fish recaptured in a sample reach immediately upstream or downstream from its original reach of marking was considered to have moved, but was not considered to have moved through a natural control reach.

Although marked sculpin were recovered in each of the six study sites they inhabited, sample sizes varied greatly among streams. Most of the sculpins (78%) were captured in only three study sites. A total of 10 sculpins were detected as having moved (5 upstream, 5 downstream) in only three sites. Moreover, capture efficiency of sculpins was believed to be low due to their close affinity to stream substrates. They commonly become lodged or camouflaged in stream substrate during electrofishing and remain undetected. Conversely, capture efficiency of salmonids was considerably higher. Because of these reasons, analysis of fish movement was conducted using only salmonid data.

Fish movement across each control reach and through culvert crossings was expressed in terms of proportional daily movement (PDM). Following Warren and Pardew (1998), PDM was calculated as $M * R^{-1} * D^{-1}$ where M is the number of recaptured fish that move, R is the total number of recaptures in the two reaches situated immediately above and below the reach in question, and D is the number of days since fish marking. Only fish moving through a natural control reach (moved at least 100 feet) or through a culvert were used in the computation of PDM. The movement measures were divided by the total number of days since the previous marking in order to standardize movement estimates for valid comparisons between sites. Directional movement was expressed similarly, with M being the number of fish that moved upstream or downstream. PDM was computed separately for each of the four sample intervals, which roughly corresponded to the climatic seasons [fall (September - October), winter (November - February), spring (March - May), summer (June - August)].

To evaluate the effects of culvert crossings on fish movement, PDM through natural reaches was compared to PDM through the culvert. A three factor analysis of variance was used to investigate the differences in upstream and downstream movement among treatments (culvert versus natural reach), season, and region. An arcsine square root transformation following Freeman and Tukey (1950) was used to achieve equality of variances and normality for analysis of variances. For all tests, $P \leq 0.05$ was considered to be indicative of significance. Treatment, season, and region specific means and standard errors are presented for examining the magnitude of differences in upstream and downstream movement among the factors and the precision of the estimates. Upstream movement and downstream movement were analyzed separately.

Recruitment of unmarked fish to the study population was also measured to examine the influence of culvert crossings on fish movement. Differences in the immigration of unmarked fishes among the natural reaches situated upstream of the culverts and the natural reaches situated downstream of the culverts were tested by using recapture data for each sample reach at each site. Immigration of unmarked fish in each sample reach for each season was estimated as N/T, where N was the total number of new captures and T was the total number of fishes captured. Under the null hypothesis that the reach position relative to a culvert crossing has no effect on fish immigration, migration would be allocated randomly among reaches within a site and would show no among-site patterns. To test this hypothesis, Friedman's method was used for randomized blocks in which within-site immigration was ranked by reach and blocked by site (Sokal and Rohlf 1981).

The effect of culverts on different life history stages of salmonids was examined. Chi-square tests were used to compare the length distribution of marked fish detected moving with the length distribution of all marked fish. Proportions of all marked fish in each length category (<65, 65 to 94, 95 to 130, >130 mm) were used to calculate expected frequencies of marked immigrants. Similarly, a chi-square test was used to compare the length distribution of recaptured fish that moved upstream through a culvert to the length distribution of recaptured fish that moved upstream through a natural control reach.

Spearman's coefficient of rank correlation was used to test for relationships between physical characteristics of the culvert pipe, stream gradient, and fish movement. Culvert slope, vertical outfall, and culvert length were correlated with upstream proportional daily movement through culverts for all seasons and regions together and for each combination of region and season separately.

3.0 RESULTS

A total of 5273 fish (4409 salmonids and 864 cottids) were captured and marked with VIEs identifying the sample reaches where they were collected during the four sampling intervals. Average number of salmonids marked per study site prior to each sampling interval was 194 (SE = 40.1) for fall, 144.7 (SE = 36.7) for winter, 78.2 (SE = 17.9) for spring, and 51.9 (SE = 10.2) for summer. For all sites, 44% of salmonids were recaptured in the fall, 30% in the winter, 40% in the spring, and 69% in the summer sampling periods (Figure 2).

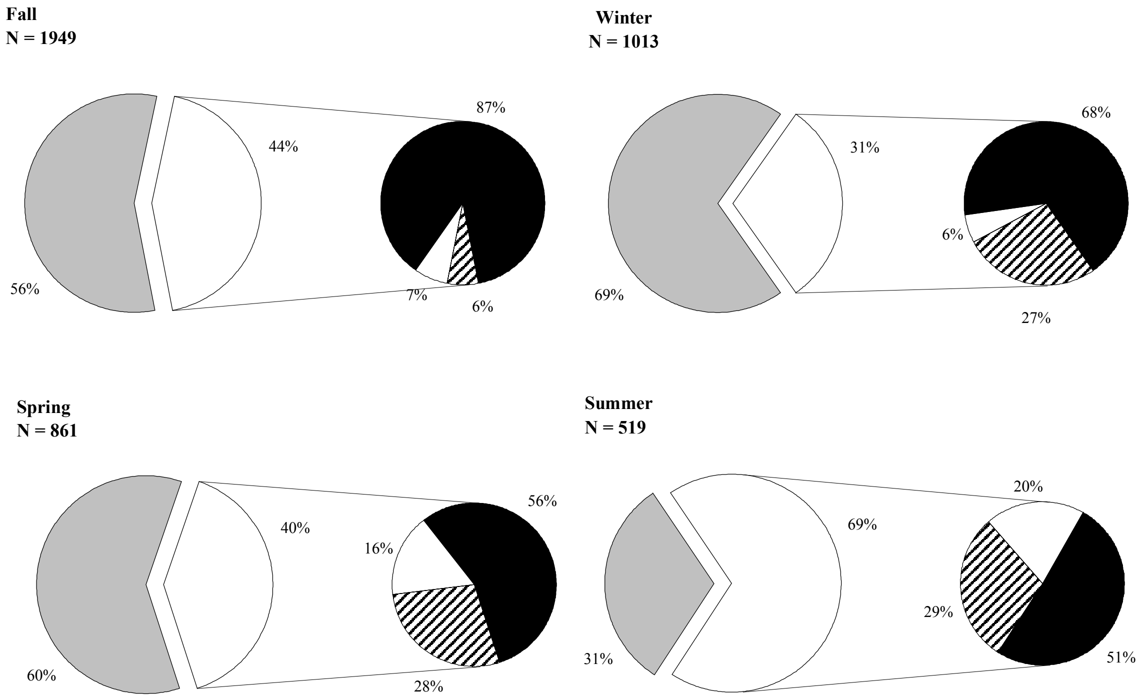

Figure 2. The Percentages of Recaptured Salmonids and Movers for All Sites during the Four Sampling Intervals.
[total number of marked fish (N) released at the beginning of each sampling interval is provided; for each sampling interval, the pie chart on the left shows the percentage of salmonids recaptured (clear exploded slice). The charts on the right show the proportions of recaptured salmonids that moved upstream (open), moved downstream (shaded), and were not detected moving (dark)]

The majority of recaptured fish (68% of salmonids and 86% of cottids) were collected in the same reaches in which they were originally marked (Figures 2 and 3). However, during the spring and summer periods in the east Cascade sites and during the summer period in the west Cascade sites, the number of fish recaptured in reaches other than where they had been marked (movers) exceeded the number recaptured in the same reach in which they had been marked (Figure 4). Downstream movement was more common than upstream movement, especially in the east Cascade study site streams during the winter, spring, and summer periods. During the fall, upstream movement detections were over three times greater than detections of downstream movement for the east Cascades sites.

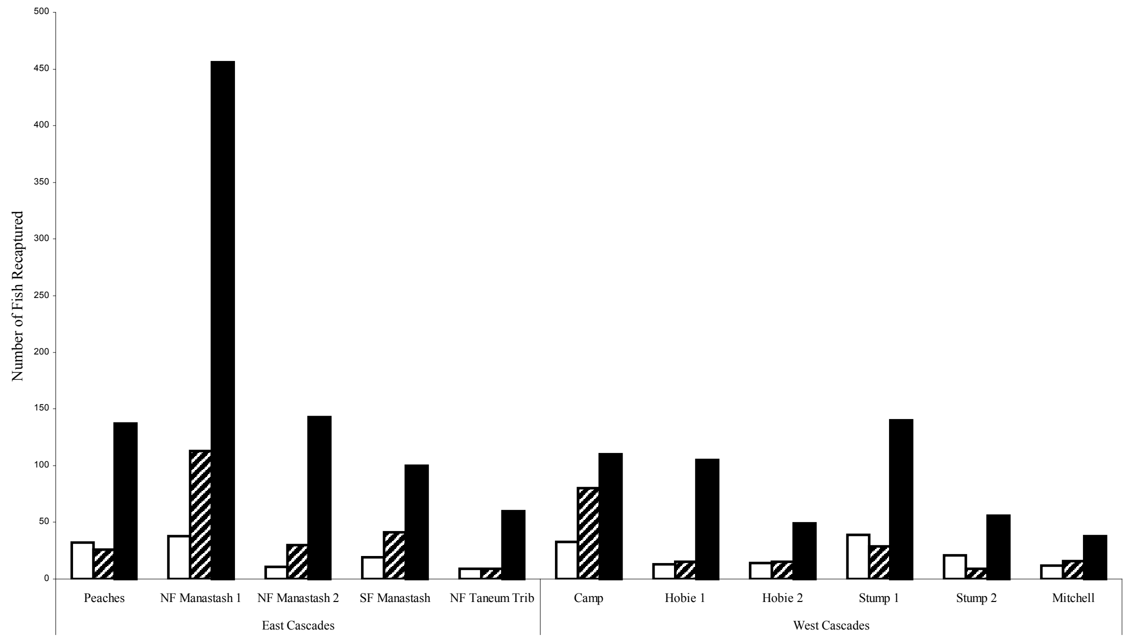

Figure 3. Number of Marked Fish Recaptured in Each Study Site that Moved Upstream (open bars), Moved Downstream (shaded bars), and Did Not Move (dark bars)

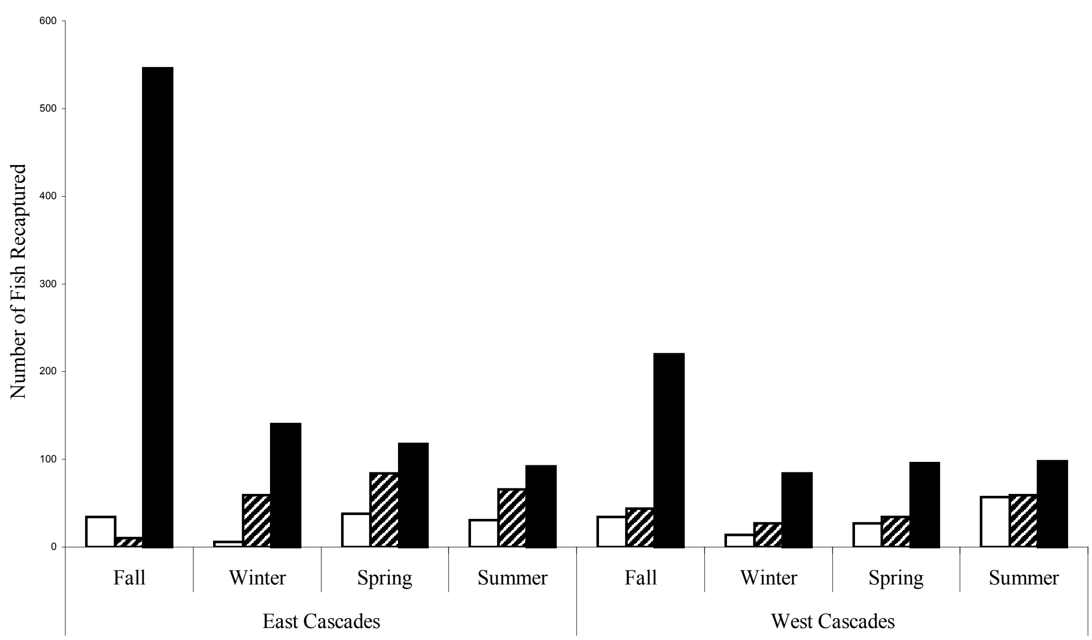

Figure 4. Number of Marked Salmonids of all Sizes Recaptured during Each Season that Moved Upstream (open bars), Moved Downstream (shaded bars), and Did Not Move (dark bars)

A total of 613 salmonids (31.6% of the recaptured salmonids) and 11 cottids (13.6% of the recaptured cottids) were determined to have moved at least as far as the next sample reach upstream or downstream. Over 50% of the salmonid movers (307 fish) but only about 4% of the cottid movers (4 fish) were captured farther than 100 ft from their point of original capture and marking, and were therefore considered to have moved through a natural control reach and used in the computation of proportional daily movement (salmonids only). The number of salmonids detected moving downstream through a control reach (207 fish) was more than double that of upstream detections (102 fish). Ten cutthroat trout, ranging in size from 114 to 165 mm, were recaptured over 700 feet upstream of their points of initial capture. The electrofishing conducted 500 feet both upstream and downstream of the sample site indicated that approximately 67 of the marked fish moved beyond the boundaries of the study reaches (43 downstream and 24 upstream). A total of 52 recaptured salmonids moved upstream through a culvert; 106 recaptured salmonids moved downstream through a culvert. An average of 5.2 salmonids were found to have moved upstream through ten of the eleven culverts, whereas an average of 3.5 salmonids moved upstream through 65 of the 77 natural control reaches. One sculpin moved upstream through a culvert but none were detected to have moved downstream through a culvert.

Both upstream and downstream movement of salmonids as determined by PDM were significantly affected by season (Table 2). No differences were found in regions (east vs. west) or in treatments (natural reaches vs. culverts). Interactions among the three factors were not significant ($\alpha = 0.05$). Upstream movement of fish through culverts was comparable with upstream movement through natural reaches. Upstream movement of salmonids was detected in ten of the eleven culverts studied. Multiple comparison tests indicated that upstream and downstream movement detections during the fall was significantly lower than movement detections during the winter, spring, and summer through both natural reaches and culverts (Figure 5).

Table 2. Results of Three-Factor Analysis of Variance Comparing Proportional Daily Movement of Fishes through Culverts and Across Natural Reaches Situated Upstream and Downstream of the Culvert

Upstream Movement			
Source of Variation	df	F	P
Culvert Effect	1	0.07	0.794
Region Effect	1	0.04	0.839
Culvert X Region	1	0.81	0.369
Season Effect	3	16.46	0.000
Culvert X Season	3	0.06	0.979
Region X Season	3	0.15	0.930
Culvert X Region X Season	3	0.07	0.978
Within	107		
Total	122		
Downstream Movement			
Source of Variation	df	F	P
Culvert Effect	1	0.1	0.758
Region Effect	1	0.28	0.596
Culvert X Region	1	2.04	0.156
Season Effect	3	33.37	0.000
Culvert X Season	3	0.3	0.824
Region X Season	3	2.55	0.059
Culvert X Region X Season	3	0.42	0.741
Within	107		
Total	122		

Larger fish predominated among the upstream immigrants. In both eastside and westside streams, significant differences occurred between observed and expected distributions of marked upstream and downstream immigrants in the four size classes (Table 3). Fewer upstream immigrants than expected were found in the two smallest size classes (<95mm). Although observed upstream movement was dominated by the two larger size classes, no significant differences were detected between observed and expected size class distribution of fish that moved up through culverts compared to the size class distribution of all of recaptured fish that moved upstream across natural reaches (Table 4).

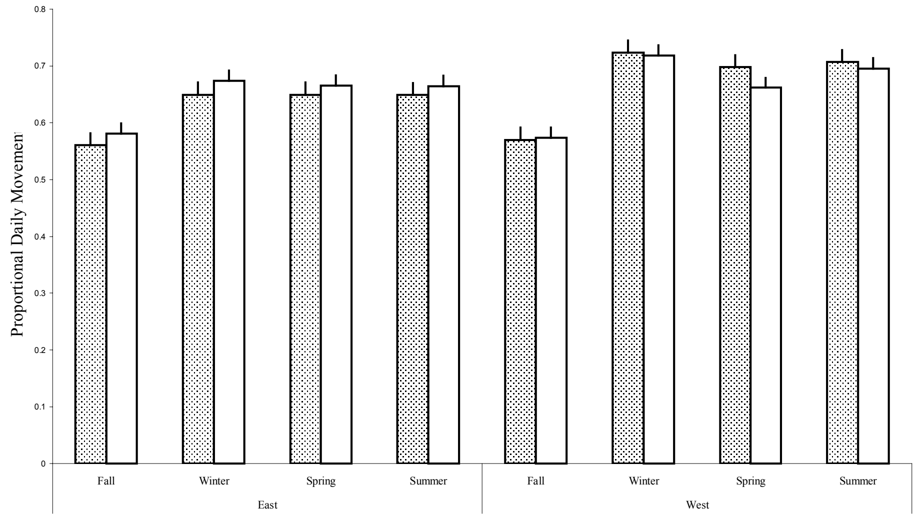

Figure 5. Mean (+SE) Upstream Proportional Daily Movement (arcsine square root transformation) of Marked Salmonids through Study Culverts (open bars) and across Upstream and Downstream Control Reaches (shaded bars) during the Four Sampling Intervals in Study Sites of the Eastside (six sites) and Westside (five sites) Cascade Mountains, Washington

Table 3. Summary of Chi-Square Analysis Comparing Upstream and Downstream Movement by Marked Fish of Four Total Length (TL) Categories
[observed frequencies represent marked fish that were recaptured in a sample reach at least 100 ft upstream from where they were marked, and expected frequencies are based on the proportion of fish marked in each TL category; chi-square values are significant at P <0.001]

Size class (mm)	Observed	Expected	χ^2
Upstream Movement			
<65	2	24	
65-94	15	43	
95-130	49	23	
>130	36	12	>50.0
Downstream Movement			
<65	20	46	
65-94	89	88	
95-130	73	47	
>130	23	24	>28.5

Table 4. Summary of Chi-Square Analyses Comparing Upstream Movement through Culverts by Marked Fish of Five Total Length Categories
[observed frequencies represent marked fish that that moved upstream through a culvert, and expected frequencies are based on the proportion of fish that moved upstream through control reaches in each TL category; chi-square values are not significant at P = 0.05]

Size class (mm)	Observed	Expected	χ^2
<65	0	1	
65-94	2	8	
95-130	27	25	
>130	22	18	6.17

Study sites showed no consistent differences in immigration of unmarked fishes into the natural reaches situated upstream of the culverts and the natural reaches situated downstream of the culverts during all seasons investigated (Friedman test: fall – P = 0.41; winter – P = 0.41; spring – P = 0.76; summer – P = 0.53). All study sites exhibited a short-term high turnover (i.e., low retention and high immigration). For all sites across all sampling intervals, 58% of fishes marked and released at the beginning of each sampling period were not recovered during the subsequent visit. Over 47% of the total fish captured after the initial tagging visit were fish that had been previously untagged (unmarked immigrants). Differences in immigration of unmarked fish were significant between size classes (Freidman test – P = 0.04; Figure 6). Immigration of the two smallest size classes of fish (<95 mm) ranked higher than that of larger size classes.

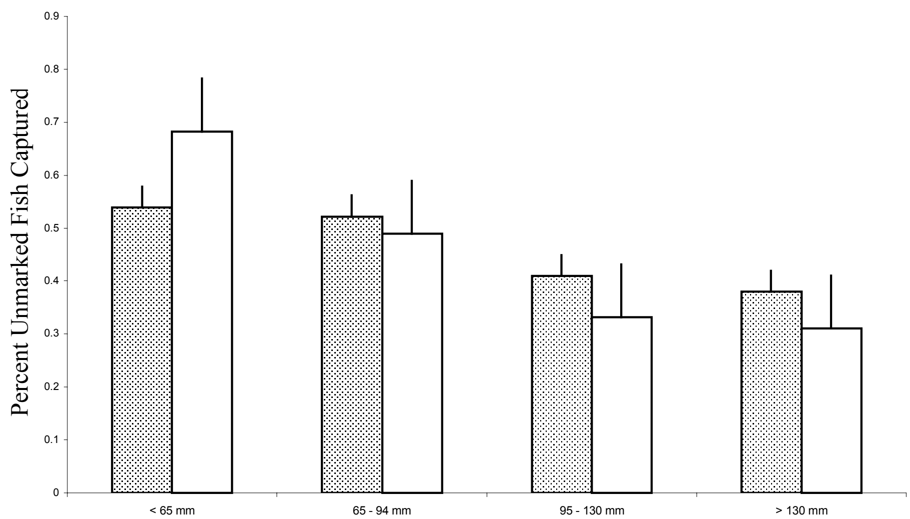

Figure 6. Mean Percentage (± SE) of Unmarked Fish Captured in Each of the Four Total Length Size Classes Downstream (shaded bars) and Upstream (open bars) of Culvert Structures

Fish movement through culvert structures was most closely related to movement of fish through natural reaches situated downstream of the culverts, but was not correlated to any of the culvert structural features (Table 5).

Table 5. Correlations (Spearman's rank) of Upstream Proportional Daily Movement (PDM) through Culverts with Culvert Structural Features and Upstream PDM through Natural Reaches

Variable	*r*	P
Slope	-0.145	0.670
Length	-0.224	0.508
Diameter	0.147	0.665
Outlet Drop	0.487	0.128
Upstream PDM in Natural Reaches	0.564	0.071

4.0 DISCUSSION

Nearly 32% of the recaptured salmonids and 14% of the recaptured cottids were determined to have moved at least as far as the next sample reach upstream or downstream; 16% of the recaptured salmonids moved more than 100 feet from their reach of original capture. During the spring and summer periods in the east Cascade sites and during the summer period in the west Cascade sites, the number of fish recaptured in reaches other than where they had been marked (movers) exceeded the number recaptured in the same reach in which they had been marked (no movement detected). These findings coupled with the high frequency of unmarked immigrant fish captured during each sampling period (50 to 69%) indicated considerable movement to and from the study reaches in most of the sites examined.

Culvert crossings investigated under this study did not affect overall and size class specific movement of salmonids relative to natural reaches. Movement (as measured by PDM) through culverts was comparable with movement through natural reaches during all seasons investigated (Figure 5). Both natural reaches and culvert crossings showed seasonal bias for fish movement. For both, fewer fish were detected moving upstream during the winter sample periods than in other seasons on the both the east and west sides of the Cascade Mountains. During the winter, less than one fish per study site was detected moving upstream through natural reaches; upstream passage through a culvert was detected at only one site during the winter sampling period. Larger fish predominated among the fish detected moving upstream through natural reaches and culverts. Although the findings do not demonstrate a significant size class bias in upstream fish passage, fewer than expected fish of the two smallest size classes moved upstream through culvert pipes when compared to the size class distribution of fish observed moving upstream. Only two young-of-year salmonids were detected moving upstream more than 100 feet in natural reaches, both in areas where channel gradient was less than 2%. This is in contrast to results of a pilot study conducted on two culvert crossings in a low gradient (~1.3%) stream dominated by coho salmon, where upstream movement of fish less than 65 mm in total length was common through both natural reaches and culverts (Cupp 2001).

From the outset of the project, it was recognized that fish may move undetected, especially if they exited the study site after marking prior to successive sampling. Moreover, fish could enter the study site between successive sampling periods and thus become recruited to the marked population. Realizing that a short-term high turnover rate of salmonids in stream reaches is not uncommon and that marked fish provide limited information with regard to upstream movement unless they are recaptured, the recruitment of unmarked fishes into the study reaches in relation to culverts was examined. By conducting multiple-pass electrofishing where passes were repeated until few or no more salmonids were captured, relatively high capture efficiencies were achieved during each visit. All salmonids were marked (excluding fish <40 mm) prior to release. It follows that a large number of unmarked fish captured during resampling indicated immigration. Kahler, Roni, and Quinn (2001) and Roni and Quinn (2001) used similar reasoning to document the movement of juvenile salmonids in Washington streams.

Immigration of unmarked fish into sample reaches situated upstream of culverts was comparable to immigration of unmarked fish into sample reaches situated downstream of culverts. It is assumed that if culverts substantially affect movement of fish, differential rates of immigration of unmarked fish into sample reaches upstream and downstream of culverts would be expected. For instance, if culverts were impeding or precluding upstream fish movement, higher immigration rates of unmarked fish into the study reaches situated downstream of the culverts would be expected. It was predicted that this would be especially noticeable in the smallest size classes of fish. However the two smallest size classes were ranked highest in immigration of unmarked fish both upstream and downstream of the culverts (Figure 6). Likewise, if culverts were impeding or precluding downstream movement of fish, higher immigration of unmarked fish into reaches upstream of the culverts would be expected. However, immigration of unmarked fish at all crossings was comparable in reaches both upstream and downstream of the culverts, further supporting the suggestion that overall fish movement was little affected by culverts.

It was originally anticipated that the culverts with the steepest slopes and highest vertical drops would have the most effect on upstream movement of fish. However, no correlation among physical characteristics of the culverts and upstream fish movement was found. The degree to which a culvert affected upstream fish movement was related most closely to the movement rates of the overall study site. Movement through culverts (as measured by PDM) was ranked the same as movement through natural reaches. As an example, fish were detected passing upstream through all but one of the culverts investigated. The one culvert in which fish did not move upstream (SF Manastash) was installed at a gradient of 12.9%. Downstream of the culvert at this site, only one fish was detected moving upstream through a natural reach or even into the next upstream adjacent reach. Several steep, cascade constrictions and small wood/boulder steps probably affected upstream movement through the reaches below the culvert. At the remaining ten sites, an average of 5.2 salmonids were determined to have moved upstream through culverts, whereas an average of 3.5 salmonids moved upstream through 65 of the 77 natural control reaches. At two of the sites (NF Manastash 2 and NF Taneum Tributary), only one fish was detected moving upstream through the each of the culverts. At the NF Manastash site, a total of five fish were detected moving upstream at least 100 ft in study reaches situated downstream of the culvert over the course of the study. However, flows upstream of and through the culvert were intermittent and the reaches were largely dry between September and March. When flows resumed in April with the onset of snowmelt, a 155 mm cutthroat trout was detected moving upstream through the culvert. The NF Manastash 2 site culvert was installed at a 2.8% gradient with a 1.2 ft outlet drop. As for the NF Taneum Tributary site, only three fish, ranging from 102 to 127 mm total length, were detected moving upstream a minimum of 100 ft, one of which passed upstream through a culvert installed at a 6.8% gradient. All of the movement detected in the NF Taneum Tributary site occurred during the late spring or summer.

Road crossing structures, primarily culvert crossings, have long been recognized for their potential to impede or prohibit the upstream movement of fish. It is recognized that fish passage through artificial structures cannot practically be provided at all flows. Under the Washington Administrative Code, assumptions are made to define the period of year during which fish passage is required, based upon the species that are expected to inhabit the stream (i.e., spawning runs of adult coho in the late fall or upstream redistribution of juvenile salmon from overwintering mainstem habitat). A high flow design discharge is selected to be the upper limit of the range through which upstream fish passage criteria are satisfied. WAC 220-110-770 requires that the high flow design discharge be the flow that is not exceeded more than 10% of the time during the months of migration.

If, at high flow design discharge, the culvert velocities are less than or equal to the allowable velocity 90% of the time, the WAC criterion is met. If not, the culvert is considered to be a barrier.

Although culvert installation requirements have been in place for several years and fish passage improvement projects have recently been emphasized, there has been little systematic effort to monitor the effectiveness of these efforts in maintaining or restoring fish passage. Moreover, the criteria on which barrier determinations are made have not been investigated for their wide application. Kahler and Quinn (1998) summarized several studies (Carpenter 1987; Belford 1986; Belford and Guold 1989) indicating that under certain conditions fish are capable of swimming through higher velocities than those indicated by current culvert design guidelines. There are few field studies of fish passage through culverts. For instance, there has not been a systematic analysis to test the assumption that stream crossing structures installed according to the design criteria in the WAC allow unimpeded passage for all species/life history stages. Likewise, no investigations have attempted to test the assumption that stream structures not installed according to the design criteria in the WAC fail to provide passage for species/life history stages that are actually attempting to move upstream.

Results of this pilot project suggest that the criteria used as the technical definition of a fish passage barrier in the forest practice regulations do not accurately portray the realized impact on fish movement. This study illustrates that many culverts that are determined to be barriers based on WAC criteria are not barriers to upstream movement during some flows. Most of the study culverts are expected to be impassable for only brief periods based on modeled hydraulic conditions. Based on daily flow records from nearby USGS stream gauging stations, calculated discharges through each of the culverts investigated exceed the velocity threshold used under state guidelines only briefly during the course of the year, and in some years may never exceed the fish passage design flow. Velocities approaching or exceeding 4 ft/sec were measured within two of the culvert pipes during fall sampling. Judging from discharge data from nearby basins, it is probable that discharge exceeded the fish passage design flows during some portion of the study period. While this study in no way indicates that the culverts are passable at the fish passage design flow, it does indicate that they are passable at some flow. Whether or not fish made successful attempts at moving upstream through natural reaches and through culverts during periods when discharge exceeded design flows remains unknown.

While results indicate that the study culverts provided fish passage equal to that in nearby natural stream reaches throughout the year, the study was not designed to determine responses of individual fish to culverts under all flow conditions. Whether the upstream movement of any individual fish was impeded or precluded by a culvert or any natural stream features during some flow conditions is unknown. Given the six to ten weeks between visits, marked fish could conceivably have attempted to ascend the stream, and either passed through the culverts beyond the study site or reversed direction and swam back downstream to their original location, or even below the study site. Such movements would have been completely undetected. Detecting the responses of upstream migrants to channel obstructions and culvert features during specific flow events would require deployment of electronic tracking devices in concert with continuous stage recorders to track discharge and culvert hydraulics. Hendricks and Gresswell (2002) provided comparisons of potential methods to detect fish movement that could be used for future investigations. Further examination of the degree to which upstream movement efforts of individual fish are thwarted and the significance on population viability may be warranted.

5.0 MANAGEMENT IMPLICATIONS

The Forests and Fish report states that road maintenance and abandonment plans will provide for repairs and maintenance work to be performed in accordance with the road maintenance and abandonment section of the Forest Practice Board Manual. It further states that road plans need not provide for the replacement of culverts functioning with little risk to public resources, even if such culverts are not consistent with the requirements for the installation of new culverts. Culverts which were legally installed and properly maintained, and which are capable of passing fish, will not be required to be replaced and brought up to new standards until the end of such culvert's functional life unless otherwise recommended by WDFW. These results demonstrate that the culvert crossings identified as barriers by the WDFW barrier assessment protocol (WDFW 1998) under this study are "capable of passing fish." Several fish were detected ascending culverts installed at nearly 4% grades, and one fish was observed passing upstream through a culvert on a 6.4% grade. Although no young-of-year fish were detected moving upstream through culvert pipes, only two fish less than 65 mm total length were detected to have moved upstream through a natural reach during the entire study. Upstream movement through the study culverts was comparable to movement through natural reaches for all size classes of fish. These findings indicate that reconsideration of the criteria used to determine the barrier status of culvert crossings may be warranted. Sampling of additional study streams and culvert crossings with a wider range of channel gradients, culvert structural features, and species assemblages is needed to examine alternative criteria for making barrier determinations of existing culverts.

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