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Increased Abundance of Rainbow Trout in Response to Large Woody Debris Rehabilitation at the West Kettle River

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In the North American Midwest there has been a lengthy history of restoring or augmenting the frequency of pools and/or cover at salmonid streams, largely as a result of the economic value of recreational fisheries that these classic trout streams support (Hunt 1993). Experience in the Pacific Northwest (PNW) with stream restoration is much more recent, and most work has been directed at anadromous fish habitat in more challenging geomorphic and hydrologic settings. Most large-scale projects have attempted to restore lost channel and habitat structuring elements that would otherwise require a century to recover naturally (Slaney and Martin 1997). This recovery time is lengthy because many forested streams of the Pacific Northwest were historically logged to streambank, with the resultant gradual loss of instream large wood. In addition, streams were cleared of large woody debris (LWD) by such ecologically damaging practices as wood removal, splash damming, channelization, or dyking.

Although there have been some early studies that questioned the success of stream restoration work in western North America (Frissel and Nawa 1992), recent broad-scale evaluations document a relatively high functionality even after significant floods (Roper et al. 1998, D'Aoust and Millar 1999). Further, recent intensive evaluations of the biological effectiveness of habitat rehabilitation in Washington and Oregon also show positive results, especially for coho salmon (Cederholm et al. 1997, Solazzi et al. 2000), but also for steelhead or cutthroat trout (Doyle et al. 1999, Roni and Quinn 2001). Only one long-term study at 14 km of Fish Creek in Oregon was inconclusive (Reeves et al. 1997), and this is probably because the coarse boulder substrate provided significant salmonid habitat features. As in the Midwest, fisheries values provide an incentive for much of this rehabilitative work. For example, sport

fisheries in British Columbia are valued at C\$40 per angler day (Scarfe 1997) expressed in part as expenditures by resident and tourist anglers in local communities.

In the Interior of British Columbia, trout sport fisheries in larger streams are commonplace, but there is little documentation of restoration to regain lost pool habitat and cover. Yet, past land use impacts from harvesting of riparian forests in the Interior have often been more severe than those on the Coast because of additive impacts

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from past placer mining, logging of private lands, riparian clearing for cattle grazing, as well as losses of meander bends for transportation corridors. Natural instream decay/loss rates of LWD (about 3% per year), without riparian re-supply, can leave a legacy of featureless streams with few pools and limited cover. Some of the impacts are long-standing to the degree that degraded streams and rivers, lacking in large woody structure and deep pools, appear normal to untrained eyes. These support only remnant trout populations, and thereby offer marginal fisheries with minimum tourist benefits to local communities. Recognition of this problem is not just a recent phenomenon: more than a century ago, Van Cleef (1885) concluded from an investigation of the Catskill streams in New York that "...the destruction of the trees bordering on streams and the changed conditions of the banks produced thereby, has resulted in the destruction of the natural harbours or hiding places of the trout, that this is the main cause of depletion, and that unless these harbours are restored, it will be useless to hope for any practical benefit of restocking them."

Generally, there has been a reluctance to direct fish habitat rehabilitation to inland rivers because of both cautionary concerns about flood damage, and a lack of experience among practitioners. There are few rivers where instream restoration of large wood has been attempted on a larger scale. There is such an example, however, at a hydro-mitigation project on the large upper Nechako River, where in 1990 about 30 LWD bundles and catchers were installed along the margins of a 20 km reach to provide rearing habitat for salmonids. Debris catchers and multiple rootwad sweepers proved to be most resilient to flood and ice events, although the unballasted rootwads shifted shoreward. However, most structures were well-utilized by juvenile chinook, and the catchers were colonised by adult rainbow trout (Slaney et al. 1994). This project demonstrated that there was a need to develop a LWD demonstration project for the Watershed Restoration Program at a large trout stream in the B.C. Interior, and an alluvial reach of the West Kettle River was selected for this purpose.

Demonstration Site Description

The West Kettle River is a 6th order system with a drainage area of about 1,870 km² (D'Aoust and Millar 1999). Its headwaters are at Big White, from where the river flows for approximately 70 km to its confluence with

the Kettle River at Westbridge. Alluvial reaches dominate the length of the river, although there are a few confined canyon reaches. Stream flows are dominated by spring melt, with peak flows in May to June. Mean annual stream flow at Westbridge is 9.2 m³/sec, about 20 km downstream of the study reach, and flow from tributaries within this reach is minor. Daily peak flows range from 62 to 135 m³/sec, and summer low flows average 3-4 m³/sec. Temperatures are moderate in summer, averaging about 15°C in mid-summer, peaking at 20°C. Waters are largely oligotrophic, but fertile enough to support moderate fish growth in the summer growth season.

The rehabilitated section is located halfway between Westbridge and Beaverdell on Highway 33, and it is bordered largely by Crown forest lands. In this alluvial reach, infrequent mainstem pools are typically associated with log jams. The alluvial demonstration section is 2.5 km in length and has a wide floodplain. The main test section is 2.0 km in length, 0.4 % in gradient with riffles about 1%. Bankfull channel width is 36 m, and the riverbed is dominated by cobble with sub-dominant gravels. The banks are dominated by sandy gravels and cobbles are secondary. Channel widening is evident in some subsections of the reach. The river transports significant quantities of large wood, but there are infrequent jam initiators in the alluvial reaches, which were largely logged to their banks on both public and private lands (Figure 1).

Dominant fish species inhabiting the river are rainbow trout and mountain whitefish; these two species support a



Figure 1. An example of a natural lateral log-jam at the West Kettle River. This river section was logged to its banks in the past, and it was used as a control in evaluating effectiveness of fish habitat rehabilitation.

recreational fishery. Other species of note are reidside shiners and dace; rarer species include longnose suckers and non-native brook trout. Whitefish spawn and rear in the mainstem, whereas rainbow prefer to spawn and rear as juveniles in several tributary streams, as these are more fertile than the mainstem. Trout rear from a few months to three years, providing a spring-time recruitment of juvenile trout, mainly 1-2 years of age, into the mainstem. The summer sport fishery is largely focused on fly-fishing for rainbow trout, which has been managed since 1990 as "catch-and-release." This has taken advantage of the growth potential of the rainbow trout population, but has also compensated for the limited frequency of pool habitat in the river. The West Kettle is somewhat unusual because it supports some large (30-50 cm) trout, which likely prey on the cyprinids.

Extensive road deactivation has been carried out in the tributary drainages of the West Kettle watershed; this will ultimately improve conditions in the mainstem. One major tributary, Trapping Creek, has also received extensive rehabilitation over a distance of several kilometers, using large wood to stabilize streambanks and bars. At this location, we learned that it was counter-productive to use laterally aligned logs that lacked both rootwads and boulder ballasting. Also counter-productive were sill-log placements in low gradients with low banks because they exacerbate bank erosion by elevating bankfull depth.

Prescriptions: Pool-forming LWD Structures

In 1990, experimental pool-forming structures were first installed in an alluvial reach of the West Kettle River. This was accomplished by driving 3 m rails level with the substrate to function as anchors for chained v-log debris catchers. Because the fixed debris catchers pilot-tested at the Nechako River had protruding rails that did not emulate natural features, floating v-logs were employed. However, porpoise-like action of the floating v-logs at flood stages largely prevented these structures from collecting sufficient debris to scour pools. This caused some connections to fail. In 1996, however, one of these floating v-log structures was re-connected to the shore with a large log. This structure then collected substantial woody debris during the large spring flood of 1997, and a large scour pool with abundant cover was established (Figure 2). This indicated that it would be possible to emulate natural lateral jams. Therefore, in 1997, a



Figure 2. A lateral log-jam formed during the flood (25 yr.) of 1997 at a "debris catcher" structure. It scoured a > 2 m deep pool, well-utilized by adult trout and whitefish.

second v-log debris catcher was re-configured, with boulder ballast added to offset log buoyancy.

In addition, seven triangular 3-log structures were placed at banks in geomorphic settings where primary or secondary pools or runs would form if large wood accumulated as lateral jams. The design was similar to that in Millar (1997), but three of the seven were modified slightly to improve LWD collection (Figure 3). Three large Interior hemlock (0.5-0.7 m diameter and 15 m in length) were used as structural members. Ballasting was based on the design charts in Slaney et al. (1997; Fig 9-12). Sufficient rounded boulders were used as ballast to achieve a safety factor of about 2 to account for expected loading with drifting LWD; 1 m³ of boulders was used per log in the channel, where fixed attachments were available on the bank. In this design, the lateral structural stability provided by the triangular construction resists the horizontal drag forces; thus, only enough ballast is needed to offset log buoyancy during bankfull flows.

The cable-epoxy method was used to secure logs to boulders in the river channel, using 1.25 cm diameter galvanized steel core cable (Slaney et al. 1997). A minimum of two cable connections per ballast boulder was used, and care was taken to improve aesthetics by drilling holes through the outer edges of logs to hide cables (Figure 3). Cable attachments on shore were either boulders, "deadhead" logs buried in the water table, or tree bases. Instream boulders ranged in diameter from an estimated 0.4 to 0.9 m³, and typically 2-3 boulders per log, or 6-8 per structure, were used to

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Figure 3. An example of a lateral triangular structure designed to collect driftwood and scour pool habitat for rainbow trout and mountain whitefish in the West Kettle River.

maximize synergy of LWD and boulders in providing prime habitat features for juvenile and adult rainbow trout. This design is similar to the debris catcher, in that it should also catch drifting LWD, thus creating a lateral jam with a scour pool and emulating the natural process of LWD-structuring of forested channels.

In 1998, four additional structures were placed in the section, adapted from a “box groin” design used in smaller streams in Europe as described in Donat (1995; Figure 4). Four parallel logs were placed in a ramp configuration so that the logs faced upstream and also sloped into the streambed (to prevent bank scour). At peak flows, the spilling of water over the logs was designed to maintain a



Figure 4. An example of a box groin designed to maintain pool habitat for trout and whitefish at a logged section of the West Kettle River.

scour pool, with overhead cover provided by the logs. Similar boulder ballasting (1 m^3 per log) and cable attachments were used to overcome buoyancy, except at the most upstream structure, which was buried to a depth of 1 m with a mixture of sand and rock. These structures were not designed to trap drifting debris (Figure 4). Also in 1998, two sets of three large debris groins were installed on banks of two streambank bends, as described in a previous issue of *Streamline* (Vol. 4, No. 2). These structures, and seven additional structures located upstream of the test reach, have performed as designed. Publication of these results is pending.

In total, nineteen large woody debris structures were installed in the 2 km alluvial test section of the West Kettle River from 1996 to 1998. Thirteen were designed as pool-forming structures, equating to one structure per 150 m of channel, and about four channel widths per LWD-forming pool, including two primary pools that existed prior to rehabilitation. Although some of the selected sites were lateral glides within riffles, this frequency did not differ markedly from the six channel widths per primary pool used routinely for boulder riffle-pool re-construction.

Physical Monitoring and Maintenance

Physical effectiveness evaluation was conducted commencing in 1997. Triangular structures were intensively monitored at each site by measuring stability of the logs. Measured stability was then compared to predicted stability from Millar (1997). Potential shifting of the apex of the triangle was measured from reference pins established on the banks. Durability, scour, and distance of shifting were also recorded for the other two types of structures, but in less detail. Maximum scour depths were recorded at all sites in mid-July, 2000.

Some maintenance was undertaken from 1997 to 1999. In 1997, surface cobble was scraped from inside the perimeter of the various structures, and in 1998, the potential scour zones (3 m upstream and lateral to the apex of the structures) were

also scraped to remove some of the cobble-boulder armour layer. Also, by 1999, a few pieces of drift wood were added to three of the eight triangular structures that had caught limited drifting debris, and a second log was attached to shore on the second rail-anchored debris catcher to enhance debris jamming. Finally, at two of the box groins, boulders were placed at the leading log to moderate velocities into the pool.

Annual Fish Enumeration Procedures

In mid-summer of 1990, two swimmers enumerated fish by counting in four lanes within subsections of the 2 km test reach, and within a 550 m reference or control reach located approximately 4 km upstream. This procedure was repeated in mid-July of 1998 as unreplicated counts over the 2 km, but with systematic coverage of pools and glides. In 1999, four swimmers completed counts in both the 2 km test reach and in the control in mid-July. These swimmers remained within standardized counting lanes as described in Slaney and Martin (1987). Counts were replicated over two days, shifting swimmers between lanes. In mid-July of 2000, replicate counts were again repeated. In this case, replicate counts in the control section were conducted by only three swimmers, with the potential error induced by having one fewer swimmer minimized because of the simple nature of the channel. Fish size over 10 cm intervals was estimated visually on each swim. The mean of these counts represents an index of abundance because they were not systematic enough to expand using visual widths as recommended by Slaney and Martin (1987). Thus, total counts per size class, per section are equivalent to a minimum estimate in each year because four swimmers would observe about 60-70 % of the wetted width of the river, including an estimated 90% of depths > 30 cm. All counts were adjusted to numbers per km to facilitate comparisons.

Thus, the primary treatment change in the 2 km test section was the placement of the thirteen pool/run-forming structures, and there were no physical changes in the reference or control section where only a single natural debris jam was located mid-section. However, catch-and-release regulations on rainbow trout were implemented at the West Kettle River in 1990. Therefore, changes in trout counts in both the test section and the control section from 1990 and to 1998-2000 reflect the effects of restricting fish harvest, as well as habitat rehabilitation.

Structural Stability, Functionality and Costs

Of the thirteen pool-forming LWD structures, only two box groins shifted in response to a prolonged bankfull flood in 1999. At one, two logs shifted

downstream by up to 10 m because of failure of epoxy on two in-stream cables. This likely resulted from inadequate ballast on an oversized (0.8 m) log. Nevertheless, the structure remained functional as a primary pool-forming measure. These two logs were re-ballasted in 1999 and triangulated to ensure stability. The two logs that had not shifted had scoured a plunge pool leading into the triangular structure. Overall, only a single box groin failed; it was displaced about 150 m by the prolonged bankfull flows of 1999. This structure vibrated loose from under 1 m of sand and rock ballast. The box groin appears to function hydraulically as a single log structure, and therefore, to resist horizontal drag forces, much more ballast is required than in triangulated multiple log structures (D'Aoust and Millar 2000). No shifting was detected in the two rail-anchored debris catchers. (The three sets of debris groins for riverbank stabilization were also resilient through two spring floods.)

After construction of triangular structures, the weight of ballasting was compared to the design target, or a safety factor of 2. Boulders and logs were re-measured, weights computed and the stability compared to the safety factor as in D'Aoust and Millar 1999, in which the factor of safety, FSB, for multiple log structures was computed as:

$$FS_B = \frac{\Sigma W'}{\Sigma F_{BL} + \Sigma F_{LB}}$$

where W' is the immersed weight of the anchor boulders, F_{BL} is the vertical buoyancy force from the logs, and F_{LB} is the lift force on the anchor boulders. The calculated factor of safety averaged 1.9 and ranged from 1.1 to 2.8. Of the seven triangular structures constructed in 1997, three shifted by up to 1 m as driftwood loaded onto some of the structures. Minor shifting (<1 m) of two structures with high safety factors of 2.2 to 2.3 resulted from some slack left in cables to deadheads or to tree bases. One of two under-ballasted structures (with a safety factor of 1.2) also shifted slightly, but remained fully functional.

Mean maximum pool depth in 2000 was 1.6 m and pool depth ranged from 0.9 m to 2.4 m. Fifty percent of the debris catchers plus triangular structures collected driftwood, forming lateral jams that occupied up to 30% of the wetted channel width during July. In 2000, the two structures with the largest jams, a triangle and a debris collector, had maximum scour depths of 2.0 m and 2.4 m respectively, and the structures with the least driftwood accumulation (triangles) had the lowest maximum depth, 0.9 m. The second debris catcher had collected only limited debris to date, but scoured to 1.1 m because of structural complexity.

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Estimated costs of the pool-forming structures were relatively low: on average, \$C1200 per triangular 3-log structure, including prescriptive costs at consultant rates and travel from outside the region. (Streambank debris groins were about twice this cost.) This low cost was largely because all sites were readily accessed by excavator from either Highway 33, or via the railway grade, or from extended gravel bars within the channel. Cost of the logs was minor owing to low market value of Interior hemlock. In comparison, costs for similar LWD structures elsewhere (Narrowlake Creek, Keogh River) were typically \$C2000 - 3000 because they incorporated 1-2 rootwads for winter refuge/cover and required heli-transport of all materials.

Responses of Rainbow Trout to LWD Structures

There was a significant effect of LWD rehabilitation on trout abundance in the treated section compared to the control section ($P < 0.05$). Prior to rehabilitation in 1990, enumeration showed that total numbers of trout > 10 cm in length were extremely low and similar in the two sections: 6 per km in the test reach and 2 per km in the control (Figure 5). In 1998, during treatment, and eight years after a shift to restricted fishing regulations, trout abundance was 62 per km in the LWD-treated reach and 28 per km in the untreated control reach, or a twofold difference. In 1999, when only maintenance was undertaken, numbers increased further, to 232 per km after LWD rehabilitation, versus 75 per km in the untreated reach, or a threefold difference. By 2000, numbers increased further to 366 per km in the rehabilitated reach whereas numbers of trout in the control was estimated at 68 per km, a difference of more than five times (Figure 5). In the treated reach, 70% of trout were closely associated with the structures, and 26% (96/km) were of catchable size (> 20 cm). However, only 3% (12) were > 30 cm, which probably reflects the short time frame, the

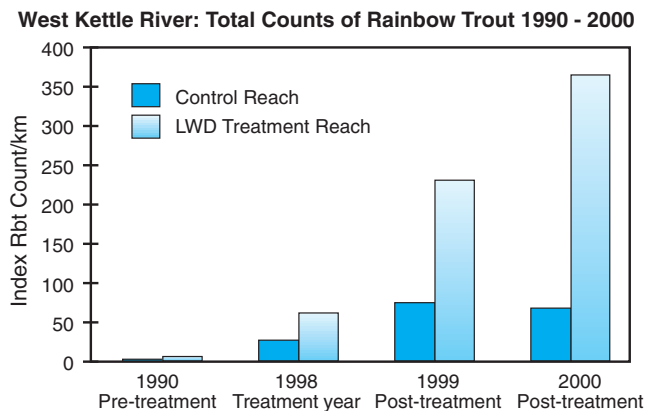


Figure 5. Response of rainbow trout (> 10 cm) to pool-forming large wood structures in 2 km of the West Kettle River.

gradual deepening of the pools, and perhaps angler pressure. The marked increase in trout abundance after treatment was associated with pool formation at the structures (mean pool depth 1.6 m). Mean numbers of trout > 20 cm per type of structure were 11.3 for the triangular structure, 6.2 for the box groin, and 17.8 for the debris catcher, although sample size was only adequate for the triangular structure.

Anglers were sampled by voluntary creel cards in 1999 and 2000. Reported catch rates were six trout per day, although catch was dominated by small trout. Assuming that catchable-sized (> 20 cm) trout provide at least 2 angler days per fish per year, 100 angler days per km could be generated; this is valued at C\$4000 per year at \$40 per angler day (Scarfe 1997). Of this, C\$3000 would be attributed to the six or seven LWD structures per km. After discounting, such a project could therefore potentially generate a positive economic benefit after only four years (or less than ten years at two times the cost, without road access).

Summary

At this large Interior stream, the West Kettle River, eighteen of nineteen structures (95%) maintained functionality through 2-3 floods, including a bankfull flood in 1999 that extended for two months. Of the pool-forming LWD structures designed to rehabilitate rainbow trout habitat, twelve of thirteen (92%) were functional after 2-3 flood events. The single failure was an under-ballasted box groin.

Cost per structure was low (C\$1200), or about half other large-scale projects, because of ease of access.

Configuration of triangulated logs to trap drifting LWD improved pool scour, as does pre-loading structures with small amounts of LWD. Similarly, removal of the cobble armour layer at lateral scour sites adjacent to structures accelerated pool scour.

A single triangular structure caused local bank scour as it loaded with LWD, indicating that bank armouring with either one of the LWD collecting logs or with rootwads is advisable on erodable banks.

For the two designs that capture driftwood to form lateral jams, the amount of wood collected was variable and not readily predictable.

LWD trapping structures supported high densities of rainbow trout, or on average 38-65 trout per structure, of which about 25% were catchable-sized fish (and the percentage of larger trout are expected to expand over time).

Over the three years after LWD treatments were implemented at the West Kettle River, total trout

abundance per km in the LWD-treated section increased by five times over the control section. Yet both sections had similar very low numbers of trout in 1990, and during treatment in 1998, the treated section had only about twice the trout abundance of the control.

Although rail-log debris collectors supported high numbers of fish per structure and were stable, sample size was small (2) and complexity of construction limits their use to where large boulders are available locally for anchors (instead of rails), unless triangulated to reduce transport of ballast to the site.

Boulder ballasted *triangulated* structures performed largely as predicted hydraulically. Over three years, 100% remained functional, and they were well-utilized by rainbow trout. Therefore these structures are considered most effective in re-establishing trout pools by employing natural processes of larger streams.

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Predicting Channel Change in Narrowlake Creek in the Central Interior: A Tool for Watershed Protection and Restoration.

Andrew Wilson

Introduction

The interaction of stream channel morphology and riparian vegetation is of fundamental interest to aquatic and terrestrial resource managers and the Watershed Restoration Program (WRP). While the biological consequences of riparian logging along fish-bearing streams are well documented (e.g. Meehan 1991, Murphy 1995), the longer-term morphological changes that occur in stream channels following streamside harvesting are less well understood. Hydrological models that predict channel change may provide tools for understanding this linkage and may aid in protecting watersheds and developing watershed restoration prescriptions. As a result of complex and extensive channel changes that have occurred at Narrowlake Creek following floodplain forest harvesting (Soto et al. 1997), stream restoration there has involved three treatments. These included bar stabilization and revegetation, streambank stabilization, riparian restoration, bridge replacement of culverts, and instream habitat rehabilitation.

Morphological change in stream channels may be a result of streamside forest harvesting. Millar (2000) developed a model to predict stream channel morphology based on the condition of riparian vegetation. This model was tested on a portion of Slesse Creek (a tributary to the Chilliwack River) downstream of an old-growth area in the headwaters. The riparian area was extensively logged in the 1950s and 1960s, and has subsequently become parkland. The model predicted that in the presence of dense riparian vegetation, Slesse Creek would form a meandering channel morphology, and that in the absence of dense riparian vegetation it would form a braided channel. These predictions were then confirmed using pre- and post-logging air photos.

The predictive model developed by Millar is useful for natural resource managers and watershed restoration practitioners interested in determining the sensitivity of stream channels to upslope activities or for developing